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INTSORMIL 2005 ANNUAL REPORT

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2005 Annual Report

INTSORMIL

Sorghum/Millet Collaborative Research Support Program (CRSP)

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

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Participants of the the Marketing & Processing for Dryland Crops in West Africa Workshop in Bamako, Mali from November 16-18, 2004.

Top Left: Mme. Cisse Fatchima from STA in Niger
Top Right: Mme. Ouattara Laurentia, Food Scientist at IRSAT/CNRST and
Mme. Triande Edith, UMAO, both from Burkina Faso

Bottom Left: Mme. Deme D. Assatou, Free Work Services in Senegal
Bottom Right: Mme. Zoundi Simone, SODEPAL in Burkina Faso

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. . . A Team Effort

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

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Introduction and Program Review

The 2005 INTSORMIL Annual Report presents the progress and notable achievements by the Sorghum/Millet CRSP during the period of July 1, 2004 - June 30, 2005. 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 in providing improved 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, NGO/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, marketing and utilization for the mutual benefit of the Less Developed Countries (LDCs) and the U.S.*** . Collaborating scientists in NARS of collaborating 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, marketing 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. 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 bird food 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, and 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 multi-disciplinary 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 and 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 stimulating 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 26, 2004-2005, there were 62 students from 23 different countries enrolled in an INTSORMIL advanced degree program and advised by an INTSORMIL principal investigator. Approximately 69% of these students came from countries other than the U.S. The number of students receiving 100% funding by INTSORMIL in 2004-2005 totaled 13. An additional 45 students received partial funding from INTSORMIL and the remaining four students were funded from inter-CRSP activities. INTSORMIL places high priortiy on training of women. In 2004-2005, 29% of all INTSORMIL graduate participants were female.

Another important category of education which INTSORMIL supports is non-degree research activities, namely postdoctoral research and research of visiting scientists with INTSORMIL PI's in the United States. During Year 26, eleven scientists improved their education as either postdoctoral scientists (1) or visiting scientists (10). Their research activities were in the disciplines of agronomy, plant breeding, economics, food science and animal nutrition research. These scientists came to the United States as postdoctoral scientists or visiting scientists from El Salvador, Ethiopia, Ghana, Mali, Morocco, Namibia, Nicaragua, and Niger. In addition to non-degree research activities there were 334 participants (228 male and 106 female) who were supported by INTSORMIL for participation in workshops/conferences.

Networking

The Sorghum/Millet CRSP Global Plan for Collaborative Research includes workshops and other networking activities such as newsletters, publications, 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, 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 networks, short-term and degree training plans for sorghum and pearl millet scientists.
- Over the years, established networking activities have been accomplished 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/Southern Africa and West Africa. In 2004 and 2005 INTSORMIL has been executing a Marketing-Processing Project funded by the USAID West Africa Regional Program (WARP) which focuses on responding to emerging market demand with improvements in the supply of consistent, quality grain of sorghum and pearl millet. Initial activities (2002-2004 supported by INTSORMIL) consisted of making contracts between farmers' groups and the rapidly grow-

ing sector of millet food processors (couscous, arraw, degue, sankal, tchakri, and yogurt with tchakri) in four countries of the Sahel (Senegal, Mali, Burkina Faso, and Niger). 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 West Africa Regional Program now encompasses six countries of the Sahelian region – Burkina Faso, Ghana, Mali, Niger, Nigeria, and Senegal - following the merger of the INTSORMIL West Africa Eastern (Niger, Burkina Faso, Nigeria) and Western (Mali, Senegal and Ghana) Regional programs in July 2004. Core institution-building programs have existed in Mali (1984) and Niger (1983), and since 2000 a regionalization effort extended INTSORMIL collaborative research projects to the remaining four countries. In April 2004, a workshop was held in Ouagadougou, Burkina Faso for the purpose of regional strategic planning and implementation of the merger. INTSORMIL host country PIs and nine U.S. PIs, as well as select administrative staff, attended the three day meeting. Progress summaries from each country were presented and strategies and work plans for country and regional programs were developed. Additionally, two new regional projects were identified through a group prioritization process in crop utilization and technology transfer with a goal of developing concept papers and proposals to seek additional outside funding for future activities.

The detailed report in the body of the annual report shows the wide breadth of research and extension activities in the West Africa Regional Program. A complement of projects spanning genetic enhancement, sustainable plant protection systems, sustainable crop production systems, and utilization and marketing exist. In most countries of the region, multi-disciplinary teams have been developed to link production agricultural systems with markets. This is particularly true in the work plans and activity reports from Burkina Faso, Mali, and Niger. Programatically, the West Africa INTSORMIL program is well positioned and is active in working towards enhancement of sorghum and millet markets through high-yielding, quality grain production, supply-chain management, and processed product and animal feed endpoints.

Most notable are INTSORMIL efforts to improve and promote poultry production in West Africa. Close personal ties with Salissou Issa and Issoufou Kapran of INRAN, Niger have been established and these relationships with Salissou and Issoufou not only demonstrate INTSORMIL commitment to development of human capital in target countries, but also evolved into demonstration experiments with broiler chicks showing the nutritional merits of sorghum-based diets. The results from these experiments were the cornerstone for a Producer Field Day held in Niamey, Niger. This Field Day drew all of the key poultry growers in the Niamey region (approximately 50) and was a tremendous success in facilitating technology transfer to end-users.

These research and extension activities and subsequent visits to poultry farms throughout the country also contributed to the formation of the Nigerien Poultry Producer's Association. Initially, the focus of this association will be on layer activities with eventual expansion into broiler production. So, INTSORMIL scientists are very excited to have been part of this critically important aspect of stimulating poultry production via technology transfer in Niger. The inevitable result of our activities is demand for sorghum as a preferred feedstuff for poultry and the generation of cash markets for sorghum producers in West Africa.

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

On-going collaborative research has progressed in each of the countries, namely Ethiopia, Eritrea, Kenya, Tanzania and Uganda. Results are highlighted in this report. Host country PIs in each country have taken keen interest in collaborating with U.S. PIs where partnerships have been developed. Because of expanded collaborative involvement in several countries in the Horn of Africa Region more U.S. PIs are needed to provide collaborative linkages with host country scientists. New PIs joining INTSORMIL are encouraged 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.

Sorghum breeding efforts in Ethiopia have been highly successful. Work on development and evaluation of experimental sorghum hybrids have resulted in identification of elite hybrids with potential for wide cultivation in lowland areas of the country. Efforts on *Striga* control have focused on regional testing of an integrated package of technologies that included tied-ridging as a water conservation measure, nitrogen fertilization, and *Striga* resistant sorghum cultivars. This activity is managed and implemented as a pilot project with supplemental funding from the Office of Foreign Disaster Assistance (OFDA) of USAID. Though, reports from Tanzania and Eritrea have not been submitted, the collaboration on sorghum breeding and in *Striga* control in both countries has progressed well. The program in Kenya has seen a setback as a result of C.K. Kamau, the sorghum breeder beginning Ph.D. degree training in South Africa. However, Christopher Mburu has continued efforts in *Striga* research in his absence. In Ethiopia a decision guide for targeting of tied-ridging is being developed, and additional research has been initiated on tied-ridging by soil fertility interactions and on skip-row technology. Also, four opportunities for low-input management of soil fertility in semi-arid eastern Uganda have been verified as economical using farmer participatory approaches; information dissemination is scheduled to begin with the second season of 2005; and more detailed research has been initiated to assess the medium-term sustainability of these practices. A study of sorghum production areas in Ethiopia, Uganda and Kenya has identified stalk borer, water deficits, Striga, bird damage, N deficiency, weeds, and shootfly as the greatest causes of yield loss.

Additional data has been compiled on sorghum production areas of Ethiopia, Kenya, Mozambique and Uganda; a GIS referenced database is being created that should be valuable to regional networking activities. .

A new project, UNL 220 initiated March 10, 2005, is designed to promote increased use of sorghum and millet by establishing an entrepreneurship education/training program coupled with follow-up technical and business support services. This training program is being coordinated and offered through the Sokoine University of Agriculture's (SUA) Department of Food Science and Technology. It is anticipated that new individual and village/cooperative ventures will be established that use sorghum and millet grain and ingredients in food products to be sold locally and in urban markets. Draft entrepreneurship training materials were adapted from those developed by the University of Nebraska's Food Processing Center with the on-site collaboration between UNL's Entrepreneurship Program coordinator Ms. Gifford and Dr. Mpagalile (who was in Nebraska through May 2005). After his return to Tanzania, Dr. Mpagalile has further coordinated material refinement and localization by including local product photographs, Tanzania Food and Drug Agency (TFDA) regulations and Tanzania Bureau of Standards (TBS) specifications. A project coordinator was hired by SUA; the individual has a B.S. degree in agricultural economics and agribusiness with a wide experience in entrepreneurship and business incubator programs in Tanzania. The first Entrepreneurial Workshop is scheduled for September 20, 2005.

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

Progress was made in all research areas. Technology (germplasm) developed by this project has been adopted by private industry and used in hybrid production or breeding programs. Germplasm was evaluated for resistance to economically important insect pests and other stresses. Selections were made to combine insect resistance with other favorable agronomic and plant traits . Germplasm was identified for advanced testing with resistance to selected insects and diseases that will contribute to production of high grain yield hybrids with wide adaptation. Thirty-four advanced elite germplasm lines were proposed for release. The germplasm lines also exhibit wide adaptation and some grain weathering resistance. The lines will be suitable for use by private industry directly as hybrid parents or as breeding lines to contribute traits to a parental line development program. Thus, collaboration with Host Country scientists resulted in progress to develop improved, high-yielding varieties or hybrids. Progeny were identified that combine several favorable traits into a single genotype. Discussion with collaborators established a framework to allow for on-farm testing of experimental germplasm in South Africa and developed a procedure for potential release of new varieties. As research continues to generate new technology, the importance of testing on-farm and soliciting producer input on research activities will increase.

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. 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. With the right varieties or hybrids and the right marketing system the natural drought stress resistance of sorghum and pearl millet can help provide a consistent supply of high quality grain for processors and consumers.

Central America (El Salvador, Nicaragua, 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 (El Salvador, Nicaragua and Honduras). Administrative procedures for reporting research results and financial expenditures have been developed. 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 continue implementation of these research priorities while expanding activity into Guatemala. Communication and coordination of the many groups involved in the program remains a challenge. The regional research directors developed a regional graduate education and short-term training plan. At present five students are in graduate degree programs. Short-term training is in progress or being planned for four scientists in food science, agronomy and agricultural economics.

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. Grain utilization issues are increasing in importance in the program. 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. Major progress was made in developing forage and grain varieties/hybrids, including line identification, testing and in seed production. A forage sorghum hybrid is planned for formal release in El Salvador and Nicaragua in November 2005. Several grain sorghum varieties/hybrids are being validated during 2005, with plans to release the best ones in 2006.

Major achievements of the past year are transfer of the improved high N use efficient sorghum variety 85SCP805 (with and without fertilizer application) to 141 small farmers, and transfer of the improved varieties ES-790, CENTA S-3, 86EO226 and CENTA RCV to approximately 500 small farmers. 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. In addition, rapid progress is being made in validation and seed increase of the forage hybrid ICSA275 X TX2784, with formal release planned for November 2005. The variety/hybrid pipeline at CENTA and CNIA/INTA indicates the potential for release of several improved grain sorghum varieties/hybrids in 2006. Progress was made in developing improved integrated crop and pest management programs. Improved ties with the food processing industries in El Salvador and Nicaragua were achieved through workshops and personal contacts, and one company, GUMARSAL has participated in grain quality research and plans to mill sorghum flour. Graduate and undergraduate educational, and short-term training efforts have improved the human capital available for sorghum research and technology transfer in Central America. In addition research and technology transfer efforts in poultry nutrition in Central America have focused on seminars given in Nicaragua and at the RAPCO Short Courses in Costa Rica. Dr. Hancock/KSU 220B used the RAPCO short courses to promote sorghum as a component in animal feeds (especially for poultry). Attendees for the short courses (limited to 35 each year) were representatives from the major livestock/feed producers in most of Latin America (i.e., Mexico, Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica, Panama, Venezuela, Colombia, Ecuador, Peru, and the Dominican Republic). The unquestionable success of these short courses results from the organizational skills of Carlos Campabadahl (Universidad de Costa Rica). So, again, collaboration with in-country specialists is a key to the success of INTSORMIL in collaborating countries.

Regional Benefits by Technical Thrust

Germplasm Enhancement and Conservation

Pearl millet [*Pennisetum glaucum* (L.) R. Br] provides a staple, primary food 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 goals of Project ARS-206 are to improve the productivity, yield stability, and pest resistance of pearl millet for African and U.S. settings and to transfer the technology to the market. Achieving these goals require 1) identifying constraints limiting production or utilization, 2) evaluating germplasm for desirable characteristics, 3) developing regionally adapted breeding lines or cultivars, and 4) working with partners and stakeholders to transfer the products of research to the marketplace.

The second year of multi-locational trials throughout West and Southern Africa was completed. Gemplasm and cultivars were characterized for agronomic characteristics and resistance to pests and diseases. Trials were conducted in Kamboinse, Burkina Faso; Manga, Ghana; Cinzana, Mali; Bengou, Niger; Maiduguri, Nigeria; Bambey, Senegal; and Longe, Zambia. An additional trial was conducted in Kwa Zulu Natal, South Africa to characterize rust resistance. Correlations of yield with several agronomic characteristics and negative associations with pests and diseases were identified. Genotypes with superior performance over multiple locations will serve as source material for breeding improved pearl millets.

Resistance to root knot nematode (*Meloidogyne incognita*) is important to provide stability to pearl millet production and to reduce nematode populations that can damage crops grown in rotation. Seventeen pearl millets from West and East Africa expressed some level of resistance. SoSat-C88, Gwagwa, Zongo, and P3Kollo were evaluated for heterogeneity of resistance, and patterns of segregation of resistance varied among the four varieties. Discreet resistant and susceptible phenotypes were identified in Zongo progeny, and it was estimated that two dominant genes for resistance segregated in this variety. Heritability of nematode reproduction determined by parent-offspring regression was 0.54. Realized heritability determined by divergent selection was 0.87.

Wild pearl millets (*P. glaucum* subsp. *monodii*) have been identified as potential sources of resistance to the parasitic weed, *Striga hermonthica*. Eighty wild accessions, nine U.S. inbreds and seven African open-pollinated varieties were evaluated with 60 EST primers and 35 SSR primers to identify genetic diversity and identify polymorphic markers that would be useful in transferring resistance. Out of 60 EST primers tested, 30 produced scorable and reproducible fragments. Out of 35 SSR primers, 33 primer pairs gave amplification products in most of the accessions. A dendrogram was constructed using the combined data of SSR and EST data. The wild accessions were grouped independently from the cultivated U.S. and African varieties. Resistant accessions PS 202, PS 637, PS 639 and PS 727 tended to be located in different clusters, suggesting they may possess different resistances to *Striga*.

Drought stress occurring from flowering through grain fill results in low and unstable yield of pearl millet. Delayed senescence, or "stay-green" is a mechanism of drought tolerance characterized by the retention of green leaf area at crop maturity. The relative chlorophyll contents of a putative stay-green and normal senescent pearl millet were compared over time, and segregation of the stay-green in an F_2 population was evaluated. The line 02F266-4 retained greater relative chlorophyll content 3 and 4 weeks after anthesis. Expression in F_1 and segregation in the F_2 indicated staygreen in this parent is a dominant or overdominant trait.

To expand domestic market outlets for pearl millet grain, four pearl millet genotypes were tested for their potential as feedstocks for ethanol production and for co-products from the fermentation process. Fermentation efficiencies of pearl millets, on a starch basis, were comparable to those of corn and grain sorghum. Because pearl millets have greater protein and lipid content, distiller's dried grains with solubles (DDGS) from pearl millet also had greater protein content and energy levels than did DDGS from corn and grain sorghum. Pearl millet should be an effective feedstock for ethanol production in the U.S.

The central clay plain of the Sudan is home to a great variety of sorghum types. With favorable rainfall distribution, heavy alluvial soils, and high seasonal temperatures the area has a long history of sorghum cultivation, and currently presents a well-developed irrigated and mechanized farming schemes. Several agronomically elite landraces have been collected from this region. Taxonomically, sorghums of the race Caudatum make up the most dominant type in Central Sudan and adjacent regions suggesting perhaps that Sudan was the center of origin for sorghums of the Caudatum race. Other studies have described Caudatum as a race with great agronomic value, better adaptation to harsh conditions, and a wide range of response to changes in photoperiod. This may explain the great contribution that sorghums from Sudan have made to global sorghum improvement efforts. The race caudatum is one of the most important races agronomically and provides genes for high yield and excellent seed quality. It has become one of the most important sources of germplasm in modern breeding programs throughout the world.

Project PRF 207 efforts led to the release in 2004 of 20 elite inbred sorghum lines including race Caudatum derivatives for use in the commercial sorghum seed industry. Material Transfer Agreements have been signed and seed distributed to seed companies in the U.S., India, South Africa, and Guatemala. Elite inbred lines of sorghum developed by PRF 207 and experimental hybrids generated from these inbred lines have been sent to collaborators in several countries. The programs in Niger, Ethiopia, and Eritrea, in particular, have made selections that are currently in multilocation testing.

Project TAM 223 made progress in all research areas. Germplasm was evaluated for resistance to economically important insect pests and other stresses. Selections were made to combine insect resistance with other favorable agronomic and plant traits. Germplasm was identified for advanced testing with resistance to selected insects and diseases that will contribute to production of high grain yield hybrids with wide adaptation.

Collaboration with LDC scientists resulted in progress to develop improved, high-yielding varieties or hybrids. Progeny were identified that combine several favorable traits into a single genotype. Discussion with collaborators established that 34 germplasm lines were proposed for release. The lines are in two sets of 17 lines each. Lines designated Tx2945 to Tx2961 are tan plant with red or white grain, resistance to biotype E greenbug, and mostly excellent disease (including foliar) resistance. Lines designated Tx2962 to Tx2978 are resistant to biotype E and I greenbug with varying levels of disease resistance. The germplasm lines also exhibit wide adaptation and some grain weathering resistance. The lines will be suitable for use by private industry directly as hybrid parents or as breeding lines to contribute traits to a parental line development program framework to allow for on-farm testing of experimental germplasm in South Africa and to develop a procedure for potential release of new varieties. 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 (germplasm) developed by this project has been adopted by private industry and used in hybrid production or breeding programs. Collaboration with research programs in Nicaragua, El Salvador, and Southern Africa (South Africa, Botswana, and Zambia) gives TAM 223 significant international activity. Impact assessment studies show a high rate of return on investment from research conducted by this project.

The KSU 220 project is a mega project consisting of four parts, KSU 220A, KSU 220B, KSU 220C/TAM 220C and KSU 220D/TAM 220D. The major emphasis of this project is to develop sorghum varieties and hybrids with enhanced nutritional and grain quality characteristics. The marketing and utilization of sorghum grain often has been limited by lower grain quality and feed value compared to other cereals. 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. Thus research project KSU 220 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. 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. Large-seeded sorghum genotypes with enhanced feed-value and grain-quality characteristics have also been identified and these genes are being incorporated into improved genetic backgrounds for deployment in regions of Africa, Central America, and the United States. 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. 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.

KSU 220D cooperating principal investigator at Texas A&M University is working 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. Plant pathologists in Burkina Faso, Mali and Nigeria have been enlisted as collaborators to survey disease problems of sorghum and millet. DNA comparisons made from non-viable spores of pearl millet downy mildew show differences great enough to predict that two different pathogen species may be involved.

Project KSU 220B training activities focus 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 course 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 2004-2005 budget year, a short course was held in Managua that was designed specifically to address issues (real and perceived) that limit the expanded use of sorghum as a feedstuff for poultry farming in Central America. 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 2003 and 2004 and animal feeding trials (accomplished in Niger) were completed in 2004 and 2005. 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.

Sustainable Production Systems

The PRF 205 project has been very active in the Horn of Africa region, the West Africa region and Mozambique this past year. The fieldwork in Amhara, Ethiopia on the introduction of *Striga* resistant cultivars and associated technologies was Completed. Mr. Yigezu Yigezu (Ethiopia) is well into writing his M.S. thesis on the potential impact of the *Striga* resistant cultivars and associated technologies. Introducing inorganic fertilizer more rapidly and developing seed production systems (probably in the public sector) are two critical innovations to accelerate the introduction of *Striga* resistant cultivars and associated technologies in Amhara, Ethiopia. Mr. Rafael Uaiene (Mozambique) finished his thesis on marketing strategies and technology introduction in maize production in central Mozambique. Mr. Uaiene won one of the Purdue University Department of Agricultural Economics prizes for best M.S. theses and his thesis was forwarded to the National Agricultural Economics M.S. thesis Competition of the American Agricultural Economics Association.

Mr. Felix Bacquedano (Nicaragua) also finished his fieldwork in Niger continuing the technology introduction/ inventory credit evaluation that Dr. Abdoulaye Tahirou had initiated. Mr. Bacquedano is also well into the analytical phase of his M.S. thesis. Both Mr. Yigezu and Mr. Bacquedano were delayed in finishing their theses by taking courses for the Ph.D. Both have been accepted into this program. Mr. Yigezu and Bacquedano are now working on their theses full time and both should be finished by September 2005. They have begun work on their prospectus for their thesis defense. Both will be concerned with constraints to technology introduction in their countries (Ethiopia and Mozambique).

Mr. Nega Wubeneh (Ethiopia) has submitted a paper to *Agricultural Systems* and Mr. Uaiene has finished a draft for a journal article submission.

The Marketing-Processing project continues to demand large amounts of field time including six trips to the Sahel in the past INTSORMIL budget year. Improving the grain quality is a critical problem area in getting farmers' incomes up, both for the farmers (doing it with tarps or threshers) and for the food processor (paying a quality premium. Farmers' incentives (higher prices for staples) are critical to the successful expansion of Inventory Credit systems.

In the Marketing-Processing project there is now more stress on quality control and on feed processors. For the feed processors and public policy makers project investigators are doing a bulletin on tannin and relative prices of sorghum as compared with maize over the last five years over all four countries, Senegal, Mali, Niger and Burkina Faso. Efforts are underway to have all English documents translated into French.

Project UNL 213 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, and 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. Present research is on double cropping pearl millet after winter wheat. 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.

Major accomplishments of UNL 213 in 2004-2005 were:

- In El Salvador, the improved photoperiod sensitive (maicillo criollo) sorghum variety 85SCP805 was identified with increased grain yield, improved NUE, and high % N fertilizer recovery for production in relay intercropping systems with maize. 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.
- Photoperiod insensitive sorghum lines were identified with high N use efficiency and/or high N fertilizer response in El Salvador (ICSVLM- 90520) and Nicaragua (ICSVLM-93076). These are being used in national program breeding programs.
- Large sorghum grain yield increases have been demonstrated in response to N fertilizer application, which is leading to an increased effort to promote N fertilizer use for grain sorghum production in Central America.
- 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 nutri-

ents from the soil at approximately the same rate as with no fertilizer application.

- Research using nodulating and non-nodulating soybean isolines has contributed new insight into the basis for enhanced yields for sorghum rotated with soybean. Soil NO_3-N differences influenced sorghum growth and yields, indicating that part of the rotation effect was due to biological N fixation by soybean (about 17 to 33%) while the rest was due to N from other sources and non-N effects.

The objectives of Project UNL 219 are to promote economic growth, improve nutrition and to increase yield. Opportunities to increase yield or to reduce production costs have been identified while promising research is continuing and technology dissemination activities have been initiated. Following verification and fine-tuning of the targeting of tied-ridge tillage for semi-arid areas of Ethiopia, extension efforts have been initiated. A decision guide for targeting of tied-ridging is being developed, two papers were presented at the 2004 ASA meeting, and a paper has been submitted to *Agronomy Journal.* Additional research has been initiated on tied-ridging by soil fertility interactions and on skip-row technology. Four opportunities for low-input management of soil fertility in semi-arid eastern Uganda have been verified as economical using farmer participatory approaches; information dissemination is to begin with the second season of 2005; and more detailed research has been initiated to assess the medium-term sustainability of these practices. Preliminary research was conducted on tillage and soil fertility management alternatives in Mozambique. Research on occasional tillage to improve the productivity of no-till sorghum production systems continues and are the subjects of the dissertation and thesis research of two graduate students; four papers are to be presented at the 2005 ASA meeting.

Improved institutional capacity. Tewodros Mesfin, who completed his M.S. degrees at Alemaya University with support from UNL 219, came to UNL as a visiting scientist. Gebreyesus Brhane has completed his M.Sc. degree with INTSORMIL support and is now the UNL 219 collaborator in Tigray, Ethiopia. Soares Xerinda completed his M.S. degree at UNL and is now the UNL 219 collaborator in Mozambique. The research of a U.S. and two international graduate students is currently supported by this project. Mr. Mesfin, Brhane and Xerinda were sponsored to IFDC training in integrated soil fertility management in Ghana. A study of sorghum production areas in Ethiopia, Uganda and Kenya has revealed stalk borer, water deficits, *Striga*, bird damage, N deficiency, weeds, and shootfly as the greatest causes of yield loss. Additional data has been compiled on sorghum production areas of Ethiopia, Kenya, Mozambique and Uganda; a GIS referenced database is being created that should be valuable to regional networking activities. Drs. Wortmann and Mamo visited their collaborators in Africa in February 2005.

Sustainable Plant Protection Systems

KSU 210 has demonstrated that 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). KSU 210 has been working with *Fusarium proliferatum*, a species known to be capable of producing high levels of the fumonisin toxins, in sorghum grain from Egypt. These strains may be the cause of the pokkah boeng disease that is common on Egyptian sorghum and, if these strains are producing mycotoxins under field conditions, they may pose an unanticipated mycotoxin exposure risk to both humans and domesticated animals.

The Scientific Writing and *Fusarium* Laboratory workshops have become successful, visible outreach efforts and that will continue. Scientific writing workshops are offered opportunistically while the KSU 210 PI is in travel status and although none were done in the 2004-2005 reporting period, over 1000 were trained in the 2003-2004 reporting period and a number of workshops have already been scheduled for the last half of 2005. Scientific Writing and *Fusarium* Laboratory 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 350 page manual based on the material taught in the *Fusarium* Laboratory workshop, needs to be converted to camera ready format, but otherwise is complete. *Fusarium* Laboratory workshops are held in odd-numbered years at KSU in Manhattan, Kansas, and in even-numbered years at a location outside the United States. The 2004 and 2005 workshops both fell into this reporting year, with 40 attendees from 16 countries in Pretoria, South Africa and 57 attendees from 17 countries in Manhattan, KS. The 2006 workshop is scheduled for Bari, Italy and the 2008 workshop is tentatively set for Penang, Malaysia.

Work with the *Fusarium* collections is progressing. Dr. Giuseppe Mulé and her colleagues in Italy 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. Walter Marasas of South Africa.

In collaboration with Dr. Ranajit Bandyopadhyay of IITA (Ibadan, Nigeria) KSU 210 is working on identifying causal agents of grain mold and head blight in sorghum in West Africa, and comparing the toxin-producing capability of these strains with similarly collected strains from maize and pearl millet. They also are organizing a conference on mycotoxins in Africa under the umbrella of the EU MycoGlobe project of which the KSU 210 PI and Dr. Bandyopadhyay are both on the steering committee, and will be co-editing the proceedings of that meeting for a volume to be published by CABI in the United Kingdom.

The extension of MSU 205 into Nicaragua and El Salvador during the past five 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 the project was involved in previous years in Honduras. In an on-farm demonstration-type program designed to compare insect and disease pest management, improved pest management technology involving timely application of selective insecticide and fungicide provided better management of a complex of insect and disease pests, respectively, and increased yield in an integrated approach to pest management than the conventional pest control practices used by local farmers in Nicaragua.

And, with the interdisciplinary participation of entomologists and plant pathologists during the past two years, considerable attention has been given to investigations involving integrated pest management within large monocropped sorghum production systems. 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 and disease problems identified in the respective countries have yielded basic biological information needed for developing and recommending effective insect pest and disease management programs. Recommendations to manage the complex of lepidopterous caterpillars and sorghum midge on sorghum in Nicaragua, and fall armyworm and stalk borers on sorghum 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 and diseases of sorghum in Mississippi. This includes fall armyworm on whorl stage plants and sorghum midge, fall armyworm, sorghum webworm, corn earworm and stink bugs on the panicles, as well as the complex of diseases on whorl and reproductive plant growth stages. Effective insecticide and fungicide use practices for control of insect pests and diseases, respectively, on sorghum and defined economic threshold levels for stink bugs on whorl and panicle stages of sorghum and the complex of diseases will assist farmers in decision-making regarding the application and effective use of pesticides to manage these pests.

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 the combining of 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.

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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.

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 goal of Project PRF 213 is to exploit the unique life cycle and parasitic traits of *Striga* especially the chemical signals required for germination, differentiation, and establishment. The project has developed an integrated *Striga* management (ISM) package (combining a resistant sorghum cultivar with inorganic fertilization and a soil moisture conservation) and has tested this in Ethiopia in a farmer-participatory approach for the last four years. The demonstration trials were performed by over 6000 farmers and adopted by tens of thousand others because of its efficacy in reducing *Striga* infestation and increasing sorghum grain yield. Over 25,000 farmers have received seed of *Striga* resistant cultivars directly from project leaders at research stations, regional bureaus of agriculture, and collaborating NGOs. These farmers have in return distributed seed to neighboring farmers through local informal seed exchange mechanisms. It is estimated that over 100,000 farmers have grown seed of *Striga* resistant sorghums from INTSORMIL. In addition to the *Striga* resistance traits, farmers have liked the varieties for their early maturity, drought tolerance, and favorable grain quality in making local food products. Agronomically, these varieties have been well suited for many of the sorghum growing regions of Ethiopia except in higher altitudes (>2700m), where long season (>180days) maturity sorghums are preferred. Fortunately, the *Striga* problem has not been as severe in the highlands of Ethiopia.

During this year the WTU 200 project PI traveled to southern Africa to review INTSORMIL activities and discuss collaborative research and educational programs. Research to manage insects of sorghum was reviewed and discussed in March with scientists in Botswana, Mozambique, and South Africa and research was planned for Ph.D. students. Research was conducted as planned with scientists in Africa. Resistance of sorghums developed by TAM 223 and commercial seed companies were evaluated for resistance to aphids. Greenbugs from Kansas and Texas were identified as biotype I. Tritrophic effects of resistant sorghum on beneficial insects were assessed. The evaluation of resistance of 20 genotypes of stored sorghum were completed and light and scanning electron microscopy used to compare morphology of seed coats of resistant versus suceptible sorghums. Graduate programs of five M.S. students and one Ph.D. student were directed. Two M.S. students graduated in August 2004, one will graduate in December 2005, and one learned English and began graduate studies. Two African students did not qualify for admission to West Texas A&M University and one potential Ph.D. student needs to take the Graduate Record Exam before admission. As planned, research results were presented at entomology, extension, farmer, and sorghum meetings.

Utilization and Marketing

Collaborative efforts continue in Niger and the surrounding region to stimulate processing of commercial sorghum and millet foods. INTSORMIL Project PRF 212 continues efforts to push high quality sorghum couscous and flours, and has recently started a project to explore the use of pregelatinized flours for thin and thick porridges and weaning foods for urban areas of the sorghum and millet growing region of West Africa. Studies at Purdue University are designed to investigate a low-cost low pressure/high temperature extruder. A West African regional team of food scientists is working on an integrated, regional crop utilization project that will culminate in a proposal for funding a larger processing effort for the region.

In 2004-05, PRF 212 showed continued progress toward nutritional improvement of sorghum grain. Improved grain quality lines of the high protein digestibility/high-lysine sorghum mutant show promise and they have a better understanding of the biochemical changes in the grain due to the mutation. 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 the TAM 226 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. The project is cooperating with principal investigators at Texas A&M University to determine if high protein digestibility and grain mold resistance can be combined. Currently, small populations have been developed to test this relationship and they have begun to create larger populations in order to completely characterize this relationship.

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.

The TAM 226 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. Additionally, for the 2004-2005 budget year, a short course was held in Managua that was designed specifically to address issues (real and perceived) that limit the expanded use of sorghum as a feedstuff for poultry farming in Central America.

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

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.

A new project, UNL 220 was initiated on March 10th, 2005 and is designed to promote increased use of sorghum and millet by establishing an entrepreneurship education/training program coupled with follow-up technical and business support services. This training program is being coordinated and offered through the Sokoine University of Agriculture's (SUA) Department of Food Science and Technology. It is anticipated that new individual and village/co-operative ventures will be established that use sorghum and millet grain and ingredients in food products to be sold locally and in urban markets. Draft entrepreneurship training materials were adapted from those developed by the University of Nebraska's Food Processing Center with the on-site collaboration between UNL's Entrepreneurship Program coordinator Ms. Gifford and Dr. Mpagalile (who was in Nebraska through May 2005). After his return to Tanzania, Dr. Mpagalile has further coordinated material refinement and localization by including local product photographs, Tanzania Food and Drug Agency (TFDA) regulations and Tanzania Bureau of Standards (TBS) specifications. A project coordinator was hired by SUA; the individual has a B.S. degree in agricultural economics and agribusiness with a wide experience in entrepreneurship and business incubator programs in Tanzania. The first *Entrepreneurial Workshop* is scheduled for September 20, 2005.

Biotechnology

Biotechnology encompasses a number of concepts and techniques based on recent knowledge of genetics, biochemistry, 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.

The goal of project TAM 230 is to combine the high grain protein digestibility trait with grain mold resistance in sorghum through the use of molecular techniques. The objectives set forth for this project are: 1) identifying high grain protein digestibility (HPD) lines from crosses between HPD line P851171 and P850029 and elite grain mold resistant lines; 2) defining molecular markers for both the HPD trait, and grain mold resistance; 3) defining the molecular basis of grain mold resistance; and 4) determining the possible gain of function the HPD trait may convey for improved animal feed nutrition and food manufacturing. The project seeks to train graduate students from Central America/Mexico and the U.S. in strategies to integrate plant molecular biology tools with pathology, breeding, nutrition and cereal chemistry to improve sorghum nutritional quality.

In one year three Ph.D students from Mexico and the U.S. and one M.S. student from Honduras have been recruited into this project. These students have been recruited with funds ($197,740) over the next 2-3 years from Texas A&M University, USDA, and Fulbright Fellowship programs. These funds represent a substantial buy-in to the funds provided by INTSORMIL. One student, Esten Mason, has accomplished our first goal by identifying four HPD lines from crosses with grain mold resistant parents. Two of these lines exhibit a floury endosperm phenotype while two lines exhibit a more desirable hard/flinty endosperm. Each line has acceptable levels of grain mold resistance. Esten is currently testing the functional use of the modified endosperm carbohydrate and surrounding protein body matrix in the HPD lines for improved ethanol production and in poultry feed. Collaboration with PIs working on existing INTSORMIL projects at Texas A&M, Kansas State, and Purdue have provided invaluable interaction and improved productivity.

Future Directions

During the past 26 years, INTSORMIL has educated more than one thousand scientists in 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. 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 too 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 26 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

Sorghum is the fourth most important cereal in Egypt (after maize, wheat and rice), and is the only one of these cereals that can be easily cultivated in the "new lands" or in very hot and arid Upper Egypt. Fusarium toxins are known to be a problem on maize in Egypt and there are published case of donkeys with leukoencephalomalacia. *Fusarium* species from section *Liseola*, with teleomorphs in the *Gibberella fujikuroi* species complex, are widely known from maize and sorghum in Egypt, but little detailed characterization has been made of these species. A common perception is that both crops have a common set of pathogens that cause stalk, ear and kernel rot and produce mycotoxins such as fumonisins and moniliformin. We examined 353 *Fusarium* isolates within section *Liseola*, recovered from both maize and sorghum. Species among these isolates were identified with AFLP markers and sexual fertility testing. We recovered representatives of *G. fujikuroi* mating populations (MPs), MP-A (*F. verticillioides*, teleomorph *G. moniliformis*), MP-D (*F. proliferatum*, teleomorph *G. intermedia*), MP-F (*F. thapsinum*, teleomorph *G. thapsina*), and MP-G (*F. nygamai*, teleomorph *G. nygamai*), along with members of an undescribed biological species closely related to *F. andiyazi*. MP-A was the most frequently recovered MP from maize (71% of recovered isolates), and MP-D was the most frequently recovered MP from sorghum (52% of recovered isolates from sorghum). Female fertile isolates were most common within MP-A (71%) and much less common in MPs D and F. Our results suggest that sexual reproduction occurs more frequently within MP-A than within MP-D or MP-F. The relatively low female fertility within MP-D and MP-F may limit genetic exchange among individuals within these species relative to that possible in MP-A.

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 Egypt, Mali, Tanzania, 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 does 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. *Fusarium* cultures were isolated from plant stalks of maize, and grain and forage sorghums. Also, *Fusarium* cultures were isolated from tops of sorghum plants that showed Pokka Boeng (twisted top) disease. Plant tissues were surface sterilized in 95% ethanol for two minutes and then planted on to semi-selective peptone PCNB medium (Nash and Snyder, 1962). The plates were incubated at 25 C for 4-7 days. *Fusarium* colonies emerged from the plant tissues were picked up and cultured on complete medium (Correll et al., 1987). Pure cultures of *Fusarium* were obtained by subculturing single spores separated by micromanipulator on 2% water agar medium. All cultures are maintained as spore suspensions in 15% glycerol at –70 C.

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 two 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 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.

Sexual cross and data analysis. Standard tester strains representing *MAT-1* and *MAT-2* from each of the eight mating populations were used to determine mating type and female fertility of the field isolates collected from maize and sorghum. Crosses were made on carrot agar medium following standard procedures developed at KSU. Field isolates were used initially as males with the standard strain as the female parent. Once mating population and mating type were identified, the field isolate was used as a female parent to assess its female fertility. The cross was considered fertile when a cirrhus of ascospores was seen emerging from a mature perithecium.

Effective population number based on mating type ratios and relative frequency of female-fertile isolates of field isolates of different mating populations was calculated based on the equations derived previously for ascomycete fungi by Leslie and Klein. The average number of female sterile mutations per isolate was calculated by using the observed frequency of the hermaphrodites as the zero term in a Poisson distribution (Leslie and Klein, 1996).

PCR and DNA sequence and analysis. To determine the mating type of sterile *Fusarium* strains, we amplified portions of mating type idiomorph *MAT-1* or *MAT-2* with PCR-based assays. We used PCR primers Gfmat1a, Gfmat1b, Gfmat2c, and Gfmat2d to amplify ~200-bp *MAT-1* or ~800-bp *MAT-2* fragments as previously described. For the b-tubulin fragments, we used PCR primers T1, T2, and T3. PCR products of b-tubulin were purified with the Wizard DNA Clean Up kit. The purified DNA products were directly sequenced by using ABI Prism BigDye Terminator Ready Cycle Sequencing Kits. Sequencing reactions were run on an ABI Prism 3700 DNA Analyzer at the Kansas State University DNA sequencing facility.

DNA sequences were edited and aligned by using the Clustal X algorithm in the BioEdit program (http://www.mbio.ncsu.edu/BioEdit/bioedit.html). Final alignments were optimized visually. Phylogenetic analyses of aligned DNA sequences were performed by using PAUP* version 4.0b10. The heuristic search option was used to infer maximum parsimony trees. Clade stability was assessed by 1000 bootstrap replications calculated from PAUP trees. Other measures, including tree length, consistency index (CI), and retention index (RI) also were calculated with PAUP* 4.0b10.

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. Most studies of *Fusarium* species done in Egypt used outdated taxonomy that placed virtually every isolate from either host in *Fusarium moniliforme*. This grouping is morphologically convenient but is inaccurate from a biological point of view with this previously single species now subdivided into 25+ species of varying frequency, distribution and economic importance. Our objectives in this study were to determine species diversity for isolates of *Fusarium* recovered from maize and sorghum, to estimate effective population number and thereby the relative frequency of sexual reproduction within these fungal populations, and to evaluate genetic diversity within these species using anonymous molecular markers (AFLPs).

Survey results. We evaluated 66 isolates from maize and 287 isolates from sorghum. For the isolates from maize, 47 were assigned to mating population A (MP-A), nine to mating population D (MP-D), two to mating population F (MP-F), and three to mating population G (MP-G). Five isolates were cross fertile with one another and are closely related to, but are distinct from *F. andiyazi* based on AFLPs and b-tubulin DNA sequences. These five isolates probably represent a previously unidentified *Fusarium* species. The general frequencies of these species is comparable to those seen in maize samples from other developed and underdeveloped countries in that MP-A is dominant, MP-D is present at a lower, but still significant, level, and MP-F is present, but not common.

Of the 287 isolates collected from sorghum, 148 isolates were assigned to MP-D, 75 to MP-F, 48 to MP-A, 3 to MP-G (*F. nygamai*) and 16 isolates to the putative new species. This distribution has several unusual features. First, *F. nygamai* has never before been reported from Egypt on any species. Second, MP-D (*F. proliferatum*) is the dominant species rather than MP-F (*F. thapsinum*). Most sorghum samples are dominated by MP-F, which produces relatively little fumonisins and results in a crop that is generally clean from the perspective of *Fusarium* mycotoxins present. The Egyptian samples were dominated by MP-D (> 50%) and also contained a significant proportion of MP-A, which also can produce high levels of fumonisins. Thus nearly 2/3 isolates of *Fusarium* from sorghum in this sample were capable of producing fumonisin mycotoxins. Even more interesting is the relative lack of MP-F, which produces little in the way of mycotoxins and dominates on sorghum crops grown in the United States and elsewhere in Africa. The complete absence of *F. andiyazi*, another species that produces little if any mycotoxins and is the dominant *Fusarium* species grown on sorghum in South Africa, also was surprising. These results suggest that the *Fusarium* species colonizing sorghum may vary by location (or a correlated variable such as climate), a pattern that is not the same as that seen in maize, which is usually dominated by either MP-A (warmer/drier) or MP-E (cooler/wetter). They also suggest that fumonisin contamination of sorghum might be a problem in Egypt even though it is not a problem elsewhere. All of the species were found throughout the Nile River valley and there did not appear to be any gross difference in species distribution based on location within the country.

We have also isolated strains of the new species from grain and stalks of maize, sorghum and millet in other parts of Africa (Nigeria, Tanzania, and Uganda). The significance of this new species as either a plant pathogen or as a mycotoxin producer has yet to be determined, but it is clearly found in a pan-African pattern and is present on grains being used for human consumption.

Sexual cross fertility. Three MPs, MP-A, MP-D, and MP-F had sufficient numbers to be analyzed for effective population number. With respect to mating type, the distribution of the *MAT-1* and *MAT-2* alleles were not widely skewed, suggesting that female fertility rather than mating type was of primary importance in determining the relative frequency of sexual and asexual reproduction. Hermaphrodites were the most common in MP-A (71%) but were much less common in MP-D (23%) and MP-F (8%). An unusual feature for this sample was the presence of strains that could function as neither male nor female parents in a sexual cross (up to 9% of the MP-F population). These strains should represent asexual lines whose genetic composition changes only as a result of mutation.

The N_e values for the various MPs are MP-A (98%), MP-D (64%) and MP-F (29%). These values suggest that sexual recombination could rapidly generate new genotypes in MP-A, but would be unlikely to do so in MP-F. The relative proportion of MP-A strains participating in sexual reproduction is 3-6%, in MP-D it is up to 1.5%, and in MP-F it is between 0.5 and 1% of the total population. Compared with global averages for these species from various hosts, the values for MP-A are somewhat higher than that normally seen, those for MP-D are somewhat lower than those normally seen, and those for MP-F are similar to or slightly lower than those previously reported. MP-A populations could recombine with relative ease to generate new genotypes, while MP-D could do so only with difficulty and MP-F only with very great difficulty.

Variation with species. Variation within a species was evaluated by using AFLP markers (Table 1). These markers have been used to construct genetic maps and for a number of previous evaluations of variation in *Fusarium* spp. and are particularly appropriate for studies such as these in which the haploid nature of the target organism enables an easy and straightforward interpretation of the results obtained.

Table 1. AFLP variation in *Fusarium* species from the *Gibberella fujikuroi* species complex collected from maize and sorghum in Egypt.

Mating population (MP) (Biological species)	Maize	Sorghum	Total	Number of AFLP haplotypes
MP-A (*F. verticillioides*)	47	48	95	74
MP-D (*F. proliferatum*)	9	148	157	126
MP-F (*F. thapsinum*)	2	75	77	55
MP-G (*F. nygamai*)	3	0	3	3
New *Fusarium* spp.	5	15	20	7
Unidentified *Fusarium* sp.	0	1	1	1
Total	**66**	**287**	**353**	**266**

Within the *Fusarium* species, examined, most MP-A and MP-D strains had different AFLP fingerprints suggesting that these strains were not clones. In a few cases the same clone was recovered from both maize and sorghum plants growing in the same general area, but clones were not observed if the strains were recovered from geographically distant locations. MP-F is highly clonal in some locations, with as few as 10 types composing > 75% of the MP-F population from the United States. Thus the Egyptian populations appear to be relatively diverse genotypically, even though the N_e values suggest that a much more clonal structure should be expected, at least for MP-F. The presence of common clones in both the maize and the sorghum samples suggests that at least some exchange between pathogen populations is occurring. Such documented exchanges for the moment are unique to Egypt, but the mechanism by which the exchanges occur could be significant for other regions as well.

Networking Activities

Editorial and committee service (2004)

Editor of *Applied and Environmental Microbiology*

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

Member of Senior Fulbright Scholar Review Panel (US – Australia – New Zealand)

Member of the MycoGlobe Steering Committee

Research Investigator Exchanges

Dr. Leslie made the following international scientific exchange visits (2004):

Australia – April 10-24
Belgium – October 21-23
China – May 9-16
Italy – June 4-9
Malaysia – April 24 – May 1
Nigeria/Benin – May 24 – June 3
Nigeria/Cameroon – October 9-21
South Africa – March 5-13, September 18 – October 2, November 2-23
South Korea – May 2-5

Seminar, Workshop & Invited Meeting Presentations

Participated in *Fusarium* Laboratory Workshop at FABI, University of Pretoria, South Africa from September 26-October 1; 40 participants and five instructors from 16 countries

15th International Plant Protection Congress, Beijing, People's Republic of China.

Science University of Malaysia, Penang, Malaysia.

Faculty of Agriculture & Life Sciences, Seoul National Univ., Seoul, South Korea.

School of Pharmacy, Peking University, Beijing, People's Republic of China.

International Institute for Tropical Agriculture, Cotonu, Benin.

African Crop Improvement Center, Univ. of KwaZulu-Natal, Pietermaritzburg, South Africa.

Dept. of Plant Science, University of the Free State, Bloemfontein, South Africa.

During 2004 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.

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

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

Prof. Dr. Walter 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 Mulè, Institute of the Science of Food Production, CNR, Bari, Italy

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

Heaton, L. A. & J. F. Leslie. 2004. Double-stranded RNAs associated with *Fusarium proliferatum* mitochondria. *Mycological Progress* **3:** 193-198.

Leslie, J. F., K. A. Zeller, A. Logrieco, G. Mulè, A. Moretti & A. Ritieni. 2004. Species diversity and toxin production by strains in the *Gibberella fujikuroi* species complex isolated from native prairie grasses in Kansas. *Applied and Environmental Microbiology* **70:** 2254-2262.

Leslie, J. F., K. A. Zeller, M. Wohler & B. A. Summerell. 2004. Interfertility of two mating populations in the *Gibberella fujikuroi* species complex. *European Journal of Plant Pathology* **110:** 611-618.

Saleh, A. A. & J. F. Leslie. 2004. *Cephalosporium maydis* is a distinct species in the *Gaeumannomyces-Harpophora* species complex. *Mycologia* **96:** 1317-1329.

Smith, J. S., J. Fotso, J. F. Leslie, X. Wu, D. van der Velde & R. A. Thakur. 2004. Characterization of bostrycoidin: an analytical analog of zearalenone. *Journal of Food Science* **69:** 227-232.

Summerell, B. A., and J. F. Leslie. 2004. Genetic diversity and population structure of plant pathogenic species in the genus *Fusarium*. In: *Plant Microbiology* (M. Gillings & A. Holmes, eds.), pp. 207-223. Bios, Oxford, United Kingdom. 290 pp.

Abstracts

Bowden, R. L., J. E. Jurgenson, J.-K. Lee, Y.-W. Lee, S. H. Hun, K. A. Zeller & J. F. Leslie. 2004. A second generation genetic map of *Gibberella zeae*. *Proceedings of the 15th International Plant Protection Congress*: 355.

Leslie, J. F. 2004. Genetics of *Gibberella zeae*. *Proceedings of the 15th International Plant Protection Congress*: 353.

Saleh, A. A., & J. F. Leslie. 2004. Biological species in the *Gibberella fujikuroi* species complex (*Fusarium* section *Liseola*) recovered from maize and sorghum in Egypt. *Proceedings of the 15th International Plant Protection Congress*: 369.

Low Input Ecologically Defined Management Strategies for Insect Pests on Sorghum

Project MSU 205
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Leopoldo Cervantes, Entomologist, University of El Salvador, San Salvador, El Salvador
Reina Serrano, Plant Pathologist, CENTA, Apdo Postal 885, San Salvador, El Salvador
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Summary

With emphasis on research directed at establishing integrated pest management practices on sorghum, MSU-205 investigations involving both insect pests and diseases in large monoculture sorghum production systems were coordinated between entomologists and plant pathologists with government, university and producer organization participation. Unlike the low input, inexpensive pest control technology utilized on small subsistence farms, the commercial operations in Nicaragua and El Salvador can involve a much higher level of insect pest and disease management technology with greater costs to the farmer. Improved insect and disease pest management practices were compared with agricultural practices utilized by farmers in an on-farm demonstration-type project in Nicaragua. The improved technology system proved to be better when yields were compared. Insecticide and fungicide treatments were evaluated in different programs, with considerable benefits obtained with timed pesticide applications for control of insect pests and diseases, respectively. The All Disease and Insect Nursery (ADIN) included sorghums that showed levels of resistance to fall armyworm and several diseases, including gray leafspot, zonate spot, downy mildew, and anthracnose. Plant pathologists in El Salvador found several superior sorghum lines and varieties, as well as native maicillo criollos, with resistance to both insect pests and diseases. The whitefly problem on sorghum in 2004 in El Salvador was not as severe as it was in 2003. In the United States the first year of a three-year sorghum-soybean crop rotation research program was completed in 2004 in Mississippi in which six crop systems were evaluated for effects on insect pests and diseases. In other studies, stink bug activities in sorghum were included in preliminary investigations; these involved identifying adult and nymph thresholds of crop damage, adult preferences for crops and non-crop vegetation and crop plant growth stages, evaluation of insecticides for stink bug control, and observations on seed diseases related to stink bug damage. Workshops on insect and disease identification and pest management with farmer participation were conducted in 2004 in Nicaragua and El Salvador. Research accomplishments have been and will be presented at professional meetings and published in scientific journals and agricultural extension-type publications.

Objectives, Production and Utilization Constraints

Nicaragua

- MSU 205 PI met with Central America collaborator scientists in INTA and UNA and NGO personnel in

ANPROSOR to develop collaborative sorghum production research plans.
- Collaborate with INTA and UNA scientists to investigate on-farm cultural and chemical methods for management of insect pests and diseases on sorghum.
- Evaluate sorghums for resistance to diseases and insect pests.
- 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 and sorghum webworms.
- Evaluate sorghums for resistance to diseases and insect pests.
- Continue research relationships with entomologist at the University of El Salvador to collaboratively investigate the serious whitefly problem first encountered in El Salvador in 2003.
- Conduct workshop on insect pest identification and control measures.

United States

- Investigate the influence of sorghum-soybean crop rotation systems on insect pest and disease occurrence and population densities, and damage to the crops. Work collaboratively with plant pathologist in describing these relationships for plant diseases on both crops.
- Investigate the stink bug complex on sorghum, including species diversity and density, nymph and adult damage to the grain, developmental rates on crop seed and insecticide efficacy.
- Continue research and academic programs for two MSU-205 Ph.D. students.

Research Approach and Project Output

Nicaragua

Entomologists and plant pathologists at INTA and UNA worked together with ANPROSOR in conducting a number of integrated pest management investigations in sorghum on large and small farms in several areas of Nicaragua in 2004. Students from UNA participated in these investigations to gain experience in various aspects of agricultural crop production and specifically with insect and disease pest management strategies. Workshops in two country zones were conducted with farmers participating. Two workshops emphasized identification of insect and disease pests, and two workshops emphasized integrated pest management practices. Eighty sorghum producers attended the four workshops. A pest identification and integrated pest management practices document was developed by the scientists and given to each participant.

Four insect and disease pest management investigations were completed during the second crop growing season. In a study to determine the influence of insecticide (cypermethrine) to control fall armyworm larvae and fungicide (benomyl) to manage diseases on vegetative sorghum, chemical spray applications were made when insect infestation levels reached 20, 30, 40 or 50% and a fungicide spray was applied at 10, 20, 30 or 50% disease severity levels as the designated integrated chemical program spray treatments. The insect infestation did not reach the 50% level. Although diseases were not observed during the early vegetative plant growth stages of sorghum, several were obvious during mid- to late season. Diseases caused by *Ramulispora sorghi, Colletotrichum graminicola* and *Cercospora sorghi* were present and each reached 60% severity level during late season. The complex of diseases reached treatment levels up to 40%, but not the 50% severity level during the designated treatment period. In this chemical application program to manage insect and disease pests on sorghum in vegetative stages, highest yields were obtained when fall armyworm and diseases were managed with insecticide and fungicide, respectively. Lowest yield was obtained in the untreated plots. No significant differences were observed among chemical treatments suggesting that sorghum will tolerate fall armyworm infestations as high as 40% and disease infection level as high as 20% during early to mid-vegetative stages. These data indicate the benefit of a combination of insecticide and fungicide chemical spray applications to manage insect and diseases, respectively, on vegetative sorghum.

In a second on-farm investigation, the number of insecticide (cypermethrin) chemical spray applications (1, 2 or 3) and fungicide (benomyl) spray application at 10, 20 or 50% disease severity levels were treatment programs designated to manage foliage feeding lepidopterous caterpillars (mainly fall armyworm) and diseases, respectively, on vegetative sorghum in small plots during the second crop growing season. The first insecticide spray application was made when 40% of the plants were infested with fall armyworm larvae; the second spray three weeks after the first at 40% insect infestation. The treatment program including three insecticide sprays plus fungicide spray at 50% disease severity level was not initiated because the vegetative stages of the crop was too short due to drought, thus insect infestation and disease severity levels were not observed on vegetative plants. Chemical spray applications on the reproductive stages of sorghum were made to program treatments 1 and 2 (above) to uniformly manage seed head insects and diseases. Fall armyworm larval infestations were observed on very young sorghum plants and increased to highest levels during late vegetative stages. No apparent difference was observed between treatments with one or two insecticide spray applications to vegetative sorghum at treatment thresholds of 40% infested plants. Diseases of vegetative sorghum caused by *Colletotrichum graminicola, Ramulispora sorghi* and *Gloeocercospora sorghi* and diseases of reproductive stages caused by *Colletotrichum* and *Cercospora sorghi* were observed and reached severity levels up to 20% of infected foliage during vegetative stages. Little apparent difference in disease severity level was observed between the two treatment programs (10 or 20% severity levels) and the untreated plots during vegetative plant growth stages. The diseases were observed at levels as high as 60% during the reproductive stages. The data suggests that one pyrethroid insecticide spray for fall armyworm control when plants are at 40% infestation level provided as good control of this pest as two insecticide applications (the second three weeks after the first) in an integrated pest management program when fungicide is applied at either 10 or 20% severity levels for disease control.

The disease caused by *Ramulispora sorghi* is not generally considered to be a significant constraint to sorghum production in Nicaragua, but this investigation revealed the vulnerability of the commercial variety Tortillero to the pathogen.

The second year of an on-farm study to compare improved insect and disease management practices with conventional sorghum production practices used by farmers was conducted. Production practices used by farmers included applications of cypermethrin insecticide, early and fall season weed control and fungicide (Benomyl or Python + pH plus) applied to the seed head. Improved practices included the biological insecticide Dipel, full season weed control and fungicide spray for disease control. Fall armyworm larvae were the principal defoliators during the vegetative stages and leaf-footed bugs during the seed development stages. The lowest cumulative infestation of fall armyworm larvae was recorded in the improved pest management treatments with the biological insecticide and the largest infestation in plots experiencing insect pest control practices with the chemical insecticide used by the farmers. Dipel was more effective than cypermethrin for control of this insect pest, but did not affect certain natural enemy (i.e., lady beetles) populations. The chemical insecticide cypermethrin was more effective than Dipel for control of leaf-footed bugs on seed heads. The plant diseases that were observed on vegetative plants were caused principally by *Macrophomina phaseolina* and *Fusarium proliferatum.* Calcium sulfate broth in the improved management treatments was more effective in disease management than either Benomyl or Python + pH plus used in the treatment representing practices used by the farmers. Diseases on the seed heads, mainly molds, were caused by *Fusarium thapsinum, Curvularia lunata* and *Aspergillus flavus* and severity of disease was lower in improved technology plots than in the plots utilizing pest management of insect pests and diseases than the conventional pest management practices employed by the farmers. The results obtained in this investigation indicate that the improved pest management technology in sorghum provided better management of insect pests and diseases than the conventional pest management practices used by the farmers.

Sorghum entries (50) in the All Disease and Insect Nursery were evaluated for resistance to insect pests and diseases during the second growing season. Insects evaluated were fall armyworm on vegetative stages and sorghum midge on the reproductive stage. Midge infestations were too low for meaningful analysis. The principal diseases included gray leaf spot caused by *Cercospora sorghi*, zonate spot caused by *Gloeocerspora sorghi,* downy mildew caused by *Peronosclerospora sorghi* and anthracnose caused by *Colletotrichum graminicola.* All sorghum entries were infested with fall armyworm larvae, with only three considered tolerant to this lepidopterous defoliator. Twenty-four lines were considered very susceptible to fall armyworm feeding damage. Six sorghum lines were considered tolerant to gray leaf spot, downy mildew and anthracnose, five lines tolerant to gray leaf spot and anthracnose, and 10 lines tolerant to anthracnose and downy mildew. Considering individual diseases, 32 lines were considered tolerant to anthracnose, 23 to downy mildew and 15 to gray leaf spot. Six of the seven sorghum lines with highest yield (greater than 1000 kg ha^{-1}) were considered tolerant to fall armyworm, but susceptible to one or more of the above diseases. This might suggest that damage by fall armyworm to sorghum during vegetative and reproductive stages should be limited to improve crop yield and that the above diseases should be further evaluated to determine influence on crop damage and yield.

El Salvador

A survey was conducted by CENTA scientists in 2004 to determine the relative importance of insect pests on sorghum as identified by sorghum farmers in five areas of El Salvador. White grubs were identified as the principal insect pest of concern in all five areas, with fall armyworm, sorghum webworm, stalk borers and sorghum midge as secondary pests. This information will be used in defining areas for establishing insect pest management studies.

Based on information obtained in the insect pest survey, two studies were conducted on a farm located where the specific pests of interest have been a problem in sorghum production. In one test, insecticide (Lorsban) applications were made at different dates to determine efficacy of the chemical pesticide on stalk borers (*Diatraea* sp.). Insecticide was applied 15 days after planting and in a second treatment 25 days after planting. These treatments were designed to protect the plants during vegetative stages. When the two insecticide treatments were compared with the untreated control, the two insecticide treatments had less damage than the control and higher yields, and although the treatment at 15 days post plant had less damage than the treatment at 25 days post plant, no yield differences was observed between these two treatments. This data suggests that a single timed insecticide spray application during early vegetative stages of sorghum can be as effective as two spray applications on vegetative sorghum for managing stalk borers on sorghum, thus reducing the cost of chemical management of this pest on sorghum.

A test was conducted to evaluate the level of sorghum webworm (*Nola sorghiella*) control obtained when Lorsban insecticide was applied at the milk stage of sorghum seed. A second treatment included Lorsban spray application at the milk stage and a second spray application 16 days after the first application. These treatments were compared with the untreated control. The insecticide treatments and the untreated control did not differ in levels of seed damage or yield. Because this insect can be responsible for considerable damage to sorghum grain at times when infestations are very large on the panicles, this type of study should be conducted again to determine appropriate insect pest management tactics.

In recent years, the evaluations of sorghum materials in the All Disease and Insect Nursery (ADIN) in El Salvador resulted in the selection of sorghums with tolerance/resistance to certain diseases. More recently, insect damage has been evaluated on sorghums in the ADIN to complement the disease evaluations. In 2004, selected sorghum lines and varieties, and native sorghums (maicillos) were evaluated at two locations for both disease and insect resistance. Information was obtained on agronomic characteristics, incidence and severity of diseases and insect damage. Ten superior lines were selected from the 2003 ADIN based on tolerance to diseases and insects, size and color of the grain, length of the panicle, aspects of plant growth, and yield for further evaluation in the 2004 ADIN. Three lines, Sureno, D2CA4624 and 96CD635, were selected from the 2004 ADIN based on the above characteristics and will be planted in 2005. Five native macillos criollos were evaluated for disease and insect resistance at two locations in 2004. One maicillos, Indio Macartus, showed resistance to diseases, whereas two macillos, Indio Macartus and Indio, showed lower levels of resistance to disease and insect pests. The rust caused by *Puccinia sorghi* appeared to be the most important disease of sorghum in El Salvador.

Whiteflies, encountered for the first time on rice, sorghum and corn in 2003 by scientists at the University of El Salvador, were again infesting these crops in 2004, although populations were lower than in 2003. Of particular research interest in 2004 was whether the whiteflies would survive during the dry season (November-April) in El Salvador. Whiteflies were collected in low numbers in late February, 2004, indicating the potential for these pests to survive the harsh hot, dry period. The insects infested rice during mid-year, then moved to corn and sorghum during the second growing season (early-September). Crops were sampled in a number of areas in El Salvador to determine the range of this pest in the country. A number of areas not sampled in 2003 were determined to be infested with whiteflies in 2004. Whiteflies were decimated on rice with insecticide sprays but survived on wild host plants until corn and sorghum were planted. A grass, *Elasine indica*, contributed to the ability of the whiteflies to survive between first and second growing seasons. Other grass species may be important in the ecology of this pest in this region of Central America. Natural enemies, many identified in 2003, were at low levels in 2004, thus contributed little to the low population levels during the year.

United States

Sorghum-soybean rotation has been reported to improve yields of the two crops over continuous cropping of individual monocrop systems. Insect pests and diseases are limiting factors in the production of these crops. Studies were conducted in 2004 and will continue through the 2006 growing season in Mississippi to evaluate sorghum-soybean rotation systems for reducing pest pressure and increasing yields of these crops. Six sorghum-soybean planting, systems were initially established in small replicated plots in 2004, namely, 1) continuous sorghum, 2) continuous soybean, 3) sorghum-soybean-sorghum rotation, 4) soybean-sorghum-soybean rotation, 5)sorghum-soybean-soybean rotation, and 6. soybean-sorghum-sorghum rotation. Insect pests were sampled at 10 day intervals and disease incidence was evaluated monthly; samples for nematodes were made in May and September. Although three-cornered alfalfa hopper and bean leaf beetle adults and velvetbean caterpillar larvae were prevalent on soybeans, and corn earworm and sorghum webworm larvae and sorghum midge adults were numerous on sorghum, the populations of the pests were below economic thresholds on the respective crops. Zonate spot was the most prevalent of the diseases on sorghum. Frogeye leaf spot and stem canker were at low to moderate levels on soybeans. Spiral nematode was at greater numbers on soybean than on sorghum, but generally considered a minor pest on both crops. Root knot nematode was at low levels on both crops. No yield differences were recorded among treatment plots for each crop in the 2004 study, as might be expected because the crops were in the first plantings in each system.

Aflatoxins occur in sorghum and can be damaging to animals feeding on the crop. The feed industry requires that seed must contain less than 20 ppb aflatoxin, the legal limit. The relationship between insect pests and levels of mycotoxin forming fungi in sorghum-soybean rotational cropping systems was initiated in 2004 and will continue in 2005 and 2006. Aflatoxins in sorghum seed in the first year of the rotational system were determined using the Vicam Afla Test. Sorghum samples from test plots contained less than 20 ppb.

Stink bugs frequently become a concern to sorghum producers in the southeastern United States. Several species, including the southern green stink bug and green stink bug, infest the sorghum panicles and feed on the seed. Sorghum seed weight, quality and yield are reduced. Studies were initiated in 2004 and will continue in 2005 and 2006 in Mississippi to obtain information on the stink bug complex on sorghum. Both the southern green and green stink bugs were observed in large numbers on sorghum and soybeans during mid-and late season in North Mississippi. The southern green stink bug was the more prevalent of the two species. The green stink bug declined in numbers during this period, whereas the southern green stink bug continued to develop to even larger populations on sorghum before the onset of cold weather. Preliminary tests were conducted utilizing southern green stink bug adults or nymphs. Tests included: 1.) levels of adult or nymph infestations responsible for economic plant damage (economic injury level) and yield reduction, 2.) adult stink bug host plant preference for sorghum, corn, soybean or cotton, 3.) adult stink bug preference for sorghum in different plant growth stages, 4.) developmental rate of stink bugs on sorghum, corn or soybean seed, 5.) evaluation of insecticides for control of stink bugs on sorghum panicles, and 6.) observations on seed disease related to stink bug damage. As these studies were preliminary, experimental procedures will be refined and the studies will be repeated in 2005.

Networking Activities

The sorghum crop production and IPM workshop organized by INTSORMIL (MSU 205 and KSU 211), UNA, INTA, and ANPROSOR in Nicaragua in 2002 served as the stimulus for further development of similar scientific meetings and workshops involving scientists, farm organization personnel, and sorghum producers in Nicaragua and El Salvador in 2003 and 2004. Two workshops were conducted in Nicaragua and one in El Salvador in 2004 and additional meetings and workshops are planned for 2005. They included 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 in Nicaragua and CENTA in El Salvador.

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. Extension of research activities on the whitefly problem with scientists at the University of El Salvador proved to be very important in understanding this new pest situation in sorghum in this region of Central America.

Popular articles and departmental reports on sorghum pests published during the past two years provide information for farmers to use in managing insect pests and diseases on sorghum to improve yield. Publications are distributed by INTA and UNA in Nicaragua and CENTA in El Salvador into farm communities with assistance from local agricultural professionals.

Publications and Presentations

Books, Book Chapters and Proceedings

Serrano, Cervantes L., R. Guzman de Serrano, A.E. Moran, C.A. Borja Melara, M. Azahar Barrera, J.L. Mayen Rafael, A. De Garcia Andrade, J.A. Trujillo, M. Hernandez and H.N. Pitre. 2004. Population behavior of the whitefly, *Aleurocybotus occiduus*, in rice and sorghum in 2004 at Nueva Concepcion, Chalatenango, El Salvador, C.A. Proc. 9th IPM International Congress. Nov. 3-5, 2004. San Salvador, El Salvador.

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.

Presentations

Serrano, Cervantes L. et. al. 2004. Population behavior of the whitefly, *Aleurocybotus occiduus*, in rice and sorghum in 2004 at Nueva Concepcion, Chalatenango, El Salvador, C.A. Ninth IPM Int'l. Congress. San Salvador, El Salvador. Nov. 3-5, 2004.

Pichardo, Sergio T., Richard E. Baird and Henry N. Pitre. 2004. Occurrence of insect pests and diseases in sorghum (*Sorghum bicolor*) (Linn.) Moench and soybean (*Glycine max* (L.) Merr. rotations in Mississippi. Miss. Assoc. Plant Pathologists and Nematologists Ann. Meeting. Feb. 22-24. Stoneville, MS

Striga Biotechnology Development and Technology Transfer

Project PRF 213

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Dr. Mbwanga, *Striga* Specialist, Tanzania

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 activities on integrated *Striga* management in Ethiopia during 2002 and 2003 crop seasons. A bigger document highlighting project activities 2001-2004 is currently under preparation. On-farm evaluation of an ISM package was conducted in four *Striga* endemic regions of Ethiopia. The package included a *Striga* resistant sorghum cultivar, soil moisture conservation, and fertilization to synergize reduction of *Striga* infestation and increased sorghum yield. A secondary objective was to promote the use of newly released *Striga* resistant sorghum cultivars and to assist in the establishment of a community based seed multiplication program. Farmers in all four regions were positive on the power of the ISM package in reducing parasitic infestation and increasing yield. Date collected clearly showed that mean *Striga* count from the ISM package was ten to fifteen times lower while grain yield of sorghum was two to three time higher than plots planted to local sorghum cultivars.

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 results in failed parasitism leading to possible development of a control strategy. Our general approach has been to assemble suitable germplasm populations for potential sources of resistance, develop simple laboratory assays for screening these germplasm, establish correspondence of our laboratory assay with field performance, establish mode of inheritance of putative resistance traits, and transfer gene sources into elite adapted cultivars using a variety of biotechnological means. Whenever possible, the methods developed will be simple and rapid, in order to facilitate screening large numbers of entries.

We place major emphasis on developing control strategies primarily based on host-plant resistance. To this end, we have in place a very comprehensive *Striga* resistance breeding program in sorghum. Over the last several years, we have generated and selected diverse and outstanding breeding progenies that combine *Striga* resistance with excellent agronomic and grain quality characteristics. All previously known sources of resistance have been 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

Integrated Striga *Management (ISM) on Sorghum in Eastern Africa*

Striga parasitizes its host plant by attaching to the root, penetrating the vascular tissue and becoming a sink for water, nutrients and photosynthates. Successful parasitism results from a succession of signals released by the host plants and required for *Striga* to germinate, attach to the host roots, and penetrate the host vascular tissue. Several control measures have been suggested to reduce *Striga* infestation but taken individually, none present complete and durable control. Hand weeding practiced yearly, and even with several weedings during a cropping season, does not provide a durable control of *Striga*. Hand weeding is also labor intensive competing for a scarce resource at critical parts of the crop season. Chemical inputs such as herbicides, fumigants or germination stimulants that lead to suicidal germination of *Striga* are rarely considered as viable options since these inputs are often unaffordable for subsistence farmers. Crop rotation, catch or trap cropping, as well as mixed-cropping are also not practicable in areas where population pressure has put greater demand on availability of arable land. Use of resistant crop cultivars, perhaps is the only practicable and economically feasible *Striga* control measure.

Considerable progress has been made in identifying good sources of host plant resistance in several crops although the degree of resistance is variable across crops. With the use of genetic resistance, a host plant is grown that lacks the capacity to produce signals required for *Striga* to successfully complete its life cycle. Resistant crop cultivars could also produce inhibitors leading to failed parasitism, a potentially effective control since it both limits damage in the current crop and avoids the build up of *Striga* seed population in the soil. Breeding for durable resistance to *Striga* in sorghum as has been a focus in our group at Purdue University where several improved *Striga* resistant sorghum cultivars have been developed and released for wide cultivation.

A more enhanced control of *Striga* can be achieved by combining two or more individual control approaches synergistically. Yet, there has been limited on-farm research undertaken to evaluate the benefits of integrating multiple control options against *Striga*. Even with highly resistant crop cultivars, a more enhanced *Striga* control and increased crop productivity can be achieved by synergistic combination of one or more agronomic practices with host plant resistance. Because damage caused by *Striga* is more severe on host crops that are already under abiotic stress caused by soil fertility depletion and moisture shortage, we proposed an Integrated *Striga* Management (ISM) project through our INTSORMIL/Purdue University collaborative program in Eastern Africa. The project targets several countries where *Striga* pressure is severe. The ISM Pilot Project started in 2001 in Ethiopia, and expanded more recently in Eritrea and Tanzania.

The goal of the ISM program is to reduce the ravages of *Striga* on sorghum production where the parasitic weed is endemic. Specific objectives were: 1) to promote a technology package that integrates host plant resistance, soil fertility enhancement, and water conservation measures for control of *Striga* and enhanced crop yield; 2) to establish a functional seed program by promoting seed production as a commercial entity and by developing seed growers' organizations; 3) to increase profitability for farmers involved in the ISM project by promoting new markets and products for sustainable use of their technology package.

Progress of work in Ethiopia is reported in here. The ISM Pilot Project was carried out in four *Striga* endemic regions of Ethiopia: Oromia, Amhara, Tigray, and Southern (Fig. 1). The implementation of the ISM program was coordinated by

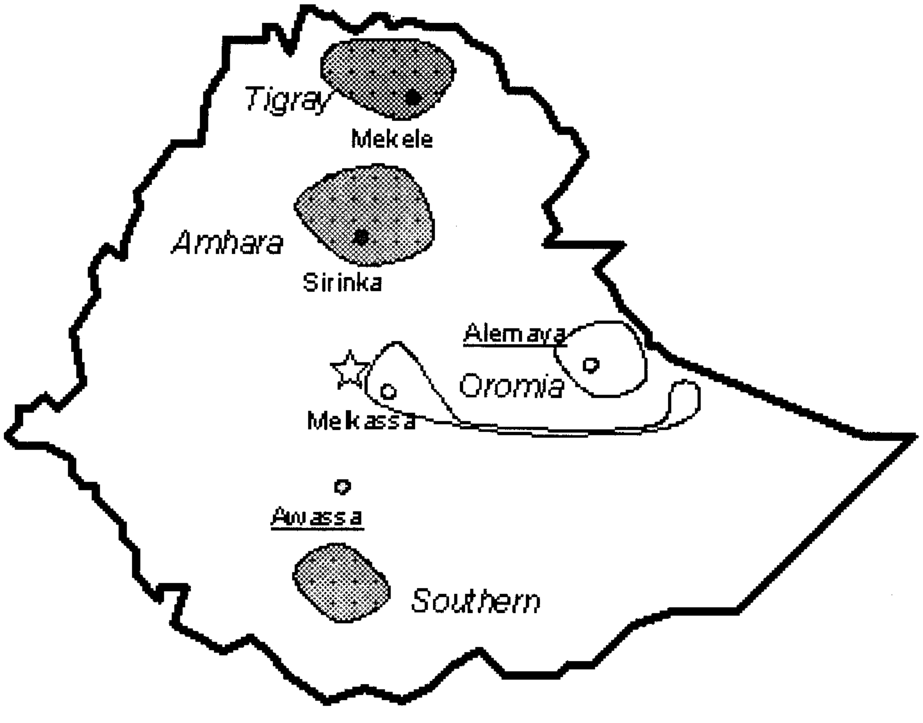

Figure 1. ISM pilot project conducted in four regions of Ethiopia: Tigray, Amhara, Oromia and Southern region (in italic), in 2002 and 2003.

the Ethiopian Agricultural Research Organization (EARO) and in collaboration with Regional Research Centers, higher learning institutions, and regional Bureaus of Agriculture (BoA). Coordination of activities and overall management was provided by Melkassa Agricultural Research Center (MARC) and Alemaya University (AU) for Oromia region; by Sirinka Agricultural Research Center (SARC) for Amhara; Tigray Agricultural Research Institute (TARI) for Tigray, and by Awassa Research Center (ARC) for the Southern region.

Project activities were conducted on farmers' fields that were primarily selected based on their history of heavy *Striga* infestation. The project was designed for one-half hectare plot sizes, though farms of various sizes were included based on land availability. Three sets of activities were carried out: 1) demonstration of the ISM package of host plant resistance, fertilization, and tied ridges; 2) popularization of *Striga* resistant varieties without providing fertilizer inputs; 3) seed production of *Striga* resistant sorghum varieties under as optimal a condition available to the farmer. Farmers were selected and grouped for each of the three activities based on their keenness to participate, apparent knowledge base, and land type and degree of infestation by *Striga* and wild sorghums.

Of eight *Striga* resistant sorghum cultivars released by Purdue University/INTSORMIL in 1995, two selections (P9401 and P9403) were officially recommended for wide cultivation under the local names of "Gubiye" (P9401) and "Abshir" (P9403). Good quality seed of 'Gubiye' and 'Abshir' were produced in large quantities both at Purdue University and Melkassa Agricultural Research Center during the previous crop season and were distributed to farmers selected to participate in the ISM project. Nitrogen fertilizer in the form of urea and diammonimum phosphate (DAP) were purchased from the local market and provided to selected participants. Tied ridgers were fabricated in the local industrial area in Nazret from a design provided by the Melkassa Research Station.

The primary technology focus was to demonstrate the benefits of combining host plant resistance with improved agronomic practices of fertility restoration and water conservation. Farmers with fields heavily infested with *Striga* and easily accessible for others to visit were selected to demonstrate the ISM package. These farmers were required to also have fields cultivated with the local landraces and under local practices nearby as control plots. For this activity, farmers were provided with *Striga* resistant sorghum seed, fertilizers (DAP and urea), and with tied ridgers as a strategy for water conservation unless other local practices were available. When needed, farmers were also shown how to row plant the seed, apply fertilizer, and construct and maintain tied-ridges.

Farmers whose fields were heavily infested with *Striga* but not in easy reach were given free seed only so they could test the improved sorghum varieties for local adaptation and their efficacy on *Striga* control as a popularization of the genetic component of the package. Fertilizer and tied ridgers were not provided to these farmers. Seed of either 'Gubyie' or 'Abshir' were distributed based on potential fit to the environment from prior testing.

The third activity of the ISM pilot project was intended to promote organized seed production and to train local farmers as seed growers. For this activity, farms were selected on the basis of soil type, soil fertility, and isolation from other sorghum fields and wild relatives of the crop. In this case, when available, farm lands free of *Striga* were chosen. If *Striga* was found in the field, special care was taken during post harvest seed processing activities to minimize contamination. Farmers involved as seed growers were advised to adopt use of inputs and improved agronomic practices. Inputs were provided free to seed producers and the use of improved water conservation practices highly recommended. Seed producers were inspected at different times during the season and the quality of their seed crop assessed. Seed crops deemed of acceptable quality were bought back by the project from farmers at an agreed upon premium over the going market price.

In both the 2002 and 2003 crop seasons, the ISM Pilot Project was undertaken in four administrative regions (Fig. 1) and focused on the three primary activities of popularization, demonstration, and seed production. For each of the three primary activities, seed of *Striga* resistant sorghums were provided free to farmers involved in the project. In 2002, about 3.6 tons of seed were distributed to 472 farmers and 6 tons were provided to 1340 farmers in 2003. Of these 6 tons of seeds, half were obtained from on farm seed multiplication activity conducted by participating farmers the previous year. The balance of seed was produced on research farms supervised by project coordinators. Farmers participating in the ISM demonstration and seed multiplication activities also received 13.8 tons of fertilizers in 2002 and 12.6 tons in 2003. Ninety tied ridgers were fabricated and distributed to participating farmers the first year and an additional 12 tied-ridgers were provided during the second year. Seed producers were assured of a premium price for their produce provided that the seed met inspection and quality standards outlined by the project personnel.

Though plots involved in the popularization activities were not monitored and performance data were not recorded by project personnel, oral reports indicated that the results were encouraging in all four regions. Farmers were impressed not only by the high level of resistance to *Striga* manifested by these cultivars, but also by the early maturity, drought tolerance, as well as the good grain quality of the *Striga* resistant varieties. During the two crop seasons, 1337 farmers grew the *Striga* resistant sorghum cultivars with seed provided by project personnel. The number of farmers who received seed of *Striga* resistant cultivars during the second year through informal exchange with neighboring farmers who grew these cultivars the previous year is not known.

Demonstration

During the first year, 145 farmers received the three components (seed, fertilizer, and ridgers) to participate in the demonstration of the ISM package promoted by the project. In the second year, 135 farmers were involved in the demonstration activity. Data on *Striga* count and grain yield recorded on the demonstration plots showed the value of the package in *Striga* control and increased productivity. The results of the demonstration activity were consistent across farms and years. Plots that received the ISM package showed drastically reduced *Striga* count with significant and concomitant increase in grain yield. Grain yields as high as 5.5 tons were recorded in some demonstration plots that received the package. In contrast, many of the local sorghum landraces grown with no input and only the local practice of hand weeding failed totally with no measurable yields recorded.

Seed Production

Emphasis here was in promoting the concept of seed as different from grain. Farmers were instructed in treating seed production differently from grain production, a lesson often difficult for traditional farmers to grasp. Traditional community-based seed production efforts often fail for this reason. Farmers do not like removing outcrosses by rogueing and meeting isolation requirement is often seen as waste of resources. During the first year of the pilot project, 83 farmers were involved in the seed multiplication activity. Of these, 46 successfully produced a total of 26.5 tons of seeds. Grow-out tests showed acceptable levels of contamination. Out of this amount, about eight tons were reported to have been purchased by NGOs, the BoA and the pilot project itself. These seed was then redistributed to 925 farmers including the 477 farmers who received the seed from the project in 2003. It has been reported that a significant quantity of seed produced by farmers who participated in the 2002 seed multiplication activity have been informally distributed to neighbors to further the popularization and diffusion of these cultivars. The exact quantity of seed that has been exchanged informally is not known, however. In the second year, 112 farmers were involved as seed growers.

Training and outreach turned out to be an important aspect of the ISM pilot project program. Project staff at MARC trained about 100 individuals from the Amhara, Oromia and Southern regions. Trainees included Subject Matter Specialists (SMS), Development Agents (DA) from the Bureaus of Agriculture and selected farmers. Regional research centers in Tigray (TARI) and Amhara (SARC) also conducted additional training for their respective staff and selected farmers. In addition, SARC provided college students from Mersa Agricultural and Technical Vocational College with lectures on the biology and control of *Striga*. DAs from different localities of the Southern and Oromia regions participated in a workshop on agronomic practices, sorghum seed production, and *Striga* biology and control. Furthermore, workshops were also organized at the end of each of the two years to gauge progress and provide a mid-term review of the ISM pilot project with participants from each of the four regions.

Fields days were also organized each year and at each of the regions to extend the technology to other farmers, to create awareness among policy makers, and to demonstrate the benefits of control of *Striga* through the ISM technology package. In 2003, MARC organized two field days involving farmers and DAs from Oromia region in western Hararghe, and in east Hararghe. Two field days were also organized in 2002 and repeated at the end of the 2003 cropping season at Sirinka. Several field days were also organized by TARI at several locations in the region.

Voluntary involvement of NGOs in the ISM program served as a good indication of the success the diffusion of the ISM technology package. During the 2002 crop season, two NGOs; (Kobo Giranna Valley Development Program (KGVDP) and Hope Ethiopia) purchased seed of *Striga* resistant sorghum cultivars produced by the research farm at SARC for distribution to collaborating farmers in the Amhara region. In the Oromia region the Red Cross purchased 1.6 tons of seed from Alemaya University to redistribute to farmers in the Fedis area. Catholic Relief Services purchased an additional 2 tons of *Striga* resistant sorghum seed from farmers involved in the seed multiplication activity in Eastern Hararghe. All of the seed was presumably distributed to farmers in the same region.

Interest in the use of *Striga* resistant sorghum cultivars and the use of the integrated *Striga* management (ISM) package of cultivars, fertilizers, and water conservation practice has increased considerably in Ethiopia. The broad-based involvement and participation of farmers, development agents, research scientists, and government officials has facilitated this success. Popularization of *Striga* resistant sorghum was conducted widely across four regions of Ethiopia. Feedback from farmers and BoA agents were all very positive, recognizing the *Striga* resistance, drought tolerance, and excellent grain quality of the two cultivars ('Gubiye' and 'Abshir') in wide distribution in the country. The demonstration of the ISM technology package showed very dramatic results in *Striga* control as well as significant enhancement of sorghum grain yield. The rationale of the ISM package of improved cultivars, fertilization, and water conservation was greatly appreciated. Increased diffusion of seed of the improved cultivars as well as acceptance of the ISM package were greatly assisted by the planned field days and workshops held at various sites during the project period. In light of the success of the efforts undertaken and recommendation of participants at regional centers, in June 2003 the government of Ethiopia declared the ISM package to be widely practiced as a national campaign in *Striga* endemic areas of the country.

Lack of a functional seed multiplication effort for sorghum in Ethiopia had hampered further diffusion of improved varieties in spite of the great demand in many areas. The ISM program has demonstrated that good quality seed could be produced by farmers selected to participate as seed growers for multiplying *Striga* resistant sorghum varieties. However the sustainable development of a viable seed multiplication enterprise requires the creation of proper incentives and formulation of a structure and entity that needs to be put in place. Furthermore, a functional seed enterprise depends on farmers' ability to pay for inputs, which in turn depends on the profitability of the practice in the farm community. We are currently working towards developing a cooperative-based community seed enterprise with necessary market outlets for both seed and grain.

Networking Activities

Workshop and Program Reviews

We have been involved in a number of engagements in our *Striga* research and development this past year. Two major programs have been underway in Ethiopia and Eritrea 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 one 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. The second, but very important, objective of the project in both countries 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 Ethiopia to kick of the demonstration and seed multiplication activities. 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

We have had individuals from India, Ethiopia, Uganda, Burkina Faso, Eritrea, Mali, Niger, and Kenya visit our *Striga* research facility at Purdue University. In addition, Dr. Hamidou Traore, a Fulbright fellow spent a year at Purdue conducting *Striga* research in our facility. His work 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 Tanzania.

Publications

Refereed Papers

Rich, P.J., C. Grenier and G. Ejeta. 2004. *Striga* resistance in the wild relatives of sorghum. Crop Sci. 44:2221-2229.

Conference Proceedings

Kapran, I., C. Grenier, and G. Ejeta. 2004. Introgression of genes for *Striga* resistance into African landraces of sorghum. McKnight Foundation Collaborative Research Program, Workshop on Millet and Sorghum-based Systems in West Africa. Niamey, Niger.

Toure, A., B. Dembele, M. Kayentao, and G. Ejeta. 2004. Genetic improvement of *Striga* resistance in sorghum. McKnight Foundation Collaborative Research Program, Workshop on Millet and Sorghum-based Systems in West Africa. Niamey, Niger.

Grenier, C., A. Deressa, Z. Gutema, G. Gebeyehu, H. Shewayrga, M. Mekuria, A. Belay, T. Tadess, N. Mengistu, O. Oumer, A. Adugna, B. Tsegaw, and G. Ejeta. 2004. Integrated *Striga* Management (ISM) in East Africa. McKnight Foundation Collaborative Research Program, Workshop on Millet and Sorghum-based Systems in West Africa. Niamey, Niger.

Invited Presentations

Ejeta, G. 2004. Understanding key developmental processes in parasitic weeds, a keynote address at the Weed Science Society of America Annual Meetings, June 21-24, Durban, South Africa.

Sustainable Management of Insect Pests

Project WTU 200

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Summary

The PI traveled to Botswana, Mozambique, and South Africa in March to review collaborative research to manage insects and develop IPM approaches for sorghum and discuss Ph.D. programs for prospective students. Texas sorghum lines were resistant, but most Botswana sorghums were damaged by sugarcane aphids at Botswana College of Agriculture. Sorghum sprayed with extracts from local plants were less damaged by aphids, sorghum midge, panicle bugs, and grain mold than the nontreated check in Mali. Stored sorghum grain treated with local plants was less damaged by lesser grain borer in Mali. Six sorghums were resistant to sorghum midge in Niger. Survival and damage by millet head miner and yield of pearl millets were evaluated in Niger. A M.S. student who graduated and returned to Mozambique in August finished evaluating resistance of stored sorghum and found weight losses of 0.8-46.8% at 105 days after infestation with maize weevils. Light and scanning electron microscopy was used to compare seed coats of susceptible versus resistant sorghums, which were twice as thick. Plant differentials were used to determine greenbugs from Kansas and Texas were biotype I. A total of 2,493 sorghums developed by TAM 223 and two commercial seed companies were evaluated for resistance to greenbug biotypes E and I. A M.S. student graduated in August after finishing assessing tritrophic effects and finding greenbugs from resistant sorghum negatively affected lady beetle eggs. A Malian M.S. student began assessing effects of photoperiod on greenbug biotypes. An Ethiopian began Ph.D. studies in fall 2004. A Malian who came to West Texas A&M University to learn English began a M.S. program in 2005. Research results were presented at entomology, extension, farmer, and sorghum meetings. The PI advised extension personnel and the National Grain Sorghum Producers on management of insects.

Objectives, Production and Utilization Constraints

Objectives

Southern Africa

Support scientists from Botswana, Mozambique, and South Africa with research to evaluate resistance and develop IPM strategies for such sorghum insect pests as sugarcane aphid, stalk borers, termites, and storage beetles. Educate graduate students in entomology and IPM.

West Africa

Support scientists from Mali and Niger with 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.

United States

Study biology, ecology, and population dynamics of insects so effective management strategies and longer-lasting plant resistance can be developed. Use standard and molecular techniques to identify biotypes of greenbugs from the field. Asssess effects of resistant sorghum on lady beetles feeding on greenbugs from the sorghum. Evaluate sorghum grain for resistance to storage insect pests and use microscopy to relate grain characteristics with resistance. Collaborate with breeders, commercial seed companies, and molecular biologists to develop sorghums 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 insects of sorghum. Participate in professional meetings to transfer insect pest management information.

Production Constraints

Southern Africa

Stalk borers; sugarcane aphid, *Melanaphis sacchari*; panicle bugs; termites; and sorghum midge, *Stenodiplosis sorghicola*; infest and reduce yields of sorghum. Sorghum midges can destroy 100% of kernels. Stalk borers bore into the plant and kill the central shoot or break the peduncle. Bugs and associated infection by pathogens reduce yield and quality of grain. Beetles consume and contaminate stored grain.

West Africa

Panicle bugs, sorghum midge, stalk borers, and beetles in stored grain are the most damaging insects of sorghum in West Africa. The worst insects of pearl millet are millet head miner, *Heliocheilus albipunctella*, that reduces grain yield and quality, and *Coniesta ignefusalis* stalk borer.

United States

Major insect pests are greenbug, *Schizaphis graminum*; sorghum midge, panicle bugs and caterpillars, and beetles and moths in stored grain. Monoculture of sorghum disrupts the ecosystem, increases severity of pests, and results in increased production costs and less yield. Insecticides prevent damage and yield loss, but overuse results in increased production costs, disruption of the ecosystem, outbreaks of secondary arthropods, resurgence of the targeted pest, and environmental contamination. Biology, insect-plant interactions, amount of damage, and economic and ecological costs of insecticides need to be understood to manage insects. 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. The insect must be identified; its biology, ecology, and population dynamics understood; abundance determined in relation to crop damage and yield loss; and control tactics used, especially conservation of natural enemies, resistant varieties, and insecticide when necessary. Information and technology from research is transferred to farmers, extension, and others.

Southern Africa

From March10-21, 2005, the PI traveled to Botswana, Mozambique, and South Africa to view current and plan collaborative research and discuss Ph.D. programs for prospective students. Mr. Chitio assessed amount of damage storage insects caused in fields of sorghum planted at three dates at Nampula Research Station in Mozambique. In South Africa, Drs. du Plessis and Peterson were assisted with evaluating sorghums for resistance to sugarcane aphid. Dr. van den Berg and students at North West University, South Africa, surveyed 25 sorghum fields each week from boot until kernel maturity and found 35 species of panicle bugs that differed in abundance over time.

In collaborative research at Botswana College of Agriculture, D. C. Munthali, M. Obopile, and M. Kelatlhilwe evaluated for resistance to sugarcane aphid seven sorghums common in Botswana (BSH 1, Mahube, Mmabaitse, Marupantsi, Macia, Phofu and Segaolane) and Texas-bred 04CA 10391, 04L 217, and 04L 295 lines. Each genotype was planted in a 7-m row in each of two cages 5.2 m long, 3.0 m wide, and 2.5 m tall. A completely randomized design was used to allocate genotypes to rows. Seeds were planted with 30 cm between plants and 50 cm between rows. Plants 4 weeks after germination in one cage were artificially infested with sugarcane aphids. The aphids were left until grain filling. Plants in the second cage were not infested. Abundance and damage by sugarcane aphids was assessed on 10 randomly selected plants in each row. Damage was scored 1-5, where 1 = 0-20, to 5 = 81-100% leaves dried or drying per plant. Damage scores were similar and significantly less (1.1-2.1) on noninfested than infested plants of all genotypes except Mmabaitse and 04AC 10391 (Table 1). Infested Mahube, Phofu, Macia, Segaolane, and Marupantsi were significantly more damaged than other genotypes. Infested 04L 217 and 04L 295 were significantly least damaged (1.1 score). Aphids caused 4.5, 3.3, 3.0, 3.0, and 2.2 fold more damage on infested than noninfested Mahube, Phofu, Segaolane, Marupantsi, and Macia, but there were no differences in damage between noninfested and infested 04L 217 or 04L 295.

West Africa

Madani Telly finished English training and began a M.S. program at West Texas A&M University. Tiecoura Traore from Mali started the second year of a M.S. program.

Dr. Yaro Diarisso assessed efficacy of local neem and *Calotropis procera* plants against aphids, sorghum midge, bugs,

Table 1. Resistance of southern African and Texas sorghums to sugarcane aphid in Botswana.

Sorghum genotype	Mean damage score (± SE) on sorghum plants not infested or infested by sugarcane aphids		Overall variety or line damage score
	Non-infested plants	Infested plants	
Macia	2.1 ± 0.10 b-e	4.6 ± 0.16 a	3.4 f
Phofu	1.5 ± 0.27 c-e	4.9 ± 0.10 a	3.2 f
Mahube	1.1 ± 0.10 e	5.0 ± 0.00 a	3.0 f
Segaolane	1.6 ± 0.22 c-e	4.5 ± 0.22 a	3.0 f
Marupantsi	1.4 ± 0.22 de	4.2 ± 0.47 a	2.8 f
Mmabaitse	2.0 ± 0.26 b-e	2.4 ± 0.16 bc	2.2 g
BSH1	1.1 ± 0.10 e	2.4 ± 0.22 bc	1.8 gh
04CA 10391	1.4 ± 0.16 de	2.8 ± 0.33 b	2.1 g
04L 295	1.5 ± 0.17 c-e	1.1 ± 0.10 e	1.3 h
04L 217	1.3 ± 0.15 de	1.1 ± 0.10 e	1.2 h
Overall treatment score	1.5 ± 0.10	3.3 ± 1.04	2.4

CV = 0.242

Means followed by the same letter in a column are not significantly different (Tukey, $P < 0.05$).

Table 2. Damage by sorghum midge, panicle bugs, and grain mold and kernel weight of S34 sorghum treated with extracts from local plants.

Treatments	Damage score by sorghum midge on 10 panicles	Damage score by bugs on 10 panicles	Rate of grain mold on 10 panicles	Weight (g) of grain from center rows
Non-sprayed check	3.1 a	4.0 a	2.2 ab	433.3 a
Neem seed jelly (200 g/l)	3.1 ab	3.2 b	2.2 ab	566.3 c
Neem seed jelly (250 g/l)	2.2 bc	3.0 b	2.1 ab	600.3 c
Calotropis procera juice (10 l/ha)	2.4 a-c	4.1 a	2.5 a	466.7 b
Dursban (5.3 ml/l)	1.5 cd	2.0 c	1.9 c	666.7 cd
Panicles protected by bag	1.0 d	1.0 d	1.0 c	700.0 d
CV	0.3673	0.1416	0.0677	
Probability	0.048	0.00	0.00	
Significance	S	HS	HS	HS

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

and grain mold on bug-susceptible S34 sorghum in Mali. A Fisher block design with six treatments and three replications was used. Plant juice was filtered and sprayed on seedlings, at the end of flowering, and at hard dough. Insects were counted a day before and week after treatment. After treatment, fewer aphids infested seedlings, especially treated with neem or Dursban. Three times more aphids were in plots before as after treatment with *C. procera*. At hard-dough, numbers of bugs were less than half after plots were sprayed with Dursban or plant extract. Fewest bugs (5) were in plots sprayed with Dursban, followed by 250 (7) or 200 g/l of neem seed jelly (<10). No bugs were on panicles protected by bags. Damage to panicles protected by bags or Dursban did not differ from each other but differed from panicles sprayed with plant extract (Table 2). Scores of damage by sorghum midge, bugs, and grain mold were 3.1, 4.0, and 2.2 on check plants and 1.5, 2.2, and 1.9 on panicles sprayed with Dursban. Panicles sprayed with greater doses of neem seed jelly (200 or 250 g/l) had less mold than panicles sprayed with lesser doses. Weight of protected grain was greater than that of the check or panicles sprayed with *C. procera*. Bags or Dursban better protected panicles from insects and mold than did plant extracts, which were better than the check.

Dr. Yaro Diarisso treated four replications of Malisor 92-1 grain in cotton-cloth bags with powder from *Calotropis procera* or *Cassia nigricans* plants. Percentage of grain damaged by lesser grain borer, *Rhyzopertha dominica*, was assessed each month for 6 months by counting and weighing numbers of damaged and nondamaged grains per treatment and replication. Damage by lesser grain borer started the third month and increased over time (Table 3). Nontreated grain was most damaged. Plant powders were more effective at greater doses. Lesser grain borer destroyed 0.4 and 2.3% of grain the third month to 4.3 and 5.1% the sixth month after treatment with 6 and 3 g, respectively, of plant powder per kilogram. Loss of nontreated grain was 3.4-7.1%. Efficacy of powder decreased and insects increased over time.

Hame Abdou Kadi Kadi and collaborators from INRAN, INTSORMIL, and ICRISAT evaluated 38 single-seed descent sorghum lines and improved varieties and 33 varieties from ICRISAT for resistance to sorghum midge at the Regional Agricultural Research Center at Maradi, Niger. At 25-50% anthesis, spikelets at the top and immature spikelets at the bottom of a panicle were removed so flowering spikelets in the middle were exposed to sorghum midge. A wire frame covered with net 20 cm wide and 40 cm long was placed

Table 3. Sorghum grain loss to lesser grain borer after treatment with powder of *Calotropis procera* or *Cassia nigricans* at Sotuba, Mali, in 2004.

Grain treatment	% loss at months after treatment			
	3 months	4 months	5 months	6 months
Calotropis procera powder (6 g/kg grain)	0.3 c	1.3 c	2.3 c	4.4 b
Calotropis procera powder (3 g/kg grain)	2.2 b	3.2 b	4.4 b	5.0 b
Cassia nigricans powder (6 g/kg grain)	0.5 c	1.7 c	2.7 c	4.2 b
Cassia nigricans powder (3 g/kg grain)	2.4 b	3.3 b	4.5 b	5.1 b
Nontreated check	3.4 a	4.7 a	5.7 a	7.1 a
CV	0.2619	0.1706	0.1274	0.1392
PPDS	0.7641	0.7595	0.7641	1.137
Significance	HS	HS	HS	HS

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

Table 4. Mean (± SE) percentages of millet head miner stages developed, damage score, and yield for infested pearl millet at Maradi, Niger, in 2004.

Pearl millet variety	% neonate larvae	% medium larvae	% large larvae	% pupae	Damage score	Yield (kg ha^{-1})
1A x TMK	14.4 ± 10.4 a-d	1.3 ± 0.7 bc	1.3 ± 0.7 b	1.3 ± 0.7 ab	2.0 ± 0.4 ab	1133.4 ± 34.3 a
ICMV IS 99001	13.8 ± 8.2 a-d	2.5 ± 2.5 a-c	0.6 ± 0.6 b	0.6 ± 0.6 b	2.3 ± 0.8 ab	1083.4 ± 34.4 a
HKP-GMS	28.5 ± 11.2 ab	11.4 ± 7.1 a	4.9 ± 4.9 ab	1.1 ± 1.1 b	2.1 ± 0.6 ab	1065.1 ± 33.2 a
TMK	21.3 ± 8.0 a-d	2.5 ± 2.5 a-c	0.0 ± 0.0 b	0.0 ± 0.0 b	1.0 ± 0.0 b	1021.7 ± 13.9 a
1A x KBH	9.9 ± 7.7 a-d	1.7 ± 1.7 a-c	0.9 ± 0.9 b	1.3 ± 0.9 b	1.3 ± 0.3 b	1000.1 ± 27.3 a
ICMH 2003	26.3 ± 9.4 ab	0.0 ± 0.0 c	0.0 ± 0.0 b	0.0 ± 0.0 b	1.3 ± 0.3 b	991.7 ± 42.9 b
ICMH 2104	18.2 ± 7.7 a-d	11.0 ± 6.6 ab	2.9 ± 2.2 ab	2.9 ± 2.2 ab	3.3 ± 0.9 a	950.1 ± 85.4 b
ICMV IS 92326	7.5 ± 7.5 b-d	1.9 ± 1.9 a-c	0.6 ± 0.6 b	0.6 ± 0.6 ab	1.5 ± 0.5 b	900.1 ± 96.2 b
ZATIB	23.8 ± 8.5 a-c	3.2 ± 3.2 a-c	1.8 ± 1.8 ab	2.3 ± 2.3 ab	1.4 ± 0.4 b	850.0 ± 29.4 b
¾ HK B-78	31.4 ± 9.2 a	3.8 ± 2.4 a-c	8.3 ± 8.3 ab	0.4 ± 0.4 b	1.8 ± 0.8 ab	825.0 ± 25.7 b
SOSAT–C 88	8.6 ± 3.5 ab	8.5 ± 4.8 a-c	11.9 ± 8.9 a	3.5 ± 2.4 ab	2.5 ± 0.9 ab	776.7 ± 59.5 b
ICMV IS 90311	3.4 ± 3.8 cd	2.5 ± 2.5 a-c	1.3 ± 1.3 b	1.3 ± 1.3 ab	1.5 ± 0.5 b	741.7 ± 26.8 b
ANKOUTESS	8.2 ± 3.6 b-d	8.2 ± 3.6 a-c	4.8 ± 2.9 ab	4.8 ± 2.9 a	2.0 ± 0.7 ab	733.4 ± 22.8 b
KBH	0.0 ± 0.0 d	0.0 ± 0.0 c	0.0 ± 0.0 b	0.0 ± 0.0 b	1.0 ± 0.0 b	628.4 ± 83.9 c
Mean	16.8	4.2	2.8	1.4	1.8	907.2
LSD	21.9	9.9	10.6	4.1	1.6	70.6
CV	58.9	67.8	24.7	25.7	64.4	54.2

Means followed by the same letter in a column are not significantly different (Student T-test, $P < 0.05$).

around a panicle. Twenty female sorghum midges collected between 0600 and 0900 were placed in each cage on two consecutive days. Five to 10 panicles of each genotype were infested. Cages were removed 15 days later and damage was scored 1-9, where 1 = <10, to 9 = >81% damaged spikelets. Panicles from the middle row were rated for damage and harvested, and panicle and grain weights determined. Sorghum midges were more abundance and caused more damage to sorghum planted on the first date. Yield losses of 99 SSD F9-1, 99 SSD F9-5, 99 SSD F9-6, 99 SSD F9-19, 99 SSD F9-27, and IRAT 204 were 60.0-70.5%. Yield losses of 99 F9-31, ICSV 745, and 99 F9-37 were 7.4, 9.3, and 10.6%. Yields were 7.6, 12.2, 14.2, and 15.2% less for ICSV 745, 99 F9-17, 99 F9-35, and 99 F9-29 planted on the second date. For ICRISAT sorghum, the greatest damage score was 7.0 and yield loss 75.6% for ICSV 93071. Damage was 2.5 for Mota Maradi, IRAT 204, and ICSV 90001, with yield losses of 33.5, 54.2, and 57.6%. Yield losses were 2.1, 6.4, and 13.5% for ICSV 90013, ICSV 90011, and 99 SSD F9-35, while damage was 1.0. DJ 6514, ICSV 197, ICSV 745, ICSV 93077, 99 SSD F9-35, and ICSV 90011-13 were resistant to sorghum midge, and DJ 6514 and ICSV 90011 were very infested but yielded only 20-30% less.

Hame Abdou Kadi Kadi and collaborators evaluated improved pearl millet varieties and ICRISAT-Niamey millet genotypes at the Regional Agricultural Research Center at Maradi, Niger. The experiment was a completely randomized block with four replications. Each 15-m^2 sub-plot had five rows 5 m long, with 1 m between rows and 1 m between hills. Spikes were covered at boot. A cage 70-90 cm long x 30 cm diameter from a wire frame covered by cotton mesh was placed over a spike at 1/3 exsertion (5-10 cm). A sticker with 40 millet head miner eggs from a farmer's field was pinned to a spike 2-3 days later. Four spikes of each genotype per replication were infested. Five days after infestation, spikes were checked for eggs. Survival of millet head miner life stages (different sized larvae, pre-pupae, and pupae) was monitored, and damage was scored 1-9. At maturity, spikes were cut and damage was assessed. Most (31.4%) and no millet head miner eggs on ¾ HK B-78 and KBH hatched (Table 4). Most medium larvae (11.4 and 11.0) were on HKP-GMS and ICMH 2104. Most large larvae (11.9%) developed on SOSAT-C88. No medium or large larvae developed on ICMH 2003 or KBH. Most pupae (4.8%) were on ANKOUTESS. No pupae developed on TMK, ICMH 2003, or KBH. Damage to ICMH 2104 was 3.3. Damage to TMK and KBH was 1.0. 1A x TMK, ICMV IS 99001, HKP-GMS, TMK, and 1A x KBH yielded most (1,133-1,0001 kg ha^{-1}). KBH yielded least (628 kg ha^{-1}). Hybrids ICMH 2003 and ICMH 2104, with 1.3 and 3.3 damage and 991.7 and 950.1 kg ha^{-1} yields, had tolerance to millet head miner. Improved varieties ICMV IS 99001, HKP-GMS, and TMK had some tolerance. Flowering of checks ZATIB and ¾ HK B-78 escaped millet head miner.

United States

Five hundred twelve and 1,625 sorghums were evaluated for resistance to greenbug biotypes I and E for TAM223. Two hundred twenty-one and 135 sorghum lines developed by Pioneer Hi-Bred International, Inc. and Milo Genetics were evaluated for resistance to biotype I.

Standard sorghum and wheat differentials were used to determine that greenbugs from Barton, Ellis, Kiowa, McPherson, Pratt, and Rush Counties, Kansas, were biotype I. Greenbugs from Archer, Baylor, Clay, Hale, Hardeman, Hidalgo, Jack, Moore, Randall, Swisher, Wichita, and Young Counties, Texas, were biotype I. In collaboration with Dr. Zhu-Salzman, molecular markers that differentiate greenbug biotypes are being used to identify and verify the biotypes of greenbugs collected from Kansas and Texas.

Master's student Tiecoura Traore began assessing effects of photoperiod on pre-reproductive period, fecundity, and longevity of greenbug biotypes E and I to understand differences between biotypes and determine best conditions to use when evaluating sorghums for resistance.

Master's student Murali Ayyanath finished assessing 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 and photoperiod of 14:10 light:dark hours. Lady beetle larvae and adults consumed similar numbers of greenbugs from resistant or susceptible sorghum. Larvae ate 1.7 and adults ate 2.0-3.1 times more greenbugs at 23 than 30°C. Each adult ate 17,124 and 16,325 greenbugs from resistant and susceptible sorghum at 23°C. Almost 8.5 times more eggs were produced per lady beetle fed greenbugs from susceptible sorghum at 23°C (2,893) than by lady beetles fed greenbugs from resistant sorghum at 30°C (342). Numbers of eggs were greatest from lady beetles fed greenbugs from susceptible sorghum. At 23°C, 91.0% hatched of 2,893 eggs by lady beetles fed greenbugs from susceptible sorghum. Only 21.8-39.4% of eggs hatched from other pairs of beetles paired as adults in four ways based on the sorghum source of greenbugs from which the lady beetles had been fed. Greenbugs from resistant sorghum negatively affected the number and viability of eggs produced by convergent lady beetles.

Master's student Fernando Chitio finished evaluating resistance of 20 genotypes of stored sorghum grain to maize weevil, *Sitophilus zeamais*, graduated, and returned to Mozambique. Five newly emerged maize weevils were put with 5.0 g of grain in each of 10 vials for 105 days. Twenty sorghums were used. Each day, each grain in the 10 vials of one kind of sorghum was evaluated for damage on a scale of 1-5, numbers of live and dead weevil adults were counted, and grain in each vial was weighed. Fewest maize weevils emerged from Sima, Macia, and Sureño - 1.7, 2.8, and 3.1 per gram of grain. Most weevils emerged from CE151 (14.2 per gram). Weight loss of grain of Sureño, Sima, Macia, and Malisor-84-7-167 was 0.8-6.6% at 105 days after infestation. Weight loss of ATx631, CE151, and SC630-11E11 was 37.2-46.8% at 105 days after infestation. Sureño was most resistant, while SC630-11E11 was least resistant. Grain weight loss was correlated to the number of maize weevils produced per gram and score of damage to grain, but not to grain size, hardness, or protein.

Michael Pendleton and E. Ann Ellis at the Microscopy and Imaging Center at Texas A&M University used light and scanning electron microscopy to relate morphology of seed coats of the 20 sorghum genotypes with resistance to maize weevils. A razor blade and hammer were used to split dry sorghum grains. The split grains were exposed to osmium vapor and coated with gold-palladium using a Hummer sputter coater. The cross-section of the seed coat of each genotype was observed by scanning electron microscopy using a JEOL JSM 6400 at 15 KeV, 12-mm working distance, and magnifications of 500-2000x. Pieces of seed coat were dried, fixed, and embedded in epoxy resin and sectioned for observation by using a Zeiss Axiophot compound light microscope at bright field magnifications of 100-600x. Grains of the different genotypes were different in cross-section, and the difference was related to resistance to maize weevil. The seed coat of the most resistant (Sureño) was twice as thick as that of susceptible SC630-11E11.

Networking Activities

Workshops

The PI presented two posters at the 24th Biennial Grain Sorghumn Research and Utilization Conference, Reno, NV, 19-22 February 2005; two posters at the 53rd Annual Meeting of the Southwestern Branch of the Entomological Society of America and Annual Meeting of the Society of Southwestern Entomologists, Albuquerque, NM, 28 February - 3 March

2005; attended the 52nd Annual Meeting of the Entomological Society of America, Salt Lake City, UT, 14-17 November 2004; and gave four presentations at the Entomology Science Conference, College Station, TX, 26-28 October 2004. The PI and M.S. students presented four posters at the Summer Crops Field Day, Bushland, TX, 31 August 2004; and the PI presented information on biotyping greenbugs at the Northern Panhandle Field Day, Stratford, TX, 25 May 2005.

Research Investigator Exchanges

From March 10-21, 2005, the PI discussed and reviewed research with scientists from Botswana College of Agriculture, INIA in Mozambique, and ARC and North West University in South Africa and met with prospective Ph.D. students.

Research Information Exchange

The PI advised extension, National Grain Sorghum Producers, and commercial seed companies on management of sorghum insect pests. Two hundred twenty-one and 135 sorghums developed for resistance to biotype I greenbug were evaluated for Pioneer Hi-Bred International, Inc. and Milo Genetics. The PI assisted Dr. John Burd, USDA-ARS, Stillwater, OK, with collecting greenbugs from wild and cultivated grasses. Reference materials and/or supplies were provided to Mr. Chitio in Mozambique, Dr. Munthali in Botswana, Dr. van den Berg in South Africa, and Dr. Yaro Diarisso in Mali.

Publications and Presentations

Publications

Chitio, F.M., B.B. Pendleton, and G.J. Michels, Jr. 2004. Resistance of stored sorghum grain to maize weevil (Coleoptera: Curculionidae). International Sorghum and Millets Newsletter 45:35-36.

Sambaraju, K.R., and B.B. Pendleton. 2005. Fitness of greenbug (Homoptera: Aphididae) on wild and cultivated grasses. Southwestern Entomologist.

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Palousek Copeland, A.L., B.B. Pendleton, and G.J. Michels, Jr. 2004. Fecundity and longevity of greenbug (Homoptera: Aphididae) affected by biotype and temperature. Pp. 132-133. In Proceedings of the Summer Crops Field Day. Bushland, TX. August 31, 2004.

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Pendleton, M., and B.B. Pendleton. 2005. Comparison of morphology of sorghum grain to resistance to maize weevil (Coleoptera: Curculionidae). P. 37. In Proceedings of the 53rd Annual Meeting of the Southwestern Branch of the Entomological Society of America and Annual Meeting of the Society of Southwestern Entomologists. Albuquerque, NM. February 28 – March 3, 2005.

Pendleton, M.W., E.A. Ellis, F.M. Chitio, and B.B. Pendleton. 2005. Comparison of morphology of sorghum grain to resistance to maize weevil. Pp. 76-78. In J. A. Dahlberg, B. Bean, S. Goldman, B. Rooney, S. Bean, J. Burd, T. Isakiet, and R. Kochenower [eds.], Proceedings of the 24th Biennial Grain Sorghum Research and Utilization Conference. Reno, NV. February 19-22, 2005.

Ayyanath, M.M. 2004. Effect of greenbugs (Homoptera: Aphididae) from resistant sorghum on the life cycle of convergent lady beetle (Coleoptera: Coccinellidae). M.S. thesis. West Texas A&M University, Canyon, TX.

Chitio, F.M. 2004. Resistance of stored cowpea to cowpea weevil (Coleoptera: Bruchidae) and sorghum to maize weevil (Coleoptera: Curculionidae). M.S. thesis. West Texas A&M University, Canyon, TX.

Presentations

Summer Crops Field Day, Bushland, TX, August 31, 2004:

Alternatives to organophosphates and carbamates for managing aphids in wheat and sorghum by Roxanne Bowling, Robert Bowling, Bonnie Pendleton, and G. J. Michels, Jr.

Fecundity and longevity of greenbug, Schizaphis graminum, affected by biotype and temperature by Anastasia L.

Palousek, Bonnie B. Pendleton, Bobby A. Stewart, G. J. Michels, Jr., and Charles M. Rush

Fecundity and longevity of greenbug on wild and cultivated grasses by Kishan R. Sambaraju and Bonnie B. Pendleton

Effects of different amounts of soil nitrogen and water on greenbug fecundity and longevity on sorghum by Suresh Veerabomma, Bonnie B. Pendleton, Bob A. Stewart, Clay A. Robinson, and G. J. Michels, Jr.

Randall County Ag Day, Canyon, TX, October 7, 2004: Fecundity and longevity of greenbug, Schizaphis graminum, affected by biotype and temperature by Anastasia L. Palousek, Bonnie B. Pendleton, Bobby A. Stewart, G. J. Michels, Jr., and Charles M. Rush

Effects of different amounts of soil nitrogen and water on greenbug fecundity and longevity on sorghum by Suresh Veerabomma, Bonnie B. Pendleton, Bob A. Stewart, Clay A. Robinson, and G. J. Michels, Jr.

Entomology Science Conference, College Station, TX, October 26-28, 2004: Alternative management strategies for greenbugs by Roxanne Bowling, Robert Bowling, Bonnie Pendleton, and Jerry Michels

Tritrophic interaction of resistant sorghum, greenbug, and convergent lady beetle by Bonnie Pendleton and Murali Mohan Ayyanath

Resistance of stored sorghum to maize weevil by Bonnie Pendleton and Fernando Chitio

Greenbug biotypes by Bonnie Pendleton and Tiecoura Traore

North American Grain Congress, Reno, NV, February 19-22, 2005: Comparison of morphology of sorghum grain to resistance to maize weevil by M. W. Pendleton, E. A. Ellis, F. M. Chitio, and B. B. Pendleton

Grain sorghum production and profit optimization with alternative water management strategies in the Texas Panhandle by L. K. Almas, W. A. Colette, and B. B. Pendleton

53rd Annual Meeting of the Southwestern Branch of the Entomological Society of America and the Annual Meeting of the Society of Southwestern Entomologists, Albuquerque, NM, February 28 - March 3, 2005: Alternatives to organophosphates and carbamates for managing aphids in wheat and sorghum by Roxanne Bowling, Bonnie Pendleton, Robert Bowling, and Jerry Michels

Comparison of morphology of sorghum grain to resistance to maize weevil (Coleoptera: Curculionidae) by Michael W. Pendleton, E. Ann Ellis, Fernando M. Chitio, and Bonnie B.Pendleton

Invited seminar, Department of Entomology, Texas A&M University, College Station, TX, April 14, 2005: Bioecology and management of greenbug. Northern Panhandle Field Day, Stratford, TX, May 25, 2005 – Biotyping greenbugs.

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

Marketing-Processing Project. The importance of improved quality became very obvious this year as some Senegalese producers added salt to their millet to get a higher weight. Moreover in several areas where farmers were making efforts to improve quality there was still a quality complaint. We need to get the tarps ('bache") out faster to the farmers' groups and continue to encourage the purchase of threshers in the villages.

On the food processor side there are high costs of cleaning. Moreover, processors receive 5 to 15% lower millet quantities with the usual range of impurities. Nevertheless, many food processors still resist paying a quality premium. There needs to be an incentive for farmers to produce a higher quality. This is a potential win-win situation rather than a bargaining power contest between farmers and processors.

Introduction of Striga resistant cultivars and associated technologies in Ethiopia. The field studies in Tigray and Amhara have shown the preference of farmers to plant early cultivars in seasons in which the rainfall starts late (about one third of the time). So it is important to incorporate the *Striga* resistance into middle and late season cultivars as well as early ones.

The importance of inorganic fertilizer was demonstrated in the field analysis in Amhara. There soils are being depleted in spite of the conventional wisdom of high fertility. Marginal analysis of yield equations indicated a 600% return. Besides higher yields in low rainfall years other advantages to *Striga* resistance in Amhara were much lower weeding costs and different rotations. The budgeting evaluation of all three of these changes is now being undertaken.

Turning the Ethiopian food crops into orphan crops in which neither the private nor the public seed sectors are involved is a serious continuing problem for introducing higher productivity and thereby higher incomes in the food crop production sector. The public sector needs to become involved again in production of these basic food crops but with an exit strategy of turning their activities over to the private sector as the demand grows with the introduction of new technologies.

Inventory Credit Programs in Karabeji, Niger. The program here is a paternalistic one in which the farmers' organization gains the benefits from the price recovery and uses the profits to buy fertilizer in bulk and distribute it to members and non-members at a lower price than available at retail. Program impact is then measured by the increase in fertilizer consumption. Unfortunately, this program provides little in-

centive for increased farmer participation. There is horizontal expansion (new members) but little vertical participation or expansion. Members contribute less than 4% of their millet production in recent years and that share is not increasing.

Objectives, Production and Utilization Constraints

The Marketing-Processing Project is a regionally supported West African AID activity to get new production technologies into the hands of sorghum and millet producers in West Africa by implementing new marketing strategies to obtain higher prices for farmers and thereby pay for the inputs involved in technological change including the payment of a risk premium. A secondary component of the project is to work with food and feed processors in the four countries involved in the project (Niger, Mali, Burkina Faso and Senegal).

The farmers then are increasing the quality and quantity of grain received by the food processors. We also want the processors to pay a quality premium and not to insist on buying all their grain at the post harvest price low. Another function of the project is then to provide the processors with better information on the choice between sorghum and maize in the feed ration (see the discussion in V. A of this report). A future activity of the project will be facilitating the franchising activities of one of the food processors of yogurt with millet grits all over the Sahel.

With workshops and continuing interaction we are facilitating the dissemination of information between processors and between processors and the farmer groups. We are constantly trying to get contracts between the two groups and to increase the understanding of the contracting as there is little experience of contract law in the Sahel. One objective of the next year in this project is to increase the service capability of the public food science labs in the four countries. Working with the food scientists in INTSORMIL and the national organizations we will also be helping with technical and management decision making in the food/feed processing sector for the traditional cereals.

There are two major research activities. We continue to monitor the technological change process and estimate the impact of new technologies being introduced. We are presently engaged in this activity in Tigray and Amhara, Ethiopia. There we have been measuring diffusion and estimating the potential impact of new *Striga* resistant sorghum cultivars and associated technologies (fertilizers and water harvesting techniques).

The second major activity is the research support of the Marketing-Processing Project discussed above. Here we seek to measure better for specific cases the gains to farmers from new technologies with and without the new marketing strategies. Last year we reported results for maize in Mozambique. This year we report on millet in Niger.

Research Approach and Project Output

The Marketing-Processing Project Results

This project starts with the basic hypothesis that the main reason for the failure of new technologies to be introduced into sorghum and millet production is that the farmer is receiving too low a price. There are two markets with which we are operating, food and feed processing. First is the rapidly expanding market for food products. This is principally for processed millet products such as couscous. These products are increasing very rapidly in demand since they are now incorporating the labor saving features previously incorporated in developed countries into wheat and rice. With the increasing value of the time of women in urban areas the demand for these products is increasing very rapidly. This is also a female dominated industry.

The project has concentrated on introducing two marketing strategies at the farm level. A principal focus has been inventory credit, so that the farmer can sell his product later in the season. Another focus is to increase the quality of the grain by getting threshing off the ground and obtaining a quality premium for the farmers.

A major objective of this Marketing-Processing Project is a more rapid introduction of Inventory Credit systems. We will need to get the banks involved as has been done in northern Nigeria. The farmers groups are functioning in the four counties and farmers are understanding better the objectives of the inventory credit and other marketing strategies. We also need to show the processors that farmers receiving higher prices is also a winning strategy for them.

One principal requirement in this food processing sector is a rapid expansion of quality and quantity of grain. We are not only attempting to more rapidly introduce technological change but also to remove the high level of impurities (5 to 15%) generally found in millet and sorghum from threshing on the ground. To improve quality not only do farmers need to get the threshing off the ground as by putting tarps beneath the grain but also there needs to be an incentive for farmers so a quality premium needs to be paid.

In this third year of the program there have been substantial successes in Senegal and Niger in introducing new marketing strategies for farmers. Here the objectives were to improve quality of the grain by getting threshing off the ground, obtain a quality premium from the food processors (millet), and facilitate more selling of their millet by farmers after a recovery from the post harvest price collapse. In both countries there was a high quality product food processor, who took the lead in paying a higher price to farmers. Then in Senegal some of the other processors followed in subsequent years after observing this model processor. Niger is the lowest income country of the four Sahelian countries, with whom we work, so there are fewer processors to imitate.

In Mali and Burkina Faso the food processors met as a group and were following collusive behavior. They argued that they did not have to pay a quality premium and wanted to buy the millet and other staples at the slowest post harvest price. Clearly, food processors will need to pay for a quality premium or there will be no incentive for farmers to get the grain off the ground. Moreover, in the absence of a price premium there will be more pressure on farmers to adulterate the product as many farmers in Senegal did in 2004 by adding salt.

In Mali and Burkina Faso we need to start again to convince processors that paying a higher price can encourage a cleaner grain as well as higher quantities and both of these are necessary for the evolution of the sector. Meanwhile, we are getting the farm producer groups to put tarps down when they are threshing and in Senegal one major cooperative is moving towards putting threshers in the village.

The concentration of the food processing has been on millet and there seems to be a processing food preference for millet in the Sahel. The second major market with which we are working is for the use of sorghum as feed. The big potential for sorghum is for its use in feed for broilers and layers. The demand for broilers expands especially fast in the development process. The Sahel can either import feed grains or raise the productivity of sorghum and provide more of their own feed grains. This is a much larger potential market than that for millet as a processed food.

Two principal reservations were consistently stated by feed processors across the Sahel, (a) a concern with the level of tannin in the sorghum and (b) the question of the ability of sorghum to compete with maize with respect to price. Food scientists in the U.S. believe that tannin is a historic problem since breeders have been working to produce high quality white sorghums without a tannin problem and farmers also tend to select for a whiter "to."

During 2005 Tahirou Abdoulaye collected the cultivars of sorghum in the field and the new cultivars, which breeders are introducing. These cultivars have now been analyzed with one or two (depending on the tannin levels) tests for tannin in the food science labs in the four countries. All the cultivars showing tannin in the simple bleach test have also been analyzed with the vanillin test in the laboratory of Lloyd Rooney at Texas A&M.

Simultaneously, with the cultivar collection Tahirou also obtained price data for sorghum and maize in various regions of all four countries for the past five years. Michigan State had initiated this activity as part of their food security project and then this activity was turned over to national groups.

The price and the tannin data will be analyzed and a bulletin prepared for the feed processors and policy makers on the conditions under which processors should substitute sorghum for maize in the rations. We also want to evaluate the aflotoxin risk, which tends to be much more likely with maize than with sorghum. But this will probably be put off until the revision of the bulletin in 2006.

Preliminary results are that tannin is generally not a problem in Mali or Niger. In Burkina where a principal product is the "dolo" beer there are some high tannin sorghums. In Senegal, where sorghum breeding has been minimal in the last three decades, many of the traditional cultivars have high tannin levels.

We also looked at the relative prices of sorghum and maize and found that there were many periods of time in the last five years that sorghum had a substantially lower price than maize in Niger and Senegal.

Impact of *Striga* resistant cultivars and associated technologies in Tigray and Amhara, Ethiopia

There was substantial excitement about *Striga* resistant sorghum cultivars as the scientific methods for identifying the resistance techniques resulted from multi-disciplinary activities at Purdue. Since the 1997 crop year the new *Striga* resistant cultivars were involved in regional trials in northern Ethiopia. The official release of the new cultivars in Ethiopia was in 1999 and 2000.These cultivars have been sporadically promoted in extension activities during the last five years.

In Tigray a diffusion study was undertaken in 2001 and then the researcher returned and re-interviewed many of the same farmers in the summer of 2003. In Amhara a field survey of the potential impact of the *Striga* resistant cultivars and associated technologies was completed in 2004. Together the researchers spent approximately seven months in the field in these two major sorghum producing regions of the country.

The sampling was selective for regions in which there were introduction programs of the new technologies pushed by the local extension services (Shararo in Tigray and the Qobo Valley in Amhara). In Tigray an estimated 8% of the farmers were utilizing the new cultivars. In Amhara selective sampling of the farmers, who had utilized the new technologies was undertaken. Here in Amhara the objective was to estimate potential impact rather than to measure diffusion.

In Tigray farmers preferred the early *Striga* resistant cultivars in seasons with late rainfall, which occur approximately one-third of the time. With normal and good early rainfall the farmers did not plant the *Striga* resistant cultivars. Farmers also reported on the earliness of the *Striga* resistant cultivars in Amhara but we only had observations of the performance over the 2001-2004 period.

The two other technologies being introduced with the *Striga* resistant cultivars were water harvesting and fertilizer. Improved production conditions (more water and higher soil fertility) are also a method of controlling *Striga*. In these better rainfall years (normal and good years, which occur approximately two thirds of the time), there was no yield advantage to the *Striga* resistant cultivars in Amhara according to the econometric analysis.

Besides a yield increase in low rainfall years two other advantages to *Striga* resistance in Amhara were identified. These include considerably lower weeding costs, as farm family members attempt to pull out the *Striga* in heavily infested regions, and a different rotational system. Hand weeding a *Striga* infestation is an extremely labor intensive activity. The economic values of these three advantages to *Striga* resistance factors are presently being estimated.

The field results indicate a potentially much higher return to the cultivars if *Striga* resistance can be incorporated into medium and long season cultivars as well as the short season ones. There is a presently an on-going process of backcrossing the *Striga* resistance into the locally established cultivars.

The yield analysis showed very high returns to fertilizer in spite of the general failure to introduce fertilization on most of the project farms. In the Qobo region the conventional wisdom is that soils are so fertile that fertilization is unnecessary. In the econometric analysis of crop yields in Qobo the marginal return to fertilizer was over 600% soundly refuting the conventional wisdom.

In Tigray there is a general recognition that soils are depleted. To increase fertilizer use improved water harvesting is necessary to reduce the riskiness of this activity. Water harvesting increases the return from fertilization in adequate and good[1] rainfall years and reduces the probability of loss from fertilization in poor rainfall years. So the extension service has been promoting various types of water harvesting over the last five years.

In both regions water harvesting continued to be introduced. In 2004 there was a shift to the Chinese pit technique. The extension system in Ethiopia works with substantial top down direction and changes priorities and principal activities annually. Staying with the one water harvesting technique over time, such as tied ridges, is expected to have a higher long run payoff than the annual shifting process. The repeated changes of extension priority also distract attention from the importance of developing public sector capacity for producing seed of the *Striga* resistant and other new cultivars.

Sorghum and most food crops in Ethiopia are presently orphan crops. They are not yet sufficiently profitable for the private sector to be interested in seed production. The public sector seed production agency has been ordered by the central government to become more profitable so it is imitating Pioneer by focusing on hybrid maize, wheat and other high value crops. The implications of these private and public policy decisions are serious for Ethiopia, whose basic food consumption activities of teff, sorghum, and several edible legumes are now being ignored in the seed sector.

Inventory Credit Programs and Fertilization in Niger

A principal objective of most inventory credit programs is to enable farmers to sell later in the season after the post harvest price collapse. For a series of financial requirements (school fees, pay to family workers for agricultural activities, financing of seasonal migration, ceremonies and in good years investment in human and physical capital) farmers feel substantial pressure to meet income goals immediately after the harvest. As a result there is an abrupt price collapse of basic commodity prices at this time.

With low seasonal prices and other factors depressing the prices, received for staples by farmers, there is a general discouragement from using new technology. New technology involves the purchase of improved seeds and fertilizers. Fertilizer is critical because of the initial low fertility and the fertility depletion of soils over time. New cultivars embody the technological innovations of the breeders. To accelerate technology diffusion new marketing strategies are introduced to increase the prices received by farmers for their staples.

There are two common forms of inventory credit programs. Farmers store their commodities in some form of group storage and receive loans for the value of their commodities at harvest. Then when prices recover, the farmers can sell their staple at the higher prices and pay for the storage and interest costs. Another basic variation is that the farmers' group or cooperative sells the crop at the higher prices after the price recovery. Then the cooperative will pay for the costs of storage and interest and then divide the profits among the members proportionately to the quantity stored. Both systems give clear incentives to farmers to use more of the new technologies because the marketing strategy has increased its profits.

A third system, practiced in our surveyed region in Niger, has the farmers' association selling later after the price has recovered, keeping the profits, and then purchasing in bulk fertilizer. This fertilizer is then made available to participants and non-participants at a lower price than they would be able to obtain.. The incentives for participating in the program are then the availability and reduction in price of the fertilizer.

We then evaluated the determinants of fertilizer use in the region. Both the direct effects of having a program in your village and the indirect effect of having a lower relative price for fertilizer (price of millet divided by the price of fertilizer) were highly significant in farmers' decisions to use fertilizer. The program was highly successful then in encouraging the use of fertilizer. (Table 1)

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[1] In very good rainfall years too much water is a possible result from some water harvesting methods. In this case the structures need to be broken down as sorghum only has short term tolerance of flooding.

Table 1. The determinants of fertilizer use in Karabedji, Niger (Probit technique)

	Coefficient	T-Stat	Marginal
Relative Price	2.63	2.51***	0.969
Program	0.79	2.30**	0.278
Income	-0.0002	-0.63	-7.0E-05
Manure	0.51	1.60*	0.512
Migration	0.18	0.642	0.179
Constant	-2.21	-2.76***	-0.817
Chi-Square	15.94***		
McFadden R-Sqd	0.10		
Log likelihood	-72.4		

Source: Authors estimation from survey data in forthcoming M.S. thesis of Felix Baquedano. *: Significant at 10 percent; **: Significant at 5 percent; and ***: Significant at 1 percent.

The downside is that the incentive effect of higher prices for the farmers' staple is achieved only indirectly through the availability and reduced price of fertilizers. This is a paternalistic system as the farmers are not believed to be able to utilize their increased prices appropriately so the farmers' organization needs to do it for them by buying the fertilizer. With the incentives diluted we would not expect participating farmers to be increasing their very small quantities of millet being sold (less than 4%) to the farmers' organizations. The data is sketchy but even though the number of farmers is increasing, the participation rate (quantity of millet harvested put into the program per farmer) appears not to be increasing.

Networking Activities

West Africa

A principal activity throughout the year has been the Marketing-Processing Project funded by the WARP (West African Regional Program of USAID). To undertake the development activities of this project requires networks between the agricultural and food science research agencies plus farmers' organizations, NGOs, and the food/feed processing sector. Substantial activity of all three principal personnel is put into maintaining these networks and collaboration.

In November 2004 this project sponsored a workshop with participants from all these sectors plus USAID and INTSORMIL in Bamako. Ouendeba Botorou did most of the organizational activity and Joan Frederick provided the financial organization and support.

We are also sponsoring the field level transfer of new sorghum technologies in Mali, Niger and Senegal in the summer of 2005. Another on-going activity is to make available in the region all our program documents in french.

As part of this activity Dr. Sanders made five trips to west Africa and will make another one in June. This Marketing-Processing Project is extremely time demanding as we are trying to implement a development program. Most of the NARS and NGOs we deal with are more used to working with a foreign aid program rather than focusing on low cost delivery of services.

Central America

This workshop evolved out of the previous visit to El Salvador and Nicaragua in the summer of 2003 by Dr. Sanders, Dr. Rooney and Felix Baquedano. There the importance of the tannin problem in the utilization of domestic sorghum or imported maize became an important issue. Since then Drs. Lloyd Rooney and Joe Hancock have given workshops on the subject and this workshop was a continuation of these activities. Sanders presented a paper in this workshop.

Publications and Presentations

Journal Articles

Abdoulaye, Tahirou, and John H. Sanders, 2005. "Stages and Determinants of Fertilizer Use in Semiarid African Agriculture: The Niger Experience," *Agricultural Economics*, 32(167-179).

Vitale, Jeffrey D., and John H. Sanders, 2005. "New Markets and Technological Change for the Traditional Cereals in Semiarid Sub-Saharan Africa: The Malian Case," *Agricultural Economics*, 32(111-129).

M.S. Thesis

R.N. Uaiene, "Maize and Sorghum Technologies and the Effect of Marketing Strategies on Farmers Incomes in Mozambique," Department of Agricultural Economics, Purdue University, 2004.

Presentations

Sanders, John H., "Marketing Strategies and Technology Adoption in Sorghum/Millet Production in West Africa," presented at the Marketing-Processing Project Workshop in Bamako, Mali, Nov. 15, 2004

Sanders, John H. "Demand Factors and New Technology in Sorghum Systems in Central America," presented at the Workshop on uses of Sorghum, Managua, Nicaragua, May 19, 2005.

Miscellaneous Publications

Ouendeba, Botorou, "Six Month Report: Marketing-Processing Project," mimeo, Niamey, Niger, 13 pages.

Ouendeba, Botorou (edited), *Amelorations des Marches et Nouvelles Technologies pour les Cultures Vivrieres au Sahel*, , INTSORMIL, Lincoln, Nebraska, bulletin included three papers translated into French and republished in 2005.

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 continues 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%) and stover yield by 612 kg ha^{-1} (38%), 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. Studies focused on grain sorghum production practices for traditional beer (dolo) production and poultry manure use for pearl millet production were initiated, while continuing on-farm research and technology transfer of animal traction zaï in Burkina Faso.

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. In 2004 the range in yields of photoperiod insensitive lines ranged from 1.8 to 3.0 Mg ha^{-1}, but only ICSVLM-90520 produced a higher yield than the best control variety of Soberano. ICSVLM-90520 had the best grain yield, was in the top 5 for stover yield, and within the top 6 for grain nitrogen use efficiency. It is recommended that the Plant Breeding program introduce this line into its crossing program and evaluate it further, and that the other lines be dropped from breeding and evaluation efforts. In Nicaragua, large differences among environments, lines and N rates were present. However, the local check variety Pinolero along with the line ICSCVLM-93076 produced approximately 3.7 Mg ha^{-1} grain surpassing the yields of rest of the varieties by 0.5 to 1.1 Mg ha^{-1}. With N application, ICSCVLM-93076 produced the highest grain yield of 5.1 Mg ha^{-1} compared to 4.2 Mg ha^{-1} for Pinolero. ICSCVM-93076 was N responsive while still producing high yields without N application. This line has been submitted to the CNIA/INTA sorghum breeding program for evaluation and use in the breeding.

In El Salvador average grain yield without N fertilizer was 2002 kg ha^{-1} while with 21 kg N ha^{-1} average yield was 2920 kg ha^{-1}, and increase in yield of 46% with a marginal return of 44 kg ha^{-1} grain production for each kg N ha^{-1}. In Nicaragua, N fertilizer application increased the average grain yield from 3.1 to 3.9 Mg ha-1 (26%), emphasizing the importance of promoting N fertilizer use to increase grain sorghum grain yields. Increased technology transfer efforts in collaboration with fertilizer input suppliers, extension service and NGOs is merited.

Research in the United States determined that rotation with non-nodulating soybean without soil amendment increased sorghum grain yield by 2.6 to 3.0 Mg $ha^{-1,}$ stover yields by 1.5 to 1.8 Mg ha^{-1}, and soil NO3-N at the vegetative growth stage. Rotation with nodulating soybean further increased grain yields by 1.7 to 1.8 Mg ha^{-1} and stover yield by 0.6 to 0.9 Mg ha^{-1}. On average grain N concentrations were increased by 0.5, 5.0 and 4.7 g kg^{-1} for continuous sorghum and sorghum rotated with non-nodulating and nodulating soybean, respectively. Cropping sequences influenced grain hardness to a lesser extent. Non-biological N fixation effect accounted for 67 to 83% of enhanced sorghum yield due to crop rotation with soybean.

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) zai 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.

Conduct research to better understand nitrogen and non-nitrogen influences of crop rotation on grain and stover yield, growth, grain quality and nitrogen nutrition of sorghum plants.

Initiate research on environment interactions with white, food-grade sorghum hybrids for grain yield and quality.

Determine recommended production practices for double-crop pearl millet production following winter wheat 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 United States 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 rain yields than other crops with late planting, double cropping research with winter wheat was initiated. Research is on-going to better understand the basis for yield enhancement and N credit for grain sorghum rotated with soybean. 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)

Nodulating and Non-Nodulating Soybean Rotation Effect on Sorghum Grain Yield and Quality (Nanga Mady Kaye, M.S. Thesis)

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-nodulating 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) was studied with the objective to separate N and non-N effects of crop rotation. Data collection done in 2003 and 2004, 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 (kernel weight, test weight, true density, and tangential abrasive dehulling device removal). Data were analyzed using analysis of variance and correlation procedures.

Research Results

In 2003 and 2004, cropping sequence x soil amendment effects were present for most parameters measured. Rotation with non-nodulating soybean without soil amendment increased grain yield by 2.6 to 3.0 Mg ha^{-1} (Tables 1 and 2), stover yields by 1.5 to 1.8 Mg ha^{-1} (Tables 3 and 4), and soil NO_3-N at vegetative growth stage. Rotation with nodulating soybean further increased grain yields by 1.7 to 1.8 Mg ha^{-1}, stover yield by 0.6 to 0.9 Mg ha^{-1}, and soil NO_3-N at vegetative growth stage. On average grain N concentrations were increased by 0.5, 5.0 and 4.7 g kg^{-1} for continuous sorghum and sorghum rotated with non-nodulating and nodulating soybean, respectively. Cropping sequences influenced grain hardness to a lesser extent. Non-nodulating soybean accounted for 67 to 83% of enhanced sorghum yield due to crop rotation with soybean. Irregardless of cropping sequence, manured plots produced the highest grain and stover yields, grain N concentration, and grain hardness. Grain yield and N supply influenced grain N to a greater extent than grain hardness. Cropping sequence and soil amendment choices are important to assure optimal sorghum grain yield and physical quality.

Environment Interaction with White, Food-Grade Sorghum Hybrid for Grain Yield and Quality (Joni Griess, M.S. Study)

Research Methods

Twelve white or cream colored commercial grain sorghum hybrids with tan plants along with eight checks with either red grain or white grain/purple plant checks were planted in randomized complete block designed experiments in six environments in 2004 (east central and central Nebraska locations with and without irrigation) and will be planted in seven environments in 2005 (Same as 2004 with additional western Nebraska location without irrigation). Plant and glume color, plant height, flowering date, lodging, grain yield and water content data was collected. Grain samples were collected from each plot to be analyzed for kernel weight and color; hardness using bulk and true density, decortication properties using the Tangential Abrasive Dehulling Device (TADD), starch, oil and protein concentrations; and starch viscosity. Field and grain quality data will be used for economic analysis of food-grade grain sorghum production for export contracts and domestic consumption.

Table 1. Influence of cropping sequence and soil amendment on grain yield and quality in 2003, Mead, NE.

Cropping sequence	Soil amendment	Grain yield	Panicles m^{-2}	100-kernel weight	Grain N	Test weight	True density	Tangential abrasive dehulling device
		Mg ha^{-1}	Number	g	g kg^{-1}	kg l^{-1}	g cm^{-3}	% removal
Continuous sorghum	Zero	2.1	10.3	2.32	10.4	0.73	1.333	43
	Nitrogen	5.8	11.5	2.40	10.9	0.78	1.348	33
	Manure	6.2	11.5	2.42	10.9	0.79	1.358	33
	Mean	4.7	11.1	2.71	10.7	0.77	1.346	37
Sorghum following non-nodulating soybean	Zero	5.1	11.0	2.34	8.3	0.77	1.340	39
	Nitrogen	7.5	12.0	2.34	10.2	0.78	1.360	30
	Manure	7.9	12.5	2.45	13.0	0.78	1.355	28
	Mean	6.8	11.8	2.38	10.5	0.78	1.352	32
Sorghum following nodulating soybean	Zero	6.7	12.5	2.32	8.9	0.77	1.348	34
	Nitrogen	7.2	12.0	2.05	13.8	0.78	1.340	31
	Manure	7.3	12.0	2.35	14.8	0.78	1.350	27
	Mean	7.1	12.2	2.24	12.5	0.78	1.346	31
	F test and contrast probabilities (F > F							
Replication (REP)		0.41	0.02	0.71	0.24	0.77	0.71	0.08
Cropping sequence (CS)		<0.01	0.01	0.39	0.16	0.10	0.35	0.02
Rotation vs continuous		<0.01	0.00	0.50	0.33	0.04	0.50	0.01
Nodulating vs non-nodulating rotation		0.60	0.15	0.30	0.10	0.74	0.22	0.43
Soil amendment (FERT)		<0.01	0.01	0.02	<0.01	<0.01	<0.01	<0.01
Manure vs nomanure		<0.01	0.03	<0.01	<0.01	<0.01	<0.01	<0.01
N vs zero		<0.01	0.02	0.17	<0.01	<0.01	0.01	<0.01
CS*FERT		<0.01	0.01	0.04	<0.01	0.00	0.01	0.06
Rotation-continuous vs manure-nomanure		0.02	0.57	0.36	0.01	0.04	0.07	0.57
Rotation-continuous vs N-zero		<0.01	0.06	0.04	0.03	<0.01	0.23	0.07
Rotation nodulating-rotation nonnodulating vs manure-nomanure		0.06	0.02	0.52	0.97	0.91	0.86	0.43
Rotation nodulating-rotation nonnodulating vs nitrogen-zero		0.01	0.01	0.03	0.02	0.85	<0.01	0.02
MSE (CS)		0.90	0.25	0.10	5.04	0.0001	0.0001	15.00
MSE (Residual)		0.49	0.32	0.01	1.77	0.0002	0.00007	5.50

Research Results

To date, grain yield, bulk, true density, kernel weights and tangential abrasive dehulling device removal have been determined for 2004 plots. Environment influenced grain yield and kernel hardness, with lowest yields and softest kernels in the dryland, low N environment, second softest kernels in the eastern Nebraska dryland environment, and highest yields and hardest kernels in the eastern Nebraska irrigated and central Nebraska dryland and irrigated environments. Preliminary analysis of hybrid data indicates that hybrid differences for grain yield across environments was variable; true density differences were small; that the hybrids Asgrow Orbit, NK8828, Macia (African line) and the experimental hybrid UNL N252X1038R had the lowest TADD removal; and that DK42-20 consistently had the best test weight. IN 2005, this same experiment is planted in seven environments in eastern, central and west-central Nebraska.

International

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

Research Methods

Four-year central studies were initiated on-station in 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-

Table 2. Influence of cropping sequence and soil amendment on grain yield and quality in 2004, Mead, NE.

Cropping sequence	Soil amendment	Grain yield	Panicles m^{-2}	100-kernel weight	Grain N	Test weight	True density	Tangential abrasive dehulling device
		Mg ha^{-1}	Number	g	g kg^{-1}	kg l^{-1}	g cm^{-3}	% removal
Continuous sorghum	Zero	3.3	15.0	2.52	8.8	0.79	1.340	44
	Nitrogen	8.2	15.0	2.81	9.8	0.82	1.375	28
	Manure	9.0	17.5	2.87	9.4	0.81	1.378	26
	Mean	6.8	15.8	2.70	9.7	0.81	1.364	33
Sorghum following non-nodulating soybean	Zero	5.9	18.5	2.73	8.2	0.81	1.370	35
	Nitrogen	8.9	17.3	2.86	10.7	0.81	1.383	27
	Manure	9.4	21.3	2.87	13.4	0.82	1.378	23
	Mean	8.1	19.0	2.80	10.8	0.81	1.377	28
Sorghum following nodulating soybean	Zero	7.7	19.0	2.68	8.4	0.81	1.370	32
	Nitrogen	9.5	18.5	2.83	11.7	0.81	1.375	22
	Manure	9.6	19.5	2.89	11.9	0.82	1.378	22
	Mean	8.9	19.0	2.80	10.7	0.81	1.374	25
		F test and contrast probabilities (F > F)						
Replication (REP)		0.32	0.58	0.58	0.32	0.39	0.71	0.32
Cropping sequence (CS)		<0.01	<0.01	0.44	0.10	0.54	0.08	0.05
Rotation vs continuous		<0.01	<0.01	0.23	0.04	0.29	0.03	0.02
Nodulating vs non-nodulating rotation		<0.01	1.00	0.79	0.81	1.00	0.61	0.26
Soil amendment (FERT)		<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01
Manure vs nomanure		<0.01	<0.01	<0.01	<0.01	0.03	0.01	<0.01
N vs zero		<0.01	0.27	<0.01	<0.01	0.02	<0.01	<0.01
CS*FERT		<0.01	0.19	0.31	<0.01	0.01	0.01	0.07
Rotation-continuous vs manure-nomanure		<0.01	0.65	0.20	<0.01	0.93	0.02	0.12
Rotation-continuous vs N-zero		<0.01	0.44	0.12	0.09	<0.01	<0.01	0.03
Rotation nodulating-rotation nonnodulating vs manure-nomanure		0.02	0.03	0.45	0.01	0.66	0.64	0.17
Rotation nodulating-rotation nonnodulating vs nitrogen-zero		<0.01	0.56	0.86	0.34	0.45	0.42	0.85
MSE (CS)		0.13	1.52	0.03	1.23	0.0001	0.0001	31.00
MSE (Residual)		0.15	1.62	0.01	0.71	0.0001	0.0001	10.08

^{1} N. Each plot was sampled prior to initiating the experiment so that soil nutrient levels after four-years could be determined. 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 yield by 58% and stover yield by 38% (Table 5). Yield increases were greater for P than N application, but the highest yields included microdose combined with P and N application. On-farm studies showed similar yield increases to on-station in Mali and Niger, but grain and stover yields with microdose application were over 100% greater than without fertilizer in Burkina Faso. Microdose application increased yield of sorghum on heavy soils in Mali, but less so than for pearl millet on the sandy soils in the regional study. Clearly the microdose application is a low cost investment that has a high probability to increase grain and stover yields across the West Africa pearl millet production area, but N and P removal is similar to zero application and thus does not alleviate soil nutrient mining concerns.

Zaï and other tillage/fertilizer treatments influence on grain sorghum yield

(Taonda Jean Baptiste - Burkina Faso)

Research Methods

On-farm research and demonstration was conducted as a follow-up to studies conducted on-station and on-farm in pre-

Table 3. Influence of cropping sequence and soil amendment effects on stover yield, stover N and plant height in 2003, Mead NE.

Cropping sequence	Soil amendment	Stover yield	Stover N	Plant height
		Mg kg^{-1}	g kg^{-1}	cm
Continuous sorghum	Zero	5.0	10	95
	Nitrogen	7.6	15	103
	Manure	8.5	16	102
	Mean	7.0	14	100
Sorghum following non-nodulating soybean	Zero	6.8	10	101
	Nitrogen	8.2	17	109
	Manure	7.9	19	110
	Mean	7.6	15	106
Sorghum following nodulating soybean	Zero	7.4	13	110
	Nitrogen	6.5	19	108
	Manure	7.6	22	107
	Mean	7.2	18	108
	F test and contrast probabilities (P > F)			
Replication (REP)		0.34	0.30	0.11
Cropping sequence (CS)		0.07	<0.01	0.01
Rotation vs continuous		0.08	<0.01	<0.01
Nodulating vs non-nodulating rotation		0.08	<0.01	0.37
Soil amendment (FERT)		0.04	<0.01	0.01
Manure vs nomanure		0.04	<0.01	0.13
N vs zero		0.09	<0.01	<0.01
CS*FERT		0.11	0.13	0.02
Rotation-continuous vs manure-nomanure		0.13	0.04	0.56
Rotation-continuous vs N-zero		0.07	0.10	0.11
Rotation nodulating-rotation nonnodulating vs manure-nomanure		0.83	0.73	0.04
Rotation nodulating-rotation nonnodulating vs nitrogen-zero		0.12	0.59	0.02
MSE (CS)		1.44	3.26	20.23
MSE(Residual)		2.00	2.43	15.22

vious years (see INTSORMIL annual reports for 2001 and 2002). This effort was done on five farms with diverse soils in the zone of Samba in 2004. Treatments were no fertilizer, no tillage check (farmer practice), zaï with compost 300 g hill^{-1} compost application, and animal traction (zaï mécanique) zaï with 300 g hill^{-1} compost application.

Research Results

The zaï treatment with compost application increased yields from approximately 180 kg ha^{-1} to 480 kg ha^{-1} on silty to silty clay soils (167%) compared farmer practice, while the animal traction zaï further increased yield to over 600 kg ha^{-1} (233% greater than farmer practice) on silty soils and to nearly 800 kg ha^{-1} (360% greater than farmer practice) on silty clay soils. These results support results previously reported, and are a part of a concerted effort by INERA to promote adoption of the use of the animal traction zaï combined with compost application.

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 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, microdose 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 conducted.

Table 4. Influence of cropping sequence and soil amendment effects on stover yield, stover N and plant height in 2004, Mead, NE.

Cropping sequence	Soil amendment	Stover Yield	Stover N	Plant height
		$Mg\ ha^{-1}$	$g\ kg^{-1}$	cm
Continuous sorghum	Zero	5.2	11	111
	Nitrogen	8.7	18	129
	Manure	8.6	19	128
	Mean	7.5	16	123
Sorghum following non-nodulating soybean	Zero	6.7	13	123
	Nitrogen	8.9	21	136
	Manure	10.4	28	132
	Mean	8.7	21	130
Sorghum following nodulating soybean	Zero	7.8	13	133
	Nitrogen	8.6	26	136
	Manure	12.6	28	133
	Mean	9.7	22	134
	F test and contrast probabilities (F > F)			
Replication (REP)		0.90	0.60	0.49
Cropping sequence (CS)		0.04	<0.01	<0.01
Rotation vs continuous		0.02	<0.01	<0.01
Nodulating vs non-nodulating rotation		0.17	0.15	0.15
Soil amendment (FERT)		<0.01	<0.01	<0.01
Manure vs nomanure		<0.01	<0.01	<0.04
N vs zero		<0.01	<0.01	<0.01
CS*FERT		0.23	0.01	<0.01
Rotation-continuous vs manure-nomanure		0.17	<0.01	0.01
Rotation-continuous vs N-zero		0.18	0.13	0.01
Rotation nodulating-rotation nonnodulating vs manure-nomanure		0.24	0.35	0.23
Rotation nodulating-rotation nonnodulating vs nitrogen-zero		0.43	0.04	0.01
MSE (CS)		2.57	6.84	30.46
MSE (Residual)		2.84	5.10	13.64

Research Results

The two-year results indicated no interaction between water management technique and fertilizer application method/rate, while variety interactions were present with both water management technique and fertilizer application/method rate. The grain yield of the variety IRAT9 was nearly double that of Framida, but stover yields and response to water management technique were similar. Tied ridges and animal traction zaï without compost increased grain yields of Framida from 463 to approximately 650 kg ha^{-1}, and IRAT9 from 787 to 884 to 1014 kg ha^{-1}. Microdose fertilizer application increased grain yield from 359 to 876 kg ha^{-1} (144% greater than zero) and microdose + 20 kg P ha^{-1} and 30 kg N ha^{-1} further increased yield to 1438 kg ha^{-1} (330% greater than zero). A similar response was found for stover yield. Recommended fertilizer rates had lower grain yields than the microdose treatments. Dolo quality tests are presently being conducted.

Weed Control X Fertilizer Study (Samba Traoré - Mali)

Research Methods

A randomized complete block designed experiment to evaluate the interactive effects of hand weeding method and fertilizer application on pearl millet grain and stover yield was conducted at the Cinzana Research Station in 2001, 2002 and 2004. Pearl millet was hill planted on ridges after fertilizer application. Hills were thinned after emergence to two plants per hill. Fertilizer treatments consisted of microdose (2 grams diammonium phosphate per hill), 6 grams of 15-15-15 per hill, and 4 t ha^{-1} manure incorporated during soil preparation plus 50 kg ha^{-1} diammonium phosphate broadcast applied after emergence. Mechanical weed control treatments consisted of complete control, weeding of ridges only, and no weeding. Grain and stover yield were determined, and data were analyzed using analysis of variance procedures.

Table 5. Fertilizer treatment influence on pearl millet, grain and stover yield, and relative increase (averaged over 4 years and 3 replications).

	Grain Yield				Stover Yield				Relative Yield Increase	
Fertilizer Treatment	**Burkino Faso**	**Mali**	**Niger**	**Mean**	**Burkino Faso**	**Mali**	**Niger**	**Mean**	**Grain**	**Stover**
	kg ha^{-1}								%	
Zero	398	772	341	504	1072	1644	3006	1907	------	------
Microdose	646	1091	524	753	1735	2789	3033	2519	58	38
Microdose + 20 kg P ha^{-1}	844	1140	743	909	2039	2974	4121	3045	96	64
Microdose + 40 kg P ha^{-1}	904	1349	624	959	2009	3854	3264	3042	104	65
Microdose + 30 kg N ha^{-1}	657	1050	608	771	1600	2870	3882	2784	61	52
Microdose + 60 kg N ha^{-1}	727	1080	608	805	1716	3090	4113	2973	70	61
Microdose + 20 kg P ha^{-1} + 30 kg N ha^{-1}	941	1216	960	1039	2239	3630	4840	3569	113	95
Microdose + 40 kg Pha^{-1} + 60 kg N ha^{-1}	1108	1274	917	1100	2402	4231	4389	3674	128	101

Research Results

Analysis of variance indicated that yield differences were due to year X weed control and year X fertilizer treatments. No weed control X fertilizer interaction effects were present. In all years, rainfall was limited late in the growing season resulting in average grain yields of 630 to 900 kg ha^{-1}, and average stover yields of 3344 kg ha^{-1} in 2001, 1635 kg ha^{-1} in 2002, and 1366 in 2004. Weed competition was much greater in 2002 than 2001, and rainfall lower in 2004 at least partially accounting for the lower stover production in 2002 and 2004. In 2001 with low weed pressure present, mechanical weeding treatments had little effect on grain and stover yield. In 2002, weeding of ridges increased grain yield by 470 kg ha^{-1} (93%) and complete weed control increased grain yield by 736 kg ha^{-1} (146%) while in 2004 weeding of ridges increased grain yield by 333 kg ha^{-1} (93%) and complete weeding increased grain yields by 481 kg ha^{-1} (134%). The application of 6 gram diammonium phosphate did not increase grain or stover yield due to salt injury reducing emergence. The manure + 50 kg ha^{-1} diammonium phosphate treatment did not increase grain yields greatly in 2001, but in 2002 increased grain yields by 912 kg ha^{-1} (150%) over the microdose treatment, and in 2004 by 303 kg ha^{-1} (57%). Complete and timely weeding combined with application of animal manure combined with N and P produced the highest grain and stover yields, except in the dry 2001 season with low weed pressure.

Pearl Millet Grain Yield Improvement Using Poultry Manure and Fertilizer (Nouri Maman, Niger)

Research Methods

In 2004, a three-pronged research effort on use of poultry manure generated by the expanding poultry industry was initiated. First, a survey of farmer practices presently using this manure source was conducted. Second, an on-farm study was conducted on nine farms with treatments being zero, 2 t ha^{-1} poultry manure and 2 t ha^{-1} poultry manure + 40 kg ha^{-1} of 15-15-15 fertilizer. Third, on-station studies were initiated to determine the best rate of poultry manure application (zero, 2, 4 and 6 t ha^{-1}) with and without supplemental P application (zero, 10, 20 and 30 kg P ha^{-1} or 100, 150 or 200 kg rock phosphate ha^{-1}). Grain and stover yield data were gathered, and analyzed by analysis of variance and with economic value/cost ratios.

Research Results

Survey results of the 10 local producers using poultry manure found that poultry manure contains 10 times more P and K (17 and 2.2 g kg^{-1}) than local cattle manure, and more total N (11.9 to 13.0 g kg^{-1}). The survey indicated that at present they receive the manure free, and apply to all the major dryland crops (pearl millet, grain sorghum, peanut and cowpea) in the Maradi region of Niger. The average rate of application is 1 t ha^{-1}. All farmers agree that the manure increased production and improved soil fertility, and only one producer indicated that application labor was a major constraint to use of poultry manure.

On-farm research found that poultry manure increased pearl millet grain and stover yield by 264 kg ha^{-1} (42%) and 1697 kg ha^{-1} (37%). Addition of complete fertilizer increased grain yield 612 kg ha^{-1} more (138% more than zero) without influencing stover yield, and this gave the highest value/cost ratio of 5.5. On-station experiments were adversely affected by the dry growing season, thus yield responses were limited. Continuing research is planned to better evaluate the short-term and long-term effects of poultry manure application on pearl millet production.

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

Research Methods

A series of studies were conducted in El Salvador and Nicaragua between 2001 and 2004 with the objective to determine if NUE differences exist among photoperiod insensitive sorghum varieties and response of these grain sorghum lines to low N fertilizer rates (47 kg ha^{-1}), and to identify high NUE varieties. At each location, 24 lines from breeding programs were initially grown initially with and without N in a randomized complete block design with four replications, and only the 16 superior performing lines being carried forward to the following years study. 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

In El Salvador, no line X N interaction was found, suggesting that variety selection and N rate should be independent management decisions. The El Salvador location in 2003 provided little useful information due to site selection of a soil with relatively high nutrient level, but in 2004 the range in yields of lines ranged from 1.8 to 3.0 Mg ha^{-1}, but only ICSVLM-90520 produced a higher yield than the best control variety of Soberano. ICSVLM-90520 had the best grain yield, was in the top five for stover yield, and within the top six for grain nitrogen use efficiency. It is recommended that the plant breeding program introduce this line into its crossing program and evaluate it further, and that the other lines be dropped from breeding and evaluation efforts. Average grain yield without nitrogen fertilizer was 2002 kg ha^{-1} while with 21 kg N ha^{-1} average yield was 2920 kg ha^{-1}, and increase in yield of 46% with a marginal return of 44 kg ha^{-1} grain production for each kg N ha^{-1}. Increased technology transfer efforts in collaboration with fertilizer input suppliers, extension service and NGOs is merited.

In Nicaragua, large differences among environments, lines and N rates were present. However, the local check variety Pinolero along with the line ICSCVLM-93076 produced approximately 3.7 Mg ha^{-1} grain surpassing the yields of rest of the varieties by 0.5 to 1.1 Mg ha^{-1}. With N application, ICSCVLM-93076 produced the highest grain yield of 5.1 Mg ha^{-1} compared to 4.2 Mg ha^{-1} for Pinolero. ICSCVM-93076 was N responsive while still producing high yields without N application. This line has been submitted to the CNIA/INTA sorghum breeding program for evaluation and use in the breeding. Nitrogen fertilizer application increased the average grain yield from 3.1 to 3.9 Mg ha-1 (26%), emphasizing the importance of promoting N fertilizer use to increase grain sorghum grain yields.

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

Research Methods

In 2003, validation and transfer trials were conducted on 40 farms in collaborations with the NGOs Ramírez Consultores, ESBESA, CONSORCIO and PRODESO. 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. In addition, the improved varieties 85-SCP-805, SOBERANO, CENTA S-3 and RCV were planted on 430 farms in Zone 3 to facilitate transfer to farmer's fields. In 2004, variety validation trials were conducted for 85-SCP-805, ES-790, CENTA S-3, and 86-EO-226 on 635 farm fields totally 162 ha.

Research Results

In 2003, 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. In 2004, the yield increase over the local check was 0.5 Mg ha^{-1} for 85-SCP-805, 0.6 Mg ha^{-1} for ES- 790, 0.4 Mg ha^{-1} for CENTA S-3 and 86-EO-226.

Validation of the Improved Forage Hybrid HF-275 (Maximo Hernández, El Salvador and José Molina, Nicaragua)

Research Methods

In El Salvador, the improved forage hybrid HF-275 was validated on 15 farms with the commonly used hybrid HF-895 used as a check. The plots were green cut for forage three times, samples dried and yields recorded on dry matter basis. Laboratory analyses for forage quality including protein, fiber and energy were done. In Nicaragua six forage sorghum hybrids were validated on-station.

Research Results

The improved HF-275 hybrid produced more forage dry matter for each harvest date, with total production of 32 Mg ha^{-1} compared to 22 Mg ha^{-1} for HF-895. Fiber contents were similar for the two hybrids, but HF-275 had higher energy content (3% higher total digestible nutrients) and 1% higher crude protein. In El Salvador, HF-275 will be validated with dairy producers in 2005 for potential release in 2006. In Nicaragua, HF-275 had one of the highest forage yields and quality among the six hybrids tested.

Networking Activities

Workshops

Central America Sorghum Utilization Workshop, 19 - 20 May 2005, Managua, NI,

Max Hernández (El Salvador) and Orlando Téllez Obregón, PCCMCA Meeting, 2 - 5 May 2005, Panama City, Panama.

Research Investigator Exchange

Nanga Mady Kaye (Chad) will complete a M.S. degree in Aug 2005.

Assisted in setting up a Ph.D. program for Siebou Pale (Burkina Faso) at the University of Natal, South Africa.

Research Information Exchange

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

Visited INTSORMIL research efforts in El Salvador, Honduras and Nicaragua in November 2004, and May 2005. Initiated interaction for collaboration with the private seed companies Cristiani Burkard and Prosemillas. USAID missions in El Salvador, Guatemala, Honduras and Nicaragua were visited in November 2004.

Organized Grain Sorghum Utilization Workshop in Managua, Nicaragua 18 - 19 May 2005.

Publications and Presentations

Abstracts

Hernández Valle, M.A. and S.C. Mason. 2005. Ensayos regionales de germoplasma fotoinsensitiva que responda a requerimientos mínimos de fertilizante nitrogenado. PCCMCA Meeting, 2 - 6 May 2005, Panama City, Panama.

Hernández Valle, M.A. and S.C. Mason. 2005. Validacion del hibrido forrajero experimental de sorgo 275. PCCMCA Meeting, 2 - 6 May 2005, Panama City, Panama.

Molina Zamora, J. A. and R. Valdivia Lorente. 2005. Evaluacíon de cinco híbridos de sorgo para forraje. PCCMCA Meeting, 2 - 6 May 2005, Panama City, Panama.

Journal Articles

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: 2138 - 2145

Maman, Nouri, S.C. Mason and D.J. Lyon. 2005. Nitrogen rate influence on pearl millet yield, N uptake and N use efficiency in Nebraska. Comm. Soil Sci. Plant Anal. (In Press).

Duarte, A.P., S.C. Mason, D.S. Jackson and J. de C. Kiehl. 2005. Grain quality of Brazilian maize genotypes as influenced by nitrogen level. Crop Sci. 45: (In Press).

Undergraduate Theses

Mario Antonio Gadea Moreno and Ruby Anayensi Altamirano Palacios. 2005. Evaluación agronómica de la variedad de sorgo (*Sorghum bicolor* L. Moench) bajo dos fuentes de fertilización en el municipio de San Ramón, Matagalpa. B.S. thesis, Universidad Nacional Agraria, Managua, Nicaragua.

Mauriel Alberto Gurdian Velazquez. 2005. Evaluación agronómica de la variedad de sorgo (*Sorghum bicolor* L. Moench) bajo dos fuentes de fertilización en el municipio y uso eficiente de nitrogeno por 15 lineas de sorgo (Sorghum bicolor L. Moench) en el municipio d Posoltega, Chinandega. B.S. thesis, Universidad Nacional Agraria, Managua, Nicaragua.

Eliezer de Jesûs Manzanarez Rugama and Francisco Josééalero Romero. 2004. Evaluación de comportamiento agronómico y el uso eficiente del nitrógeno de 12 líneas de sorgo (*Sorghum bicolor* L. Moench) en el municipio de San Ramón, Matagalpa. B.S. thesis, Universidad Nacional Agraria, Managua, Nicaragua.

Yolanda María Herrera Chavarría and Chepita Clementian García Pichardo.2004. Evaluación agronómica y el uso eficiente de nitrogeno en 15 líneas de sorgo (*Sorghum bicolor* L. Moench) con dos niveles de fertilizacion nitrogenada en el municipio de Zambrano. B.S. thesis, Universidad Nacional Agraria, Managua, Nicaragua.

Ramiro Antonio Manzanares Rugama and Roberto Salomón Hernádez Gadea. 2004. Evaluació del efecto de la fuente de nitrógeno y del fraccionamiento de la fertilización en el rendimiento del sorgo para grano (*Sorghum bicolor* (L.) Moench) y uso eficiente del nitrógeno en Tisma, Masaya. B.S. thesis, Universidad Nacional Agraria, Managua, Nicargua.

Soil and Water Management for Improving Sorghum Production in Eastern Africa

Project UNL 219

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Summary

Promote economic growth, improve nutrition, increase yield. Opportunities to increase yield or to reduce production costs have been identified while promising research is continuing and technology dissemination activities have been initiated. Following verification and fine-tuning of the targeting of tied-ridge tillage for semi-arid areas of Ethiopia, extension efforts have been initiated. A decision guide for targeting of tied-ridging is being developed, two papers were presented at the 2004 ASA meeting, and a paper has been submitted to Agronomy Journal. Additional research has been initiated on tied-ridging by soil fertility interactions and on skip-row technology. Four opportunities for low-input management of soil fertility in semi-arid eastern Uganda have been verified as economical using farmer participatory approaches; information dissemination is to begin with the second season of 2005; and more detailed research has been initiated to assess the medium-term sustainability of these practices. Preliminary research was conducted on tillage and soil fertility management alternatives in Mozambique. Results of research on how soil properties relate to P availability for diverse soils of eastern Africa was presented at the 2004 ASA meeting. A paper is under review with Agronomy Journal reporting the results of the first phase of starter fertilizer research for no-till sorghum production in eastern Nebraska and the second phase of this research is to be completed in 2005. Research on occasional tillage to improve the productivity of no-till sorghum production systems continues as the dissertation and thesis research of two graduate students; four papers are to be presented at the 2005 ASA meeting.

Improved institutional capacity. Tewodros Mesfin, who completed his M.S. degrees at Alemaya University with support from UNL 219, came to UNL as a visiting scientist. Gebreyesus Brhane also completed his M.Sc. degree with our support and is now our collaborator in Tigray. Soares Xerinda completed his M.S. degree at UNL and is now our collaborator in Mozambique. The research of a U.S. and two international graduate students is currently supported by this project. Mr. Mesfin, Brhane and Xerinda were sponsored to IFDC training in integrated soil fertility management in Ghana. A study of sorghum production areas in Ethiopia, Uganda and Kenya has revealed stalk borer, water deficits, *Striga*, bird damage, N deficiency, weeds, and shootfly as the greatest causes of yield loss. Additional data has been compiled on sorghum production areas of Ethiopia, Kenya, Mozambique and Uganda; a GIS referenced database is being created that should be valuable to regional networking activities. Drs. Wortmann and Mamo visited their collaborators in Africa in February 2005.

Objectives, Production and Utilization Constraints

Ethiopia

- Conduct on-station and on-farm research at four locations to verify and fine-tune the targeting of tied-ridging and to determine fertilizer interactions with water management.
- Co-supervise soil and water management research projects of two M.Sc. students (Gebreyesus Brhane and Tewodros Mesfin Abebe) at Alemaya University. Host two

of these students to the U.S.

- Conduct training for field extension staff at 2 or 3 locations on aspects of water and nutrient management.

Uganda

- Conduct on-farm research in two counties in eastern Uganda to validate and fine-tune low input approaches to soil fertility management and to develop a reduced tillage system for small scale farmers.

Mozambique

- Conduct tillage and soil fertility in collaboration with Soares Xerinda.
- Collect data for sorghum production areas in Mozambique.

Eritrea and Tanzania

- Explore opportunities for collaboration.
- Invite participation in Ethiopia workshops for extension staff.

U.S.

- Complete research on N response for sorghum following soybeans.
- Complete the first phase of research on starter fertilizer for no-till sorghum and study of other aspects of starter fertilizer for no-till sorghum.
- Mentor an INTSORMIL sponsored graduate student to completion of M.S. degree at UNL.
- Develop recommendations and extension publication on starter-fertilizer application in no-till system and publish results in referred journals.
- Conduct research on occasional tillage in no-till sorghum-soybean systems with support to the research of a Ph.D. student and a M.S. student who are involved in this research.
- Fine-tune the N recommendation for sorghum following soybean.

Africa and U.S.

- Continue to collect sorghum yield response and nutrient uptake data for evaluation of the QUEFTS concepts in estimation of applied nutrient needs.
- Characterize sorghum production areas of Ethiopia, Kenya and Uganda using data collected in 2003-2004.
- Complete research on P sorption for soils of Ethiopia, Uganda, and Mozambique.
- 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 mechanization options continued with trials established in three semi-arid sorghum production locations in 2004 and 2005which vary in elevation from 1300 to 1600 m. The locations include Welench'iti, Miesso, and Mekele 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 the row planter 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 reducing runoff and improved crop performance. 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. These results were reported at the 2004 ASA meeting.

In his thesis research, Tewodros Mesfin observed improved yield with tie-ridging compared with no-till or conventional tillage in the Central Rift Valley with little or no ground cover by crop residues. 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 tied-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). The research results were reported at the 2004 ASA meeting and a paper is under review with *Agronomy Journal.*

Brhane, G., C. Wortmann, M. Mamo, H. Gebrekidan, and A. Belay. 2005. Micro-basin tillage for grain sorghum production in semi-arid areas of northern Ethiopia. *Agronomy J. (in review).*

Training workshops were conducted for extension staff on practices to reduce water loss and to improve efficiency of water and nutrient use; these were in Melkassa in February 2005 and in Mekele in June 2005. An operational plan was developed and resources provided to extension staff for technology dissemination beginning in 2005. Demonstrations were installed on farmers' fields at Miesso, Siraro, Chiro, and Adama areas with follow up by our partners.

Table 1. Mean soil water volume, yield, and harvest index yield sorghum as affected by tillage treatments in 2003 and 2004 at Abergelle in northern Ethiopia.

	2003				2004			
	Soil water	Grain yield	Stover yield	HI	Soil water	Grain yield	Stover yield	HI
Treatments	$m^3\ m^{-3}$	$Mg\ ha^{-1}$		$Mg\ Mg^{-1}$	$m^3\ m^{-3}$	$Mg\ ha^{-1}$		$Mg\ Mg^{-1}$
Flat plant[‡]	0.26	0.79	3.87	0.17	0.24	0.79	3.87	0.17
$TR_{-4WAP}IF$	0.35	2.50	9.67	0.21	0.35	2.50	9.67	0.21
$TR_{-4WAP}OR$	0.30	2.00	7.53	0.20	0.30	2.00	7.53	0.20
$TR_{0WAP}IF$	0.32	2.16	8.84	0.19	0.32	2.16	8.84	0.19
$TR_{0WAP}OR$	0.29	1.70	6.80	0.20	0.29	1.70	6.80	0.20
Shilshalo	0.27	1.30	5.24	0.19	0.25	1.30	5.24	0.19
TR_{4WAP}	0.29	1.70	6.64	0.20	0.27	1.70	6.64	0.20
LSD 0.05	0.032	0.056	0.258	0.037	0.011	0.056	0.258	0.037

[‡] Flat plant = planting with a flat soil surface. TR = tied-ridging; WAP = weeks after planting; IF and OR = in-furrow and on-ridge planting, respectively. *Shilshalo* = a traditional ridging practice conducted four weeks after planting.

Discussions were held with the sorghum research team in Ethiopia and it was agreed to study some aspects of tied-ridging in 2005; this research has been initiated and equipment for monitoring soil water availability has been provided. Research on skip-row planting as a means to improve water availability during grain fill has been initiated. Opportunities for greater utilization of sorghum grain were investigated with beef feeding operations in Nazareth.

Gebreyesus Brhane and Tewodros Mesfin were invited to visit UNL in 2004 but Gebreyesus was not able to obtain a U.S. visa. Gebreyesus Brhane and Tewodros Mesfin participated in the IFDC training in Accra, Ghana on integrated soil fertility management.

Nutrient and water management research in Uganda. The economic and agronomic feasibility of four low input practices for soil fertility management were verified through research conducted with farmers in two communities each of Kumi and Katikwe Districts. Results are to be presented by Dr. Kaizzi at the 2005 ASA meeting. Preparations have been made for technology dissemination to begin with the second season of 2005; including collaboration with the USAID supported Agricultural Enhancement Support Project (APEP). Participatory research is continuing on the development of a reduced tillage system with farmers. Research on the medium and long-term sustainability of the low input practices has been initiated.

Project activities in Mozambique. Soares Xerinda completed his M.S. degree at UNL in August 2004 and returned to Mozambique in September. He did a small survey to assess adoption of reduced tillage and no-till practices by small scale farmers and found very little adoption despite years of promotion by extension, with the support of Sasakawa Global 2000. Preliminary trials to investigate tillage by soil fertility interactions were established at three locations, although quality of the results will be limited due to late planting. Data were collected on sorghum production in Mozambique. Soares Xerinda participated in the IFDC training in Accra Ghana on integrated soil fertility management.

Project activities in Tanzania. A visit in August 2005 is planned to discuss potential activities in 2005-2006 that will complement regional projects.

Phosphorus fixation of soil in Ethiopia, Uganda, and Mozambique. Phosphorus sorption isotherms were determined for 36 soil samples collected from Ethiopia, Uganda, and Mozambique. Clay content accounted for 78% of the variation in P sorption over all soil samples. Oxalate extractable Al accounted for 93% of the variance in P sorption for soils of Uganda and Mozambique. Organic carbon accounted for 31% of the variance in P sorption. The model $Y = 28.2 + 0.87*Clay + 11.8*Ca$ accounted for 90% of the variation in P sorption. Data of this research was presented at the 2004 ASA meeting. Results are being compiled for a journal publication.

Creation of sorghum database for eastern and southern Africa. In addition to the 19 sorghum production areas delineated for Ethiopia, Uganda and Kenya, another five have been determined for Mozambique but only part of the data has been collected. We have not obtained needed information for Tanzania and Eritrea. Collaboration with ASARECA-ECARSAM was explored. For the sorghum production areas in Ethiopia, Uganda and Kenya, the greatest causes of yield loss have been identified as stalk borer, water deficits, *Striga*, bird damage, N deficiency, weeds, and shootfly. The importance of sorghum uses was determined by assigning 100 points to different uses and adjusting for production area; the results are 16 for baked foods, 15 for injera, 10 for cooked foods, 10 for fuel, nine for fodder, seven for non-alcoholic beverages,

Table 2. Starter fertilizer effect on grain sorghum yield under no-till conditions in southeastern Nebraska in 2002 and 2003. Means of three trials per location.

	Beatrice 2002	Pickrell, 2002	Beatrice, 2003	Firth, 2003
	----------Mg ha^{-1}	----------	----------	----------
Control	6.13	6.17	4.52	6.69
N+P, 50x50 mm	6.61	6.34	4.38	7.19
N+P, over-the-row	6.31	6.46	4.80	6.55
N+P, in-furrow	6.20	6.30	4.75	6.83
N+P+S_{as}[†], 50x50 mm	6.40	6.28	4.66	6.55
N+P+S_{as}, over-the-row	6.19	6.28	4.40	6.73
N+P+S_{as}, in-furrow	5.97	6.48	4.86	6.88
N+P+S_{ats}[†], in-furrow	6.23	6.26	4.72	6.86
		P>F		
Treatment (Trt)	*	*	NS	NS
Trt x topographic position	*	*	**	NS
		Contrasts and mean differences		
Starter mean vs control	0.15	-0.11	0.13	0.09
N+P vs N+P+S_{as}	0.32	-0.23	0.00	0.14
50x50 vs OR & IF[‡]	0.26*	-0.06	-0.18	0.12

*, **, NS significant at 0.05, 0.01, and not significant.

[†] S_{as} and S_{ats} = sulfur with ammonium sulfate and ammonium thio-sulfate as the S source.

[‡] Starter fertilizer placement methods: 50x50 = 50 cm to the side and 50 cm deep, OR = over-the-row, and IF = in-furrow.

four for alcoholic beverages, and 29 for other uses. Sole crop production was estimated to be the main cropping system (84%) and corn and bean are the main associated crops in intercropping.

Starter fertilizer for no-till sorghum production in Nebraska. The first phase of this research was completed and a paper submitted to *Agronomy Journal.* Yield response was more frequent in upland environments than in bottomlands where placement at 5 cm to the side and 5 cm deep and in-furrow placement were generally more effective than over-the-row placement. Starter fertilizer reduced grain moisture at harvest by 9 to 28 g kg^{-1} in 25% of the environments. Overall, however, response of no-till grain sorghum to starter fertilizer application was not economical (Table 2).

Wortmann, C., S. Xerinda, and M. Mamo. 2005. No-till row crop response to starter fertilizer in eastern Nebraska: II. rainfed sorghum. *Agronomy J. (in review).*

Fine-tune the N recommendation for sorghum following soybean. **Eleven trials were conducted in 2004 and the field research is to be completed with the nine trials that have been established in 2005. Field work will be completed in 2005.**

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. Andres is investigating the effects of: soil C dynamics and microbial activity; crop yield; and soil physical properties. Juan Pablo is investigating effects on: nutrient redistribution with tillage; mycorrhyzal colonization; and plant nutrient uptake. Juan Pablo found mycorrhyzal colonization to be much reduced with tillage and with manure application, and the effect persisted throughout the season (Fig. 1); P uptake and grain yield, however, were not affected by the tillage treatments. Andres observed a tillage effect on the composition of microbial communities, little effect on total microbial biomass, and a greater effect on mycorrhyzal biomass (Fig. 2), but the agronomic significance of these shifts has not yet been determined. Various aspects of this research, including treatment effects on yield and soil organic matter, will continue for another five years. Four papers are being prepared for 2005 ASA. Presentations are being prepared for two extension field days in July 2005.

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 mass and root length per plant, soil and solution chemistry, and soil mycorrhizal. Results indicated that above ground sorghum biomass was not affected by acid treatments. However, root proliferation was very limited in treatments with pH lower than 5.0 in the subsurface soil layer. Soil solution aluminum and manganese levels increased significantly for the unlimed soil 35 days after planting compared to soils limed to 5.5 and 6.3. This decrease was correlated to a significant pH drop in the unlimed soil. M.Sc. graduate student, Greg Miller, is completing his research in 2005.

Networking Activities

Collaboration with extension organizations in Africa increased. Training workshops and extension programming with

Figure 1. The effect of one-time tillage in an otherwise continuous no-till system on mycorrhizal colonization of soybean roots at R6.9 in a sorghum-soybean rotation.

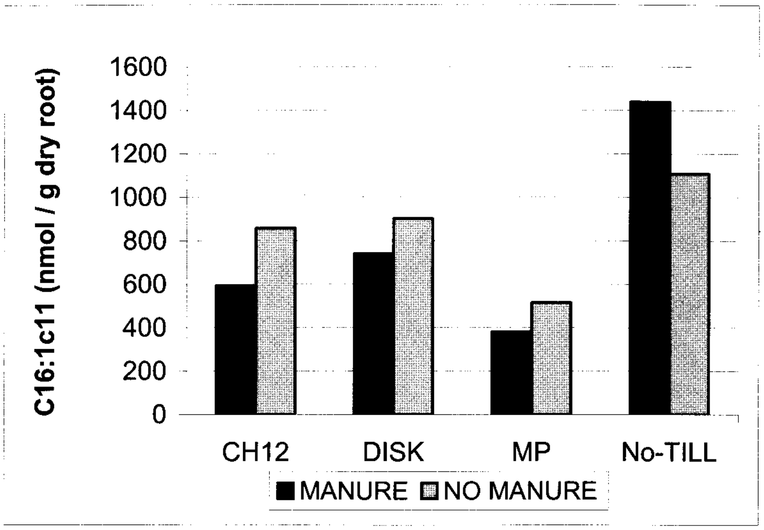
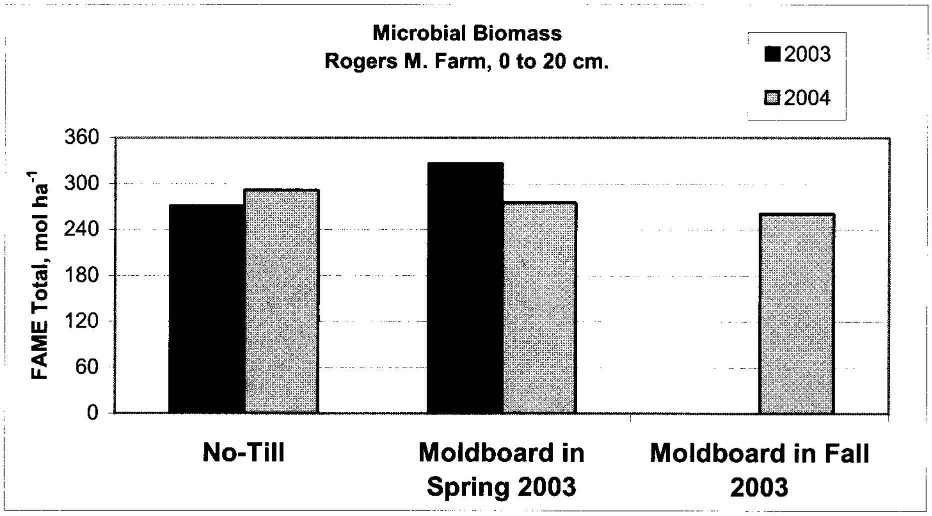


Figure 2. The effect of one-time tillage in an otherwise continuous no-till system on soil microbial and mycorrhizal biomass.



extension staff in Ethiopia are expected to lead to promotion of tillage and soil fertility management options. Arrangements are underway in Uganda to work with a number of extension organizations, with facilitation support from the USAID supported APEP, to promote soil fertility management options; arrangements are also being made to employ farmer-to-farmer and field school approaches. Opportunities for collaboration with the ASARECA-ECARSAM network were explored but we have not identified any opportunity 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

Journal Articles

Brhane, G., C. Wortmann, M. Mamo, H. Gebrekidan, and A.Belay. 2005. Micro-basin tillage for grain sorghum production in semi-arid areas of northern Ethiopia. *Agronomy J. (in review).*

Wortmann, C., S. Xerinda, M. Mamo, and C. Shapiro. 2005. No-till row crop response to starter fertilizer in eastern Nebraska: I. Irrigated and rainfed corn. *Agronomy J. (in review).*

Wortmann, C., S. Xerinda, and M. Mamo. 2005. No-till row crop response to starter fertilizer in eastern Nebraska: II. rainfed sorghum. *Agronomy J. (in review).*

Dissertations and Theses

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Gebreyesus Brhane. 2004. Tied Ridging As *In Situ* Rain Water Harvesting Method For Improving Sorghum (*Sorghum bicolor* L.) Yield at Abergelle area, Tigray Regional State. M.S. thesis. Alemaya University.

Tewodros Mesfin. 2004. Effect of *in-situ* water harvesting on the growth, yield and water use efficiency of sorghum (*Sorghum bicolor* (L.) Moench) under semi-arid conditions of Ethiopia. M.S. thesis. Alemaya University.

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Mesfin, T., M. Mamo, C. Wortmann. 2004. Tillage and Crop Residue Management Effects on Soil Water and Sorghum Yield in the Central Rift Valley of Ethiopia. *American Society of Agronomy National Meeting,* Seattle, WA, Oct. 31-Nov. 4.

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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, a high quality temporary grazing crop in livestock production in the U.S. and Australia, and a widely grown cover crop in Brazil. 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 stressful 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 nematodes (*Meloidogyne arenaria and M. incognita*), and chinch bug (*Blissus leucopterus leucopterus*). Drought is the primary abiotic stress common to all production environments.

The goals of this project are to improve the productivity, yield stability, and pest resistance of pearl millet cultivars, and to transfer the technology to the market. 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, and evaluating and selecting improved progeny as potential new cultivars, and 4) working with partners and stakeholders to transfer the products of research to the marketplace.

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.

Production and Utilization Constraints

- Developing the commercial potential of pearl millet requires an understanding of the needs of potential markets, identifying specific markets in which pearl millet has a competitive advantage, and providing a consistent product that meets market standards.
- Constraints to producing high-quality grain include both abiotic and biotic constraints. The impact of pearl millet genotype, diseases, and environmental constraints, and 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.

Research Approach and Project Output

Genotype and Environmental Effects on Pearl Millet Yield

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 Kamboinse, Burkina Faso; Manga, Ghana; Cinzana, Mali; Bengou, Niger; Maiduguri, Nigeria; Bambey, Senegal; and Longe, Zambia for multi-location evaluation of stability of grain yield. Descriptor data recorded included days to flowering, height, panicle dimensions, downy mildew, smut, and head miner incidence, zonate leaf spot severity, striga infestation, and yield. An additional trial was conducted in Kwa Zulu Natal, South Africa to characterize rust resistance to the indigenous rust (*Puccinia substriata* var. *indica*) population.

Research Findings

Data collected represents year two of a two-year study. The germplasm varied for several characteristics (Table 1). ICMV IS 90311 had the lowest incidence of downy mildew and Tifgrain 102 was the most susceptible. Minor variation for zonate leaf spot was observed at Ghana, with early varieties GB 8735, 68A x 086R, and 01MisoNCD2-NE having the greatest severity. Smut incidence was high at Ghana, with incidence up to 65.5% on Tift 99B. Head miner was only found on a few entries, with up to 65.5% incidence on Tift 99B. Grain yield was lowest for the A_4 restorer 99-72, and greatest for Gwagwa.

Grain yield was correlated with days to flowering (R^2=0.400, P=0.01), plant height (R^2=0.774, P<0.001), and panicle length (R^2=0.374, P=0.0176). Grain yield was negatively correlated with downy mildew incidence (R^2=-0.616, P<0.001), zonate leaf spot severity (R^2=-0.518, P=0.006), smut incidence (R^2=-0.575, P<0.0001), and head miner incidence (R^2=-0.426, P=0.0061)

Twenty pearl millets from West Africa (Zatib, Zongo, HKP-GMS, CIVT, SoSat C-88, Taram, SoSank, ICMV IS 89305, ICMV IS 90311, NKO x TC1, Guefoue, Indiana 05, NKK, Manga Nara, Arrow, PT 732B, P1449-2, Gwagwa, LCIC 9702, GB 8735) and 8 varieties from the Southern Africa region (Bontle, Okashana white, SALR early, SALR photosen, PMV2, P71, 842B, NUP 21 SA gold) were evaluated for rust resistance in a screenhouse trial at Pietermaritzburg, South Africa. All varieties were susceptible to rust. Severities on January 13, 2005 ranged from 35% for the late-maturing varieties NKO x TC1 and Guefoue, to 83% for early maturing GB 8735. Some variation in infection suggests that resistance is heterogeneous within these varieties. Two selections from the U.S. (01-964 and 02-281) were resistant.

Root-Knot Nematode Resistance in Pearl Millets from West and East Africa

Research Methods

Resistance to *Meloidogyne incognita* is important to provide stability to pearl millet production and to reduce nematode populations that can damage crops grown in rotation with pearl millet. *Meloidogyne* spp. are the most economically important plant-parasitic nematodes in the southern United States as well as in West Africa, with *M. incognita* being the dominant species in both regions The objectives of this study were to determine if resistance to *M. incognita* exists in pearl millets from West and East Africa, and to determine if heterogeneity for resistance exists within selected varieties. Resistance was assessed as nematode egg production/g root in greenhouse trials. Seventeen pearl millets of diverse origin were evaluated as bulk (S_0) populations. Thirty selfed (S_1) progeny selections from SoSat-C88, Gwagwa, Zongo, and

Table 1. Agronomic characteristics and disease and pest resistance of diverse pearl millet varieties grown in Burkina Faso, Ghana, Mali, Niger, Nigeria, Senegal, and Zambia in 2004.

Entry	Flowering (days to 50%)	Height (cm)	Panicle length (cm)	Panicle diameter (cm)	Downy mildew incidence	Zonate Leaf spot (%)	Smut incidence	Head miner incidence
Gwagwa	60.6	213.9	24.1	2.4	4.9	2.0	12.6	0.0
NKK	69.4	263.2	40.2	2.5	11.5	1.8	25.9	0.0
GB 8735	47.2	159.6	20.0	2.5	28.8	4.5	14.2	12.8
SoSat C-88	56.4	200.3	26.9	2.9	6.0	1.5	14.5	0.0
SoSank	58.6	188.6	24.4	3.0	5.7	2.0	19.4	0.0
ICMV IS 89305	59.6	220.9	48.4	2.1	5.4	2.0	21.1	0.0
Taram	58.7	217.5	63.1	2.5	6.3	1.8	22.8	0.0
NKO x TC1	76.5	245.0	34.6	2.2	8.2	1.5	17.6	6.8
Kapielga (Burkina local)	68.1	267.3	26.5	2.2	9.6	1.5	9.4	0.0
Arrow	52.4	217.6	32.9	2.0	15.4	2.0	14.7	0.0
Indiana 05	78.9	257.4	42.6	2.6	9.4	1.3	9.4	0.0
ICMV IS 90311	59.5	204.0	37.1	2.2	3.4	2.8	19.6	0.7
CIVT	55.9	205.7	49.7	2.0	6.1	1.5	16.4	0.0
HKP (GMS)	56.8	210.3	50.5	1.9	9.8	2.0	18.8	1.1
Synthetic 1-2000	73.1	240.5	35.0	2.7	4.0	1.3	16.5	0.0
Toronio (Mali local)	66.7	249.4	34.3	2.3	14.8	1.8	19.3	0.0
P1449-2	59.5	172.5	28.3	2.2	10.8	2.8	35.4	16.7
Manga Nara	49.6	176.3	20.0	2.7	29.4	3.3	23.3	7.4
Zatib	58.7	220.6	48.0	2.5	5.6	3.0	24.8	0.0
Guefoue 16	76.6	261.8	35.3	2.1	7.0	1.3	7.4	1.9
Zongo	62.8	247.0	70.2	2.4	10.7	3.3	32.7	0.0
LCIC 9702	55.4	165.4	25.0	2.7	12.9	2.5	18.8	0.0
IBMV8401Mx68A4R4w	46.7	121.6	30.9	2.3	15.5	3.0	25.1	4.2
Tongo Yellow	51.6	197.7	22.7	2.8	17.2	3.0	29.2	0.0
Sadore (Niger) local	66.2	235.1	54.2	2.3	13.8	2.3	23.6	0.0
PT732B	60.8	130.1	21.8	2.0	43.4	2.5	83.4	0.0
3/4 HK	59.5	134.0	45.1	2.1	15.0	2.5	67.2	0.0
DMR 15	62.6	165.3	23.4	2.5	16.4	2.0	50.2	0.0
DMR 72	62.5	194.0	30.1	2.2	8.1	1.8	36.2	0.0
3/4 Souna	57.6	118.8	38.0	2.1	12.5	3.5	26.4	0.0
3/4 ExBornu	55.6	111.6	38.8	2.1	22.7	2.8	41.0	0.0
Bongo short head	51.1	150.1	13.0	3.2	22.2	3.5	28.0	0.0
68A x 086R	41.8	102.1	21.7	2.0	42.8	4.5	8.4	16.3
DMR 68	58.9	196.0	28.2	2.3	18.4	2.8	58.2	0.0
TG102	42.5	93.0	28.0	2.1	49.3	3.0	30.3	1.9
99M59043Mw x 68A4R4	44.5	90.9	20.9	2.3	30.4	3.8	18.6	1.3
T454	50.3	115.6	27.4	2.0	46.1	2.8	26.8	0.0
01Miso NCD2-NE	49.8	100.1	31.4	1.9	31.8	4.5	30.5	0.0
T99B	51.0	74.2	20.6	2.0	47.8	3.3	65.5	65.5
99-72	56.6	125.8	18.7	3.3	17.9	3.3	57.2	43.8
lsd (P=0.05)	3.4	18.0	4.3	0.1	11.9			
Burkina Faso	.	151.3	31.7	.	2.1	.	.	.
Ghana	.	193.2	33.4	.	32.7	2.5	28.0	4.5
Mali	50.6	194.0	34.0	.	16.5	.	.	.
Niger	67.7	167.2	36.1	2.6	5.8	.	.	.
Nigeria	66.5	154.9	34.0	.	31.8	.	.	.
Senegal	55.7	200.5	37.1	2.3	7.3	.	.	.
Zambia	66.9	217.2	31.0	.	.	.	.	.
lsd (P=0.05)	1.3	8.3	1.9	0.1	5.2	1.3	32.7	2.0

P3Kollo were evaluated for heterogeneity of resistance within variety. Reactions were verified in 13 S_2 progeny of each of the four varieties.

Research Findings

All African varieties expressed some level of resistance. P3Kollo was among the least resistant of the African varieties, Zongo and Gwagwa were intermediate, and SoSat-C88 was among the most resistant. In S_1 evaluations, each of these varieties was heterogeneous for resistance. Progeny reaction varied from highly resistant to highly susceptible. Patterns of apparent segregation of resistance varied among the four varieties. Discreet resistant and susceptible phenotypes were identified in Zongo progeny, and it was estimated that two dominant genes for resistance segregated in this variety. Averaged across progenies, egg production on the four varieties was less ($P < 0.001$) than on the susceptible hybrid HGM-100, but was not different from resistant hybrid TifGrain 102. Reproduction of *M. incognita* on the S_2 progeny tended to confirm the results from inoculations of S_1 progeny. Heritability of nematode reproduction (standardized as the ratio of the value to HGM-100) determined by parent-offspring regression was 0.54. Realized heritability determined by divergent selection was 0.87.

Assessment of Genetic Diversity among Pearl Millet Populations using SSR and EST Markers and Relationship with Resistance to Striga

Research Methods

Wild pearl millets (*P. glaucum* subsp. *monodii*) from sub-Saharan Africa have been identified as potential sources of resistance to the hemi-parasitic weed, *Striga hermonthica*. Eighty wild accessions, nine U.S inbreds and seven African open-pollinated varieties were evaluated with 35 SSR primers and 60 EST primers to identify genetic diversity and identify polymorphic markers that would be useful for facilitating transfer of resistance.

Genomic DNA was extracted from two-three week old seedling leaf tissue. PCR fragments of EST primers were subjected to digestion with Himf 1 enzyme and fractionated on 12% polyacrylamide on a Hoefer vertical-gel apparatus (SE600). PCR fragments of SSR primers were evaluated for polymorphisms on 3% ultra pure agarose1000 gels. Gels were stained in ethidium bromide and photographed under the Fluor S multi imager (Bio-Rad). PCR fragments were scored for presence or absence of DNA fragments in each genotype. Dendograms were constructed with the Numerical Taxonomy Multivariate Analysis System 2.1, which discriminated all pearl millet accessions and grouped them in distinct clusters. Cluster analysis was conducted with the unweighted pair-group method using the arithmetic average. PCR fragments were analyzed using DICE coefficient, with SHAN module for cluster analysis. Level of genetic diversity within and between populations (F-statistics and genetic distance) was calculated with Pop Gene 32 software.

Research Findings

Out of sixty EST primers tested, 30 produced scorable and reproducible fragments. Out of 35 SSR primers, 33 primer pairs gave amplification products in most of the accessions. Twenty-eight marker loci were polymorphic out of 33 amplified primers. In total, 96 putative alleles were observed. A dendrogram constructed using the combined data of SSR and EST data resulted in 23 clusters at 85% similarity coefficient. The seven West African varieties were grouped in one cluster, whereas the U.S. accessions were clustered in two groups. The wild accessions were grouped independently from the U.S. and African cultivated varieties. Resistant accessions PS 202, PS 637, PS 639 and PS 727 showed consistently low *Striga* emergence across multilocation trials and tended to be located in different clusters, suggesting they may possess different resistances to *Striga*.

Statistics of genetic diversity within and between accessions were calculated for the sample of 96 accessions using EST and SSR primer data separately. Maximum genetic diversity values of 0.263 with EST and 0.295 with SSR primer data were found between wild accessions and U.S. varieties. Wild accessions and African landraces were genetically less diverse with minimum genetic diversity value 0.1862 with EST and 0.1882 with SSR data. Comparisons between the three subsets of this population highlighted that African open-pollinated accessions were genetically less divergent from the wild accessions than were the U.S. accessions.

Expression and Segregation of Stay-Green in Pearl Millet

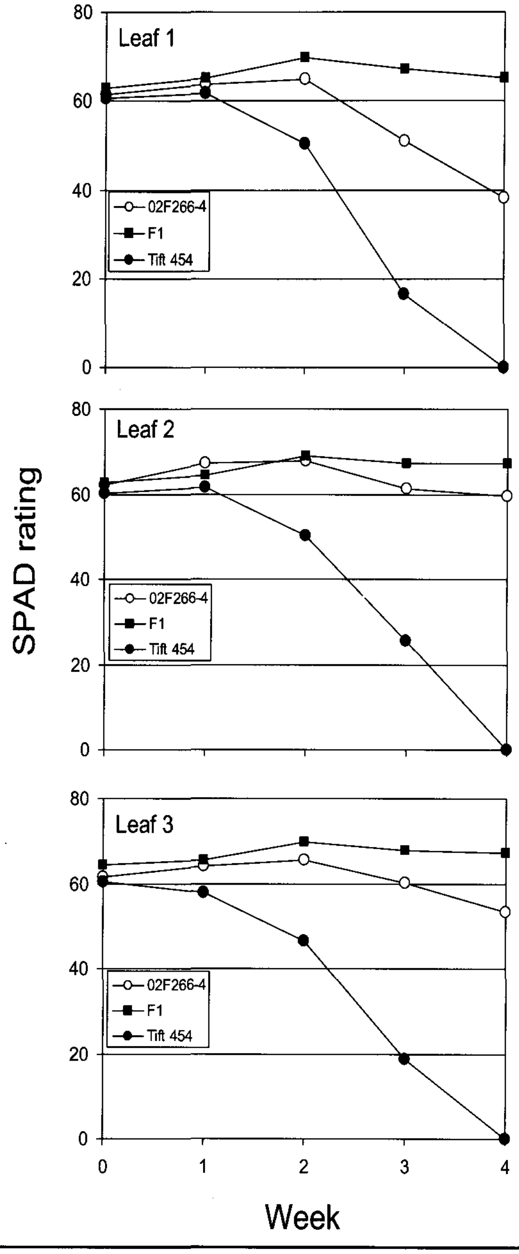
Research Methods

Drought stress occurring from flowering through grain fill results in low and unstable yield of pearl millet. Delayed senescence, or "stay-green" is a mechanism of drought tolerance characterized by the retention of green leaf area at crop maturity under water-stressed environments. Based upon information from the sorghum model, the stay-green trait should have multiple benefits in pearl millet improvement. The objectives of these experiments were to 1) quantitatively compare the chlorophyll content of a putative stay-green and normal senescent pearl millet over time, and 2) obtain preliminary information on the inheritance of the stay-green through segregation in an F_2 population.

Pearl millets developed by the USDA-ARS were evaluated in the field at Tifton, GA in 2004. 02F266-4 is a putative stay-green inbred, resistant or tolerant to prevalent diseases, insect pests and drought in the southeastern U.S. 02F266-4 was crossed with a normal senescent, agronomically elite line Tift 454, which is an A_1 restorer for hybrid production. F_1 and F_2 progenies were produced from crosses between the two parents.

Relative chlorophyll content of 02F266-4, Tift 454 and their F_1 were compared. At stigma emergence, relative chlorophyll content was measured on the top three leaves (with flag leaf taken as leaf 1) of four marked plants per plot from the main tiller with a SPAD 502 Chlorophyll Meter. Data were collected at 7 d intervals for a total of 5 ratings. Segregation of the stay-green trait was assessed in 02F266-4, Tift 454, and their F_1 and F_2 progenies. During early vegetative growth, 236 F_2s, 19 F_1s, 29 plants of Tift 454 and 10 plants of 02F266-4 were marked at random and monitored for panicle emergence. Using the SPAD 502 Chlorophyll Meter, relative chlorophyll measurements were taken on the second uppermost leaf of the main tiller. A stay-green value which reflected the magnitude and duration of the relative chlorophyll content was calculated for each plant by the trapezoidal method.

Figure 1. Changes in chlorophyll content, as measured by SPAD ratings, in pearl millet genotypes Tift 454, 02F266-4, and their F_1. First reading was taken at stigma emergence. Leaf 1 = flag leaf, Tift 454 = senescent type, 02F266-4 = stay-green type.



Research Findings

Minor differences in SPAD ratings among genotypes were observed at stigma emergence, but over time, the top three leaves of 02F266-4 and the F_1 maintained greater levels of chlorophyll than Tift 454 (Figure 1). SPAD ratings of 02F266-4 were similar to that of the F_1, but greater ($P < 0.05$) than that of Tift 454 in weeks one and two. In weeks three and four, SPAD rating of the F_1 was greater ($P < 0.05$) than that of 02F266-4, and ratings of both genotypes were greater ($P < 0.05$) than that of Tift 454 (Figure 1). The data indicate a level of dominance or over-dominance in the expression of relative chlorophyll content in the F_1.

Stay-green mean (+ standard error) of Tift 454 (1548 + 237) was less than ($P<0.001$) the means of 02F266-4 (2001 + 196), the F_1 (2104 + 113), and the F_2 (1917 + 227). Stay-green mean of 02F266-4 did not differ ($P>0.05$) from that of the F_1 or F_2, but the F_1 and F_2 means differed ($P<0.001$). Although not statistically different, the numerically greater stay-green value for the F_1 suggested overdominance, with degree of dominance = 1.46. Stay-green in the F_2 population was skewed toward normal senescent types, which may reflect a segregation of homozygous recessive plants with lower stay-green values.

Use of the SPAD meter to measure relative chlorophyll content provided a quantitative assessment of the stay-green trait. The data confirmed previous observations that 02F266-4 expressed stay-green characteristics. Any of the leaves evaluated were suitable for measurements, but expression was greatest in leaf 2. Whereas SPAD ratings indicated the magnitude of the relative chlorophyll content at a point in time, a stay-green value could be calculated as a measure of the magnitude and retention of chlorophyll content over time for assessing the distribution of the trait within populations.

Ethanol Production from Pearl Millet

Research Methods

To expand domestic market outlets for pearl millet grain, four pearl millet genotypes were tested for their potential as feedstocks for ethanol production and coproducts from the fermentation process. Fermentation was performed both in flasks on a rotary shaker and in a 5-L bioreactor by using *Saccharomyces cerevisiae* (ATCC 24860).

Research Findings

For rotary shaker fermentation, the final ethanol yields ranged from 8.7% to 16.8% (v/v) at dry mass concentrations of 20 to 35%, and the ethanol fermentation efficiencies were between 90.0 and 95.6%. The ethanol fermentation efficiency at 30% dry mass on a 5-L bioreactor reached 94.2%, which was greater than that from fermentation in the rotary shaker (92.9%). Results showed that fermentation efficiencies of pearl millets, on a starch basis, were comparable to those of corn and grain sorghum. Because pearl millets have greater protein and lipid contents, distiller's dried grains with solubles (DDGS) from pearl millet also had greater protein content and energy levels than did DDGS from corn and grain sorghum. Pearl millet should be an effective feedstock for ethanol production in the U.S.

Networking Activities

As part of the effort to expand pearl millet production in the U.S. PI presented information on "Grain Pearl Millet for the Southeastern U.S.", or "Pearl Millet Cooperative Marketing Opportunities" at the following meetings:

Coffee County Grain Pearl Millet Field Day, Douglas GA, September 14, 2004

Workshop for Small, Beginning, and Limited Resource Farmers. Fort Valley State University, Fort Valley, GA. November 4, 2004

Vidalia Onion Growers Committee, Vidalia, GA. November 17, 2004

Sustainable Agriculture and Conservation Tillage Conference, Perry, GA February 16, 2005

Federation of Southern Cooperatives Annual Farmers Conference, Albany, GA February 18, 2005.

Grower training meetings in Sumter, Schley, and Marion Counties (February 22, 2005), Terrell County (March 2, 2005), and Washington County (April 5, 2005), Georgia.

Sunbelt Agricultural Expo, Moultrie, GA, July 12, 2005. Sumter Country "Grain Pearl Millet Field Day", Plains, GA, July 13, 2005

Georgia Young Farmers Summer Conference, Augusta, GA July 19, 2005

Coordinated with Sorghum and Millet Crop Germplasm Advisory Committee to write "Pearl Millet" section of Sorghum and Millet Vulnerability Statement. Statement outlined status of crop vulnerability, needs, and pests of concern, and was submitted by the committee to USDA-ARS for prioritizing food security issues. August 2004.

Collaborated with George Ewing, Compatible Technology International, Golden Valley, MN, to evaluate small equipment developed by CTI designed to hull and grind pearl millet in a typical Africa village setting.

Research Investigator Exchanges

Traveled to South Africa (March 13-16, 2005), Zambia (March 16-20, 2005), and Namibia (March 21-24, 2005) to review current INTSORMIL research progress and prioritize future collaborative research plans.

Hosted Simon Awala, Ministry of Agriculture, Water and Forestry, Republic of Namibia for scientific research project conducted at Tifton, GA from August 26 to October 25, 2004.

Hosted visits with David Hoisington, ICRISAT Global Theme Leader for Biotechnology. April 26, 2005, and Shankar Poddotturi, Pioneer Hi-Bred International Sorghum and Pearl Millet Project Coordinator and Breeder, July 12-13, 2005.

Publications and Presentations

Journal Articles and other Publications

Wilson, J.P., Hess, D.E., Hanna, W.W., Kumar, K.A., and Gupta, S.C. 2004. *Pennisetum glaucum* subsp. *monodii* accessions with striga resistance in West Africa. Crop Protection 23:865-870.

Wilson, J.P. and Devos, K.M. 2004. Linkage groups associated with partial rust resistance in pearl millet. International Sorghum and Millets Newsletter 45:51-52.

Jurjevic, Z., Wilson, D.M., Wilson, J.P., Geiser, D.M., Juba, J.H., Mubatanhema, W., Rains, G.C., and Widstrom, N. 2005. *Fusarium* species of the *Gibberella fujikuroi* complex and fumonisin contamination of pearl millet and corn in Georgia, USA. Mycopathologia 159:401-406.

Books, Book Chapters, and Proceedings

Dahlberg, J., Wilson, J.P., and Snyder, T. 2004. Sorghum and pearl millet-health foods and industrial products in developed countries. Pgs. 42-59 in: Alternative Uses of Sorghum and Pearl Millet in Asia. International Crops Research Institute for the Semi-Arid Tropics. Patancheru 502 324, Andhra Pradesh, India: 364 pp. ISBN 92- 9066-471-1.

Breeding Grain Mold Resistance in High Digestibility Sorghum Varieties

Project TAM 230

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Summary

Combine High Digestibility Sorghum with Grain Mold Resistance

The goal of this proposal is to combine the improved nutritional grain quality sorghum (i.e. high protein digestibility HPD) with high levels of grain mold resistance. Project objectives are to evaluate advanced F_5 recombinant inbred lines (RILs) derived from crosses between HPD parents and male and female lines resistant to grain mold. Lines have been identified from three sets of RILs that carry both the HPD trait and acceptable scores of grain mold resistance. A number of the HPD lines express the floury endosperm phentoype common to the HPD parents. This trait is undesirable for some end-use purposes. However, several lines from two sets of RILs were identified that express a normal flinty/hard endosperm phenotype.

Identify QTLs regulating grain mold resistance and high grain protein digestibility

The three RIL populations derived from elite Texas male/female parents by HPD parent crosses are of insufficient size for mapping QTLs regulating grain mold resistance. Each set is, however, of sufficient size for mapping the high digestibility trait. Thus, a new Fulbright Fellow graduate student from Honduras will join this project in the fall of 2005 and will focus on mapping the HPD trait and testing if the modified HPD endosperm matrix improves starch digestibility and ethanol production.

Given these results new crosses between HPD parents and grain mold resistant parents such as 'Sureño' have been made. The F_2 progeny from these crosses have been collected during the current growing season. A graduate student from Mexico has been using an existing set of 150 RILs derived from crosses between 'Sureño' and 'RTx430' to map loci regulating resistance to grain mold. In this effort, our strategy has been to score resistance to single-grain mold agents. As such, individual plants for the entire set of RILs have been inoculated with only Fusarium thapsinum or Curvularia lunata. The entire RIL population is currently being phenotypically scored for resistance to each pathogen. This data will be used to map loci regulating grain mold resistance. It is our hypothesis that this strategy will reveal that smaller discrete sets of QTLs confer resistance to individual species of grain mold. As such, the pyramiding of resistance loci from unique sources into a single package for improved grain mold resistance will become possible. A time course of tissue collection has been collected for each RIL following infection with Fusarium thapsinum and Curvularia lunata. This tissue will be used as part of our objective to link the expression of key defense genes with the inheritance of individual QTLs for grain mold resistance.

Test the physical and functional properties of highly digestibility sorghums in food and feed products.

Each F_6 RIL scored to possess the HPD trait has been planted in replicated plots at five locations throughout Texas. Grain from each location will be evaluated for grain mold resistance to determine if genotype-by-environment variation exists in the HPD lines. The surplus grain collected from these locations will be supplied to collaborators for chicken feed quality analysis (in collaboration with Dr. J. Hancock INTSORMIL project KSU 220B) and a characterization of the potential gain of function that the HPD trait may provide for food products (in collaborations with Dr. L. Rooney INTSORMIL project TAM 226).

Objectives, Production and Utilization Constraints

Objectives

- Evaluate the combinability of the high protein digestible trait with grain mold resistance.
- Identify QTLs regulating mold resistance and high grain protein digestibility.
- Link QTLs controlling mold resistance to changes in the expression of genes that contribute to mold resistance for future utilization in genetically engineering improved resistance to grain mold.
- Test the physical and functional properties of highly digestibility sorghums in food and feed products.

Constraints

The development of new high yielding sorghum varieties with improved nutritional quality is a key attribute needed to increase the commercial utilization of sorghum. The HPD trait that is also associated with high lysine content is one such attribute that may spur increased utilization of sorghum. However, for the HPD trait to be widely adopted lines must be developed with hard endosperms for improved milling capacity and better food application potential; as well, the trait must be incorporated into lines possessing grain mold resistance. The overall goal of this project is to use molecular techniques to facilitate the development of HPD varieties with optimal endosperm characteristics and viable levels of grain mold resistance.

Research Approach and Project Output

Evaluation of High Grain Digestibility trait in advanced RIL populations

Three_F_5 RIL populations_developed by W. Rooney (INTSORMIL project TAM-220C) were examined for the high protein digestibility trait. Grain mold ratings were also determined for each line. The three populations consisted of 21 F5 RILs derived from a cross between the high digestibility line P850029 and Tx635; 37 F5 RILs derived from a cross between P850029 and Tx436; and 41 F5 RILs derived from a cross between the HPD line P851171 and GCPO124. All RILs, plus the parents for each population, were evaluated for the high protein digestibility trait using the turbidity assay developed by B. Hamaker (INTSORMIL project PRF-212). Those individuals with protein digestibility scores near that of the HPD parent were evaluated a second time using the same turbidity assay. In the second analysis, 2 to 4 sister lines from each line that appeared to carry the HPD trait were also analyzed. Figures 1 and 2 highlight the lines that were scored to possess the HPD trait (HPD parents and RILs are highlight in black bars, low protein digestibility parents and RILs have white bars). One to two lines from each population were identified as having the HPD trait. After confirming the presence of the HPD trait, each HPD RIL, parents, and low digestibility lines from each cross were planted in replicated plots at five locations throughout Texas in conjunction with W. Rooney (TAM 220C). Grain mold ratings and the HPD turbidity assay will be used to determine the genotype-by-environment stability of the HPD trait as it relates to grain mold resistance. The HPD lines identified are being further analyzed by transmission electron microscopy to verify the presence of the abnormal protein bodies.

Hard Vitreous Endosperm in HPD lines

The endosperm texture and microstructure of each RIL that appeared to possess the HPD trait were analyzed by light and scanning electron microscopy. The HPD parent, P851171, exhibits an opaque floury endosperm throughout (Figure 3b). This phenotype was also found in some of the HPD RILs such as11278-1 (Figure 3d). The parents such as GCPOC124, used to derive the populations, have a hard endosperm composed of a central opaque region surrounded by a large vitreous portion (Figure 3a). This same phenotype was found in RIL 11286-1 (Figure 3c). However, the vitreous portion of the 11286-1 endosperm had a modified structure when compared to either parent. The microstructure in this HPD RIL, with a vitreous/flinty endosperm phenotype, had densely packed polygonal starch granules lacking in the continuous protein matrix normally found (Figure 3c). The polygonal starch granules are common to the vitreous endosperm (Figure 3a), yet the lack of surrounding protein matrix is unique to this HPD RIL. We are currently testing the hypothesis that this lack of protein matrix surrounding the starch granules will provide increased access for amylases in ethanol production. As well, this hard endosperm matrix carrying the HPD trait should provide improved milling properties over the opaque/floury HPD lines.

Antifungal Protein Association with Grain Mold Resistance

Sorghums (93 lines and hybrids) were grown in 2004 in TAES Field Plantation in College Station under ambient con-

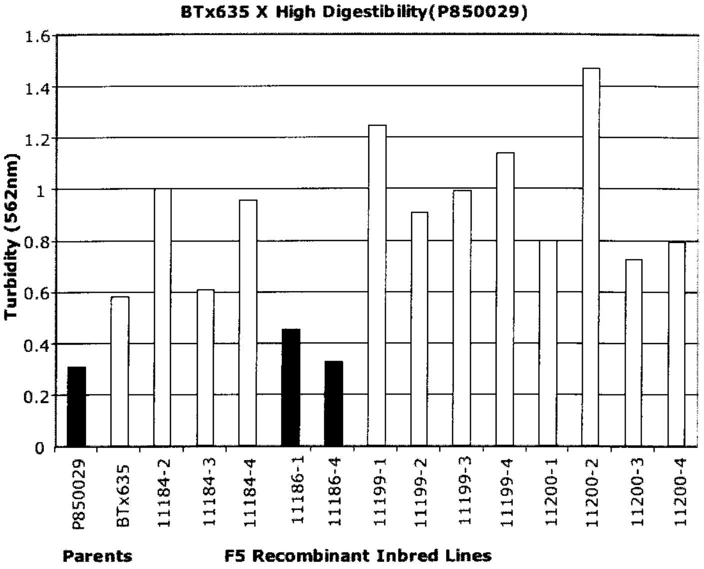

Figure 1. Turbidity assay of RILs and parents of RILs BTx635 and HPD line P850029. A 60 mg flour samples used for each pepsin digestion turbidity assay were incubated at 37°C for 60 min as described by Aboubacar et al., 2003. RILs with the same number are sister lines. The HPD line P85009 and RILs that have been scored as carrying the HPD trait are highlighted in black.

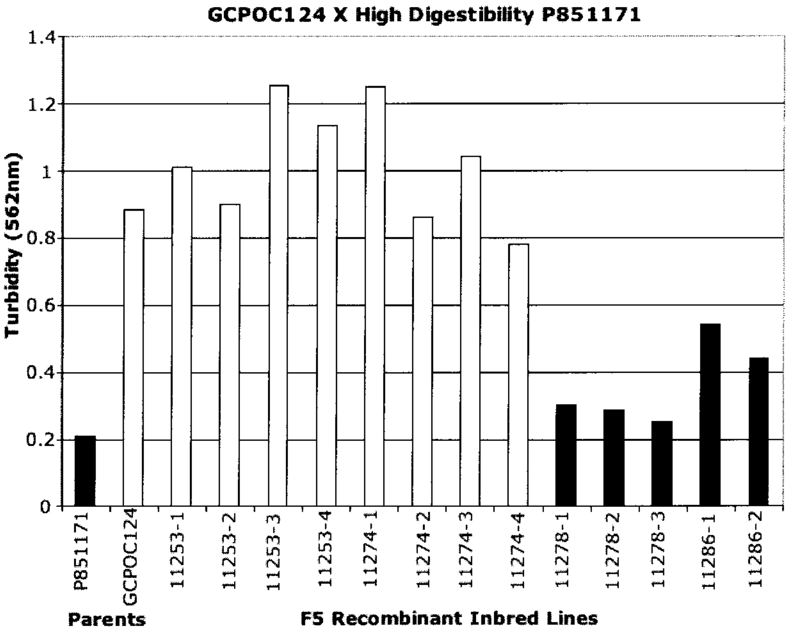

Figure 2. Turbidity assay of RILs, and parents of RILs GCPOC124 and HPD line P851171. A 60 mg flour samples used for each pepsin digestion turbidity assay were incubated a 37°C for 60 min as described by Aboubacar et al, 2003. RILs with the same number are sister lines. The HPD line P851171 and RILs have been scored as carrying the HPD trait are highlighted in black.

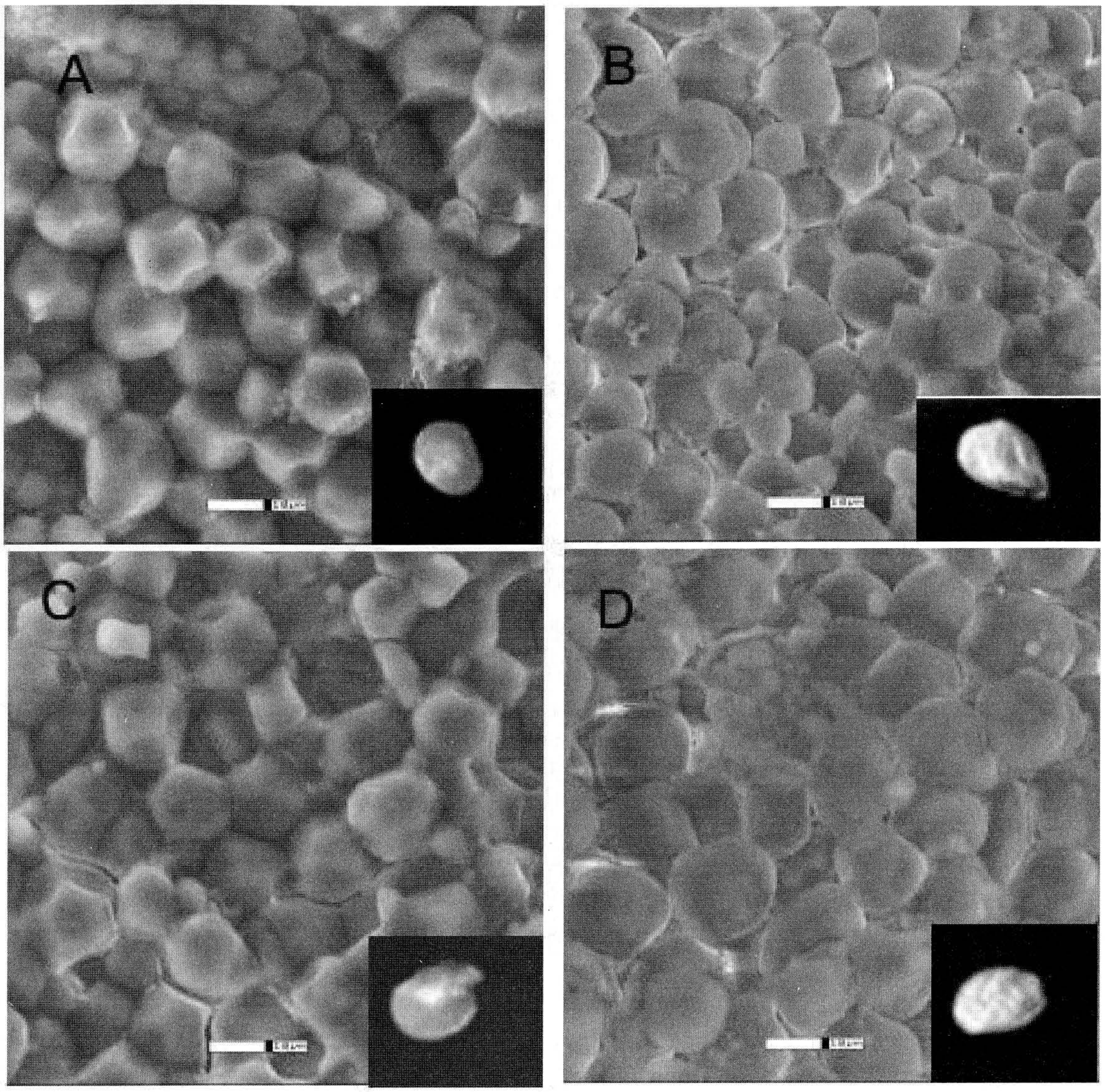

Figure 3. Longitudinal sections (inset) and scanning electron micrographs of (A) hard vitreous endosperm parent GCPOC124, (B) HPD opaque mutant parent P851171 (C) HPD mutant RIL 11278-1 with modified hard vitreous endosperm, (D) HPD mutant RIL 11286-1 with opaque floury endosperm.

ditions (not inoculated, no additional misting). Sorghums (52 red and 41 white) were sampled at physiological (30 DAA) and combined harvest maturity (50 DAA). Chitinase and sormatin in caryopses of sorghum at 30 and 50 DAA were determined. The percentage loss in chitinase and sormatin from 30 to 50 DAA were referred to as the retention rate. Grain mold rating, germination rate, phenol content, seed density, hardness and seed color (L, a and b values) were also measured.

Grain mold rating and germination rate are significantly correlated with both chitinase and sormation retention but not with phenol content and SKHT hardness (Table 1). Seed density is correlated with grain mold rating but not with germination rate. Thus, sorghums that are more resistant to molds retain more chitinase and sormatin from 30 to 50 DAA than those that are susceptible. On the other hand, the study did not show a relationship between mold resistance and phenol content or seed hardness. Clearly, chitinase and sormatin contribute to limit mold damage of sorghum.

Evaluation of 33 hybrids and their respective male and female parents were also conducted in 2004. The hybrids had improved mold resistance, seed germination and seed density and increased retention of chitinase and sormatin when compared to their parents. This indicates a potential additive effect of combining mold resistance loci. More work needs to be conducted to quantify the hybrid vigor component of grain mold resistance.

Table 1. Correlations between grain mold rating score and seed properties (n=93).

Attribute	Mold Rating	Germination Rate (%)	Seed Color (L)	Seed Color (a)	Seed Color (b)	Seed Density	Hardness (SKHT*)	Phenols (mg/g)	Chitinase Retention
Germination Rate	-0.49								
Seed Color (L value)	0.33	-0.20							
Seed Color (a value)	-0.56	0.39	-0.82						
Seed Color (b value)	0.34	-0.24	0.93	-0.73					
Seed Density	-0.21	0.17	0.26	-0.18	0.20				
Hardness (SKHT*)	0.02	0.07	0.09	-0.18	0.08	0.65			
Phenols (mg/g)	-0.16	0.24	-0.57	0.59	-0.52	-0.12	-0.08		
Chitinase Retention	-0.51	0.42	-0.36	0.43	-0.34	0.05	0.05	0.36	
Sormatin Retention	-0.46	0.44	-0.27	-0.24	-0.24	0.07	-0.06	0.31	0.74

Marked correlation in bold type are significant at $p<0.05$.
*SKHT = Single Kernel Hardness Tester.

Networking Activities

Dr. Hays traveled to Pretoria, South Africa, in October 2004 to present a talk on the use of biotechnology in the development of new high nutritional quality sorghum varieties at the White Food Sorghum Workshop at the University of Pretoria. Collaborations with Medson Chisi, Sorghum Breeding, Golden Valley Research Station, Zambia, and John Taylor, University of Pretoria, were developed at this meeting on priorities for testing potential food products that could be developed from the modified endosperm HPD lines.

We currently have one graduate student from Mexico, one from Honduras, and one domestic student working on and funded by this INTSORMIL project. We have leveraged INTSORMIL research funds to obtain $125,000 in additional funding for two graduate student fellowships. As well, we recruited a fully funded Fulbright Fellow graduate student from Honduras. Thus, three students are currently being funded by outside sources to work on this INTSORMIL project.

Publications and Presentations

Workshops Meetings

Dirk B. Hays. 2004. Sorghum Biotechnology: Combinability of high grain digestibility with grain mold resistance, USAAID-INTSORMIL, White Food Sorghum Workshop, University of Pretoria, Pretoria, South Africa.

Dirk B. Hays, 2004. Using biotechnology to develop resistance in cereals to pathogens with extant diversity, Department of Plant Pathology, Texas A&M University.

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

Project PRF 207
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Mr. C.K. Kamau, Sorghum Breeder, KARI, Kenya
Dr. Peter Esele, Plant Pathologist, NARO, Uganda
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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. We also undertake in this project studies on collection, assessment, and exploitation of sorghum germplasm from around 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 document results of a collaborative study on analysis of genetic diversity among sorghums from Sudan.

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

Analysis of Genetic Diversity in Sudanese Sorghums

Sorghum originated in the Northeast quadrant of Africa over 3000 years ago, and slowly dispersed into other parts of Africa eventually spreading its area of cultivation into Asia and the rest of the world. Diversity of sorghum appears to be highly correlated with duration of domestication and the type of farming practiced in an area. High level of diversity was reported in sorghums from Ethiopia, a primary center of origin, from India, a secondary center of domestication, as well as from China, another important center of diversity for sorghum. Phenotypic diversity on 415 sorghum landraces from Ethiopia and Eritrea showed high phenotypic diversity along adaptation zones. Among 2343 Indian landraces from the sorghum ex-situ collection maintained at the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT), higher phenotypic diversity among accessions from different states than those from within a state was reported. Among 10,386 Chinese sorghum landraces kept at the national gene bank in Beijing, high degree of phenotypic diversity was observed in the collection with report of the most diversity in landraces from regions with the longest history of sorghum cultivation.

Sudan is one of the most important centers of sorghum domestication and cultivation. Sorghum is grown in every region of the country where it is possible to raise a crop. Nearly 80% of the total grain production in the country is obtained from sorghum. It is the staff of life for all Sudanese. In many parts of the country the crop is wholly utilized. The grain is used for making kisra (unleavened bread from fermented dough), a local porridge asida, a non-alcoholic beverage abreih, and a local beer marisa. The stalks are used as building material and the straw is utilized as animal feed or as source of fuel. Sorghums from the Sudan have also impacted sorghum improvement efforts globally. They have served as germplasm sources for improvements in yield, drought tolerance, stalk strength, insect and disease resistance, as well as nutritional quality. Early introductions of sorghum into the USA were primarily from Sudan. Sudan was probably the place where mutations for height and maturity took place in nature and where

'U.S. type sorghums' originated providing excellent opportunity for gene transfer between tropical and temperate. Indeed many varieties such as *hegaris, feteritas, zera zeras* and *kurgis* have contributed much towards breeding of improved sorghum varieties in both USA and India. In spite of their immense global importance, however, no organized diversity analysis has been reported on sorghums of the Sudan except for a few collection reports describing apparent variability among Sudanese sorghum landraces.

We recently completed an extensive evaluation and characterization of Sudanese sorghums kept at gene banks in Sudan, India, and the USA. This was undertaken as a collaborative effort among several institutions, including ICRISAT, the International Sorghum and Millet Collaborative Research Support Program (INTSORMIL), the United States Department of Agriculture (USDA), and the Agricultural Research Corporation (ARC) of the Sudan. As a result of this effort, fresh seeds of approximately 2800 well catalogued Sudanese sorghum landrace accessions are currently kept at gene banks in the USA, India and Sudan. The scientific value of these collections is better appreciated if a comprehensive analysis of the genetic diversity is undertaken. The objective of this study, therefore, is to develop a better understanding of the diversity and distribution of the present collection and to provide a basis for formulating policy for future action.

Univariate analyses were performed on morphological characteristics to describe phenotypic variability and its distribution across regions. Basic descriptive statistics of means, standard error, variance, and coefficient of variation, were performed on 10 quantitative traits. Geographical partitioning of diversity was assessed though variance analysis. Ten qualitative characters were encoded with from two to 13 classes. To reduce the statistical limits due to small group size, we grouped some of these classes. Frequency distributions for the 10 discrete characters were determined by grouping observations according to regional origin. Deviation from the expected frequency, as obtained from the distribution in the total landrace collection, was assessed using a Chi-2 test. Morphological diversity was also estimated by considering multiple characters together. Principal component analysis was performed on the 10 quantitative characters using standardized data.

Racial Classification

Race classification of *Sorghum bicolor* proposed by Harlan and de Wet in 1972 defines five races (Bicolor, Caudatum, Durra, Guinea and Kafir) and their 10 intermediates based on spikelet and panicle shape at maturity. In our landrace collection, all the races except the Guinea-Kafir intermediate, were present (Table 1 & 2). Four landraces belonging to the subspecies *Sorghum drummondii* (an annual weedy species) were also present in the collection. Landraces collected from farmers' fields included all the races except for Kafir, its intermediates, and Guinea-Bicolor. Race distribution in these landraces was heavily skewed toward the Caudatum race (80.5%) and its intermediate forms. Racial distributions were markedly different among regions. Sorghums from El Gezira included 14 races made up mainly of Caudatum and its intermediate races. Among landraces from the Kassala region, six races were present with races Caudatum and Durra equally represented. Race Bicolor represented as high as 16% of the landraces from Kassala. In the Blue Nile region, six races of sorghum were included with race Caudatum as the most dominant (49%) followed by its intermediate Guinea-Caudatum (27%). More races were included in landrace sorghums from Upper Nile where there too, 70% of the landraces were classified as Caudatum. The less diverse region, race-wise, was Equatoria, where only 10 Caudatum, four Guinea, and four Guinea-Caudatum landraces were reported. However, such a bias in the racial distribution may only be a reflection of the reduced number of accessions collected from this region.

Plant Morphology and Phenology

Among sorghums originating from Kassala and Blue Nile regions, number of basal tillers (BT) always exceeded the unit. Sorghums from El Gezira had the highest number of basal tillers, with up to six basal tillers per plants, and consequently showed the largest coefficient of variation (CV=0.52). The shortest and earliest sorghums recorded during the post-rainy season (PHTR=85 cm and FLR=41 days) were also found in El Gezira. Accessions from the Blue Nile region were the tallest (PHTR=350 cm) and among the latest (FLR=103 days) sorghums. Sorghums from the Upper Nile region were among the smallest and earliest sorghums with the smallest upper limit of range values for both height ($PHTR_{max}$=260 cm) and days to flowering (FLR_{max}=82 days). The lowest limits in range of both PHTR and FLR values were the highest for sorghums from Equatoria ($PHTR_{min}$=170 cm and FLR_{min}=84 days). In addition, sorghum from Equatoria had very small coefficient of variation for flowering (CV=0.07) and for height (CV=0.12). Furthermore, the earliest sorghum accessions from Equatoria flowered later than the latest flowering sorghum from Upper Nile.

Panicle Characteristics

The range of values for peduncle exertion (PEDEX) showed that no sorghum from Equatoria had poor exertion as the minimal exertion recorded was nine centimeters. There was reduced variability for exertion among Equatoria sorghums as reflected by the small coefficient of variation (CV=0.31). Variances among regions were homogeneous and mean comparison indicated that landraces from Equatoria were significantly more exerted than acessions from all other regions. The highest values for ear head length (EHLG) and ear head width (EHWD) were found among sorghums from Kassala region (EHLG=44 cm and EHWD=25 cm). Sorghum from Blue Nile tended to include mostly accessions with long and large panicles. Based on mean comparison for these two panicle characteristics, sorghums from Kassala and Blue Nile regions appear to possess larger panicles than those from Gezira, Upper Nile and Equatoria.

Kernel Characteristics

In comparison with other regions, sorghum originating from Kassala had both the smallest and the largest kernel size (GRS), 1.8 mm and 5 mm, respectively, as well as the highest 100-seed weight (SWT=7.3 g). Consequently landraces from Kassala exhibited the largest coefficient of variation for GRS (CV=0.17) and for SWT (CV=0.34). El Gezira appeared as the region for sorghums with the smallest seed weight (SWT= 1.32 g). Sorghums originating from Equatoria showed both the highest value for the lower boundary and the lowest value for the upper boundary of GRS (GRS_{min}=2.5 mm, GRS_{max}=3 mm) and the lowest upper boundary for SWT (SWT_{max}=3.4 g). This reduced variability was also expressed by the smallest coefficient of variation for GRS and SWT (CV=0.05 and CV=0.15, respectively).

Nodal Tillers

Agronomic evaluation for presence or absence of nodal tillers (NT) showed that Sudanese landraces have a great tendency to produce nodal tillers. Though classified as a qualitative trait, nodal tiller production is highly affected by the environment. Despite a predominance of sorghums with presence of nodal tillers in the collection (92%), significant differences were found among regions. Landraces from Upper Nile and Equatoria were characterized with higher frequency of absence of nodal tillers. In Equatoria, the proportion of accessions without tillers to those with nodal tillers was reverse of what was found in the total collection. At the other extreme were accessions from El Gezira and Blue Nile region where almost all landraces produced nodal tillers and all landraces from Kassala were uniquely characterized with presence of nodal tillers.

Table 1. Geographical distribution and local source of the landraces from Sudan.

Province	Locality	Landraces from Institute	Landraces from Farmer's	Total
El Gezira	Gezira	749	0	749
	Wad Medani 124 E	0	1	1
	El Rafda	0	1	1
	El Nagi (Rufa)	0	2	2
	Rufa	0	1	1
	Missing	*58*	*0*	*58*
	Total	747	5	752
Kassala	Alareida	0	1	1
	Doka	0	4	4
	Doka 10 N	0	1	1
	El Azaza	0	2	2
	El Rwashida	0	1	1
	Gedaref 82 W	0	9	9
	Huri	1	0	1
	Kafai	0	3	3
	Kassab	0	3	3
	Komshetta	0	3	3
	Kumur	0	2	2
	Omshidara	1	0	1
	Sabarna	0	2	2
	Samsum 16 SE	0	2	2
	Samsum 20 SW	0	1	1
	Samsum 37 N	0	1	1
	Umsinebra	0	5	5
	Umgargura	0	3	3
	Total	2	43	45
Blue Nile	Abugarin (41 SW Damazin)	0	2	2
	Abu-ramad	0	4	4
	Amarasazili (61 NW Damazin)	0	1	1
	Bau	0	8	8
	Bel-ar	0	1	1

Table 1. cont'd - Geographical distribution and local source of the landraces from Sudan.

Province	Locality	Landraces from Institute	Landraces from Farmer's	Total
	Buck	0	2	2
	Damazin	0	7	7
	Dindro (144 SW Damazin)	0	3	3
	Duel (93 NW Assossa)	0	1	1
	Galgani (158 NW Damazin)	0	1	1
	Geneisa	0	1	1
	Kurmuk	0	8	8
	Lawni (Abu Hugar)	0	1	1
	Onsa (13 N Kurmuk)	0	2	2
	Radeef	0	2	2
	Singa	0	19	19
	Sennar	0	3	3
	Ulu (177 SW Damazin)	0	1	1
	Ulu (219 SW Damazin)	0	2	2
	Wad el Nile	0	4	4
	Total	0	73	73
Upper Nile	Tozi	144	0	144
	Total	144	0	144
Equatoria	Imeila	0	1	1
	Labalwa	0	2	2
	Lowudo	0	1	1
	Loronyo	0	3	3
	Lafon	0	4	4
	Mura-Ikotos	0	6	6
	Magwe	0	1	1
	Total	0	18	18
Missing		*972*	*13*	*985*
Total landraces		1865	152	2017

Table 2. Race distribution in different regions and in the total collection of sorghum landraces from Sudan.

Race	El Gezira	Kassala	Blue Nile	Upper Nile	Equatoria	Total
Bicolor	8	7	1	1	0	79
Caudatum	292	12	36	101	10	889
Durra	90	13	8	10	0	209
Guinea	14	0	0	2	4	35
Kafir	2	0	0	0	0	2
CB: Caudatum-Bicolor	55	0	1	3	0	110
DB: Durra-Bicolor	16	2	0	0	0	42
GB: Guinea-Bicolor	3	0	0	0	0	7
KB: Kafir-Bicolor	3	0	0	1	0	7
DC: Durra-Caudatum	104	7	7	12	0	231
GC: Guinea-Caudatum	129	4	20	13	4	342
KC: Kafir-Caudatum	15	0	0	1	0	34
GD: Guinea-Durra	19	0	0	0	0	24
KD: Kafir-Durra	2	0	0	0	0	2
Drummondii	0	0	0	0	0	4
Total	752	45	73	144	18	2017

Plant, Glume and Midrib Color

Most entries in the Sudan collection (93%) had plants with pigmentation (PIG) with no significant differences among regions for pigmentation. Approximately one-half of the collection contained dark (black/purple) glumes (53%) and again evenly distributed among regions. Approximately, 11% of the landraces from El Gezira had red glume (GLC) which was significantly different from frequency of red glumes in the total collection (16%). The proportion of accessions with sienna glume color was the smallest in accessions from the Upper Nile (6%) in contrast to a higher proportion in collections from Blue Nile (37%), Kassala (33%) and El Gezira (24%) regions as well as in the entire collection (19%). Mahogany glume color represented 12% of the collection and this trait was the lowest (3%) among sorghums originating from Blue Nile and the highest (20%) in accessions from the Upper region. Midrib color (MRC) for the entire Sudan collection was mainly distributed between two classes, white and dull midrib colors represented 62% and 36% of the collection, respectively. Yellow midribs were rare in the Sudan collection. Only a small portion of the landraces in the total collection had yellow midrib (2%), but sorghums from Kassala had an unusually high (29%) frequency of yellow midrib types.

Panicle Characteristics

For panicle compactness and shape (EHCS), a higher proportion of accessions of the entire collection were characterized with compact panicles (56%). Frequency of compact panicles was significantly higher in sorghums from El Gezira and from Upper Nile (69% for each). In the total collection, sorghums with loose panicles included 40% with loose and stiff branches and 3% for panicles with loose drooping branches. El Gezira sorghums were less commonly characterized with loose panicles. Sorghums from Upper Nile had a significantly smaller (17%) frequency of landraces with loose stiff branches, and a relatively higher frequency of landraces with loose drooping branches (14%). In major contrast to sorghums from all the other regions as well as the entire collection, landraces from Equatoria were more uniquely characterized with loose panicles. Most of the Sudan collection (68%) was classified as containing easily threshable (THR) panicles, except for sorghums from Kassala where 20% were recorded as difficult to thresh in contrast to a 6% average for the entire collection. Partly threshable sorghums were significantly higher in collections from El Gezira and Upper Nile, and significantly reduced for accessions from Kassala, Blue Nile, and Equatoria. Only sorghums originating from Blue Nile contained a very high frequency, 97%, of freely threshable panicles.

Kernel Color

This trait (GRC) was characterized as physical appearance of the kernels, notwithstanding the genetic basis for the expression of this trait. Approximately 55% of the collection was evenly distributed between sorghums with brown seeds and those with grey seeds. Straw, red, white, and yellow kernels were found in 15%, 13%, 11% and 5% of the collection, respectively.

Glume Coverage

Assessment of glume coverage of kernels (COV) in the Sudan collection resulted in 48% of the collection to be uncovered with only up to 1/4 of the seed covered by the glume, 40% of the collection with 1/2 of kernel covered by glume, and 12% of the collection with kernels 3/4 to fully covered by glume.

Endosperm Characteristics

Endosperm texture (TEX) was significantly different among sorghums from different regions. Fewer landraces in the Sudan collection possessed corneous endosperm (6%). A higher proportion of landraces had kernels with either partly corneous or partly to completely starchy endosperm 40% and 54%, respectively.

Estimates of Diversity

Diversity was estimated using the Shannon-Weaver diversity index calculated from frequency distribution of multiple morphological traits. Estimates were based on phenotypic variability of the landraces, only considering the qualitative characters. Great global index of diversity was found in the total collection (H'=0.80). Within region, however, the range of index of diversity varied from H'=0.60 for accessions from Equatoria, to H'=0.79 for sorghums from El Gezira. Pair-wise comparison of the indices using *t*-test revealed significant differences (at $p<0.05$ probability-level) between the diversity indices obtained from Blue Nile (H'=0.67) and the total collection (H'=0.80) as well as between Blue Nile and El Gezira (H'=0.79).

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 10 countries in 2004.

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

Project KSU 220

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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 including mold resistance 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 countries in Africa and Central America.

Improve Nutrition and Yield

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. Efforts are also being made to determine if high protein digestibility and grain mold resistance can be combined. Currently, small populations have been developed to test this relationship. Genes that contribute to grain mold and disease resistance are being tagged to simplify future incorporation into useful cultivars.

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.

Improve Institutional Capacity

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. 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 also were initiated in 2003 through interaction with Dr. Salissou Issa, Head of the Animal Husbandry Unit at the INRAN Rainfed Crops Program in Niger. These efforts include farm visits, feeding trials, and poultry field days 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, animal nutrition 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.

Promote Economic Growth

Plant breeders traditionally have placed little emphasis on end-use value of sorghum for human and animal consumption. Our research project attempts to address this weakness in sorghum and millet crop improvement through the integration of traditional plant breeding with biotechnology to develop elite hybrids and cultivars with improved nutritional and grain quality traits. 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.

Objectives, Production and Utilization Constraints.

Objectives

- Identify and map genes associated with improved grain and feed quality characteristics.
- Develop robust biotechnology tools for tagging genes that contribute to grain mold resistance and enhanced nutritional value.
- Develop high-yielding sorghum cultivars with improved feed quality and grain mold resistance using both conventional breeding techniques and marker-assisted selection technology.
- Provide technology transfer and technical assistance in promoting the use of improved sorghums and millet in poultry feeding in the developing regions of West Africa and Central America.

Constraints

New entrepreneurial opportunities for production of animal feeds and products in developing countries including meat and eggs are needed to move sorghum and millet from subsistence crops to value-added commodities. However, the marketing and utilization of sorghum grain often has been limited by lower grain quality and feed value than other cereals. Sorghum kernels are exposed to the environment as they mature and grain mold problems are common. Grain mold involves a complex of potential pathogens and as for other diseases, selection for resistance leads to changes in the pathogen populations. Thus breeding efforts must be continuous just to maintain high production and quality standards. However, even in the absence of contaminating fungi, sorghum grain typically has lower digestibility and metabolizable energy values as compared to other cereals, providing another target for improvement through application of technology-assisted plant breeding.

Research efforts are needed to address food quality and feed efficiency traits in sorghum and millet. Components of feed quality are frequently defined in terms of animal performance or metabolizable energy value. These traits can be measured in animal feeding trials, but these experiments are costly and not amenable to high-throughput testing as required in a plant breeding program. This research project attempts to 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. The recognition of the true nutritional value of grain sorghum by animal producers will lead to greater health and productivity in regions of the world where hunger and poverty are major issues.

Research Approach and Project Output

Research Methods

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.

Crop improvement efforts to develop cultivars adapted to environments in West Africa, 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 that incorporate *Striga* resistance 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 maturity genes *Ma5* and *Ma6*.

The underlying objective for research to identify and map genes related to grain quality is to develop a better understanding of the genetic control of important quality traits and generate genetic markers that can be used by sorghum improvement programs in the near future. Combining these traits into one genotype is a significant challenge that could be facilitated by the use of molecular technology. The 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. In general, PCR based methods are being used. These include AFLP and SSR protocols that permit rapid identification of DNA polymorphisms linked to key characters in segregating populations. In addition, prospective disease resistance genes have been identified based on DNA sequence homology to conserved regions found in cloned genes from other species. These resistance gene analogs are being mapped on the standard sorghum mapping population (BTx623 X IS3620C). Students from Africa, Honduras and the U.S. are being trained who will be able to take advantage of marker technology, either directly in their respective national programs or through continued collaboration following return to their home countries.

Technical assistance and technology transfer efforts in poultry production and nutrition are focused on workshop and short course activities as well as feeding trials and demonstrations. In 2004-2005, feeding trials were conducted to demonstrate and compare feed value of corn- and sorghum-based poultry rations in West Africa. Replicated trials to evaluate performance of broiler chickens in Niger were completed in 2004. At the conclusion of the study, poultry producers from the region were invited to participate in a review of the research project. The producers were very interested in the results and suggested that the researchers at INRAN conduct a similar study to evaluate the efficacy of sorghum-based feed rations for layer production. The dialogue that developed around this project ultimately led to the formation of the Nigerian Poultry Producers Cooperative in 2004.

Research Findings

Analysis of Sorghum and Maize for Differences in Poultry Feed Quality

Poultry and egg production is increasing in countries throughout the developing world. Maize-based feed rations are common in many areas of Africa and Central America because grain is cheap and readily available. In most of these areas, sorghum is valued for human consumption and sells for a higher price than maize. However, in certain areas such as Niger, locally produced sorghum is generally less expensive than imported maize. In these areas, sorghum could play an important role in formulating feed rations for animals such as poultry; however, animal producers generally will not feed sorghum-based rations because of misconceptions about tannins in sorghum and the relative feed value of the grain. These concerns generally are unfounded because improved sorghum cultivars are low in tannin and have feed-value nearly equivalent to maize given the appropriate processing to maximize the feed value.

A technical assistance and technology transfer program was developed in Niger through interactions with Dr. Salissou Issa, Head of Animal Husbandry, INRAN. A research exhibition area was developed to highlight best management and production practices for sorghum cultivars as well as demonstrate applied poultry production procedures using sorghum-based feed rations.

The objective of this study was to evaluate the feed quality of traditional coarse-ground (> 1,200 microns) and finely-ground (< 700 micron particle size) maize-based rations using maize imported from Nigeria in comparison with finely-ground (< 700 micron particle size) sorghum-based rations using a locally produced landrace variety called Mota Galmi and an improved tan-plant variety called IRAT204. Rations formulated using 60% milled corn or sorghum were fed to broiler chicks in government production facilities near Niamey, Niger. The experiment was conducted with five replications for each treatment and 25 chickens per pen with pens arranged in a randomized complete block design. Feed intake was determined daily and the bird weights were determined at day 7, 21, 35, 49, and 60.

No significant differences in poultry performance were detected in comparisons between the fine- or coarse-grind maize at any point in the experiment (Table 1). Poultry performance was significantly better with the maize-based diets as compared to the sorghum-based diets at 21, 35, 49, and 60 days for bird weight and feed intake. Comparisons among the sorghum-based diets indicated that broiler chickens produced using the sorghum landrace Mota Galmi were significantly heavier than the chickens produced using IRAT204 at 21, 35, 49, and 60 days. Feed intake was highest for the maize-based diets followed by the Mota Galmi- and IRAT 204-based diets. Differences in bird weight were strongly correlated with differences in feed intake and no differences in the gain to feed ratio were detected at day 60. Yet even with the slight nutritional advantages for the maize-based diets, the results of this study were consistent with previous reports indicating that chickens fed locally produced sorghum varieties perform quite well given the price advantage for sorghum compared to maize.

Table 1. Average broiler chicken performance using feed rations based on fine- and coarse-ground maize samples in comparison with feed rations based on fine-ground improved and local sorghum varieties.

Treatment	Bird weight 7d	21d	35d	49d	60d	Feed Intake	Gain to Feed Ratio
	g bird^{-1}					g bird^{-1}	
Maize – Coarse grind	90.4	307	868	1601	2355	4553	0.52
Maize	91.4	310	884	1603	2341	4690	0.50
IRAT204	83.6	233	638	1193	1896	3733	0.51
Mota Galmi	90.8	281	773	1435	2188	4230	0.52
LSD[†] ($p<0.05$)	6.5	25.3	46.4	68.5	83.1	302	0.03
	NS	***	***	***	***	***	NS

[†] LSD = least significant difference; NS=nonsignificant differences among rations; *** indicates significance at α=0.001

Table 2. Effects of imazapyr and metsulfuron herbicide seed dressings on emergence, height, and plant injury of tolerant and susceptible sorghum genotypes at 21 days after planting.

Herbicide	Seed Dressing	Emergence[†] Tol.	Emergence[†] Susc.		Height Tol.	Height Susc.		Plant Injury Tol.	Plant Injury Susc.	
		---- % ----			---- mm ----			---- % ----		
Control	0 g seed^{-1}	80	90		236	204	***	0	0	
Imazapyr	0.01875 g seed^{-1}	83	46	***	183	19	***	16	91	***
	0.0375 g seed^{-1}	83	33	***	160	10	***	28	99	***
	0.075 g seed^{-1}	83	28	***	151	5	***	33	100	***
	0.15 g seed^{-1}	78	28	***	132	9	***	47	100	***
	0.3 g seed^{-1}	76	28	***	145	6	***	53	100	***
Metsulfuron	0.00625 g seed^{-1}	78	37	***	154	14	***	24	96	***
	0.0125 g seed^{-1}	82	28	***	118	13	***	37	97	***
	0.025 g seed^{-1}	76	24	***	107	8	***	50	99	***
	0.05 g seed^{-1}	73	23	***	86	5	***	61	100	***
	0.1 g seed^{-1}	72	30	***	76	5	***	68	100	***

[†] Tol=Herbicide tolerant; Susc=Herbicide susceptible
*** indicates difference is significant at α=0.001 level

Striga Resistance

Several researchers attending the 2004 West Africa Regional Workshop in Ouagadougou, Burkina Faso indicated an interest in developing a regional research effort focusing on control of *Striga*. The use of crop cultivars with resistance to *Striga* has been widely acknowledged as the most practical and economically feasible control measure for subsistence farmers in Africa. Sources of genes conditioning host-plant resistance to *Striga* have been identified in sorghum. These resistance genes disrupt the intricate relationship between the parasite and its host. The mechanisms of resistance that have been identified to date include: 1) low production of germination stimulant, 2) low production of haustorial factor, 3) hypersensitive response, and 4) incompatible response. Varieties that incorporate *Striga* resistance in high yielding genetic backgrounds are being developed through the efforts of researchers in national programs in West Africa and abroad. Continued effort is needed in identifying and cataloging genes that can be used to control *Striga* and in technology transfer to incorporate these traits into adapted varieties.

Although genetic resistance has been shown to provide good control of *Striga*, varying degrees of infestation generally are observed even in resistant varieties. Although this level of control improves plant health and yield potential, the seed bank for *Striga* continues to be regenerated each year since each of the surviving *Striga* plants can produce thousands of seeds. Furthermore, given the virulence and extent of genetic variability in *Striga*, it is likely that recurring use of resistant varieties may result in weed populations that at capable of overcoming host-plant resistance.

This project focuses on the development of a new technology to control *Striga* that compliments research efforts in host-plant resistance. The technology is based on the use of low-dose herbicide seed treatments and has been shown to be effective in controlling *Striga* in imidazolinone (IMI)-herbicide tolerant maize. A similar technology for controlling *Striga* should be effective in sorghum and should contribute both to control of *Striga* as well as improved management of the seed bank. Experiments were conducted to evaluate the tolerance of sorghum to seed treatments with imazapyr and metsulfuron herbicides. The results of these experiments are shown in Table 2. In the control treatment with no herbicide application, emergence values for a tolerant and susceptible genotype were similar and no plant injury effects were noted. The resistant genotype was somewhat taller than the susceptible genotype. In contrast, very large and significant differences in emergence, height, and plant injury were noted between the tolerant and susceptible genotypes for each of the imazapyr and metsulfuron seed treatments. In each case, the tolerant genotype expressed better emergence, greater height, and lower plant injury. Based on the results of this study, three rates of each herbicide were selected and are being evaluated to determine the efficacy of these treatments in controlling *Striga* under field and greenhouse conditions.

Host Pathogen Interactions

Molecular tags suitable for use in marker-assisted selection were identified for the anthracnose resistance gene in SC748. Map data for sorghum disease resistance gene analogs, though limited, suggests that the genes are distributed to chromosome segments in clusters matching those of rice. Messenger RNA extracts were prepared from florets of two mold resistant and two susceptible cultivars 48h after inoculation at anthesis with spores of *F. thapsinum* and/or *C. lunata*. The most notable observation to date is increased expression of a chitinase gene in resistant vs. susceptible cultivars. In a related project, AFLP DNA fingerprinting has shown considerable differences in pathotypes 1 and 3 of *P. sorghi* (the downy mildew pathogen), and that a new metalaxyl resistant pathotype most likely arose as a mutant of pathotype 3. Many of the accessions in the sorghum germplasm collection are already being screened to identify potential sources of resistance to the new pathotype..

Breeding Activities

Efforts to incorporate the large seeded trait with grain mold resistance are being continued. Several F_4 generation lines have been identified that possess large seed with mold resistance improved from that of KS115. Because mold resistance is not yet suitable for use in production systems, it is likely that additional backcrossing of these F_4 lines will be necessary to continue the improvement of grain mold resistance. We also are cooperating with TAM 224 to determine whether 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.

In cooperation with Drs. Medson Chisi and Neal McClaren, a set of Southern African cultivars and breeding lines were used as pollinators to create a set of hybrids to determine the level of heterosis present in this germplasm. The field evaluation has been completed and preliminary analysis of the data indicates that several lines show superior levels of heterosis with A-lines from the TAES program (Table 3). Quality analysis is currently being completed at this time.

Efforts in the development of tan plant hybrids are continuing. New and current tan plant hybrids have been evaluated in Texas, Kansas and Nebraska annually to determine their region of adaptation and grain quality parameters. Current tan plant full season maturity hybrids are high yielding and adapted to limited irrigation environments. While early and mid-season tan plant hybrids are now available, additional breeding efforts are needed to increase grain yields and adaptability of these maturity groups. Currently, early maturity tan plant hybrids are not as competitive in yield potential as traditional feed type hybrids, with emphasis on the development of disease resistant, drought tolerant types.

When comparing traditional hybrids with tan hybrids, trends observed in past years are similar to those observed this year. Across all hybrids, tan hybrids tend to be later but they are similar in yield and plant height (Table 3). This is reflected in maturity classes and the availability of hybrids. For example, there are several full season tan-plant hybrids on the market that have high yield potential, and good quality. There are only a few tan-plant hybrids in the early and mid-season, and in general, their performance relative to the traditional hybrids needs to be improved.

Grain Molds and Weathering Improvement

In collaboration with TAM 224, several progeny with high digestibility have been derived from crosses of TAES germplasm with P850029 and P851171. These lines have been grown in multi-location trials to determine if highly digestible lines with grain mold resistance can be developed. These trials were established and are currently ongoing. In addition, several populations segregating for multiple grain quality traits are being grown to determine the mode of inheritance for each trait.

Related Studies- Characterization and inheritance of anthracnose resistance - Anthracnose is a major disease of sorghum [*Sorghum bicolor* (L.) Moench]. Breeding for stable host plant resistance to this disease has been difficult due to the variable nature of the pathogen and an incomplete under-

Table 3. Comparison of the productivity of tan plant and pigmented plant hybrids in the 2003 Tan Plant Hybrid Test. Data included in this table is combined from five locations in Texas.

Location		Plant Color	Plant Height in.	Panicle Exsertion in.	Days to Anthesis	Desirability Rating	Grain Yield lbs/acre
College Station	Purple (Traditional)	P	52	3	74	5.1	5,036
	Tan (Food Type)	T	52	2	77	4.7	4,622
	L.S.D. (P<.05)		ns	ns	***	ns	ns
Gregory	Purple (Traditional)	P	48	5	69	4.5	3,279
	Tan (Food Type)	T	45	4	73	4.8	2,303
	L.S.D. (P<.05)		ns	ns	***	ns	*
Hondo	Purple (Traditional)	P	55	4	67	4.3	5,868
	Tan (Food Type)	T	52	4	70	3.9	5,275
	L.S.D. (P<.05)		ns	ns	***	*	ns
Halfway	Purple (Traditional)	P	46	3	73	4.3	7,024
	Tan (Food Type)	T	47	4	74	3.6	6,643
	L.S.D. (P<.05)		*	ns	*	**	ns
Perryton	Purple (Traditional)	P	53	4	78	4.5	7,123
	Tan (Food Type)	T	53	5	79	3.9	7,073
	L.S.D. (P<.05)		ns	*	**	**	ns
Combined	Purple (Traditional)	P	51	4	72	4.5	5,666
	Tan (Food Type)	T	50	4	75	4.2	5,183
	L.S.D. (P<.05)		*	ns	***	**	ns

standing of the 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 F_2 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. We are collaborating with Clint Magill in an effort to map the resistance in SC748-5.

Networking Activities

Workshops and Meetings

Great Plains Sorghum Conference – September 14-15, 2004, Manhattan, Kansas, USA.

Sorghum Genomics Planning Session – September 26-27, 2004, Ithaca, New York, USA.

NSF Sorghum Genomics Workshop – November 9, 2004, St. Louis, Missouri, USA.

Sorghum Improvement Conference of North America (all 4 PIs)– February, 2005, Reno, Nevada, USA.

Sorghum Germplasm Committee Meeting – February, 2005, Reno, Nevada, USA.

Research Investigator Exchanges

Dr. 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, 2004.

The External Evaluation Panel was hosted at Kansas State and Texas A&M Universities as part of the INTSORMIL review process in September 2004.

Dr. Tuinstra visited the INRAN and IER research programs in Niger and Mali in October of 2004 to review collaborative research activities and coordinate research activities for 2005.

Dr. David Jordan, Sorghum Breeder from Hermitage Research Station in Queensland, Australia, was hosted in visits to Kansas State and Texas A&M Universities during November of 2004.

Mr. Souley Soumana, a M.S. student at KSU, was sponsored in a trip to Niger and Mali to conduct his thesis research project.

Dr. Hancock participated in the INTSORMIL Crop Utilization Meeting held in Ouagadougou, Burkina Faso, December 2004.

Dr. Tuinstra visited collaborators at Wageningen University in the Netherlands on sabbatical leave to conduct greenhouse trials to test efficacy of herbicide seed dressings in controlling *Striga*

Dr. Hancock collaborated with Dr. John Sanders on a visit to Senegal for a review of the potential for expanding poultry markets to increase demand for sorghum as a feed grain, January 2005.

Dr. W.L. Rooney, accompanied by Dr. Gary Peterson, traveled to Central America in January 2005. In Nicaragua the pair met with Réné Clara and Rafael Obando to plan activities and evaluate germplasm. In Guatemala, Mr. Clara, Dr. Peterson and Dr. Rooney visited with seed companies Cristiani Burkhard and ProSemillas regarding the potential use of germplasm from INTSORMIL breeding programs.

Dr. 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, February 2005.

A collaborative IPM-CRSP proposal was prepared, involving Dr. Magill, TAMU, Adama Neya, Burkina Faso, Mamourou Diourté, A.M. Maliu, and S,K. Nutsugah, Ghana but was not funded. Other potential sources of funding are being queried.

Dr. Magill and Seriba Katilé, Mali met with Dr. Norman Borlaug to seek his advice on potential donors for improving technology capacity useful for breeders in Africa.

Dr. Hancock collaborated with Drs. Lloyd Rooney and John Sanders to present a seminar on "Myths About Sorghum as a Feedstuff" during the Sorghum Utilization Conference in Managua, Nicaragua, May 2005.

Germplasm and Research Information Exchange

Coordinated the tan plant hybrid trial that is designed to evaluate commercially available tan plant (improved grain quality) sorghum hybrids for agronomic adaptation and grain quality parameters. The test was grown at nine locations in Kansas and Texas.

Distributed 12 elite parent lines, 20 elite hybrids, 90 large-seeded breeding lines, and 12 large-seeded hybrids from KSU 220A to national program scientists for evaluation in Niger, Mali, Ghana, and Senegal.

Distributed a replicated experiment to evaluate efficacy of herbicide seed treatments in controlling *Striga* to collaborators in Niger and Mali.

Distributed a replicated experiment to evaluate new sources of *Striga* resistance from West African with the appropriate checks, and corresponding hybrids to collaborators in Niger and Mali.

Distributed three new KSU parent lines to seven commercial seed companies.

Publications and Presentations

Journal Articles

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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 emphasizes developing sorghum germplasm, parental lines, or varieties with resistance to selected insects as well as resistance to other selected biotic or abiotic stresses. Primary objectives are to identify, characterize and utilize the genetic diversity of grain sorghum to develop improved cultivars, germplasm, or parental lines resistant to 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), rust (caused by caused by *Puccinia purpurea* Cooke) and charcoal rot (caused by *Macrophomina phaseolina* (Tassi) Goid). Project emphasis has evolved with increased emphasis 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, and resistance to specific diseases and/or insects. Relevant populations are also evaluated for drought resistance, primarily stay-green (post-flowering drought tolerance).

Increase Yield, Promote Economic Growth, Improve Nutrition

Sorghum varieties or hybrids with resistance to multiple stresses provide farmers with the potential to produce a consistent supply of high quality grain for household or off-farm

use by end-use industry. The also will be used by private industry in hybrid development programs and by public scientists as a source of novel genetic combinations. Seventeen biotype E greenbug/disease resistant lines and 17 biotype E/I greenbug resistant have been proposed for release. The biotype E resistant lines also express wide adaptation and resistance to several diseases. The lines are tan plant, white grain or 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 nontraditional uses.

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. Leo Mpofu (Zimbabwe) and Mr. Joaquim Mutiliano (Mozambique) will complete their M.S. degrees at Texas A&M University in mid- to late-2005. Mr. Mpofu is a non-INTSORMIL supported student. Mr. Niaba Teme (Mali) will complete requirements for the Ph.D. degree at Texas Tech University in late 2006.

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 locale. Sorghums with enhanced environmental fitness will reduce the impact of abiotic and biotic stress. In a cropping system, stress occurs concurrently. Genetic resistance to multiple stresses will reduce environmental risk and enhance productivity. This becomes especially important as production ecosystems change the natural balance between the crop and the ambient environment.

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 integrated production systems. In an integrated production system plant stress does not occur as single event sequentially but as concurrent multiple events. Thus while research can be conducted on individual stress (abiotic or biotic) factors, resistance to multiple stress must be present in a hybrid or variety to promote sustainable, environmentally friendly, and economically profitable production systems. Incorporation of improved genetics (new hybrids or varieties) into an integrated crop production system requires a multi-disciplinary research program. Varieties or hybrids genetically resistant to stress will readily integrate with other inputs into an integrated, ecologically sound production and stress control strategy with large potential benefits in subsistence and mechanized agriculture. Development of multiple stress resistant sorghum is a continual effort in response to a dynamic evolving production agroecosystem.

Research Approach and Project Output

Research Methods

Collaborative host country research is supported through short-term training, graduate education, germplasm exchange and evaluation, site visits, and research at nursery locations in Texas and in two regional programs - Southern Africa and Central America. Southern Africa research is primarily focused on incorporating resistance to sugarcane aphid, disease resistance, adaptation, and improved end-use traits into potential new cultivars. 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 develop germplasm with multiple stress resistance, wide adaptation, and improved end-use traits.

Germplasm is evaluated for resistance to economically important insects in field nurseries and/or greenhouse facilities. Sources of germplasm for evaluation are introductions from other sorghum research programs, exotic lines, and fully converted exotic lines from the sorghum conversion program. Introduced germplasm is crossed to elite resistant germplasm and to germplasm with superior trait(s). A primary selection criteria is insect resistance in addition to 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 several stresses into a single high grain yield genotype with improved end-use traits. For insects important in host countries 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 host country cooperator in replicated trials for evaluation for resistance to the specific insect under the local production system (fertilizer, tillage, plant population, etc.). Disease readings, agronomic and yield data are collected if possible.

Table 1. Grain yield, midge damage rating, and days to 50% anthesis, for selected entries in the 2004 Midge Line Test at Santa Rosa, Nicaragua, and Corpus Christi and Lubbock, TX.

	Yield	Midge Damage Rating	Days to 50% Anthesis		Plant Height		
Designation	Santa Rosa	Corpus Christi†	Santa Rosa	Lubbock	Santa Rosa	Corpus Christi	Lubbock
	kg ha^{-1}				----------	cm	----------
(Tx2883*(Tx2864*(Tx436*(Tx2864*PI550607))))-PC1-SM1-CM2-SM2-CM2-CABK-CMBK	6002	2.5	65	69	142	130	86
(Tx2883*(Tx2737*(Tx436*(Tx2783*PI550607))))-PC4-SM1-CM2-SM2-CG2-CABK-CMBK-CGBK	5194	5.0	60	68	151	140	112
(Tx2880*(86EO361*(Tx2880*PI550607)))-PC2-PR6-LG7-CG3-CM2-CM2-CGBK-CMBK-CG2	5144	4.5	62	69	152	128	122
(Tx2880*(86EO361*(Tx2880*PI550607)))-PC1-PR10-LG34-CG2-CM3-CG1-BGBK-CABK-CG2	5066	7.5	69	68	154	118	110
(Tx2880*(86EO361*(Tx2880*PR550607)))-PC1-PR10-LG34-CG1-CG1-CG2-CMBK-BGBK-CG1	4784	8.5	58	71	147	110	117
(Tx2883*(Tx2737*(Tx2783*PI550607))))-PC2-SM3-CM1-SM1-LGBK-CABK-CABK	4609	2.0	59	70	148	118	100
(Tx2783*(Tx2737*(Tx436*(Tx2783*PI550607))))-PC1-SM2-CM1-SM1-CMBK-CABK-BGBK-CGBK	4223	5.5	66	70	139	122	122
(91CC515*MR114-90M11)-SM4-LMBK-CM1-SM2-SM1-HM1-CMBK-CMBK	3943	2.0	62	69	121	105	105
(7ML54/7BRON132/((IS2549C*Tx2767)*Tx2876)*MB108B)-SM3-SM1-CM1-CM1-CMBK	3852	2.5	64	70	148	135	130
00MLT165/01MLT156/(PM12713*Tx2880)-CM5-CM3-	3709	3.5	58	72	136	115	107
(Tx2883*(Tx2737*(Tx436*(Tx2783*PI550607))))-PC1-SM2-CM1-SM2-SM2-CABK-BGBK-CMBK	3626	4.0	64	70	122	120	99
(Tx2880*(Tx2880*(GR108-90M24*(Tx2862*(Tx430*(Tx2862*PI550607))))))-PR1-SM1-CM1-CM2-LGBK-BGBK-BGBK	3556	4.0	59	72	157	120	105
(Tx2880*(Tx2880*(Tx2864*(Tx436*(Tx2864*PI550607)))))-PR3-SM6-CM3-CM1-CM2-CABK	3430	3.5	60	69	131	108	107
Tx2880	3392	2.9	67	69	141	100	94
(Tx2880*(Tx2880*(Tx2864*(Tx436*PI550607)))))-PR2-LG24-CG2-CG1-CG1-CA1-CMBK	3333	2.0	67	70	118	115	115
(Tx2880*(GR127-90M39*(Tx2862*(Tx2864*PI550607))))-PC1-SM1-SM1-CM2-CG2-BGBK-CABK	3303	7.0	67	69	125	118	105
(Tx2883*(Tx2864*(Tx436*(Tx2864*PI550607))))=PC1-LG4-CG2-CM1-CM2-CABK-BGBK	3263	3.0	65	69	118	115	86
(Tx2880*(Tx2880*(Tx2864*(Tx436*(Tx2864*PI550607)))))-PR3-SM6-CM3-CM3-CG3-BGBK-CABK	3130	5.0	58	68	148	113	105
MEAN	2249	4.3					
LSD.05	550	1.8					

†Rated on a scale of 1 = 0-10% damaged kernels, 2 = 11-21%, up to 9 = 80-100% damaged kernels.

Research Findings

Sorghum Midge Resistance

Sorghum midge is the most ubiquitous insect of sorghum. It poses a production risk in many areas where sorghum is grown. Four primary means exist to control sorghum midge - cultural, biological, chemical, and genetic. Within many production systems, cultural and biological methods provide some measure of control. Genetic resistance can provide a low cost, stable, and durable measure of control. However, 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 wide-spread 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 planting two weeks or more resistant hybrids will generally out-yield susceptibly hybrids without insecticide application. With increasing environmental concern regarding pesticide application and fewer insecticides available to control sorghum midge interest in the development and use of midge-resistant hybrids could increase. The grain yield discrepancy for sorghum midge resistant hybrids in the United States results primarily from the research methodology required to screen for sorghum midge. A small portion of the research program is still directed at the development of superior A- or R-lines suitable for use in hybrid production systems.

Primary emphasis in the sorghum midge resistance program has shifted to developing varieties suitable for use in host country production systems. The varieties should be tan plant, white grain, possess disease resistance, drought tolerance, about 1.5 meters in height, and express a moderate level of resistance to sorghum midge. The 2004 Midge Line Test (63 entries x 2 replications) was grown at Corpus Christi and Lubbock, Texas and Santa Rosa, Nicaragua. Partial results are shown in Table 1. The midge damage rating of 4.3 indicated a

Table 2. Greenbug damage rating and selected disease and agronomic characteristics of Tx2945 through Tx2961 and selected checks.

Line	Plant color	Grain color	Greenbug damage rating[†]	Head smut[‡]	Rust[§]	Grain mold -	Grain mold -	Insecticide phytotoxicity[#]	Days to 50% anthesis[††]	Plant height
				%		CC[¶]	CS[¶]			cm
Tx2945	Tan	Red	3.5	0	1.2	2	2	1.1	75	112
Tx2946	Tan	Red	3	1	1	1.5	1.8	1.1	73	117
Tx2947	Tan	White	1.5	0	1	2.2	2.5	1.2	76	109
Tx2948	Tan	Red	2	0	1	1.5	1.8	2	74	109
Tx2949	Tan	Red	2.5	0	1	1.5	1.8	1.6	76	109
Tx2950	Tan	Red	4	0	1	2	1.5	1.5	76	107
Tx2951	Tan	White	2	0	1	2.2	2.2	1.2	76	89
Tx2952	Tan	Red	3.5	0	1	1.8	2.2	1.2	73	79
Tx2953	Tan	Lemon Yellow	3	0	1	2	2.5	1.1	78	101
Tx2954	Tan	Red	4	0	1	2.2	2.5	1.2	78	86
Tx2955	Tan	Red	2	0	1	2	2	1.1	73	102
Tx2956	Tan	Red	3	0	1	1.6	2.2	1.6	74	91
Tx2957	Tan	White	4	0	1	2.2	2.5	1.2	72	107
Tx2958	Tan	White	2	0	1	2.5	2.8	2	74	112
Tx2959	Tan	White	1	0	1.1	2.2	1.8	1.5	74	91
Tx2960	Tan	White	2	0	1	2.8	2.2	1.8	74	112
Tx2961	Tan	Red	3	0	1.4	2.8	2.2	1	74	99
Tx2783 (check)	Purple	Red	3	0	1.2	2	2	1.8	74	119
RTx430 (check)	Purple	White	8	3.3	1.1	3	3.2	2.2	78	102
RTx436 (check)	Tan	White		0	1	2.5	2.2	1.8	80	117

[†] Rated on a scale of 1 = 10% leaf tissue death, 2 = 20% leaf tissue death, etc., 9 = 100% leaf tissue death.

[‡] Average over two years at Corpus Christi, TX.

[§] Average over two years at Isabela, PR. Rated on a scale of 1 = disease inconspicuous or present on an occasional plant, 2 = disease over 50% prevalence with low severity causing little damage, 3 = disease 100% prevalent, up to 25% of leaf area destroyed, 4 = disease 100% prevalent, over to 25% of leaf area destroyed, 5 = leaf death.

[¶] CC = Corpus Christi, TX. CS = College Station, TX. Average over two years on a scale of 1 = no mold damage, 2 = moderately resistant to mold with seed slightly discolored, 3 = moderately susceptible with significant discoloration, 4 = extensive discoloration and deterioration of seed, 5 = seed destroyed.

[#] Rated on a scale of 1 = no leaf discoloration to 5 = 100% leaf discoloration.

[††] Average over two years at Lubbock, TX.

Table 3. Greenbug damage rating and selected disease and agronomic characteristics of Tx2962 through Tx2978 and selected checks.

Line	Plant color	Grain color	Greenbug damage rating[†]		Head smut[‡]	Rust[§]	Grain mold -	Grain mold -	Insecticide phytotoxicity[#]	Days to 50% anthesis[††]	Height
			Biotype E	Biotype I	%		CC[¶]	CS[¶]			cm
Tx2962	Purple	Red	3	6	0	1	2	2	2	76	102
Tx2963	Tan	Red	2.7	7	0	1	1.5	2.2	1.6	72	102
Tx2964	Tan	Red	2	4.5	0	1	1.4	2	1.5	73	102
Tx2965	Purple	Red	2.4	5	0	1	2	1.8	3	70	107
Tx2966	Purple	White	2.8	2	0	1.5	3.2	2.5	2.8	74	91
Tx2967	Purple	White	3	3	9	1.5	3.2	2.8	2.8	68	91
Tx2968	Purple	White	2.7	2.5	4.5	2	3.5	3.2	2.4	71	81
Tx2969	Purple	White	2.7	3	15.6	1.5	3.5	3.5	2.1	71	102
Tx2970	Purple	Red	2	6	0	1.2	1.8	1.5	1.5	74	91
Tx2971	Purple	Red	2.3	6	5.4	1	1.8	1.8	2	75	97
Tx2972	Purple	Red	2.8	4	3.8	1	2.2	4.2	2.8	77	102
Tx2973	Purple	Red	2.4	4	3.8	1	2.2	2.2	2	71	102
Tx2974	Purple	Red	2.8	5	2.5	1	3	1.8	1.6	76	97
Tx2975	Purple	White	5.2	5	20.6	1.7	2.8	2.5	2.2	72	102
Tx2976	Tan	White	5.8	6.5	1.5	1.8	3	3	1.7	74	102
Tx2977	Purple	White	2.2	3.5	0	1.8	2.8	2.7	2.8	71	102
Tx2978	Purple	White	6	4.7	2.9	1.2	2.8	2.5	2.2	71	97
Tx2783 (check)	Purple	Red	3	8	0	1.2	2	2	1.7	74	119
Tx430 (check)	Purple	White	8	8	1.7	1.2	3	3.2	2.2	78	102
Tx436 (check)	Purple	White			0	1.2	2.5	2.2	1.7	79	117

[†] Rated on a scale of 1 = 10% leaf tissue death, 2 = 20% leaf tissue death, etc., 9 = 100% leaf tissue death.

[‡] Average over two years at Corpus Christi, TX.

[§] Average over two years at Isabela, PR. Rated on a scale of 1 = disease inconspicuous or present on an occasional plant, 2 = disease over 50% prevalence with low severity causing little damage, 3 = disease 100% prevalent, up to 25% of leaf area destroyed, 4 = disease 100% prevalent, over to 25% of leaf area destroyed, 5 = leaf death.

[¶] CC = Corpus Christi, TX. CS = College Station, TX. Average over two years on a scale of 1 = no mold damage, 2 = moderately resistant to mold with seed slightly discolored, 3 = moderately susceptible with significant discoloration, 4 = extensive discoloration and deterioration of seed, 5 = seed destroyed.

[#] Rated on a scale of 1 = no leaf discoloration to 5 = 100% leaf discoloration.

[††] Average over two years at Lubbock, TX.

moderate population density of sorghum midge at anthesis. Several entries sustained less than 30% yield loss. Sufficient midge were not present during anthesis at Santa Rosa, Nicaragua to evaluate the trial for midge damage. Thus the yield (kg ha^{-1}) should be a good indication of the lines performance as varieties in a tropical environment. Despite a low test mean (2249 kg ha^{-1}) many entries produced significantly (LSD.05 = 550 kg ha^{-1}) more grain that the test mean. Analysis of the data led to the conclusion that it is possible to select varieties for a moderate level of resistance to sorghum midge with moderate to high grain yield potential. Several of the lines were selected for continued evaluation.

Greenbug Resistance and Germplasm Release

Selections to develop germplasm resistant to biotype I were made. Resistance to greenbug biotypes is conditioned by several genes and a moderate level of resistance is desired. Crosses to introgress resistance gene(s) into other germplasm were made. Progress is apparent is selecting for biotype I greenbug resistance and resistance to other biotic or abiotic stresses. A number of advanced progeny of diverse background were selected for additional evaluation as lines (for agronomic traits, adaptation, disease resistance, and grain weathering resistance) or a hybrid parents (for grain yield potential, adaptation, disease resistance, and grain weathering resistance.

Thirty-four germplasm lines have been proposed for release. The lines are in two sets based upon resistance to greenbug. Seventeen lines designated as Tx2945 through Tx2961 are resistant to biotype E greenbug (Table 2). All of the lines are tan plant and possess either red, white, or lemon yellow pericarp. The lines possess excellent resistance to several diseases including head smut and rust. Maturity varies from 73 to 78 days after planting and is in the range of Tx2783 (74 days after planting) and RTx430 (78 days after planting). All of the lines are earlier than RTx436 (80 days after planting. The lines will provide breeders with a source of multiple biotic stress resistance in a tan plant background and be useful as a source of novel gene combinations or directly as hybrid parents. The seventeen lines designated as Tx2962 through Tx2978 are resistant to both biotype E and biotype I greenbug (Table 3). Fourteen of the lines are purple plant color and three are tan plant color. The level of disease resistance will vary with the line and disease. All of the lines reach 50% between 68 and 76 days after planting and reach anthesis earlier than Tx2783 (74 days after planting), RTx430 (78 days after planting), and RTx436 (79 days after planting). In 2003, the lines were evaluated as hybrid parents in a replicated yield trial (94 entries x 3 replications) grown at Lubbock, TX under moderate drought stress. Fourteen of the top 15 hybrids with the highest grain yield were resistant to biotype I greenbug.

Sugarcane Aphid Resistance

The sugarcane aphid (*Melanaphis sacchari*) is an insect pest of sorghum throughout Southern Africa. Collaborative research between TAM-223, the South African Agricultural Research Corporation - Grain Crops Research Institute, the University of the Free State, the Botswana College of Agriculture (BCA), 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, Texas for evaluation and selection in semi-tropical south Texas. 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 the mid-altitude ARC-GCI in Potchefstroom and the low-altitude,

Table 4. Sugarcane aphid damage rating, grain yield, and grain mold rating of selected entries in the 2004 Sugarcane Aphid Test at Potchefstroom and Burgershall, South Africa.

				Grain Yield		
Pedigree	Potchefstroom[†]	Burgershall[†]	Greenhouse[‡]	Potchchefstroom	Mt. Makulu	Grain Mold[§]
				–kg ha^{-1}–	–kg ha^{-1}–	
(CE151*TAM428)-LG8-BG1-LG1	2.3	1.7	1.0	5390	4008	3.8
(Macia*TAM428)-LL9	1.3	1.7	1.0	4430	6401	3.5
(SV1*Sima/IS23250)-LG15-CG1-BG2-BGBK-LBK	2.0	2.3	1.0	4290	3090	4.0
(Segaolane*WM#322)-CG1-BGBK-CCBK-LBK	3.0	2.3	1.0	4260	5503	3.2
((6BRON126/87BH8606-6*GR107-90M46)*CE151)-LG2-CG1-BG2-BG1-CG1-CABK	3.7	2.7	1.7	4030	4977	4.0
(Town*EPSON2-40/E#15/SADC)-LG1-BGBK-CCBK-LBK	3.3	2.3	1.3	4020	1936	4.5
(SDSL89426*6OB124/GR134B-)-LG5-CCBK-CCBK-LBK	2.7	2.3	1.7	4000	4651	3.8
(EPSON2-40/E#15/SADC*A964)-CG3-BGBK-CCBK-LBK	3.7	2.7	5.0	3870	2747	3.3
(CE151*TAM428)-LG15-LG1-BG1-BGBK-LBK	2.3	2.3	1.3	3760	4644	3.8
(EPSON2-40/E#15/SADC*A964)-LG2-CG1-BG1-BG2-CGBK	3.3	2.7	3.0	3550	3336	3.3
(6OB128/(Tx2862*6EO361)*CE151)-LG16-CG1-LGBK-LG2-LBK	2.3	1.7	1.3	3440	2079	4.0
Kuyuma	4.3	3.3	3.0	3410	5943	4.2
(Macia*TAM428)-LL2	1.0	1.3	1.0	3320	3302	3.7
WM#177	1.0	1.0	1.7	3270	4268	3.5
(6BRON161/((7EO366*Tx2783)-HG54)*CE151)-LG1-BGBK-CCBK-LBK	1.3	1.0	1.0	3250	5435	3.8
(Marupantse*TAM428)-HM7*CA1-CG1-CA3	3.3	3.3	1.7	3230	1262	3.7
(Macia*GR128-92M12)-HM20-CA2-CG1-CGBK	1.7	2.0	1.0	3220	3968	3.8
(6OB128/(Tx2862*6EO361)*CE151)-LG27-LG1-BG1-LG1-CGBK	3.0	2.3	1.3	3200	1117	3.3
PRGC/E#69414	1.7	2.0	1.0	3180	4815	4.2

Table 4. cont'd - Sugarcane aphid damage rating, grain yield, and grain mold rating of selected entries in the 2004 Sugarcane Aphid Test at Potchefstroom and Burgershall, South Africa.

				Grain Yield		
Pedigree	Potchefstroom[†]	Burgershall[†]	Greenhouse[‡]	Potchchefstroom	Mt. Makulu	Grain Mold[§]
				–kg ha^{-1}–	–kg ha^{-1}–	
(96AD34/6BRON116/5BRON131/(80C2241*GR108-90M30)-HG46-*WM#177)-CG2-BG1-LG1-CGBK	3.3	2.0	1.0	3180	4086	3.3
CE151	2.0	3.3	2.0	3110	2921	4.5
TAM428	1.7	2.0	1.3	3090	4586	3.8
Sima (IS23250)	1.7	1.3	1.0	2970	7082	3.8
WM#322	1.7	1.3	1.3	2650	3186	4.0
FGYQ353	2.7	2.0	1.0	2590	2687	3.3
Ent.62/SADC	1.3	1.3	2.0	2480	3988	4.2
SDSL89426	2.7	1.7	1.7	2310	3571	4.0
Segaolane	5.0	5.0	4.3	670	5040	3.3
Macia	5.0	5.0	3.3	620	2866	3.7
Mean	3.2	2.9	2.4	2350	3689	3.6

[†] Rated on a scale of 1 = 0-10% plant necrosis or plant tissue covered by aphids, 2 = 11-25%, 3 = 26-50%, 4 = 51-70%, 5 = 71-90%, up to 6 = 91-100% plant necrosis or plant tissue covered by aphids.

[‡] Rated on a scale of 1 = no aphids present, 2 = light infestation and no dead leaves, 3 = moderated infestation and no dead leaves, 4 = high infestation and many dead leaves, up to 5 = majority of plants dying.

[§] Rated on a scale of 0 = no grain mold present to 5 = grain mold on all kernels with significant grain deterioration.

sub-tropical Burgershall Research Station near Hazyview, South Africa or Gaborone, Botswana.

A 100-entry test, three replication test was evaluated for resistance to sugarcane aphid and adaptation to local production systems. Spreader row of susceptible sorghum were planted two weeks prior to the test to insure presence of aphids. Aphid damage is evaluated when the majority of entries are 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. Partial results of the trial are presented in Table 4.

The local check cultivar Segaolane (from Botswana) was rated at 4.3 and the resistant check TAM428 was rated at 1.3. Forty-seven entries and 36 entries respectively at Potshefstroom and Burgershall were rated as highly resistant (one or two). Many entries (43 at Potchefstroom and 35 at Burgershall) were rated as susceptible. A greenhouse seedling stage trial was also conducted. Partial results are shown in Table 4. Seedlings were inoculated 10-days after emergence and plants were rated for damage 21 days after infestation. Plants were rated using a 1 to 6 scale, where 1 = 0-10% plant necrosis or plant tissue covered by aphids and plants highly resistant, 2 = 11-25% plant necrosis or plant tissue covered by aphids and plants highly resistant, 3 = 26-50% plant necrosis or plant tissued covered by aphids and plants resistant, 4 = 51-70% plant necrosis or plant tissue covered by aphids and plants slightly susceptible, 5 = 71-90% plant necrosis or plant tissued covered by aphids and plants susceptible, and 6 = 91-100% plant necrosis or plant tissue covered by aphids and plants highly susceptible. Partial results of the trial are presented in Table 4. Sixty-seven entries were rated as highly resistant (50 entries rated at one and 17 entries rated at two). Only 21 entries were rated as susceptible to highly susceptible. Results of the field and greenhouse trials led to the conclusion that a number of entries express resistance in the seedling stage and consistent resistance over locations. The objective of this research is to develop an improved cultivar with resistance to sugarcane aphid. Insect screening data identified a number of entries with excellent resistance. To be useful to the small farmer, grain yield and processing characteristics must be at least equal to local standard checks. The Potchefstroom trial was harvested to collect data on grain yield. The average grain for the test was 2300 kg ha^{-1}. Sixty entries produced more grain than the mean. The eleven entries with this highest grain yield was all experimental entries that produced more grain than the highest yielding local check (Kuyuma). Of the 60 entries that produced more grain than the mean, 26 are highly resistant to sugarcane aphid in field at two locations (rating 2.3 or less) and the greenhouse trial (rating 1.7 or less). The three entries with the highest grain yield also possess excellent resistance to sugarcane aphid. For the Mt. Makulu location forty-three entries produced more grain yield than the test mean (3689 kg ha^{-1}). Differences in grain yield between the two locations were apparent with only a few entries ranking high for grain yield at both locations. The entry with the highest yield at Mt. Makulu ranked 97th in the Potchefstroom test. Two entries produced excellent grain yield at both locations. Entries with high grain yield and excellent resistance to sugarcane aphid were also identified at Mt. Makulu.

Based on the data obtained a replicated yield test will be developed for evaluation at three locations in South Africa. The objective of the test will be to identify potential varieties use to the small hectarage South Africa farmer. The experimental entries will be compared to standard check varieties for adaptation, grain yield, and end-use process traits. Additionally, 39-entries from the sugarcane aphid test were selected for subsequent evaluation and use in the new ARC-GCI sorghum breeding program.

The sugarcane test is provided to collaborators under a Memorandum of Agreement (MOA) between the Texas Agricultural Experiment Station (TAES) and the collaborating institution. The MOA restricts use to other than the stated evaluations, and prohibits secondary distribution or seed increase. To enable subsequent evaluations of selected experimental entries TAES has sent a new MOA to the ARC-GCI permitting seed increase and testing of the selected entries. Those that will be identified as suitable for use as open pollinated varieties will be jointly released by the TAES and ARC-GCI, and ARC-GCI will control seed stocks and distribution to small farmers.

West Africa (Mali) Graduate Education

Research was on-going in the Ph.D. research of Mr. Niaba Teme. The title of the dissertation is "Molecular marker analysis of quantitative trait locs (QTL) in BC_2 derived lines influencing grain yield and yield components in sorghum (*Sorghum bicolor* (L.) Moench)". The research hypothesis is that progeny derived from the backcrossing of SC170-14E (a fully converted zera zera sorghum from Ethiopia) will produce more grain yield as lines and hybrid parents, and that QTLs influencing grain yield can be identified. All field research and data have been collected. Activity is now directed at molecular analysis of the progeny. Screening of 197 BC2 derived SC170-14E population progeny to detect simple sequence repeat (SSR) loci in the progeny is on-going. At the present time 144 primer pairs have been screened of which 32 were informative. Screening for informative loci will continue in the next year. It is anticipated that the research will be completed in the fall of 2006.

Networking Activities

Workshops and Meetings

Participated in the White Sorghum Workshop at the University of Pretoria co-sponsored by the South Africa Sorghum Forum and INTSORMIL, 21-22 October 2004, Pretoria, South Africa.

Participated in INTSORMIL Technical Committee meeting 19-20 February 2005, Reno, NV.

Participated in INTSORMIL Technical Committee meeting 5-6 May 2004, Kansas City, MO.

Participated in ad-hoc committee meeting to draft a long-term Strategic Technical Plan, 13-15 June 2005, Lincoln, NE.

Research Investigator Exchanges

Zambia and South Africa - 10-23 October 2004. In Zambia met with Ministry of Agriculture, Department of Agricultural Research scientists to discuss national and regional sorghum and millet research. Met with representatives of South African Breweries (SAB) to discuss use of sorghum in "Eagle" beer. Met with the Executive Director of the Golden Valley Agricultural Research Trust to discuss future collaboration between Golden Valley and INTSORMIL, and to deliver a copy of the Memorandum of Understanding (MOU) to formally establish collaboration. In South Africa, met with representatives of the University of Free State to discuss the status of the Ph.D. program of an INTSORMIL sponsored student. Discussed options for expanding graduate education at the University of the Free State. In Potchefstroom, met with ARC-GCI collaborators to discuss on-going research for sugarcane aphid resistance. In Pretoria, participated in the White Sorghum Workshop at the University of Pretoria co-sponsored by the South Africa Sorghum Forum and INTSORMIL

Nicaragua and Guatemala - 3-8 January 2005. In Nicaragua, evaluated cooperative trials provided to INIA by the INTSORMIL/Texas A&M University sorghum breeding programs. Trials provided to INIA include the ADIN (All Disease and Insect Nursery), Midge Line Test (MLT) and hybrid observations. Discussed and evaluated on-farm trials of improved and indigenous varieties in the Estelí region. In Guatemala, evaluated sorghum trials provided to Cristiani Burkard through a Texas Agricultural Experiment Station Materials Transfer Agreement. Viewed hybrid production fields at the Cristiani Burkard research facility. Discussed opportunities for future collaboration. Discussed sorghum research with Prosemillas representatives and viewed hybrid production fields. Discussed possible future collaboration in testing and developing hybrids for Central America.

South Africa, Botswana, and Zambia - 17 April - 1 May 2005. During a visit to the University of the Free State at Bloemfontain reviewed the progress and status of an INTSORMIL supported graduate student (Ms. Phoebe Ditshipi). Ms. Ditshipi is conducting research on stalk rots of sorghum. Reviewed research progress of Mr. Michael Tesfaendrias (Eriteria). Mr. Tesfaendrias (a non-INTSORMIL supported graduate student) is conducting Ph.D. research on "Grain Mold of Sorghum with Specific Reference to Grain Quality in South Africa" under the supervision of Dr. Neal McLaren. Met with Drs. Charl van Deventer and McLaren to discuss development of an INTSORMIL sponsored Ph.D. research program on grain mold resistance in white grain sorghum. The program will involve plant pathology and plant breeding. At Cedara, viewed several sorghum research trials provided to collaborators by the Texas A&M University sorghum breeding program. Cedara is an excellent location to screen for foliar diseases. At Potchefstroom, evaluated the sugarcane aphid test and planned future activity. Discussed the possibility of testing selected entries in on-farm trials for potential use as varieties. In Botswana, traveled to Maun to met with Dr. Stephen Chite (DAR sorghum breeder). Evaluated replicated trials provided by Texas A&M University. Discussed the status of the DAR sorghum breeding program. In Gaborone, met with Dr. G.S. Maphanyee (DAR Director) and Dr. Pharoah Mosupi (Chief Arable Research Officer) to discuss INTSORMIL collaboration and the future of DAR sorghum and pearl millet research. Met with DAR crops researchers to discuss INTSORMIL regional activities. Met with Dr. David Munthali (Botswana College of Agriculture entomologist) to discuss on-going research and plan future activity. In Zambia, discussed the status of collaborative activity in the country and region. Met with an USAID team that was evaluating training in Southern Africa. The team was composed of John Thomas (interim head of USAID/Washington Office of Agriculture), Cristin Springet (USAID/Washington), Dr. Irv Witter (Bean/Cowpea CRSP Director) and Dr. Mywish Maredia (Bean/Cowpea CRSP Associate Director). Traveled to Ndola to visit the Northern Breweries (South African Breweries subsidiary) plant. Met with Mr. Orwell Monga, Plant Manager to discuss the use of sorghum to brew a new mid-level lager beer for Zambia named Eagle.

Germplasm and research information exchange

- Germplasm was distributed to private companies as requested and to the following countries, including but not limited to: Nicaragua, El Salvador, Guatemala, South Africa, Botswana, Zambia and Mozambique. 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.
- Serve on Ph.D. committee of N. Teme (Mali) at Texas Tech University. Serve on the M.S. committee of 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:

Dr. R. D. Waniska, Cereal Chemistry, Dept. 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

Dr. D.T. Rosenow (retired), Sorghum Breeding, Texas Agricultural Experiment Station, Texas A&M University Agricultural Research and Extension Center, Rt. 3 Box 219, Lubbock, TX 79403-9803 (TAM-222)

Publications and Presentations

Abstracts

Peterson, G.C. 2004. Cultivation of white sorghum - a U.S. perspective. White Sorghum Workshop, October 21-22, 2004, University of Pretoria.

Presentations

Peterson, G.C. 2004. Cultivation of white sorghum - a U.S. perspective. White Sorghum Workshop, October 21-22, 2004, University of Pretoria.

Teme, N., D.T. Rosenow, G.C. Peterson, W. Xu, M.S. Pathan, H.T Nguyen, C.A. Woodfin, A. Herring, and R.J. Wright. 2004. Identification of QTLs influencing heterosis in grain sorghum (*Sorghum bicolor* (L.) Moench). North American Grain Congress Conference and 24th Biennial Grain Sorghum Research and Utilization Conference, February 21-22, 2005, Reno, NV.

Miscellaneous Publications

Rosenow, D.T., J.A. Dahlberg, G.C. Peterson, J.E. Erpelding, J.W. Sij, L.E. Clark, A.J. Hamburger, P. Madera-Torres and C.A. Woodfin. 2003. Release of 49 converted sorghum germplasm lines from the sorghum conversion program. International Sorghum and Millets Newsletter 44:57-59.

Teme, N., D.T. Rosenow, G.C. Peterson, and R.J. Wright. 2004. Improvement of harvest index in sorghum through use of exotic germplasm. International Sorghum and Millets Newsletter 45:20-23.

Crop Utilization and Marketing

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

Project PRF 212

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Purdue University

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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, EARO, Nazret Research Station, P.O. Box 436, Nazret, Ethiopia
Ms. Betty Bugusu, Cereal Scientist, KARI, Katumani Natl Dryland Farming Res. Ctr, P.O. Box 340, Machakos, Kenya
Mr. Ababacar N'Doye, Research & 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; Dr. Moustapha Benmoussa, Plant Molecular Biologist, Purdue University, West Lafayette, IN 47907
Dr. Brian Larkins, Plant Molecular Biologist, University of Arizona, Tucson, AZ 85701
Dr. Tae Wae Moon, Food Chemist, Seoul National University, Seoul, Korea

Summary

The PRF-212 project at Purdue University is involved in fundamental and applied research to solve food quality and nutritional problems of sorghum and millet. In collaborative efforts in West Africa, a majority of our work focuses on the goal of commercializing high quality sorghum and millet products. The overall aim of our research is to make sorghum and millet more competitive as grains for human and animal nutrition, and for utilization in traditional and processed foods. In the past year, we continued to progress in the area of nutritional improvement of sorghum grain. In collaboration with breeders at Purdue, a modified, improved grain quality high protein digestibility/high-lysine sorghum mutant was tested in the field with promising results and a strategy was developed to further improve grain quality. Biochemical studies involving differential protein expression of the mutant showed a plietrophic response with higher expression of a range of proteins. Consistent increases in chaperone proteins in likely response to a misfolded g-kafirin protein make this later protein a candidate mutant protein. In a related study in our group, though not funded through the INTSORMIL project, g-zein, the maize counterpart to the hard to digest g-kafirin protein, was protein engineered to be highly digestible protein, as a recombinant *E. coli-* expressed protein. This shows that single amino acid changes can have dramatic effects on digestibility. In this case, the g-kafirin protein was previously shown to be responsible for the overall lower digestibility of sorghum protein. In related studies, we have shown that low protein digestibility of cooked sorghum is linked to its low starch digestibility, and that improvement in the former leads to higher starch digestibility. In this year, the role of the protein web-like structures that form during cooking and contain gelatinized starch was made clearer to starch digestion property. Starch associated with protein structures was less digestible that free gelatinized starch. Manipulation of starch digestion rate, both up and down, is desirable to produce more digestible sorghum foods for populations with marginal energy intake and for slowly digestible, low glycemic foods for health benefit.

Work continues on couscous and high quality flour processing in Niger with efforts to contract good, clean grain for processing competitive products. A regional effort in West Africa is underway to develop a strategy and proposal to stimulate processing of high quality sorghum and millet products

using supply chain management linking producers to processors. At Purdue, studies have been initiated on development of low-cost, quality pregelatinized flours for use in thin and thick porridges and weaning foods. Other studies showed significant grain decortication effect on porridge firmness. Starch structural aspects have been identified that influence staling properties of sorghum, and show that variability exists that can potentially be used to identify cultivars with improved food staling and keeping qualities.

Objectives, Production and Utilization Constraints

Objectives

- Determine the relationships among the physical, structural, and chemical components of grains and food to improve food and nutritional quality of sorghum and millet.
- Determine the biochemical basis for the relatively poor protein and starch digestibility of sorghum grain and many cooked sorghum products.
- Develop laboratory screening methods for use in developing country breeding programs to evaluate and improve the food quality characteristics of sorghum and millet grain.
- 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

Food Products

Couscous and High Quality Flour Processing

Our collaborative efforts to stimulate couscous and high quality flour production continue in Niger with more emphasis on regional strategies to commercialize sorghum and millet products. A group of food scientists/technologists with representatives from each of the six INTSORMIL-collaborating West African countries assembled in Ouagadougou in December 2004 to strategize on a regional approach to obtain funding for incubation units at the NARS food technology laboratories, to better interact with local and regional processors. This INTSORMIL regional-sponsored activity is being continued with the drafting of a proposal for funding processing activities.

As described in previous annual reports, PRF-212 and the INRAN Food Technology Laboratory have set up a cereal processing unit at INRAN/Niger 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*. The core of the sorghum/millet processing unit consists of a commercial scale grain decorticator (dehuller) and hammer mill, a central mechanized agglomerator designed and fabricated at CIRAD, France by J. Faure, a mixer for flour wetting, a couscousierre (steamer), and a large passive solar drying unit. The ability to produce high quality sorghum and millet flours is essential for the commercial success of any flour-based product.

Various market tests have shown high acceptability of couscous and flours produced in the unit. Current work, in collaboration with O. Botorou and economists, is on contracting farmers to provide a pure, clean grain source for processed products. This is critical to make consistent, acceptable products. A recent achievement of the group (funded through IFAD, Millet and Sorghum Initiative) is the fabrication of the agglomerator locally in Niamey and assisting a local entrepreneur in setting up her own mechanized processing facility. Two contractual agreements between farmers and the INRAN food technology laboratory were implemented to obtain 10 tons of high quality sorghum grains (5 tons of *cv.* SEPON 82 and 5 tons of *cv.* MDK).

Pregelatinized Sorghum Flour Products

In this M.S. level study (M. Moussa, INRAN/Niger), a drum-drier and an unusual, and comparably low-cost, low pressure, high temperature extrusion system are being used to produce pregelatinized sorghum flours for possible commercialization as instant porridge (thin or thick) and weaning food mixes. Pregelatinization is a common way of starch modification, where a starch slurry is completely cooked and dried. Pregelatinized starches have the important functional property of cold water absorption and swelling, and are used as viscosity builders in many food applications. Extrusion cooking (high temperature and pressure) and drum drying are the most common methods used to produce pregelatinized food products. The low pressure, high temperature process employed in this project produces non-expanded products that can then be ground to pregelatinized flours. Another advantage of pregelatinized products is their good shelf-life property due to decreased water activity that reduces or eliminates enzyme activity, particularly lipases and lipoxygenases that degrade residual fat.

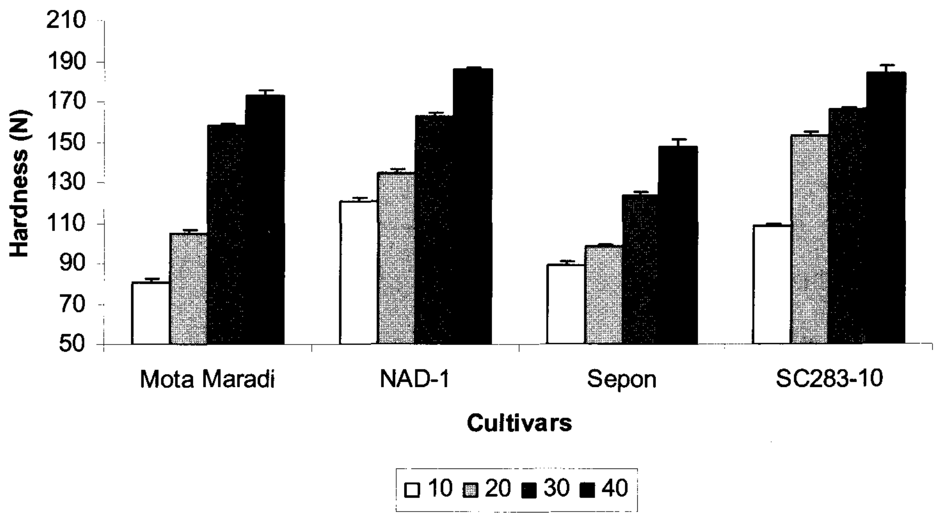
Objectives of this study, include: 1) understanding the effect of processing methods and process variables on pregelatinized flour quality, 2) the effect of different sorghum varieties on product quality, 3) optimization of process parameters and sorghum varieties, and 4) cost analysis, and 5) sensory evaluation of foods made from the pregelatinized flour to be conducted at Purdue and in a West African community. The low pressure, high temperature extruder is used with comparison to product made from a drum-drier.

The viscosity of the paste, which is critical to its eating quality, depends to a large extent on the degree of gelatinization of the starch granules and the extent of their molecular breakdown. Initial studies have been conducted using the extruder identify good extrusion conditions and to understand these two parameters in relation to paste quality. Moisture content of the feed was the major factor determining gelatinization extent. An increase in moisture content from 12% to 40% at a working die pressure of 95 psi produced a progressive decrease of Rapid ViscoAnalyzer peak viscosity , trough, and setback from 1262-517 cp, 985-396.5 cp, and 1781-336 cp, respectively; as well as an increase in final viscosity from 732.5-2766.5 cp for the various samples. Consequently, these changes indicate a transformation of the starch with lowest peak viscosity representing essentially complete starch gelatinization. Further studies will define quality in terms of molecular breakdown and other changes to optimize the process. Sensory evaluation will consider a small range of thin and thick pastes made from pregelatinized flours from the extrusion and drum-drying processes, and will be compared to control pastes using the traditional cooking process.

Effect of Decortication Level on Porridge Texture

Sorghum and millet are typically decorticated (outer kernel layer removed) prior to grinding to flours and used for thick porridges in West and East Africa. In this study, the effect of decortication on sorghum porridge texture was examined. Mean values of flour gel hardness from the decorticated samples are shown in Figure 1. Flour gels of the fours cultivars increased in stiffness as flour decortication level increased from 10 to 40%. Gels made from *cv*'s NAD-1 and SC283-14 were the hardest at all decortication levels (NAD-1: 120, 134, 163, 186 N at 10, 20, 30 and 40%; and SC283-14: 109, 153, 167, 184 N at 10, 20, 30 and 40%) followed by those made from Mota Maradi (81.1, 105, 158, 173 N at 10, 20, 30, and 40%), while those made from Sepon (89, 99, 124, 148 N at 10, 20, 30, and 40%) were the softest except at 10% kernel removal. Although having lower starch concentration, cultivar Mota Maradi had harder gels (except at 10%) than those of Sepon, indicating that some other factor such as amylopectin fine structure may have contributed. For example, another study in our laboratory (Lin et al 2002 Cereal Chem. 79:354-358) showed that the proportion of amylopectin long chains was highly and positively correlated with maize gel hardness. Correlation analysis indicated that starch concen-

Figure 1. Effect of decortication (10, 20, 30 and 40% levels) on porridge hardness.



tration is strongly associated with gel hardness within a cultivar. The correlation coefficients were 0.92, 1.0, 0.86 and 0.99 for Mota Maradi, NAD-1, Sepon, and SC283-14, respectively.

Thus, gels made from the cultivars became stiffer as decortication level increased, which is desirable since consumers have greater preference for firmer gels. These results indicate that good quality sorghum-based products or products containing sorghum flours can be obtained by adjusting milling conditions. However, economic forces lean towards greatest recovery of flour (lowest decortication level). A somewhat higher priced, highly decorticated flour, though, may be suitable for some consumers and food processes. Processing of high quality sorghum-based products is of increasing importance in sorghum-growing regions of Africa due to current emphasis on commercialization of products made from locally grown grains for sale in urban areas.

Starch Structure and Keeping Quality of Sorghum and Tef Injera

In collaboration with John Taylor and Senayit Yetneberk (then doctoral student from EARO Ethiopia) at University of Pretoria, starch properties were analyzed for several cultivars of sorghum and one cultivar of tef and related to the staling of injera, an Ethiopian fermented flat bread. Injera is a major food product for much of the population of Ethiopia. A traditional fermented flat bread, injera may be made from one or more of the following grain sources: tef, sorghum, millet, maize, barley, or wheat. The texture of injera is critical for consumer acceptance. High quality injera should be bendable and light with small air bubbles or "eyes" evenly distributed throughout the bread. A soft pliable texture is important as injera is often used as an edible utensil for consuming meat or vegetable stews. Tef is a traditionally used to make injera, however it is one of the more expensive grains found in Ethiopia and sorghum is a suitable substitute. Injera made from sorghum does not typically store well, while injera made from tef can retain a soft pliable texture for up to 3 days after baking. In the study of Yetneberk and Taylor, a range of sorghum cultivars were used to make injera with different keeping quality and were compared to tef injera.

Regarding starch characteristics, no relationship was found between the average molecular weight of amylose and amylopectin and injera staling. Chromatographic profiles of isoamylase digested amylopectin, which provides information on its fine structure, showed no significant difference in the proportions of fraction I (FrI, long chains), fraction II (FrII, intermediate chains), and fraction III (FrIII, short chains) among sorghum cultivars; while tef cultivar DZ-01-196 had a significantly higher proportion of FrI and a significantly lower proportion of FrIII compared with sorghum cultivars. Analysis of average number degree of polymerization (DP_n) for FrII indicated that sorghum cultivars with shorter DP_n for FrII produced slower staling injera compared with sorghum cultivars with longer FrII DP_n. Though there is not a clear indication of starch molecular properties needed to improve staling, a complementary study reported last year showed a high correlation with the proportion of amylopectin long chain fraction and development of longer term gel hardness (related to staling). Variation in sorghum cultivars was noted that may offer a future way, through genetics, to develop sorghum cultivars with improved staling properties.

Nutritional Quality Improvements in Sorghum

We continue to work 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. Also, the more recent finding by B. Bugusu in our group shows comparably high starch digestibility in mutant flour sorghum pastes. 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 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. Increasing energy (starch) utilization of staple cereals, particularly of sorghum with somewhat poor digestibility characteristics, is additionally critical for subpopulations that have chronically low caloric intake.

Collaborative work on digestibility aspects of sorghum was carried out in the 1990's with J. Axtell (deceased), and has recently been renewed with G. Ejeta.

Grain Quality

High protein digestibility lines with a previously reported intermediate, and unique in nature, modified hard endosperm trait are currently being tested for stability over environments. 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/High-Lysine Mutant

Through an understanding of the biochemical changes that occur due to the high protein digestibility/high-lysine mutation, an approach can be identified to identify the mutant gene, as well as develop ways to alter protein digestibility and quality characteristics of sorghum. Seed developmental studies in our laboratory have supported and expanded previous findings in India (collaboration with A. Chandrashekar) that expression of the BiP chaperone protein is much higher in the mutant grain than wild-type beginning at 20 days after pollination; the period that kafirin synthesis is at its highest. 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.

In the past year in a study in our laboratory by M. Benmoussa (partially funded through INTSORMIL), total proteins (kafirins and non-kafirins) from wild and mutant-type lines were separated by a high resolution 2-dimension gel electrophoresis, stained and analyzed by PDQuest software to determine differential protein expression (Figure 2). Spots differing in the mutant were identified by Maldi-TOF mass spectrometry. Data analysis resulted in the identification of the differing spots in the sorghum mutant as GTP-binding protein, chaperonin hsp 70 Kd, ribosomal protein S2, protein disulfide isomerase precursor (PDI) , luminal binding protein (BiP) 75, 70 and 45 Kd, plastid-localized – maize 50S ribosomal protein, glyceraldehyde 3-phosphate dehydrogenase, triosephosphate-isomerase, malate dehydrogenase, chloroplast 30S ribosomal protein S7, S-adenosylmethionine synthetase 2, RNA polymerase I, maturase, actin, actin depolymerising like protein, chloroplast inner envelope protein, and flavonoid 3',5'-hydroxylase.

Thus, there was a plietrophic response in protein expression caused by the point mutation for the high protein digestibility/high-lysine phenotype. Results showed that the expression of many proteins was affected in the mutant. Flavonoid metabolism was affected due to the mutation. Most evident, again, were the high expression of a number of chaperone proteins. Enhanced expression level of chaperon proteins is apparently in response to a misfolded kafirin protein, perhaps g-kafirin making it a candidate gene for mutational analysis. Cytoskeleton-related proteins were also affected; in particular the expression of actin was reduced. (Figure 2)

Related Study on Maize g-Zein Digestibility

Improving nutritional availability of prolamins is of interest in food, feed and biofuel applications. g-Prolamin, g-kafirin in sorghum and its counterpart g-zein in maize, has been shown in previous studies in our laboratory to determine the overall digestibility of prolamins due to their location at the protein body periphery and their hard-to-digest characteristic. These proteins additionally influence digestibility of starch. In a related study from our laboratory (though not funded through INTSORMIL), we recently showed that a protein engineering approach can be successfully used to increase g-prolamin digestibility.

Work done by S.H. Lee (doctoral student in our laboratory) tested hypotheses that certain single amino acid changes

Figure 2. High resolution 2-dimension gels of total protein extracts from wild-type and high protein digestibility mutant sorghum seeds.

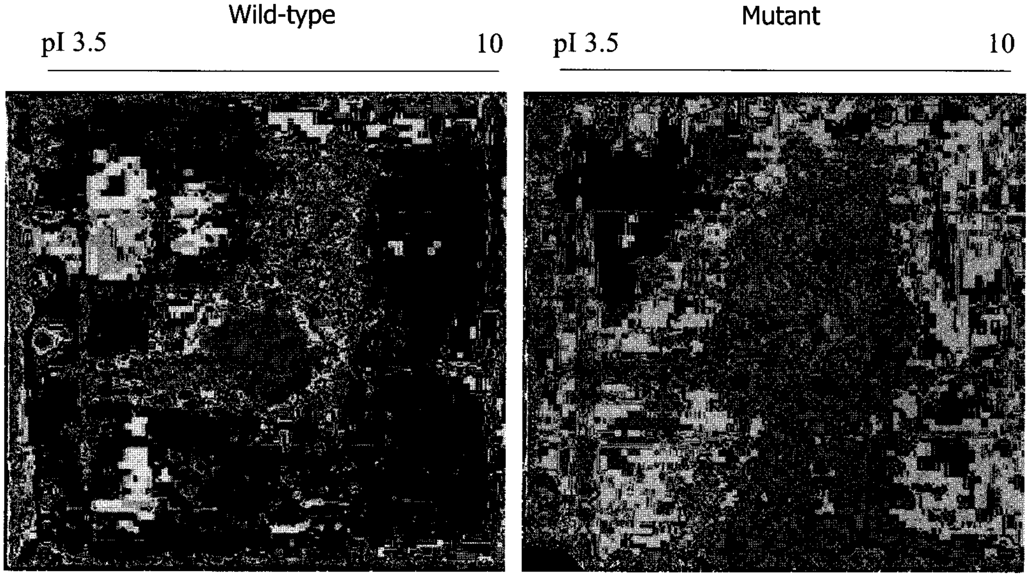


Figure 3. Western blot of time-course pepsin digestions of expressed recombinant γ-zein proteins by pET-24a(+) indicated by the arrow. Note the rapid digestion of the Cys mutant protein.

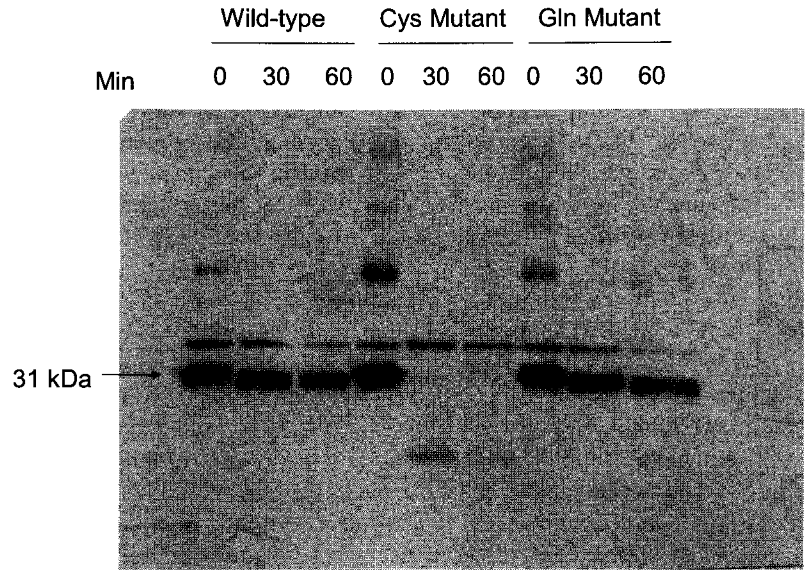
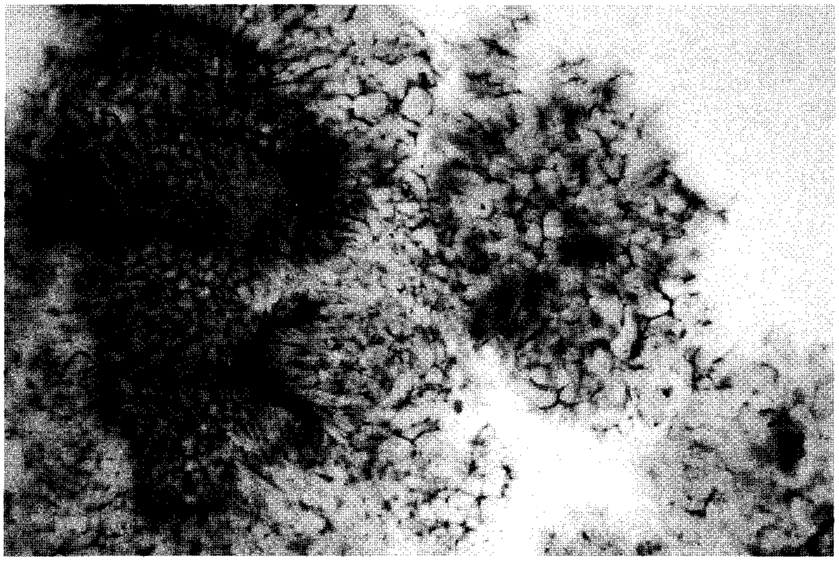


Figure 4. Cooked sorghum (P721N) paste with dual staining (protein – Gelcode (blue/dark); starch – periodic acid staining (pink/light) showing containment of much of the gelatinized starch in a 3-dimensional protein web-like structure. Evidence shows that starch digestion is slowed in these structures, particularly with hard to digest protein.



would improve overall digestion properties of g-zein. Due to the high sequence homology between g-zein and g-kafirin, one could expect a similar response to amino acid alterations in g-kafirin. A g-zein clone (originally from B. Larkins group) was subjected to site-directed mutagenesis using the QuickChange™ site-directed mutagenesis kit (Stratagene, CA) with two specifically designed oligonucleotides shown above following manufacturer's protocol. Obtained mutated plasmids ligated with the expression vectors, pET-30a(+) and pET-24a(+), were transformed into Rosetta-gami™ 2(DE3) bacterial cells, followed by screening positives on LB agar plates containing kanamycin and induction with IPTG. Two mutants, Cys and Gln, were chosen for digestion experiments. Proteins were digested with pepsin, trypsin, or chymotrypsin. Figure 3 shows results of pepsin digestion of the wild-type, Cys mutant, and Gln mutant recombinant expressed proteins. By changing one Cys residue to Ala, pepsin digestibility increased dramatically. This convincingly shows that compact folding of the protein causes its hard-to-digest character, and that the unfolded protein digests very quickly.

This protein engineering approach, therefore, holds promise as a way of improving digestibility through transformation of such mutated gene clones into maize and sorghum plants. Because the g-prolamin has poor digestibility and surrounds the more digestible a-kafirin major storage protein, its improvement in digestibility conceivably could positively affect overall protein digestibility, as well as starch digestibility. This could confer a nutritional improvement of the grain for animal feed and human food, and possibly for biofuels. This approach, however, does imply a "genetic modification" that must be considered in its application.

Starch Digestibility of Cooked Sorghum Foods

Our work on starch digestion properties of cooked sorghum foods has a two-fold application. Both derive from the comparably low starch digestibility, or slowly digestible starch property, that characterizes many sorghum foods. In poor, high sorghum-consuming regions, populations not meeting UN-set requirements for energy intake would benefit from more highly digestive sorghum varieties, while in over-consuming, obese-prone populations in developed, and some urban areas of developing countries, would gain from sorghum's slower digesting property. Our research has addressed both aspects of starch digestibility of sorghum-based foods.

As previously reported, starch digestibility was found to be improved in the high protein digestibility mutant sorghum due to the fast digesting protein component. In a larger sense, though, this suggests that normal sorghum varieties that inherently have higher protein digestibility would likewise have higher starch digestibility. Highly digestibility sorghums would be valuable in weaning foods and other foods where high availability of macronutrients is important.

Secondly, sorghum proteins were previously reported to form web- and sheet-like structures that constrain swelling of the gelatinized granules and reduce starch digestion rate and overall digestibility. Figure 4 shows a light micrograph of such web-like structures in cooked sorghum porridge (double-stained with protein in the darker network and starch in dispersed within). Following digestion up to 60 minutes with a-amylase, remaining starch was found associated with the protein network; gelatinized starch initially outside the confines of the protein network was digested first. This shows that protein contained starch has a slower digesting property than does free starch, and explains why sorghum-based foods are less digestible than other cereals such as rice where proteins aggregate on cooking. Maize was found to behave somewhat similarly to sorghum, but faster digesting proteins of cooked maize foods likely, in turn, expose starch for more ready digestion. We believe that the high protein digestibility/high-lysine sorghum mutant has higher starch digestibility in cooked porridge due to rapid protein digestion that releases gelatinized starch from this dense protein network. Ability to manipulate this trait from high to low starch digestibility would be quite useful in sorghum and other grains.

Networking Activities

In November 2004, Dr. Hamaker traveled to Bamako, Mali to participate in a meeting on the contracting and marketing regional project of J. Sanders and O. Botorou.

Dr. Hamaker traveled to Ouagadougou in December 2004 to participate in a West African regional crop utilization group meeting. This group is charged with developing a proposal to stimulate sorghum and millet processing in the region.

In February 2005, Dr. Hamaker traveled to Reno, Nevada to attend an INTSORMIL Technical Committee meeting and the following biennial sorghum meetings.

Publications and Presentations

Abstracts

Woo, H.D., Choi, S.J, Ha, H.J., Hamaker, B.R. and T.W. Moon., In vitro protein and starch digestibility of sorghum in the presence of sodium bisulfite, Institute of Food Technologists annual meeting, Las Vegas, July.

Han, X.Z., BeMiller, J.N. and Hamaker, B.R., Channels in starch granules affect extractability of granule-bound starch synthase, Institute of Food Technologists annual meeting, Las Vegas, July.

Benmoussa, M., Suhendra, B., Aboubacar, A. and Hamaker, B.R. Effects of starch granule morphology on sorghum starch digestibility, American Association of Cereal Chemists annual meeting, San Diego, September.

Bugusu, B.A. and Hamaker, B.R.. Effect of protein microstructure on starch digestibility of cooked sorghum porridge, American Association of Cereal Chemists annual meeting, San Diego, September.

Benmoussa, M., Chandrasheker, A. and Hamaker, B.R., Profiling endosperm protein expression of a high protein digestibility sorghum mutant, American Association of Cereal Chemists annual meeting, San Diego, September.

Barth, A.M. and Hamaker, B.R., Effect of starch properties on sorghum product functionality, American Association of Cereal Chemists annual meeting, San Diego, September.

Hamaker, B.R. and Bugusu, B.A., Comparably low starch digestibility of sorghum foods and its health implications, American Association of Cereal Chemists annual meeting, San Diego, September.

Journal Articles

Han, X.Z., Benmoussa, M., Gray, J.A., BeMiller, J.N. and Hamaker, B.R. 2005. Detection of proteins in starch granule channels. *Cereal Chem.* 82(4):351-355.

Dissertations and Theses

Barth, A.M. 2004. Role and proposed mechanism of starch retrogradation in determining sorghum porridge texture. M.S.

Food and Nutritional Quality of Sorghum and Millet

Project TAM 226
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Ms. Eliette Palacio, Seed Technologist, INTA, Managua, Nicaragua
Dr. Javier Bueso, Associate Professor, Escuela Agricola Panamericano, Zamarano, Honduras
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Summary

New, more-efficient, higher-yielding white tan photosensitive varieties from the IER breeding program in Mali have excellent properties for food processing. They escape significant weathering/ molding that adversely affects earlier insensitive white tan sorghums which led to their failure. Farmers were pleased with the grain quality for their own food and appreciated the opportunity to sell the grain at a potential premium. The principle of supply chain management from seed to food products has been demonstrated; however, more work to obtain wide-spread 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. There are some significant successes in this area.

United States value-enhanced white food sorghums developed in part by this project and promoted by the U.S. Grains Council in Japan continued to be used by the Japanese food industry to market snacks and several other products. The white sorghums are color sorted, decorticated, 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.

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. Other food companies are developing new food products and preparing mixes for special markets.

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

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 is 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. Red tan plant hybrid sorghums have excellent milling properties compared to red purple plant sorghums.

Tannin and other special sorghums have excellent levels of antioxidant power, high dietary fiber and impart attractive dark natural color to baked products. They can be incorporated into a wide variety of products. Small quantities of tannin sorghum bran were an effective preservative for ground beef patties.

Workshops on food sorghums and special tannin sorghums as health foods were presented in South Africa, Central America, Mali and to technical conferences and industry personnel in the USA.

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 need new 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. Profit for all from the seed to the processor is necessary.

Significant Accomplishments

Profitable Food and Feed Markets for Sorghums and Millet

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 occurs only when sufficient margins are available to produce increased profits for all parties in the supply chain. Successful development of this system is difficult and requires patience and practical programs to educate key managers, farmers and processors.

Several extruded salty snacks and milled products based on identity preserved 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 purchased by consumers provided convenience, good taste, appearance and consistent quality is available at competitive prices.

White sorghum for brewing beer is gaining momentum since South African Breweries (SAB) initiated contracting for white sorghum. The supply chain management is a key component of their program that is occurring in several Southern and East African countries. In South Africa, interest in white food sorghum is increasing especially in the small holder areas of Limpopo State.

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, the improved grain quality for their own food processing and potential premium prices. It is important to recognize that these farmers still have this attitude even though they had a bad experience with grain traders who defaulted on the initial contracts.

In Central America, a similar situation exists where farmers prefer tortillas made from white tan sorghum varieties instead of the native Criollos, which have purple glumes. The varieties Sureño, Soberano, Dorado and others with white tan plant color are used 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 Identity preserve food sorghums for processing is necessary for consistent success. The opportunities exist to stimulate use of white food sorghums in Central America since a source of grain is available, but inexpensive technologies that can be used to decorticate sorghum and mill it into flour or meal are required along with supply chain management.

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 and stores 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 larger formal baking industry in San Salvador to use white sorghum flour. Ms. R. Vilma Calderon, Food Technologist, CENTA, has worked with a rice miller to process white food sorghum into flour and decorticated products. The flour is acceptable to bakers in San Salvador.

Compatible Technology Incorporated, an NGO located in St. Paul, Minnesota, has developed an Omega VI grinder that provides an opportunity to grind decorticated sorghum into flour or meal in an economically effective way. The mill can be locally manufactured and may be an effective method of grinding decorticated grain into flour. These mills can be locally manufactured and are significantly more effective than the current grinders used for sorghum by the molineros. They can be operated by hand or by using a motor. Ms. Vilma Ruth Calderon, M.S. graduate student from El Salvador is evaluating the mill and CTI is modifying it for grinding sorghum into flour. Work will continue.

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 (Figure 1). The concepts proven successful in Japan apply directly to use of the white sorghums in Central America and elsewhere. Bland flavor sorghum flour has an advantage over corn flour as a substitute for wheat flour and in producing certain types of snacks, i.e., extruded fried potato sticks. This affords an opportunity to utilize sorghum in popular food items.

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 hillside producers. The technologies developed in El Salvador can be utilized in Nicaragua; a workshop in Managua featured presentations by CENTA personnel and a commercial Salvadoran baker who demonstrated to Nicaraguan bakers the use of white sorghum flour.

Health Foods from Special Sorghums

The potential to produce healthy foods from sorghum is quite high. A team of graduate students won first prize in the American Association of Cereal Chemistry International Meeting for producing "Vita Bread" containing sorghum bran, flax seed, gluten and other ingredients. The bran is high in dietary fiber, antioxidants and natural brown or black pigments that impart attractive colors to baked products such as cookies and multigrain breads. Ms. Lindsey Hines, M.S. student, has developed combinations of sorghum bran, wheat gluten, flax and beta-glucans into mixes for bread machines following up previous research in our laboratory (Figure 2). A bread that contains modest levels of high tannin sorghums as a source of antioxidants is currently being sold by a commercial bakery.

The effect of tannins and cooked sorghum on glycemic index is being measured by a new graduate student. This is an effort to demonstrate another healthy feature of sorghum. In related studies, rat feeding trials are underway to evaluate tannin and special black sorghums that contain tannins and anthocyanins in high levels. Our interactions with the sorghum breeding program has led to different sorghums with significant variation in total phenols, antioxidant levels, color and potential applications as healthy food ingredients.

Gluten Free Breads for Celiacs

Ms. Lindsey Hines, M.S. student, also developed a gluten free bread for gluten intolerant people based on a blend of starches, xanthan gum, tannin sorghum bran, inulin and flax seed which produced excellent bread. The inulin improved loaf volume and softened the bread crumb significantly over the control bread while the dark color of the sorghum bran improved appearance and enhanced nutritional value significantly.

Figure 1. Extruded snack product prepared from white sorghum, coated with a savory flavoring. White sorghum provides a bland substrate that does not interfere with the flavors.

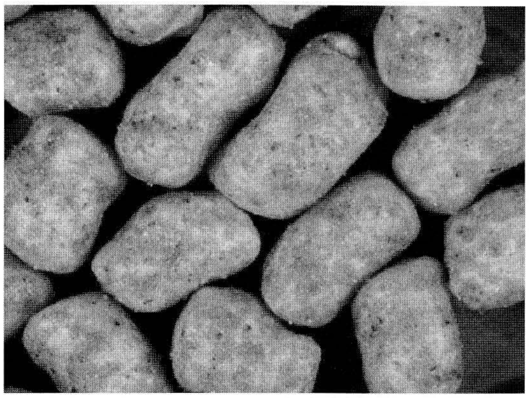
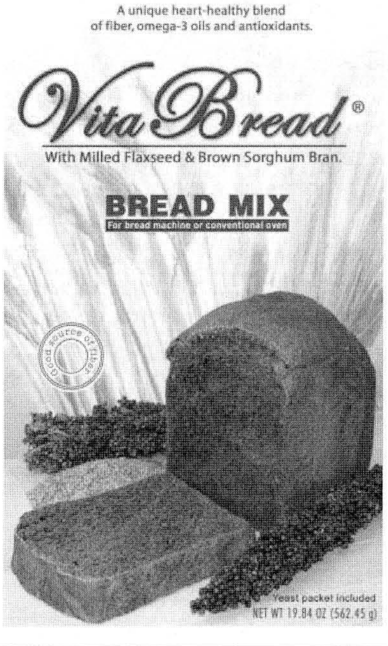


Figure 2. VitaBread mix, a prototype bread machine mix with high levels of antioxidants from brown sorghum and good nutritional factors including flaxseed. The mix is one of several prototype products showing the successful and tasty use of brown tannin sorghums in common food products.



This information was presented to Disney World chefs in Orlando Florida who are very interested in baked products without gluten for special diets. A five-member team made a wide variety of gluten-free foods and demonstrated them.

Extrusion Processing

It is possible to produce expanded sorghums directly from whole or ground white or tannin sorghum grains using low-cost friction extruders. These smaller extruders are used in areas where infrastructure limits costly sophisticated processes. Thus, the ability to produce snacks directly from whole clean grain is a distinct advantage for sorghum. Extrudates of 100% whole tannin sorghums would have excellent nutritional properties. More work is needed to document their properties.

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 corn meal 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 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 affect expansion ratio, crispiness and bulk density.

Mr. Alejandro Perez, M.S. graduate student, demonstrated that whole grain, cracked whole grain and decorticated grain of waxy, heterowaxy and nonwaxy sorghums had significantly different extrusion properties which can lead to snacks and ready to eat breakfast cereals with different degrees of expansion and texture. For example, waxy whole grain extrudates had a softer texture with less expansion than nonwaxy or heterowaxy extrudates. These sorghums have different levels of amylose and have potential for use in numerous products.

Sorghum Starch, Malting and Brewing Studies

Dr. S.O. 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 and was a key speaker in the Nicaraguan white sorghum utilization workshop.

Tannins and Phenols

Ms. Linda Dykes, Ph.D. candidate, has documented the antioxidant level, tannin content and easily extractable phenols in a large number of sorghum samples from special studies of U.S. cultivars of known genetics compared to sorghums form West African countries including Niger, Mali, Burkina Faso and Senegal. She confirmed that sorghums containing B1B2S_ genes had the highest levels of phenols, tannins and antioxidant activity. Sorghums with dominant B1B2ss had significantly lower levels of tannins and antioxidant activity. She confirmed that sorghums without a pigmented testa did not have detectable levels of condensed tannins using HPLC and the vanillin assay with blanks subtracted to remove background noise.

The HPLC analysis of procyanidins (condensed tannins) indicated that tannin 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 might 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.

West African sorghums (140 plus samples) were evaluated for presence of pigmented testa using the chlorox bleach method; those testing positive were analyzed with the vanillin-HCl method. Most West African sorghums did not contain tannins in the grain; however, those cultivars that did contain tannins had low levels of tannins. Most had only the B1B2 genes which give low levels of tannins. Other samples were blends of tannin and tannin free grains. Overall, the incidence of tannins in sorghum grown in those four West African countries is low and does not significantly affect sorghum value for livestock feeds. Education of buyers and producers will alleviate the production of tannin sorghums except in special locations where they are needed.

Many myths about tannins that negatively affect the perception of sorghum as a feed exist; information from these studies should provide clear signals that sorghums are excellent feed for livestock as well as human foods. Dr. Sanders (PRF 205) and his colleagues are providing leadership to overcome these problems. A brochure on "Myths About Tannins" is in preparation and will be provided to the food, feed and related industries. The lack of understanding regarding tannins creates significant reluctance toward the use of sorghum by feeders and human nutritionists. Workshops in Central American, West Africa and Southern Africa spoke to this issue. More efforts are required to overcome the myths about tannins in sorghum because the confusion leads to poor acceptance of sorghum as food or feeds.

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. This work was in collaboration with Drs. Tuinstra, Peterson and W.L. Rooney who conducted the evaluation trials. Red and white sorghum hybrids grown at several locations in Texas and Kansas 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. 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 more effectively predicts 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 red tans might be useful for decortication and produce better food and poultry feed than the white tan sorghums currently being grown.

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.

Mold Resistance of Sorghum: Effect of Antifungal Proteins and Other Grain Properties

We presented the results of our work "Biochemical and Physical Traits Associated with Sorghum Grain Mold Resistance" in September 2004 at American Association of Cereal Chemists (AACC) Meeting in San Diego, California. This presentation was based on the evaluation of sorghums collected in 2003 from TAES Field Plantation in College Station. Sorghums (44 elite lines and hybrids) included 31 with red pericarp and 13 with white pericarp. Chitinase and sormatin in caryopses of sorghum at 30 and 50 days after anthesis (DAA) were determined. Mold resistance was more consistently related to the retention of antifungal proteins (AFP) from 30 to 50 DAA, than on seed physical traits such as seed density and color.

Table 1. Correlations between gain mold rating score and seed properties (n=93).

Attribute	Mold Rating	Germination Rate (%)	Seed Color (L)	Seed Color (a)	Seed Color (b)	Seed Density	Hardness (SKHT*)	Phenols (mg/g)	Chitinase Retention
Germination Rate	**-0.49**								
Seed Color (L value)	**0.33**	-0.20							
Seed Color (a value)	**-0.56**	**0.39**	**-0.82**						
Seed Color (b value)	**0.34**	**-0.24**	**0.93**	**-0.73**					
Seed Density	**-0.21**	0.17	0.26	-0.18	0.20				
Hardness (SKHT*)	0.02	0.07	0.09	-0.18	0.08	**0.65**			
Phenols (mg/g)	-0.16	**0.24**	**-0.57**	**0.59**	**-0.52**	-0.12	-0.08		
Chitinase Retention	**-0.51**	**0.42**	**-0.36**	**0.43**	**-0.34**	0.05	0.05	**0.36**	
Sormatin Retention	**-0.46**	**0.44**	**-0.27**	**-0.24**	**-0.24**	0.07	-0.06	**0.31**	**0.74**

Marked correlation in bold type are significant at $p \leq 0.05$.
*SKHT = Single Kernel Hardness Tester.

Table 2. Sorghum traits and mold response among hybrids and parents.*

Sorghum Attribute	Hybrid	Female Parent	Male Parent	LSD (α=0.05)
Mold Rating Score (1-5)	2.8 b	3.3 a	3.4 a	0.3
Germination Rate (%)	80 a	75 a	57 b	7
Chitinase Retention (%)	-2 a	-23 b	-28 b	8
Sormatin Retention (%)	0 a	-30 b	-28 b	10
Seed Density (g/cm^3)	1.370 a	1.342 c	1.356 b	0.013

*means in the same row with the same letter are not significantly different.

Sorghums (93 lines and hybrids) were grown in 2004 in the TAES Plantation in College Station under ambient conditions (not inoculated, no additional misting). Sorghums (52 red and 41 white) were sampled at physiological (30 DAA) and combine harvest maturity (50 DAA). The percentage loss in chitinase and sormatin from 30 to 50 DAA was referred to as the retention rate. Gain mold rating, germination rate, phenol content, seed density, hardness and seed color (L, a and b values) were also measured.

Grain mold rating and germination rate were significantly correlated with both chitinase and sormatin retention but not with phenol content and SKHT hardness. Seed density was correlated with grain mold rating but not with germination rate. Thus, sorghums that are more resistant to molds retain more chitinase and sormatin from 30 to 50 DAA than those which are susceptible. On the other hand, the study did not show a relationship between mold resistance and phenol content or seed hardness. Clearly, chitinase and sormatin contribute to limit mold damage of sorghum (Table 1).

From the sorghums evaluated in 2004, a subset comprising 33 hybrids and their respective male and female parents were evaluated to look into the inheritance pattern of antifungal proteins as it relates to mold resistance. The hybrids had improved mold resistance, germination, density and increased retention of chitinase and sormatin when compared to their parents (Table 2).

Our studies have shown that antifungal proteins significantly contribute to mold resistance in both red and white varieties. We found that hybrids had increased retention of antifungal proteins as compared to either of the parents as they mature in the field. Consequently, mold resistance of the hybrids was enhanced. However, mold resistance in sorghums is a complex interaction of various physical and chemical properties of the grain including antifungal proteins. All of these are affected by genetics of the plant and environmental conditions.

Networking Activities

Southern Africa

Graduate students in the Food Science Department at the University of Pretoria from many African countries participate in a Regional Program conducted jointly between CSIR and University of Pretoria. INTSORMIL's interaction with Professor Taylor and his colleagues at the University of Pretoria informs many future African food industry leaders of the potential role of sorghum and millets as food and industrial ingredients. Several workshops and related research projects have been mutually beneficial to all parties.

In October 2004, the University of Pretoria, INTSORMIL and the South African Sorghum Forum jointly sponsored a workshop on white sorghums for food with participants from Southern Africa and graduate students from the University of Pretoria. The University of Pretoria hosted the workshop which filled the auditorium with feed, food and seed industry personnel along with small entrepreneurs and major sorghum users in the malting and brewing industries. Both feed and food potentials were discussed and progress was made to determine actions required to promote use of sorghum in profitable food and feed applications. There is significant interest by South African Breweries and many smaller companies to access improved quality sorghums for use in lager beer.

Significant progress was made but investment in development of sorghum varieties and hybrids with improved processing properties is required for the long-term with practical demonstrations of its use in the short term. It is important to understand that sorghum use is decreasing in brewing of opaque beer but increasing in decorticated meals for porridges in spite of a 14% value-added tax on sorghum in South Africa. The current strong interest in white sorghums for brewing into Lager beer may influence policy to develop improved sorghum hybrids for Southern Africa.

Ms. Nomusa Ngwenya-Dlamini, Bulawayo, Zimbabwe, is working on a Ph.D. in food science at Texas A&M University and the University of Pretoria. She was awarded a Fulbright Fellowship to complete her Ph.D. program at TAMU. Professor J.R.N. Taylor, University of Pretoria, is a coadvisor on her Ph.D. dissertation involving antioxidants from sorghum. She taught food science courses at the National University of Zimbabwe in Bulawayo. She is on schedule to complete requirements in 18 months or more because she had already done some research on antioxidants in traditionally processed sorghums in South Africa. Professor Taylor will be in the U.S. to participate in her Ph.D. examination and orals this September.

Professor Taylor's research program is optimizing processes using local equipment for dry milling of sorghum and millet. For example, Mr. M. Kabile of Botswana is evaluating dry milling of sorghum as his Ph.D. research at the University of Pretoria. Dr. Lloyd Rooney participates on these advisory committees.

Publications related to injera production by Dr. S. Yetneberk, Ethiopia who completed her Ph.D. at University of Pretoria were completed this past year and she returned to Ethiopia to work on sorghum quality.

Central America, Mexico and South America

Dr. L.W. Rooney traveled to Managua, Nicaragua to develop collaborative research plans and to participate in a workshop on utilization of sorghum for human and animals which was jointly sponsored by INTA, AMPROCESSORS and INTSORMIL. Collaborators in El Salvador (CENTA) and Dr. J Bueso, Associate Professor, EAP, Zamarano Honduras were key participants. In addition, Dr. Serna Saldivar, Professor and Head of the food technology department at Monterrey Institute of Technology summarized his research on sorghum utilization in brewing. The workshop included a commercial baker from El Salvador who made pan dulce and other products from composites of white sorghum and wheat flours. Personnel from CENTA and EAP in Central America presented excellent papers and demonstrations of sorghum food use. Drs. Sanders, Rooney and Hancock presented information on economics, food processing and practical feeding value of sorghum. Myths about sorghum tannins were discussed.

Dr. L.W. 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 five graduate students from Central America and Mexico partially funded on TAM 226. We are able to leverage our INTSORMIL funds by using additional research funds from private industry, TAMU graduate fellowships 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.

Ms. Vilma Ruth Calderon, food technologist, CENTA, joined our laboratory in January 2005 for a M.S. program in food science and technology. Ms. Y. Eliette Palacio, seed technologist, INTA was admitted to TAMU for a M.S. program but could not enroll because of health problems. She likely will enroll at ITESM in Monterrey Mexico for a M.S. program jointly with Texas A&M. Dr. Saldivar, Professor, ITESM will be her major professor.

Two scientists from Central America are scheduled for training.

West Africa

Ms. Yara Koreissi, Food Scientist, IER, Mali and Mr. Luis Sandoval, undergraduate student at EAP in Honduras were short-term trainees in the Cereal Quality Laboratory. Ms. Koreissi completed her M.S. in public health at Tulane University and is currently participating in a three-month training program to gain experience in cereal technology and processing. She will return to the food technology lab in the IER in Bamako. Mr. Sandoval returned to EAP to complete his B.S. program.

Mr. Joseph Gayin, Assistant Research Scientist, Food Research Institute, CSIR, Accra, Ghana, was a Borlaug Fellowship participant in our laboratory from September 1-30, 2004 where he gained experience in cereal technology and processing quality of sorghum and maize.

Dr. Lloyd Rooney participated in a workshop in Bamako, Mali on utilization and marketing of sorghum and millet feed and food products. He summarized current information on sorghum tannins and how they can be determined in market channels and how they affect quality for humans and animals. He is also participating in the West African project on marketing by providing information and analysis of West African sorghums for tannins. The information indicates that there are some sorghums containing condensed tannins produced in West Africa but the cultivars that have tannins do not have large quantities of tannins and do not reduce feeding value significantly. Only a few cultivars were found with high levels of tannins. A chlorox bleach test was used to distinguish the tannin types in market samples. Research on analysis of tannins and other phenols in sorghum continues since these compounds are considered health promoters.

A brochure to provide facts on tannins and debunk misinformation about sorghum has been drafted and will be made available to policy makers and potential users of sorghum.

North America

Several papers were presented at the American Association of Cereal Chemists Conference, San Diego, California and the Institute of Food Technologists Conference. We presented information on the utilization of whole grain sorghums for special dietary foods and whole grain products. Participants included many small and large food companies interested in diversifying products. Special sorghums for use in baked and extruded products were of interest to several companies. Some trials were made and interest continues with supply chain management a key need to secure adequate supplies of grain.

A special seminar and demonstration of gluten free products from white sorghum was presented to 52 Disney World chefs. The program organized by the National Sorghum Producers Association created interest and currently some small companies are trying to meet Disney's specifications for sorghum based bakery mixes.

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 (44) from all over the world (14 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

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.

Publications and Presentations

Journal Articles

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Rooney, L.W. 2004. Practical uses of white food sorghum. INTSORMIL White Sorghum Workshop, October 20-22, University of Pretoria, Pretoria, South Africa.

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Rooney, L.W. 2004. Innovations in cereal processing. International Association for Cereal Science and Technology (ICC) Bread and Cereals Symposium, October 26-28, Johannesburg, South Africa.

Rooney, L.W. 2004. Myths and facts about sorghum tannins. Workshop on Sorghum/Millet in West Africa, INTSORMIL, November 16-18, Bamako, Mali.

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Entrepreneurship and Product Development in East Africa: A Strategy to Promote Increased Use of Sorghum and Millet.

Project UNL 220

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Summary

This new project was initiated on March 10th, 2005 and is designed to promote increased use of sorghum and millet by establishing an entrepreneurship education/training program coupled with follow-up technical and business support services. This training program is being coordinated and offered through the Sokoine University of Agriculture's (SUA) Department of Food Science and Technology. It is anticipated that new individual and village/cooperative ventures will be established that use sorghum and millet grain and ingredients in food products to be sold locally and in urban markets. Draft entrepreneurship training materials were adapted from those developed by the University of Nebraska's Food Processing Center with the on-site collaboration between UNL's Entrepreneurship Program coordinator Ms. Gifford and Dr. Mpagalile (who was in Nebraska through May 2005). After his return to Tanzania, Dr. Mpagalile has further coordinated material refinement and localization by including local product photographs, Tanzania Food and Drug Agency (TFDA) regulations and Tanzania Bureau of Standards (TBS) specifications. A project coordinator was hired by SUA; the individual has a B.S. degree in agricultural economics and agribusiness with a wide experience in entrepreneurship and business incubator programs in Tanzania. The first *Entrepreneurial Workshop* is scheduled for September 20th, 2005; 19 entrepreneurs (or entrepreneurial groups) have been identified as initial workshop participants prior to any advertising. It is anticipated that approximately 15 individuals will attend the first workshop, which will serve as a prototype for future efforts. As part of the workshop, participant's efforts to further develop (or initially develop) their businesses will be supported by business and technical assistance provided by a network of SUA and UNL specialists.

Host Country Program Enhancement

Central America
(El Salvador, Honduras, Nicaragua)

Stephen C. Mason
University of Nebraska

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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 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 (PROSEMILLAS), allowing activities in Guatemala, primarily for testing of hybrids/varieties and coordinating support of the sorghum industry in Central America. Formal collaboration with the Universidad José Matías Delgado (in Food Science) and informal collaboration with the Universidad de El Salvador (Entomology) has been established during the past three 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 2004-2005. Regional program expenses included those associated with sponsoring a workshop, short-term training, equipment purchases and administrative travel. The private seed company Cristiani Burkart provided $1000 in support of a regional workshop on sorghum grain utilization which occurred 18 and 19 May, 2005 in Managua, Nicaragua.

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 (PROSEMILLLAS) 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), with recent studies documenting improved N use efficiency and N fertilizer response of cultivars spurring interest in increased use of fertilizer.

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. Forage sorghums are important feed sources for large dairy and beef producers also.

Research Accomplishments and Planning

Sorghum Utilization Workshop

A two-day regional workshop on sorghum grain use for human food, animal feed, beer and industrial uses was held18 to 19 May, 2005 in Managua, Nicaragua. Presentations on economics and utilization were presented by regional, Mexican and U.S. experts with approximately 60 persons attending from the private and public sector. A proceedings was published on CD, widely distributed throughout Central America, and posted to the INTA web site in Nicaragua.

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, Dr. Larry Claflin, and many collaborating scientists participated in this annual meeting 1 to 5 May, 2005. Most oral papers on grain sorghum were presented by INTSORMIL collaborators, and Rafael Obando Solis won the award for outstanding paper in the sorghum and rice section. The 2006 meeting is scheduled to be held in Managua, Nicaragua.

Undergraduate Research Theses in Nicaragua and El Salvador

Undergraduate students are required to complete a research thesis as part of the Bachelor of Science degree. During 2004-2005, nine students completed thesis research at the Universidad Nacional Agraría on grain sorghum with support from INTSORMIL agronomy projects and two undergraduate theses in food science in El Salvador with support from CENTA.

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 intercropping systems with maize) 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. Collaborative ties have been made with Dr. Guilles 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. Forage hybrids are being developed jointly in El Salvador and Nicaragua.

Research Results

Evaluation of forage sorghum hybrids continued, with the hybrid ICSA275 X TX2784 proving superior in yield and forage quality in both El Salvador and Nicaragua. Seed of the inbred lines were increased with anticipated release of this hybrid in Nov. 2005 concurrently with a regional forage sorghum workshop.

In Nicaragua, breeding programs for white grain, tan plant and red grain sorghums continued. Several white grain hybrids (ATX2752 X RTX430, A9614 X RTX436, A9614 X RTX437, ATX631 X R9624 and ATX631 X RTX437) have been selected from the Texas A & M University IFSAT tropical grain nursery with yields between 5.2 and 6.4 Mg ha^{-1}. Red grain hybrids from the ITAT tropical grain nursery with good adaptation and high yields were ATX631 X RTX437, A9715 X RTX430, ATX631 X RTX436, ATX2752 X Roo36 and ATX2752 XRTX437 with yields between 3.3 and 3.6 Mg ha^{-1}.A, B and R lines of these hybrids are being tested for adaptation as CNIA/INTA moves towards release. Other nurseries for hybrids HyobCA and GCP from CENTA (El Salvador) are being evaluated. The photoperiod insensitive varieties RCV, Soberano and Jocoro from CENTA are being tested for possible release in Nicaragua, and the African variety Macia obtained from Texas A & M University is being evaluated for possible release. The photoperiod insensitive red grain varieties ICSV-LM90538, (SR-16)-10-1-1-3, (SR-17)-10-2-2-2 and (205 + 206)-Bulk are being tested for release, as are the photosensitive varieties Souroukoukou, 99PRE-EIME117, 86EO226, ES-790 and PRE-EIME153. In Nicaragua there is much interest in a production of sorghum syrup, and the forage hybrid ICSA275 X TX2784 is being tested for this end-use. Seed is being increased of the best varieties listed above, with intent of conducting validation trials in 2006.

In El Salvador, photoperiod sensitive lines coming from the Escuela Agricola Panamericana (Zamorano, Honduras) evaluated for yield potential and agronomic adaptation at two CENTA experiment stations. None produced higher yields than existing varieties, but will tested further under farmer conditions. The breeding program made selections of 57 lines of photoperiod sensitive breeding nurseries, crossed photoperiod sensitive lines with improved sorghums, and produced 12 grain hybrids for evaluation in 2005. Seed was increased for transfer of the varieties during 2005.

Regional PCCMCA trials were conducted for 20 sorghum hybrid entries from Christiani Burkart, Monsanto and PROSEMILLAS, a common check hybrid and a local check hybrid at eight locations in El Salvador, Guatemala, Honduras and Nicaragua. The hybrids MSD528, Ambar and CB8027-1 produced the highest average yields. Evaluations were made for the first time for downy mildew, with the hybrids CS8027-1, X5397, CB8042, INTA-Trinidad, Ambar and SR340 showing high susceptibility.

Plant Protection Research

Research Methods

Efforts to move beyond disease identification to developing integrated pest management strategies was the focus with collaboration between university, government and producer associations. Insecticide and fungicide applications were evaluated, and ADIN nurseries were used to identify host-plant resistant germplasm New research was initiated on whitefly problems in El Salvador, and stink bug in both El Salvador and Nicaragua. Workshops on insect and disease identification and pest management were held in both countries.

Research Results

Entomologists and plant pathologists at INTA and UNA worked together with ANPROSOR in conducting a number of integrated pest management investigations in sorghum on large and small farms in several areas of Nicaragua in 2004. Workshops in two country zones were conducted with 80 farmers emphasizing identification of insect and disease pests, and two workshops emphasized integrated pest management practices. A pest identification and integrated pest management practices bulletin was developed by the scientists and given to each participant.

Four insect and disease pest management studies were completed during the second crop growing season. In a study to determine the influence of insecticide (cypermethrine) to control fall armyworm larvae and fungicide (benomyl) to manage diseases on vegetative sorghum, chemical spray applications were made when insect infestation levels reached 20, 30, 40 or 50% and a fungicide spray was applied at 10, 20, 30 or 50% disease severity levels. The highest yields were obtained when fall armyworm and diseases were managed with insecticide and fungicide. These data indicate the benefit of a combination of insecticide and fungicide chemical spray applications to manage insect and diseases.

In a second on-farm study, the number of insecticide (cypermethrin) chemical spray applications (1, 2 or 3) and fungicide (benomyl) spray applications at 10, 20 or 50% disease severity levels to manage foliage feeding lepidopterous caterpillars (mainly fall armyworm) and diseases. Fall armyworm larval infestations were observed on very young sorghum plants and increased to highest levels during late vegetative stages. No apparent difference was observed between treatments with one or two insecticide spray applications at the treatment threshold of 40% infested plants. Diseases of vegetative sorghum caused by *Colletotrichum graminicola, Ramulispora sorghi* and *Gloeocercospora sorghi* and diseases of reproductive stages caused by *Colletotrichum* and *Cercospora sorghi* were observed and reached severity levels up to 20% of infected foliage during vegetative growth and at levels as high as 60% during reproductive stages. The data suggests that one pyrethroid insecticide spray for fall armyworm control when plants are at 40% infestation level provided as good control of this pest as two insecticide applications (the second three weeks after the first) in an integrated pest management program when fungicide is applied at either 10 or 20% severity levels for disease control.

The second year of an on-farm study to compare improved insect and disease management practices with conventional sorghum production practices used by farmers was conducted. Production practices used by farmers included applications of cypermethrin insecticide, early and fall season weed control and fungicide (Benomyl or Python + pH plus) applied to the seed head. Improved practices included the biological insecticide Dipel, full season weed control and fungicide spray for disease control. Fall armyworm larvae were the principal defoliators during the vegetative stages and leaf-footed bugs during the seed development stages. The lowest cumulative infestation of fall armyworm larvae was recorded in the improved pest management treatments with Dipel application and the largest infestation in plots with chemical insecticides used by the farmers. Dipel was more effective than cypermethrin for control of this insect pest, while not affecting natural enemy (i.e., lady beetles) populations. The chemical insecticide cypermethrin was more effective than Dipel for control of leaf-footed bugs on seed heads. The plant diseases that were observed on vegetative plants were caused principally by *Macrophomina phaseolina* and *Fusarium proliferatum.* Calcium sulfate broth was more effective in disease management than either Benomyl or Python + pH plus. Diseases on the seed heads, mainly molds, were caused by *Fusarium thapsinum, Curvularia lunata* and *Aspergillus flavus* and severity of disease was lower in improved technology plots than farmer technology plots.

Sorghum entries (50) in the All Disease and Insect Nursery were evaluated for resistance to insect pests and diseases. The principal diseases included gray leaf spot caused by *Cercospora sorghi*, zonate spot caused by *Gloeocerspora sorghi,* downy mildew caused by *Peronosclerospora sorghi* and anthracnose caused by *Colletotrichum graminicola.* All sorghum entries were infested with fall armyworm larvae, with only three considered tolerant to this lepidopterous defoliator. Twenty-four lines were considered very susceptible to fall armyworm feeding damage. Six sorghum lines were considered tolerant to gray leaf spot, downy mildew and anthracnose, five lines tolerant to gray leaf spot and anthracnose, and 10 lines tolerant to anthracnose and downy mildew. Considering individual diseases, 32 lines were considered tolerant to anthracnose, 23 to downy mildew and 15 to gray leaf spot. Six of the seven sorghum lines with highest yield (greated than 1000 kg ha^{-1}) were considered tolerant to fall armyworm, but susceptible to one or more of the above diseases.

El Salvador

A survey was conducted by CENTA scientists in 2004 to determine the relative importance of insect pests on sorghum as identified by sorghum farmers in five areas of El Salvador. White grubs were identified as the principal insect pest of concern in all five areas, with fall armyworm, sorghum webworm, stalk borers and sorghum midge as secondary pests.

Two studies were conducted on a farm located where the specific pests of interest have been a problem in sorghum production. In one test, insecticide (Lorsban) applications were made at different dates to determine efficacy of the chemical pesticide on stalk borers (*Diatraea* sp.). When insecticide treatments were compared with the untreated control, the insecticide treatments had less damage than the control and higher yields, and although the treatment at 15 days post plant had less damage than the treatment at 25 days post plant, no yield differences was observed between these two treatments. This data suggests that a single timed insecticide spray application during early vegetative stages of sorghum can be as effective as two spray applications on vegetative sorghum for managing stalk borers on sorghum, thus reducing the cost of chemical management of this pest on sorghum.

In 2004, selected sorghum lines and varieties were evaluated at two locations for both disease and insect resistance. Information was obtained on agronomic characteristics, incidence and severity of diseases and insect damage. Ten superior lines were selected from the 2003 ADIN based on tolerance to diseases and insects, size and color of the grain, length of the panicle, aspects of plant growth, and yield for further evaluation in the 2004 ADIN. Three lines, Sureño, D2CA4624 and 96CD635, were selected from the 2004 ADIN based on the above characteristics and will be planted in 2005. Five macillos criollos were evaluated for disease and insect resistance at two locations in 2004. One maicillo, Indio Macartus, showed resistance to diseases, whereas two macillos, Indio Macartus and Indio, showed low levels of resistance to insect pests.

Whiteflies, encountered for the first time on rice, sorghum and corn in 2003 by scientists at the University of El Salvador, infested these crops again in 2004, although populations were lower than in 2003. Whiteflies were able to survive during the dry season (November-April), then infested rice during mid-year, and moved to corn and sorghum during the second growing season (early-September). Crops were sampled in a number of areas in El Salvador to determine the range of this pest in the country. A number of areas not sampled in 2003 were determined to be infested with whiteflies in 2004. Whiteflies were controlled on rice with insecticide application but survived on wild host plants until corn and sorghum were planted. A grass, *Elasine indica*, contributed to the ability of the whiteflies to survive between first and second growing seasons. Other grass species may be important in the ecology of this pest in this region of Central America. Natural enemies, many identified in 2003, were at low levels in 2004, thus contributed little to the low population levels present.

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.

Research Results

A student at the Universidad Jose Matias Delgado in El Salvador developed a machine to decorticate sorghum grain as part of his undergraduate thesis. Relationships were developed with the private company GUMARSAL to conduct decortification and particle size research. Decortification reduced the yield by 16%, losing about 2% of weight in the germ and another 2% in endosperm attached to the pericarp. The flour particle size decreased with decortification which was desirable, but the nutritional quality also decreased.

Efforts in 2004-2005 focused on evaluation of photoperiod sensitive varieties, both for nutritional and flour quality traits. The varieties De Leche, Enanon and Peruano Blanco had the highest nutritional quality, had predominately floury endosperm. De Leche and Enanon had no tanins, and the variety de leche had the smallest flour particle size with 75% passing through a 0.5 mm screen. Test tests of baked products showed a preference for mixing sorghum and wheat flour, with 40 to 60% sorghum flour being acceptable.

Agronomy Research

Research Methods

A series of studies were conducted in El Salvador and Nicaragua between 2001 and 2004 with the objective to determine if NUE differences exist among photoperiod insensitive sorghum varieties and response of these grain sorghum lines to low N fertilizer rates, and to identify high NUE varieties. At each location, 24 lines from breeding programs were initially grown initially with and without N in a randomized complete block design with four replications, and only the 16 superior performing lines being carried forward to the following years study. 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.

In 2003, validation and transfer trials were conducted on 40 farms in collaborations with the NGOs Ramírez Consultores, ESBESA, CONSORCIO and PRODESO. Validation trials with local variety with and without 47 kg ha^{-1} N, the new improved nitrogen use efficient variety 85-SCP-805 without N and with 47 kg ha^{-1} N were tested on hillside locations with poor soils. In addition, the improved varieties 85-SCP-805, SOBERANO, CENTA S-3 and RCV were planted on 430 farms in Zone 3 to facilitate transfer to farmers fields. In 2004, variety validation trials were conducted for 85-SCP-805, ES-790, CENTA S-3, and 86-EO-226 on 635 farm fields totally 162 ha.

In El Salvador, the improved forage hybrid HF-275 (ICSA275 X TX2784) was validated on 15 farms with the commonly used hybrid HF-895 used as a check. The plots were green cut for forage three time, samples dried and yields recorded on dry matter basis. Laboratory analyses for forage quality including protein, fiber and energy were done. In Nicaragua, 6 forage sorghum hybrids were validated on-station.

Research Results

In El Salvador, no line X N interaction was found, suggesting that variety selection and N rate should be independent management decisions. The El Salvador location in 2003 provided little useful information due to site selection of a soil with relatively high nutrient level, but in 2004 the range in yields of lines ranged from 1.8 to 3.0 Mg ha^{-1}, but only ICSVLM-90520 produced a higher yield than the best control variety of Soberano. ICSVLM-90520 had the best grain yield, was in the top five for stover yield, and within the top six for grain nitrogen use efficiency. It is recommended that the plant breeding program introduce this line into its crossing program and evaluate it further, and that the other lines be dropped from breeding and evaluation efforts. Average grain yield without nitrogen fertilizer was 2002 kg ha^{-1} while with 21 kg N ha^{-1} average yield was 2920 kg ha^{-1}, and increase in yield of 46% with a marginal return of 44 kg ha^{-1} grain production for each kg N ha^{-1}. Increased technology transfer efforts in collaboration with fertilizer input suppliers, extension service and NGOs is merited.

In Nicaragua, large differences among environments, lines and N rates were present. However, the local check variety Pinolero along with the line ICSCVLM-93076 produced approximately 3.7 Mg ha^{-1} grain surpassing the yields of rest of the varieties by 0.5 to 1.1 Mg ha^{-1}. With N application, ICSCVLM-93076 produced the highest grain yield of 5.1 Mg ha^{-1} compared to 4.2 Mg ha^{-1} for Pinolero. ICSCVM-93076 was N responsive while still producing high yields without N application. This line has been submitted to the CNIA/INTA sorghum breeding program for evaluation and use in the breeding. Nitrogen fertilizer application increased the average grain yield from 3.1 to 3.9 Mg ha^{-1} (26%), emphasizing the importance of promoting N fertilizer use to increase grain sorghum grain yields.

In 2003, 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. In 2004, the yield increase over the local check was 0.5 Mg ha^{-1} for 85-SCP-805, 0.6 Mg ha^{-1} for ES- 790, 0.4 Mg ha^{-1} for CENTA S-3 and 86-EO-226.

The improved HF-275 hybrid produced more forage dry matter for each harvest date, with total production of 32 Mg ha^{-1} compared to 22 Mg ha^{-1} for HF-895. Fiber contents were similar for the two hybrids, but HF-275 had higher energy content (3% higher total digestible nutrients) and 1% higher crude protein. In El Salvador, HF-275 will be validated with dairy producers in 2005 for potential release in 2006. In Nicaragua, HF-275 had one of the highest forage yields and quality among the six hybrids tested.

Improved Variety Transfer

In El Salvador, CENTA in collaboration with the NGOs Ramírez Consultores, ESBESA, CONSORCIO and PRODESO transferred seed of the improved variety 85SCP805 to 141 producers (planted on 62.2 ha), ES-790 to 97 producers (planted on 71.4 ha), CENTA S-3 to 118 producers (planted on 24.5 ha), 86EO226 to 27 producers (planted on 22.8 ha) and CENTA RCV to 74 producers (planted on 16 ha). This provided direct benefit to 635 producers in 2004, who will share seed with neighbors further extending the transfer of these improved varieties.

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 maicillos 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 resistance, 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, and is in the process of doing the same for UNA.

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 and Vilma Ruth Calderón in food science at Texas A & M University, Sergio Pichardo Guido (Nicaragua) is pursuing a Ph.D. in plant pathology and Mario Parada Jaco (El Salvador) at Mississippi State University. Eliette Palacio (Nicaragua) and Margarita Alvarado de Torres (El Salvador) are in short-term training in food science at Texas A & M University. Leonardo Gracia (Nicaragua) and Gilberto Sandoval (El Salvador) are scheduled for short-term training in agronomy and agricultural economics in 2005.

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 (PROSEMILLAS) in Guatemala, and new initiatives 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 strengthened collaborative linkages.

Travel

Regional coordinator René Clará and many collaborating scientists attended the PCCMCA meeting 1 to 5 May, 2005 in Panama City, Panama. Most papers in the sorghum session were presented by INTSORMIL Collaborators.

Dr. Henry Pitre visited El Salvador and Nicaragua in Nov., 2003 to assist with plant protection collaborative research.

Drs. Lloyd Rooney, Joe Hancock, John Sanders and Sergio Serna-Saldivar gave presentations at the regional sorghum grain utilization workshop held in Managua, Nicaragua, 18 to 19 May, 2005.

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 and Cristiani Burkard in Guatemala to provide assistance on sorghum seed production.

Dr. John Yohe, Director, Dr. Stephen Mason (Technical Committee Chair) and INTSORMIL Board of Directors participated in the INTSORMIL Board Meeting 16 to 17May, 2005 in Managua, Nicaragua.

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

Gebisa Ejeta
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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. This collaboration has resulted in an array of technical developments that have impacted on sorghum agriculture in Sudan. Technologies have been generated as a result of the collaborative efforts that have 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 have been 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. With limited funds available to the INTSORMIL/Horn of Africa, it has not been possible to initiate a full range of collaborative projects with each of the NARS in the region. Instead, the intent has been to establish a full complement of collaborative partnerships with the Institute of Agricultural Research in Ethiopia and to use this program as a hub from which to network with the other member countries of the Horn. A line item for networking has been built into the budget of the INTSORMIL/Horn of Africa program, 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 imitative 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 – Kidane Ghiorghis, EARO; Charles Wortmann/ Martha Mamo, INTSORMIL.

Striga Management – Fasil Redda, EARO, MOA; 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, IAR; Larry Claflin, KSU.

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: Joseph Oryokot, NARO; Charles Wortmann, INTSORMIL.

Eritrea

Sorghum Breeding – Tesfamichael Abraha, DARHRD; Gebisa Ejeta, INTSORMIL.

Eritrea – Neguse Abraha, DARHRD

Entomology – Asmelash Woldai, DARHRD; Henry Pitre, INTSORMIL.

Striga Management – Goitom Ghobezai, DARHRD; Gebisa Ejeta, INTSORMIL.

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 & 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 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 pro-

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	Sudan	Uganda
Varietal Development	X	X		X	X
Striga	X	X	X	X	X
Crop Protection					
Pest	X	X	X	X	X
Diseases	X	X	X	X	X
Drought	X	X	X	X	X
Production	X	X	X	X	X
Technology Transfer	X	X	X	X	X
Training – Long-term	X	X	X		X
- Short-term	X	X	X	X	X
Socio-economics				X	
Utilization	X	X	X		X
Information Exchange				X	X
Germplasm Introduction	X	X	X		X
Soil/Water Conservation	X		X		
Seed Production & Marketing	X	X	X	X	X

duction 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

Sorghum Breeding in Ethiopia

Tesfaye Tesso, Ethiopian Agricultural Research Organization, Melkasa Research Station, Nazret.

A collaborative research agreement between the Ethiopian Agricultural Research Organization (EARO) and the International Sorghum and Millet Research Program (INTSORMIL) has been very successful both in terms of generating sorghum improvement/production technologies as well as building research capacity of the national program. Since the agreement was signed in 1996, the Ethiopian Sorghum Research program has been working closely with INTSORMIL and Purdue University on key constraints of sorghum production and research in Ethiopia. Major emphasis was given to problems and research subjects where the national program lacks sufficient capacity such as *Striga* resistance breeding, research to enhance drought tolerance and breeding hybrid cultivars. The collaborative research program expanded over the years and at present constitutes almost half of the sorghum research activity in the country. The most rewarding outcome of this collaboration was the release of three *Striga* resistant varieties, originally developed by Purdue University for large-scale production in Ethiopia. These varieties are making significant impact and changing the course of sorghum production in *Striga* infested regions of the country. The other positive outcome of this collaboration to our national program is in the area of capacity building: training of personnel involved in sorghum research and purchase of equipment and supplies in order to strengthen the program.

The following are highlights of sorghum research conducted in the 2004 crop season:

Introduction and evaluation of advanced germplasm materials.

Large number of advanced germplasm materials including *Striga* resistance germplasm, drought tolerant hybrids, and a number of additional hybrid materials for preliminary observation were introduced from Purdue University and evaluated in replicated plots at Melkassa Research Center. In addition, seeds of selected materials from previous year introductions were also imported for further evaluation.

The material was primarily evaluated for adaptation, yield, reaction to pests and diseases and maturity along with standard check for comparison. A number of germplasm entries excelled the check both in terms of yield and earliness. Seeds of these materials have been requested for further tests at multiple locations in the next phase of the evaluation. The table shown below describes the total number of introductions evaluated in 2004 and the number of materials selected for further test.

Test nursery	Number of Entries	
	Introduced	Selected
Drought Tolerant hybrids (Set-I)	30	14
Drought Tolerant hybrids (Set-II)	34	19
Striga resistance hybrids	38	17
Test Cross Hybrids	58	13
Hybrid Observation	90	16
Drought tolerance hybrids (Set III)	35	17
Total	285	96

Hybrid Trials

The majority of sorghum producers in Ethiopia are subsistence farmers growing low yielding local landraces. A number of open pollinated improved varieties have been released for different agro-ecologies over the last 30 years. Quite a few of them, especially early maturing lowland varieties are well accepted by farmers and widely grown in drought stress areas. Although hybrid cultivars generally are better than the open pollinated varieties in many aspects, no hybrid cultivars are grown in Ethiopia at present though results of preliminary hybrid trials conducted in Ethiopia were encouraging. This was due to lack of persistent effort to commercialize sorghum hybrids in the country. The outstanding reason for this is the high turnover of staff in the program that at times parental lines are lost because inexperienced junior researchers suddenly take over the program. A more organized and extensive hybrid evaluation started recently in collaboration with Purdue University through INTSORMIL support. Large number of hybrid entries are introduced each year from Purdue and evaluated at Melkassa Research Center in Ethiopia where thorough selections are made for agronomic adaptation. The following season, seeds of selected hybrids and parental lines are requested for further testing at multiple environments. Parental lines of promising hybrids are also acquired and multiplied at the center for further testing.

Major emphasis in our hybrid trial was placed on development of early maturing hybrid cultivars for moisture stressed areas where sorghum is the primary source of food. Results of multi-location tests showed that hybrid sorghums give 20-25% better yield over the high yielder open pollinated check. From tests conducted until 2004, five hybrids have been identified that consistently out-yielded the best open pollinated varieties at all locations. Preparations are being made to request official release of these hybrids for commercial production in moisture stress areas of Ethiopia.

In 2004 season, we conducted three sets of hybrid trials (Advanced Sorghum Hybrid Trial, ASHT-I, Advanced Sorghum Hybrid Trial, ASHT-II and Elite Sorghum Hybrid Trial, ESHT). Each set consisted of 16-24 entries. Unlike the local varieties, the hybrid entries mature early in 110-120 days and have short stature, only 130-180cm height. Evaluations were made at the low land testing stations, Melkassa, Miesso and Kobo in central, eastern and northern parts of Ethiopia, respectively. Out of a total of 59 hybrids evaluated under the three sets, 45 of them excelled the standard high-yielder check with some of the entries giving up to 40% higher yield. Mean performance of the entries is given in Tables 3 through 5.

Striga Resistant Variety Trials

Striga is the major biotic factor affecting sorghum production in Ethiopia. Over half of the sorghum fields in the country are believed to have been highly infested by the parasite. The problem is further expanding with new fields continually becoming under infestation. Yield losses due to the parasite are high in all infested areas. Although various control options have been suggested, most are less applicable in subsistent farms for various reasons. Host plant resistance is recognized as the most effective method of controlling the weed.

In an effort to identify additional resistant varieties that are best adapted to major *Striga* infested regions of the country, a *Striga* resistance trial consisting of 12 genotypes was carried out at two *Striga* infested locations in northern Ethiopia along with local and standard checks. The entries were

Mean grain yields of *Striga* resistant varieties tested at *Striga* infested locations in 2004.

No.	Entry	Grain yield		
		Kobbo	Sirinka	Mean
1	99MI5003	3.73	1.26	2.49
2	99MI5008	3.87	1.38	2.63
3	99MI5012	3.16	1.25	2.21
4	99MI5015	3.43	0.97	2.20
5	99MI5032	2.98	3.15	3.06
6	99MI5046	2.84	1.14	1.99
7	99MI5052	3.44	1.52	2.48
8	99MI5063	3.87	1.77	2.82
9	99MI5073	4.26	1.62	2.94
10	99MI5081	4.16	1.62	2.89
11	2000MW6016	2.55	1.57	2.06
12	2000MW6052	3.65	1.67	2.66
13	P-9401	2.10	2.16	2.13
14	Local check	3.70	1.51	2.60
	LSD (0.05)	0.927		NS
	CV (%)	19.01	35.99	35.09

selected among populations derived from crosses between adapted sorghum varieties and known *Striga* resistance sources. Among the twelve entries tested, six and ten genotypes out-yielded the standard and local checks respectively. The Standard check, P-9401, is a *Striga* resistant variety released for large-scale production through the assistance provided by INTSORMIL/Purdue University. It gives the best yield under *Striga* pressure and may be out-yielded by local varieties when *Striga* infestation is low. In this case the yield of the standard variety was lower than the local check at Kobo and the other way at Sirinka. Data on *Striga* count was not available to further explain this phenomena.

Introgression of Striga Resistance trait in to adapted landraces

The success in the release of three stable *Striga* resistant varieties in Ethiopia led to increased emphasis on *Striga* resistance breeding. Over years of cultivation, farmers based, on certain desirable agronomic characteristics, selected and identified their own cultivars for specific end use. Some of the traits farmers consider as desirable are yield potential, bird tolerance, stalk yield, etc. Almost all of these varieties are susceptible to *Striga* though some of them grow and give reasonable yield under moderate infestation. This study was thus aimed at enhancing *Striga* resistance of these varieties through introgression of the resistance trait through back crossing. Ten farmers preferred sorghum varieties adapted to different regions were selected and crossed to Stable resistance sources, SRN-39 and Framida.

In 2004 off-season nursery, BC2F1 population were developed from nine of the ten recurrent parents and this was advanced to BC2F2 families during the main season. Some 60 to 100 BC2F2 families were developed from each population and advanced to BC2F3 will be evaluated in *Striga* infested fields to identify families carrying the desired resistance trait.

Agronomy Research in Uganda

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Sorghum ranks third after maize and finger millet, occupying 21% of the total land under cereals in Uganda (MAAIF 1999). Sorghum yield per unit area of production is declining like other crops in Sub-Saharan Africa (Sanchez et al., 1996; FAO, 1999). Some of the main contributing biophysical factors are nutrient/soil fertility depletion (Sanchez et al., 1997), inherent low soil fertility particularly N and P deficiencies (Bekunda et al., 1997), cultivation of marginal land, poor soil-, water- and crop-management practices. Agricultural statistics indicate an increase in acreage under sorghum but with declining yield and the crop is being replaced by maize in its traditional production areas, which is no good because these areas are marginal for maize production. This may result into serious food shortages and a reduction in household income. Maintaining and increasing sorghum production in these areas is important for food security and improved income for the smallholder farmers.

The strategies include, (1) Herbaceous and grain legumes in improved fallows and rotation with sorghum, (2) A combination of kraal manure and inorganic fertilizers, (3) Use of low levels of inorganic N and P fertilizers (4) Minimum tillage for soil organic matter, improvement, water conservation

Table 3. Mean grain yield (ton/ha) of early maturing sorghum hybrids tested under Elite Sorghum Hybrid Trial in 2004.

No.	Entry	Melkassa	Miesso	Kobbo	Mean
1	P-9501A X ICSR-14	6.28	3.18	5.63	5.03
2	ICSA-21 X ICSR 50	6.28	3.60	5.20	5.03
3	ICSA-22 X M-4850	6.38	3.33	5.05	4.92
4	ICSA-15 X M-5568	5.93	4.15	4.85	4.98
5	P-9534A X KCTENT # 17 DTN	7.13	2.68	5.70	5.17
6	ICSA-15 X ICSR-14	6.00	3.58	4.63	4.73
7	ICSA-34 X ICSR-14	5.95	338	5.70	5.01
8	ICSA-90003 X SDSL 89426	7.30	2.48	5.08	4.95
9	ICSA-34 X 98 MW 6001	5.33	3.18	4.13	4.21
10	ICSA-34 X 98 MW 6002	4.98	3.50	4.55	4.34
11	ICSA-34 X 98 MW 6100	5.23	3.68	5.03	4.64
12	ICSA-34 X P-894108	5.08	4.40	5.83	5.10
13	ISCA-21 X 98MW 6001	5.30	4.43	4.18	4.63
14	ICSA-21 X 98MW 6002	4.70	3.95	4.25	4.30
15	ICSA-21 X 98 MW 6100	5.38	3.80	4.23	4.47
16	Teshale	0.56	0.38	0.46	0.47
	LSD (0.05)	NS	10	10.8	NS
	CV (%)	19.92	19.78	15.48	18.83

Table 4. Mean grain yield of early maturing sorghum hybrids tested under Advanced Sorghum Hybrid Trial (Set- I) in 2004.

No.	Entry	Melkassa	Miesso	Kobbo	Mean
1	P-9526 A X ICSR – 161	6.8	2.3	7.1	5.4
2	P-9526 A X ICSR - 50	7.5	2.8	8.7	6.3
3	P-9526 A X ICSR –14	5.8	2.5	6.3	4.9
4	P-9526 A X ICSR – 16	7.1	2.7	7.3	5.7
5	P-9526 A X 3443-2-OP	5.0	2.2	7.1	4.8
6	A1 X M 91057	5.3	2.1	6.0	4.5
7	A1 X PRL 983993	5.5	1.0	6.2	4.2
8	A2 X A 3566	4.3	1.1	5.3	3.6
9	A3 X P 89001	4.1	0.9	5.6	3.5
10	A3 X MR 732	3.9	1.5	5.6	3.7
11	A3 X MR 747	3.0	2.4	5.1	3.5
12	A3 X K 669	2.9	1.2	3.0	2.3
13	A3 X MR 750	5.1	1.5	5.7	4.1
14	A3 X PDL 984953	4.0	1.6	5.0	3.5
15	A4 X PRL 984025	4.3	1.7	5.2	3.7
16	A4 X PDL 984953	4.8	2.1	5.6	4.2
17	A4 X PRL 983923	4.2	2.0	5.2	3.8
18	A4 X A 3566	5.4	1.6	7.5	4.8
19	A4 X P 89001	4.0	0.6	4.8	3.1
20	A4 X PDL 984926	4.5	1.9	5.2	3.8
21	A6 X PRL 983993	4.1	1.8	5.0	3.6
22	A6 X PRL 983950	5.1	0.8	3.7	3.2
23	A6 X M 9057	5.5	2.3	5.2	4.3
24	Teshale (3443-2-OP)	5.4	2.5	5.9	4.6
	LSD (0.05)	2.06	1.01	2.75	1.17
	CV (%)	25.59	34.51	28.73	30.18

Table 5. Mean grain yield of early maturing sorghum hybrids tested under advanced sorghum hybrid trial (Set-II) in 2004.

No.	Entry	Melkassa	Miesso	Kobbo	Mean
1	A6 X A 3566	4.3	14	54	3.7
2	ABON 34 X PRL 983935	4.3	3.0	6.1	4.5
3	ABON 34 X P 89001	4.6	2.3	6.6	4.5
4	ABON 34 X MR 747	5.1	2.2	5.6	4.3
5	ABON 34 X PRL 983993	4.4	2.3	5.9	4.2
6	ABON 34 X PDL 984921	4.5	2.3	6.4	4.4
7	ABON 34 X PP 630	5.2	2.4	5.9	4.5
8	ABON 34 X A 3566	5.7	2.1	6.0	4.6
9	ABON 34 X PRL 984046	4.5	2.7	5.0	4.1
10	ABON 34 X P 89002	5.6	2.8	6.3	4.9
11	ABON 34 X P 89009	4.8	2.1	6.3	4.4
12	ABON 34 X P-9405	5.0	2.2	5.2	4.1
13	ABON 34 X PRL 983923	4.8	2.3	5.7	4.3
14	ABON 34 X PRL 983945	3.8	2.5	6.5	4.3
15	ABON 34 X PRL 983978	5.7	3.6	7.3	5.6
16	ABON 34 X PRL 984000	4.7	2.4	5.6	4.2
17	ABON 34 X PRL 984042	4.9	2.7	7.2	4.9
18	ABON 34 X PRL 984067	5.2	2.8	5.4	4.5
19	ABON 34 X PRL 984084	5.3	2.8	7.2	5.1
20	ABON 34 X PDL 984850	5.6	2.7	7.1	5.1
21	ABON 34 X PDL 984858	5.3	2.2	7.4	5.0
22	Teshale	4.8	2.3	5.2	4.1
	LSD (0.05)	NS	0.86	1.21	0.61
	CV (%)	14.1	2.12	11.9	14.5

and timely planting.

Farmer managed (on-farm) adaptive research trials (for technology generation), demonstrations and exposure visits by farmers to research institutes (for technology dissemination) were undertaken. A total of 120 farmers participated in the field trials.

Results presented in Tables 6 and 7 show increases [range 33 – 170% above the farmers' practice] in sorghum grain yield in response to different strategies employed. This confirms that low soil fertility is a constraint to sorghum production and the alternative strategies are effective in addressing it.

Capacity Building

One of the major areas of collaboration between EARO and INTSORMIL was building the capacity of the national program to execute organized research to enhance sorghum production and productivity in the country. This was achieved

Table 6. Sorghum grain yield in response to alternative strategies at Opwatetta parish during the short rains of 2004.

Strategies					
Inorganic fertilizers & kraal manure		Inorganic fertilizers, cowpeas, and mucuna - rotation		Minimum tillage	
Treatment	Yield (t ha^{-1})	Treatment	Yield (t ha^{-1})	Treatment	Yield (t ha^{-1})
Farmer practice	1.5	Farmer practice	1.0	Conventional tillage	0.9
(30 kg N + 10 kg P) ha^{-1}	2.9	Previous cowpeas	2.0	Glyphosate + (30 N + 10 P) ha^{-1}	2.1
2.5 t ha^{-1} manure	2.3	(30 N + 10 P)*	2.5	Glyphosate	1.4
30 kg N ha^{-1}	2.0	Mucuna relay	2.7	Lasso – Atrazine + NP*	2.2
(30 kg N + 2.5 t) ha^{-1} manure	3.8			Lasso	1.5
LSD$_{5\%}$	0.6	LSD$_{5\%}$	0.56	LSD$_{5\%}$	0.5

Table 7. Sorghum grain yield (t ha^{-1}) in response to alternative strategies at Opwatetta (A) & Kadesok (B) during 2005 long rains.

Strategies								
Inorganic fertilizers & kraal manure			**Inorganic fertilizers, cowpeas-rotation & mucuna**			**Minimum tillage**		
Treatment	**Site**		**Treatment**	**Site**		**Treatment**	**Site**	
	A	**B**		**A**	**B**		**A**	**B**
Farmer practice	1.4	1.7	Farmer practice	1.4	1.8	Conventional tillage	1.8	1.8
(30 kg N + 10 kg P) ha^{-1}	2.7	3.2	Previous cowpeas	2.2	3.2	Glyphosate + (30 N + 10 P) ha^{-1}	4.0	3.8
2.5 t ha^{-1} manure	2.5	3.5	30 kg N ha^{-1}	2.4	3.5	Glyphosate	3.0	3.3
30 kg N ha^{-1}	2.4	3.8	Mucuna relay	3.0	4.0			
(30 kg N + 2.5 t) ha^{-1} manure	2.8	3.9						
LSD$_{5\%}$	0.29	0.25	LSD$_{5\%}$	0.39	0.27	LSD$_{5\%}$	0.58	1.0

through formal and informal training opportunities and through provision of key equipment and supplies that are essential for smooth running of the program. EARO scientists have received long-term graduate education and short term training at INTSORMIL institutions. In addition, INTSORMIL has supported graduate education of EARO staff members at Alemaya University.

Training

Researchers at the national Sorghum Research program through the platform provided by INTSORMIL had opportunity to work with and learn from experiences of collaborating PIs in the United States. Each year, the national program discuss and develop research agendas together with the regional INTSORMIL coordinator, make joint field evaluations and selections and prepare and publish research outcomes together. In addition, three of the national sorghum research staff have been given formal graduate training opportunity through the project. Two of these (One Ph.D. and one M.S.) joined the local University at Alemaya in 2004 and received their school fee and stipends from the project.

Equipment and Supplies

The program receives its field and office equipment and supplies from INTSORMIL through the regional coordinator. Computers, printers, digital camera, GPS, balances, books, have been received in the past few years and other office and laboratory supplies are made available upon request. The project also provided vital assistance in the area of communication. Access to World Wide Web and direct telephone connection became possible through the assistance provided by the project.

In 2004, the program received two laptop computers to meet shortage of computation facilities especially for graduate students working on their thesis and over 15,000 pollination bags for field crossing

Short-term Visits

Several INTSORMIL scientsis including Dr. Gebisa Ejeta, Dr. John Sanders, Dr. Charles Wortman, and Dr. Martha Mamo have visited national research programs in the Horn of Africa during the last crop season.

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

Gary C. Peterson
Texas A&M University

Coordinators

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Summary

Increase Yield and Promote Economic Growth

Research activity emphasizes developing sorghum germplasm, parental lines, or varieties with resistance to selected insects as well as resistance to other selected biotic or abiotic stresses. Primary objectives are to identify, characterize and utilize the genetic diversity of grain sorghum to develop improved cultivars, germplasm, or parental lines resistant to 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), rust (caused by caused by *Puccinia purpurea* Cooke) and charcoal rot (caused by *Macrophomina phaseolina* (Tassi) Goid). Project emphasis has evolved with increased emphasis 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, and resistance to specific diseases and/or insects. Relevant populations are also evaluated for drought resistance, primarily stay-green (post-flowering drought tolerance).

Increase Yield, Promote Economic Growth, Improve Nutrition

Sorghum varieties or hybrids with resistance to multiple stresses provide farmers with the potential to produce a consistent supply of high quality grain for household or off-farm use by end-use industry. The also will be used by private industry in hybrid development programs and by public scientists as a source of novel genetic combinations. Seventeen biotype E greenbug/disease resistant lines and 17 biotype E/I greenbug resistant have been proposed for release. The biotype E resistant lines also express wide adaptation and resistance to several diseases. The lines are tan plant, white grain or 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.

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. Leo Mpofu (Zimbabwe) and Mr. Joaquim Mutiliano (Mozambique) will complete their M.S. degrees at Texas A&M University in mid- to late-2005. Mr. Mpofu is a non-INTSORMIL supported student. Mr. Niaba Teme (Mali) will complete requirements for the Ph.D. degree at Texas Tech University in late 2006.

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 locale. Sorghums with enhanced environmental fitness will reduce the impact of abiotic and biotic stress. In a cropping system, stress occurs concurrently. Genetic resistance to multiple stresses will reduce environmental risk and enhance productivity. This becomes especially important as production ecosystems change the natural balance between the crop and the ambient environment.

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 integrated production systems. In an integrated production system plant stress does not occur as single event sequentially but as concurrent multiple events. Thus while research can be conducted on individual stress (abiotic or biotic) factors, resistance to multiple stress must be present in a hybrid or variety to promote sustainable, environmentally friendly, and economically profitable production systems. Incorporation of improved genetics (new hybrids or varieties) into an integrated crop production system requires a multi-disciplinary research program. Varieties or hybrids genetically resistant to stress will readily integrate with other inputs into an integrated, ecologically sound production and stress control strategy with large potential benefits in subsistence and mechanized agriculture. Development of multiple stress resistant sorghum is a continual effort in response to a dynamic evolving production agroecosystem.

Research Approach and Project Output

Research Methods

Collaborative host country research is supported through short-term training, graduate education, germplasm exchange and evaluation, site visits, and research at nursery locations in Texas and in two regional programs - Southern Africa and Central America. Southern Africa research is primarily focused on incorporating resistance to sugarcane aphid, disease resistance, adaptation, and improved end-use traits into potential new cultivars. 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 develop germplasm with multiple stress resistance, wide adaptation, and improved end-use traits.

Germplasm is evaluated for resistance to economically important insects in field nurseries and/or greenhouse facilities. Sources of germplasm for evaluation are introductions from other sorghum research programs, exotic lines, and fully converted exotic lines from the sorghum conversion program. Introduced germplasm is crossed to elite resistant germplasm and to germplasm with superior trait(s). A primary selection criteria is insect resistance in addition to 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 several stresses into a single high grain yield genotype with improved end-use traits. For insects important in host countries 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 host country cooperator in replicated trials for evaluation for resistance to the specific insect under the local production system (fertilizer, tillage, plant population, etc.). Disease readings, agronomic and yield data are collected if possible.

Research Findings

Sorghum Midge Resistance

Sorghum midge is the most ubiquitous insect of sorghum. It poses a production risk in many areas where sorghum is grown. Four primary means exist to control sorghum midge - cultural, biological, chemical, and genetic. Within many production systems, cultural and biological methods provide some measure of control. Genetic resistance can provide a low cost, stable, and durable measure of control. However, 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 wide-spread 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 planting two weeks or more resistant hybrids will generally out-yield susceptibly hybrids without insecticide application. With increasing environmental concern regarding pesticide application and fewer insecticides available to control sorghum midge interest in the development and use of midge-resistant hybrids could increase. The grain yield discrepancy for sorghum midge resistant hybrids in the United States results primarily from the research methodology required to screen for sorghum midge. A small portion of the research program is still directed at the development of superior A- or R-lines suitable for use in hybrid production systems.

Primary emphasis in the sorghum midge resistance program has shifted to developing varieties suitable for use in host country production systems. The varieties should be tan plant, white grain, possess disease resistance, drought tolerance, about 1.5 meters in height, and express a moderate level of resistance to sorghum midge. The 2004 Midge Line Test (63 entries x 2 replications) was grown at Corpus Christi and Lubbock, Texas and Santa Rosa, Nicaragua. Partial results are shown in Table 1. The midge damage rating of 4.3 indicated a moderate population density of sorghum midge at anthesis. Several entries sustained less than 30% yield loss. Sufficient midge were not present during anthesis at Santa Rosa, Nicaragua to evaluate the trial for midge damage. Thus the yield (kg ha^{-1}) should be a good indication of the lines performance as varieties in a tropical environment. Despite a low test mean (2249 kg ha^{-1}) many entries produced significantly (LSD.05 = 550 kg ha^{-1}) more grain that the test mean. Analysis of the data led to the conclusion that it is possible to select varieties for a moderate level of resistance to sorghum midge with moderate to high grain yield potential. Several of the lines were selected for continued evaluation.

Greenbug Resistance and Germplasm Release

Selections to develop germplasm resistant to biotype I were made. Resistance to greenbug biotypes is conditioned by several genes and a moderate level of resistance is desired. Crosses to introgress resistance gene(s) into other germplasm were made. Progress is apparent is selecting for biotype I greenbug resistance and resistance to other biotic or abiotic stresses. A number of advanced progeny of diverse background were selected for additional evaluation as lines (for agronomic traits, adaptation, disease resistance, and grain weathering resistance) or a hybrid parents (for grain yield potential, adaptation, disease resistance, and grain weathering resistance.

Thirty-four germplasm lines have been proposed for release. The lines are in two sets based upon resistance to greenbug. Seventeen lines designated as Tx2945 through Tx2961 are resistant to biotype E greenbug (Table 2). All of the lines are tan plant and possess either red, white, or lemon yellow pericarp. The lines possess excellent resistance to several diseases including head smut and rust. Maturity varies from 73 to 78 days after planting and is in the range of Tx2783 (74 days after planting) and RTx430 (78 days after planting). All of the lines are earlier than RTx436 (80 days after planting. The lines will provide breeders with a source of multiple biotic stress resistance in a tan plant background and be useful as a source of novel gene combinations or directly as hybrid parents. The seventeen lines designated as Tx2962 through Tx2978 are resistant to both biotype E and biotype I greenbug (Table 3). Fourteen of the lines are purple plant color and three are tan plant color. The level of disease resistance will vary with the line and disease. All of the lines reach 50% between 68 and 76 days after planting and reach anthesis earlier than Tx2783 (74 days after planting), RTx430 (78 days after planting), and RTx436 (79 days after planting). In 2003, the lines were evaluated as hybrid parents in a replicated yield trial (94 entries x 3 replications) grown at Lubbock, TX under moderate drought stress. Fourteen of the top 15 hybrids with the highest grain yield were resistant to biotype I greenbug.

Sugarcane Aphid Resistance

The sugarcane aphid (*Melanaphis sacchari*) is an insect pest of sorghum throughout Southern Africa. Collaborative research between TAM-223, the South African Agricultural Research Corporation - Grain Crops Research Institute, the University of the Free State, the Botswana College of Agriculture (BCA), and WTU-200 is directed at developing improved varieties with aphid resistance and other acceptable

Table 1. Grain yield, midge damage rating, and days to 50% anthesis, for selected entries in the 2004 Midge Line Test at Santa Rosa, Nicaragua, and Corpus Christi and Lubbock, TX.

	Yield	Midge Damage Rating	Days to 50% Anthesis		Plant Height		
Designation	Santa Rosa	Corpus Christi†	Santa Rosa	Lubbock	Santa Rosa	Corpus Christi	Lubbock
	kg ha^{-1}					----------cm----------	
(Tx2883*(Tx2864*(Tx436*(Tx2864*PI550607))))-PC1-SM1-CM2-SM2-CM2-CABK-CMBK	6002	2.5	65	69	142	130	86
(Tx2883*(Tx2737*(Tx436*(Tx2783*PI550607))))-PC4-SM1-CM2-SM2-CG2-CABK-CMBK-CGBK	5194	5.0	60	68	151	140	112
(Tx2880*(86EO361*(Tx2880*PI550607)))-PC2-PR6-LG7-CG3-CM2-CM2-CGBK-CMBK-CG2	5144	4.5	62	69	152	128	122
(Tx2880*(86EO361*(Tx2880*PI550607)))-PC1-PR10-LG34-CG2-CM3-CG1-BGBK-CABK-CG2	5066	7.5	69	68	154	118	110
(Tx2880*(86EO361*(Tx2880*PR550607)))-PC1-PR10-LG34-CG1-CG1-CG2-CMBK-BGBK-CG1	4784	8.5	58	71	147	110	117
(Tx2883*(Tx2737*(Tx2783*PI550607))))-PC2-SM3-CM1-SM1-LGBK-CABK-CABK	4609	2.0	59	70	148	118	100
(Tx2783*(Tx2737*(Tx436*(Tx2783*PI550607))))-PC1-SM2-CM1-SM1-CMBK-CABK-BGBK-CGBK	4223	5.5	66	70	139	122	122
(91CC515*MR114-90M11)-SM4-LMBK-CM1-SM2-SM1-HM1-CMBK-CMBK	3943	2.0	62	69	121	105	105
(7ML54/7BRON132/((IS2549C*Tx2767)*Tx2876)*MB108B)-SM3-SM1-CM1-CM1-CMBK	3852	2.5	64	70	148	135	130
00MLT165/01MLT156/(PM12713*Tx2880)-CM5-CM3-	3709	3.5	58	72	136	115	107
(Tx2883*(Tx2737*(Tx436*(Tx2783*PI550607))))-PC1-SM2-CM1-SM2-SM2-CABK-BGBK-CMBK	3626	4.0	64	70	122	120	99
(Tx2880*(Tx2880*(GR108-90M24*(Tx2862*(Tx430*(Tx2862*PI550607))))))-PR1-SM1-CM1-CM2-LGBK-BGBK-BGBK	3556	4.0	59	72	157	120	105
(Tx2880*(Tx2880*(Tx2864*(Tx436*(Tx2864*PI550607)))))-PR3-SM6-CM3-CM1-CM2-CABK	3430	3.5	60	69	131	108	107
Tx2880	3392	2.9	67	69	141	100	94
(Tx2880*(Tx2880*(Tx2864*(Tx436*PI550607)))))-PR2-LG24-CG2-CG1-CG1-CA1-CMBK	3333	2.0	67	70	118	115	115
(Tx2880*(GR127-90M39*(Tx2862*(Tx2864*PI550607))))-PC1-SM1-SM1-CM2-CG2-BGBK-CABK	3303	7.0	67	69	125	118	105
(Tx2883*(Tx2864*(Tx436*(Tx2864*PI550607))))=PC1-LG4-CG2-CM1-CM2-CABK-BGBK	3263	3.0	65	69	118	115	86
(Tx2880*(Tx2880*(Tx2864*(Tx436*(Tx2864*PI550607)))))-PR3-SM6-CM3-CM3-CG3-BGBK-CABK	3130	5.0	58	68	148	113	105
MEAN	2249	4.3					
LSD.05	550	1.8					

†Rated on a scale of 1 = 0-10% damaged kernels, 2 = 11-21%, up to 9 = 80-100% damaged kernels.

Table 2. Greenbug damage rating and selected disease and agronomic characteristics of Tx2945 through Tx2961 and selected checks.

Line	Plant color	Grain color	Greenbug damage rating[†]	Head smut[‡]	Rust[§]	Grain mold -	Grain mold -	Insecticide phytotoxicity[#]	Days to 50% anthesis[††]	Plant height
				%		CC[¶]	CS[¶]			cm
Tx2945	Tan	Red	3.5	0	1.2	2	2	1.1	75	112
Tx2946	Tan	Red	3	1	1	1.5	1.8	1.1	73	117
Tx2947	Tan	White	1.5	0	1	2.2	2.5	1.2	76	109
Tx2948	Tan	Red	2	0	1	1.5	1.8	2	74	109
Tx2949	Tan	Red	2.5	0	1	1.5	1.8	1.6	76	109
Tx2950	Tan	Red	4	0	1	2	1.5	1.5	76	107
Tx2951	Tan	White	2	0	1	2.2	2.2	1.2	76	89
Tx2952	Tan	Red	3.5	0	1	1.8	2.2	1.2	73	79
Tx2953	Tan	Lemon Yellow	3	0	1	2	2.5	1.1	78	101
Tx2954	Tan	Red	4	0	1	2.2	2.5	1.2	78	86
Tx2955	Tan	Red	2	0	1	2	2	1.1	73	102
Tx2956	Tan	Red	3	0	1	1.6	2.2	1.6	74	91
Tx2957	Tan	White	4	0	1	2.2	2.5	1.2	72	107
Tx2958	Tan	White	2	0	1	2.5	2.8	2	74	112
Tx2959	Tan	White	1	0	1.1	2.2	1.8	1.5	74	91
Tx2960	Tan	White	2	0	1	2.8	2.2	1.8	74	112
Tx2961	Tan	Red	3	0	1.4	2.8	2.2	1	74	99
Tx2783 (check)	Purple	Red	3	0	1.2	2	2	1.8	74	119
RTx430 (check)	Purple	White	8	3.3	1.1	3	3.2	2.2	78	102
RTx436 (check)	Tan	White		0	1	2.5	2.2	1.8	80	117

[†] Rated on a scale of 1 = 10% leaf tissue death, 2 = 20% leaf tissue death, etc., 9 = 100% leaf tissue death.

[‡] Average over two years at Corpus Christi, TX.

[§] Average over two years at Isabela, PR. Rated on a scale of 1 = disease inconspicuous or present on an occasional plant, 2 = disease over 50% prevalence with low severity causing little damage, 3 = disease 100% prevalent, up to 25% of leaf area destroyed, 4 = disease 100% prevalent, over to 25% of leaf area destroyed, 5 = leaf death.

[¶] CC = Corpus Christi, TX. CS = College Station, TX. Average over two years on a scale of 1 = no mold damage, 2 = moderately resistant to mold with seed slightly discolored, 3 = moderately susceptible with significant discoloration, 4 = extensive discoloration and deterioration of seed, 5 = seed destroyed.

[#] Rated on a scale of 1 = no leaf discoloration to 5 = 100% leaf discoloration.

[††] Average over two years at Lubbock, TX.

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, Texas for evaluation and selection in semi-tropical south Texas. 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 the mid-altitude ARC-GCI in Potchefstroom and the low-altitude, sub-tropical Burgershall Research Station near Hazyview, South Africa or Gaborone, Botswana.

A 100-entry test, three replication test was evaluated for resistance to sugarcane aphid and adaptation to local production systems. Spreader row of susceptible sorghum were planted two weeks prior to the test to insure presence of aphids. Aphid damage is evaluated when the majority of entries are 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. Partial results of the trial are presented in Table 4.

The local check cultivar Segaolane (from Botswana) was rated at 4.3 and the resistant check TAM428 was rated at 1.3. Forty-seven entries and 36 entries respectively at Potshefstroom and Burgershall were rated as highly resistant (one or two). Many entries (43 at Potchefstroom and 35 at Burgershall) were rated as susceptible. A greenhouse seed-

Table 3. Greenbug damage rating and selected disease and agronomic characteristics of Tx2962 through Tx2978 and selected checks.

Line	Plant Color	Grain Color	Greenbug damage rating[†]		Head smut[‡]	Rust[§]	Grain mold -	Grain mold -	Insecticide phytotoxicity[#]	Days to 50% anthesis[††]	Height
			Biotype E	Biotype I	%		CC[¶]	CS[¶]			cm
Tx2962	Purple	Red	3	6	0	1	2	2	2	76	102
Tx2963	Tan	Red	2.7	7	0	1	1.5	2.2	1.6	72	102
Tx2964	Tan	Red	2	4.5	0	1	1.4	2	1.5	73	102
Tx2965	Purple	Red	2.4	5	0	1	2	1.8	3	70	107
Tx2966	Purple	White	2.8	2	0	1.5	3.2	2.5	2.8	74	91
Tx2967	Purple	White	3	3	9	1.5	3.2	2.8	2.8	68	91
Tx2968	Purple	White	2.7	2.5	4.5	2	3.5	3.2	2.4	71	81
Tx2969	Purple	White	2.7	3	15.6	1.5	3.5	3.5	2.1	71	102
Tx2970	Purple	Red	2	6	0	1.2	1.8	1.5	1.5	74	91
Tx2971	Purple	Red	2.3	6	5.4	1	1.8	1.8	2	75	97
Tx2972	Purple	Red	2.8	4	3.8	1	2.2	4.2	2.8	77	102
Tx2973	Purple	Red	2.4	4	3.8	1	2.2	2.2	2	71	102
Tx2974	Purple	Red	2.8	5	2.5	1	3	1.8	1.6	76	97
Tx2975	Purple	White	5.2	5	20.6	1.7	2.8	2.5	2.2	72	102
Tx2976	Tan	White	5.8	6.5	1.5	1.8	3	3	1.7	74	102
Tx2977	Purple	White	2.2	3.5	0	1.8	2.8	2.7	2.8	71	102
Tx2978	Purple	White	6	4.7	2.9	1.2	2.8	2.5	2.2	71	97
Tx2783 (check)	Purple	Red	3	8	0	1.2	2	2	1.7	74	119
Tx430 (check)	Purple	White	8	8	1.7	1.2	3	3.2	2.2	78	102
Tx436 (check)	Purple	White			0	1.2	2.5	2.2	1.7	79	117

[†] Rated on a scale of 1 = 10% leaf tissue death, 2 = 20% leaf tissue death, etc., 9 = 100% leaf tissue death.

[‡] Average over two years at Corpus Christi, TX.

[§] Average over two years at Isabela, PR. Rated on a scale of 1 = disease inconspicuous or present on an occasional plant, 2 = disease over 50% prevalence with low severity causing little damage, 3 = disease 100% prevalent, up to 25% of leaf area destroyed, 4 = disease 100% prevalent, over to 25% of leaf area destroyed, 5 = leaf death.

[¶] CC = Corpus Christi, TX. CS = College Station, TX. Average over two years on a scale of 1 = no mold damage, 2 = moderately resistant to mold with seed slightly discolored, 3 = moderately susceptible with significant discoloration, 4 = extensive discoloration and deterioration of seed, 5 = seed destroyed.

[#] Rated on a scale of 1 = no leaf discoloration to 5 = 100% leaf discoloration.

[††] Average over two years at Lubbock, TX.

ling stage trial was also conducted. Partial results are shown in Table 4. Seedlings were inoculated 10-days after emergence and plants were rated for damage 21 days after infestation. Plants were rated using a 1 to 6 scale, where 1 = 0-10% plant necrosis or plant tissue covered by aphids and plants highly resistant, 2 = 11-25% plant necrosis or plant tissue covered by aphids and plants highly resistant, 3 = 26-50% plant necrosis or plant tissued covered by aphids and plants resistant, 4 = 51-70% plant necrosis or plant tissue covered by aphids and plants slightly susceptible, 5 = 71-90% plant necrosis or plant tissued covered by aphids and plants susceptible, and 6 = 91-100% plant necrosis or plant tissue covered by aphids and plants highly susceptible. Partial results of the trial are presented in Table 4. Sixty-seven entries were rated as highly resistant (50 entries rated at one and 17 entries rated at two). Only 21 entries were rated as susceptible to highly susceptible. Results of the field and greenhouse trials led to the conclusion that a number of entries express resistance in the seedling stage and consistent resistance over locations.

The objective of this research is to develop an improved cultivar with resistance to sugarcane aphid. Insect screening data identified a number of entries with excellent resistance. To be useful to the small farmer, grain yield and processing characteristics must be at least equal to local standard checks. The Potchefstroom trial was harvested to collect data on grain yield. The average grain for the test was 2300 kg ha^{-1}. Sixty entries produced more grain than the mean. The eleven entries with this highest grain yield was all experimental entries that produced more grain than the highest yielding local check (Kuyuma). Of the 60 entries that produced more grain than the mean, 26 are highly resistant to sugarcane aphid in field at two locations (rating 2.3 or less) and the greenhouse trial (rating 1.7 or less). The three entries with the highest grain yield also possess excellent resistance to sugarcane aphid. For the Mt. Makulu location forty-three entries produced more grain yield than the test mean (3689 kg ha^{-1}). Differences in grain yield between the two locations were apparent with only a few entries ranking high for grain yield at both locations. The entry with the highest yield at Mt. Makulu ranked 97th in the Potchefstroom test. Two entries produced excellent grain yield at both locations. Entries with high grain yield and excellent resistance to sugarcane aphid were also identified at Mt. Makulu.

Based on the data obtained a replicated yield test will be developed for evaluation at three locations in South Africa. The objective of the test will be to identify potential varieties use to the small hectarage South Africa farmer. The experimental entries will be compared to standard check varieties for adaptation, grain yield, and end-use process traits. Addi-

Table 4. Sugarcane aphid damage rating, grain yield, and grain mold rating of selected entries in the 2004 Sugarcane Aphid Test at Potchefstroom and Burgershall, South Africa

				Grain Yield		
PEDIGREE	**Potchefstroom†**	**Burgershall†**	**Greenhouse‡**	**Potchchefstroom**	**Mt. Makulu**	**Grain Mold§**
				–kg ha⁻¹--	–kg ha⁻¹--	
(CE151*TAM428)-LG8-BG1-LG1	2.3	1.7	1.0	5390	4008	3.8
(Macia*TAM428)-LL9	1.3	1.7	1.0	4430	6401	3.5
(SV1*Sima/IS23250)-LG15-CG1-BG2-BGBK-LBK	2.0	2.3	1.0	4290	3090	4.0
(Segaolane*WM#322)-CG1-BGBK-CCBK-LBK	3.0	2.3	1.0	4260	5503	3.2
((6BRON126/87BH8606-6*GR107-90M46)*CE151)-LG2-CG1-BG2-BG1-CG1-CABK	3.7	2.7	1.7	4030	4977	4.0
(Town*EPSON2-40/E#15/SADC)-LG1-BGBK-CCBK-LBK	3.3	2.3	1.3	4020	1936	4.5
(SDSL89426*6OB124/GR134B-)-LG5-CCBK-CCBK-LBK	2.7	2.3	1.7	4000	4651	3.8
(EPSON2-40/E#15/SADC*A964)-CG3-BGBK-CCBK-LBK	3.7	2.7	5.0	3870	2747	3.3
(CE151*TAM428)-LG15-LG1-BG1-BGBK-LBK	2.3	2.3	1.3	3760	4644	3.8
(EPSON2-40/E#15/SADC*A964)-LG2-CG1-BG1-BG2-CGBK	3.3	2.7	3.0	3550	3336	3.3
(6OB128/(Tx2862*6EO361)*CE151)-LG16-CG1-LGBK-LG2-LBK	2.3	1.7	1.3	3440	2079	4.0
Kuyuma	4.3	3.3	3.0	3410	5943	4.2
(Macia*TAM428)-LL2	1.0	1.3	1.0	3320	3302	3.7
WM#177	1.0	1.0	1.7	3270	4268	3.5
(6BRON161/((7EO366*Tx2783)-HG54)*CE151)-LG1-BGBK-CCBK-LBK	1.3	1.0	1.0	3250	5435	3.8
(Marupantse*TAM428)-HM7*CA1-CG1-CA3	3.3	3.3	1.7	3230	1262	3.7
(Macia*GR128-92M12)-HM20-CA2-CG1-CGBK	1.7	2.0	1.0	3220	3968	3.8
(6OB128/(Tx2862*6EO361)*CE151)-LG27-LG1-BG1-LG1-CGBK	3.0	2.3	1.3	3200	1117	3.3
PRGC/E#69414	1.7	2.0	1.0	3180	4815	4.2
(96AD34/6BRON116/5BRON131/(80C2241*GR108-90M30)-HG46-*WM#177)-CG2-BG1-LG1-CGBK	3.3	2.0	1.0	3180	4086	3.3
CE151	2.0	3.3	2.0	3110	2921	4.5
TAM428	1.7	2.0	1.3	3090	4586	3.8
Sima (IS23250)	1.7	1.3	1.0	2970	7082	3.8
WM#322	1.7	1.3	1.3	2650	3186	4.0
FGYQ353	2.7	2.0	1.0	2590	2687	3.3
Ent.62/SADC	1.3	1.3	2.0	2480	3988	4.2
SDSL89426	2.7	1.7	1.7	2310	3571	4.0
Segaolane	5.0	5.0	4.3	670	5040	3.3
Macia	5.0	5.0	3.3	620	2866	3.7
Mean	3.2	2.9	2.4	2350	3689	3.6

†Rated on a scale of 1 = 0-10% plant necrosis or plant tissue covered by aphids, 2 = 11-25%, 3 = 26-50%, 4 = 51-70%, 5 = 71-90%, up to 6 = 91-100% plant necrosis or plant tissue covered by aphids.

‡Rated on a scale of 1 = no aphids present, 2 = light infestation and no dead leaves, 3 = moderated infestation and no dead leaves, 4 = high infestation and many dead leaves, up to 5 = majority of plants dying.

§Rated on a scale of 0 = no grain mold present to 5 = grain mold on all kernels with significant grain deterioration.

tionally, 39-entries from the sugarcane aphid test were selected for subsequent evaluation and use in the new ARC-GCI sorghum breeding program.

The sugarcane test is provided to collaborators under a Memorandum of Agreement (MOA) between the Texas Agricultural Experiment Station (TAES) and the collaborating institution. The MOA restricts use to other than the stated evaluations, and prohibits secondary distribution or seed increase. To enable subsequent evaluations of selected experimental entries TAES has sent a new MOA to the ARC-GCI permitting seed increase and testing of the selected entries. Those that will be identified as suitable for use as open pollinated varieties will be jointly released by the TAES and ARC-GCI, and ARC-GCI will control seed stocks and distribution to small farmers.

West Africa (Mali) Graduate Education

Research was on-going in the Ph.D. research of Mr. Niaba Teme. The title of the dissertation is "Molecular marker analysis of quantitative trait locs (QTL) in BC_2 derived lines influencing grain yield and yield components in sorghum (*Sorghum bicolor* (L.) Moench)". The research hypothesis is that progeny derived from the backcrossing of SC170-14E (a fully converted zera zera sorghum from Ethiopia) will produce more grain yield as lines and hybrid parents, and that QTLs influencing grain yield can be identified. All field research and data have been collected. Activity is now directed at molecular analysis of the progeny. Screening of 197 BC2 derived SC170-14E population progeny to detect simple sequence repeat (SSR) loci in the progeny is on-going. At the present time 144 primer pairs have been screened of which 32 were informative. Screening for informative loci will continue in the next year. It is anticipated that the research will be completed in the fall of 2006.

Networking Activities

Workshops and Meetings

Participated in the White Sorghum Workshop at the University of Pretoria co-sponsored by the South Africa Sorghum Forum and INTSORMIL, 21-22 October 2004, Pretoria, South Africa.

Participated in INTSORMIL Technical Committee meeting 19-20 February 2005, Reno, NV.

Participated in INTSORMIL Technical Committee meeting 5-6 May 2004, Kansas City, MO.

Participated in ad-hoc committee meeting to draft a long-term Strategic Technical Plan, 13-15 June 2005, Lincoln, NE.

Research Investigator Exchanges

Zambia and South Africa - October 10-23, 2004. In Zambia met with Ministry of Agriculture, Department of Agricultural Research scientists to discuss national and regional sorghum and millet research. Met with representatives of South African Breweries (SAB) to discuss use of sorghum in "Eagle" beer. Met with the Executive Director of the Golden Valley Agricultural Research Trust to discuss future collaboration between Golden Valley and INTSORMIL, and to deliver a copy of the Memorandum of Understanding (MOU) to formally establish collaboration. In South Africa, met with representatives of the University of Free State to discuss the status of the Ph.D. program of an INTSORMIL sponsored student. Discussed options for expanding graduate education at the University of the Free State. In Potchefstroom, met with ARC-GCI collaborators to discuss on-going research for sugarcane aphid resistance. In Pretoria, participated in the White Sorghum Workshop at the University of Pretoria co-sponsored by the South Africa Sorghum Forum and INTSORMIL

Nicaragua and Guatemala - January 3-8, 2005. In Nicaragua, evaluated cooperative trials provided to INIA by the INTSORMIL/Texas A&M University sorghum breeding programs. Trials provided to INIA include the ADIN (All Disease and Insect Nursery), Midge Line Test (MLT) and hybrid observations. Discussed and evaluated on-farm trials of improved and indigenous varieties in the Estelí region. In Guatemala, evaluated sorghum trials provided to Cristiani Burkard through a Texas Agricultural Experiment Station Materials Transfer Agreement. Viewed hybrid production fields at the Cristiani Burkard research facility. Discussed opportunities for future collaboration. Discussed sorghum research with Prosemillas representatives and viewed hybrid production fields. Discussed possible future collaboration in testing and developing hybrids for Central America.

South Africa, Botswana, and Zambia - April 17 - May 1, 2005. During a visit to the University of the Free State at Bloemfontain reviewed the progress and status of an INTSORMIL supported graduate student (Ms. Phoebe Ditshipi). Ms. Ditshipi is conducting research on stalk rots of sorghum. Reviewed research progress of Mr. Michael Tesfaendrias (Eriteria). Mr. Tesfaendrias (a non-INTSORMIL supported graduate student) is conducting Ph.D. research on "Grain Mold of Sorghum with Specific Reference to Grain Quality in South Africa" under the supervision of Dr. Neal McLaren. Met with Drs. Charl van Deventer and McLaren to discuss development of an INTSORMIL sponsored Ph.D. research program on grain mold resistance in white grain sorghum. The program will involve plant pathology and plant breeding. At Cedara, viewed several sorghum research trials provided to collaborators by the Texas A&M University sorghum breeding program. Cedara is an excellent location to screen for foliar diseases. At Potchefstroom, evaluated the sugarcane aphid test and planned future activity. Discussed the possibility of testing selected entries in on-farm trials for potential use as varieties. In Botswana, traveled to Maun to met with Dr. Stephen Chite (DAR sorghum breeder). Evaluated replicated trials provided by Texas A&M University. Discussed the status of the DAR sorghum breeding program. In Gaborone, met with Dr. G.S. Maphanyee (DAR Director) and Dr. Pharoah Mosupi (Chief Arable Research Officer) to discuss INTSORMIL collaboration and the future of DAR sorghum and pearl millet research. Met with DAR crops researchers to discuss INTSORMIL regional activities. Met with Dr. David Munthali (Botswana College of Agriculture entomologist) to discuss on-going research and plan future activity. In Zambia, discussed the status of collaborative activity in the country and region. Met with an USAID team that was evaluating training in Southern Africa. The team was composed of John Thomas (interim head of USAID/Washington Office of Agriculture), Cristin Springet (USAID/Washington), Dr. Irv Widders (Bean/Cowpea CRSP Director) and Dr. Mywish Maredia (Bean/Cowpea CRSP Associate Director). Traveled to Ndola to visit the Northern Breweries (South African Breweries subsidiary) plant. Met with Mr. Orwell Monga, Plant Manager to discuss the use of sorghum to brew a new mid-level lager beer for Zambia named Eagle.

Germplasm and Research Information Exchange

Germplasm was distributed to private companies as requested and to the following countries, including but not limited to: Nicaragua, El Salvador, Guatemala, South Africa, Botswana, Zambia and Mozambique. 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. Serve on Ph.D. committee of N. Teme (Mali) at Texas Tech University. Serve on the M.S. committee of 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:

Dr. R. D. Waniska, Cereal Chemistry, Dept. 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

Dr. D.T. Rosenow (retired), Sorghum Breeding, Texas Agricultural Experiment Station, Texas A&M University Agricultural Research and Extension Center, Rt. 3 Box 219, Lubbock, TX 79403-9803

Publications and Presentations

Abstracts

Peterson, G.C. 2004. Cultivation of white sorghum - a U.S. perspective. White Sorghum Workshop, October 21-22, 2004, University of Pretoria.

Presentations

Peterson, G.C. 2004. Cultivation of white sorghum - a U.S. perspective. White Sorghum Workshop, October 21-22, 2004, University of Pretoria.

Teme, N., D.T. Rosenow, G.C. Peterson, W. Xu, M.S. Pathan, H.T Nguyen, C.A. Woodfin, A. Herring, and R.J. Wright. 2004. Identification of QTLs influencing heterosis in grain sorghum (*Sorghum bicolor* (L.) Moench). North American Grain Congress Conference and 24th Biennial Grain Sorghum Research and Utilization Conference, February 21-22, 2005, Reno, NV.

Miscellaneous Publications

Rosenow, D.T., J.A. Dahlberg, G.C. Peterson, J.E. Erpelding, J.W. Sij, L.E. Clark, A.J. Hamburger, P. Madera-Torres and C.A. Woodfin. 2003. Release of 49 converted sorghum germplasm lines from the sorghum conversion program. International Sorghum and Millets Newsletter 44:57-59.

Teme, N., D.T. Rosenow, G.C. Peterson, and R.J. Wright. 2004. Improvement of harvest index in sorghum through use of exotic germplasm. International Sorghum and Millets Newsletter 45:20-23.

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

Bruce Hamaker
Purdue University

Coordinators

Issoufou Kapran, INRAN/INTSORMIL Coordinator Eastern Region, B.P. 429, Niamey, Niger
Aboubacar Touré, IER/INTSORMIL Coordinator Western Region, Sotuba Research Station, BP 262, Bamako, Mali
Bruce Hamaker, Regional Coordinator, Food Science Dept., Purdue University, West Lafayette, IN 47907
Katy Ibrahim, Administrative Assistant, Intl Programs in Agriculture, Purdue University, West Lafayette, IN 47907

Collaborative Program

The West Africa Regional Program now encompasses six countries of the Sahelian region – Burkina Faso, Ghana, Mali, Niger, Nigeria, and Senegal - following the merger of the West Africa Eastern and Western Regional programs in July 2004. Core institution-building programs have existed in Mali and Niger, and since 2000 a regionalization effort extended INTSORMIL collaborative research projects to the remaining four countries. In April 2004, a workshop was held in Ouagadougou, Burkina Faso for the purpose of regional strategic planning and implementation of the merger. INTSORMIL host country PI's and nine U.S. PI's, as well as select administrative staff, attended the three day meeting. Progress summaries from each country were presented, strategies and work plans for country and regional programs were developed. Additionally, two new regional projects were identified through a group prioritization process in crop utilization and technology transfer with a goal of developing concept papers and proposals to seek additional outside funding for future activities.

The following report shows the wide breadth of research and extension activities in the West Africa Regional Program. A complement of projects spanning genetic enhancement, sustainable plant protection systems, sustainable crop production systems, and utilization and marketing exist. In most countries of the region, multidisciplinary teams have developed to link production agricultural systems with markets. This is particularly true in the workplans and activity reports from Burkina Faso, Mali, and Niger. Programatically, the West Africa INTSORMIL program is well positioned and is active in working towards enhancement of sorghum and millet markets through high-yielding, quality grain production, supply-chain management, and processed product and animal feed endpoints.

List of Disciplines and PI Collaborators

Genetic Enhancement – Sorghum and Millet

Sorghum: SARI, Ghana – I. Aktoplé; IER, Mali – A. Touré, S.B. Coulibaly; INRAN, Niger - I. Kapran; IAR, Nigeria - P. Marley; ISRA, Senegal – N. Cissé; KSU, U.S. - M. Tuinstra; PU, U.S. – G. Ejeta; TAM, U.S. – B. Rooney, D. Rosenow

Millet: IER, Mali – M. Sanago; INRAN, Niger, A. Issaka; LCRI, Nigeria – I. Angarawai; ISRA, Senegal – A. Fofana; USDA/ARS, U.S. – J. Wilson

Sustainable Plant Protection Systems

Entomology: SARI, Ghana – P. Tanzubil; IER, Mali – N. Diarisso, Y. Doumbia, M. N'Diaye; INRAN, Niger - H. Kadi Kadi; ISRA, Senegal – D. Badiane; WTAMU, U.S. – B. Pendleton

Plant Pathology: INERA, Burkina Faso – A. Neya; SARI, Ghana - S.K. Nutsugah; IER, Mali - M. Diourte; INRAN, Niger – A. Kollo (on leave); ISRA, Senegal – M. Wade; TAM, U.S. – C. Magill; KSU, U.S. - J. Leslie

Striga: INERA, Burkina Faso –H. Traore; IER, Mali – B. Dembébé, M. Kayentao; INRAN, Niger – I. Kapran; PU, U.S. – G. Ejeta

Sustainable Crop Production Systems

Agronomy: INERA, Burkina Faso - J.B. Taonda, P. Siebou; SARI, Ghana – S. Buah; IER, Mali – M. Bagayoko, M. Doumbia, A. Toure, S. Traore; INRAN, Niger – S. Sirifi, N. Mamane; UNL, U.S. – S. Mason

Economics: INRAN, Niger – T. Abdoulaye; PU, U.S. – J. Sanders

Utilization and Marketing

Cereal Technology and Processing: IRSAT, Burkina Faso – B. Bougouma; IER, Mali – F. Cisse; INRAN, Niger – K. Saley, M. Moussa; University of Maiduguri, Nigeria – I. Nkama; ITA, Senegal – A. N'Doye; PU, U.S. – B. Hamaker; TAM, U.S. – L. Rooney

Poultry: INRAN, Niger – S. Issa; KSU, U.S. – J. Hancock

Marketing: INRAN, Niger - A. Tahirou; PU, U.S. – J. Sanders

Sorghum/Millet Constraints Researched

Sorghum and pearl millet are staple food crops of the West Africa Sahelian region including the countries of Burkina Faso, Ghana (northern region), Mali, Niger, Nigeria (northern region), and Senegal. In 2004, together they comprised in Burkina Faso 2,362 mMT vs. 689 mMT for the sum of maize, rice and wheat, in Mali 1,465 vs 1,249 mMT, in Niger 3,080 vs. 87 mMT, in Nigeria 14,310 vs. 8,392 mMT, and in Senegal 511 vs. 686 mMT. Compared to other cereals, sorghum and millets are drought tolerant crops and their importance as a food resource has increased due to drought and desertification which affects some of the countries in this region. Sorghum and millet production in the 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, anthracnose, Downey mildew, and *Striga*.

One of major land production constraints is the low soil fertility in the region. Low soil phosphorus content, nitrogen deficiency and water stress are the major soil related problems. This low soil fertility combined with low yield and unstable yields of local cultivars significantly affects sorghum and millet production in an area where the population increase and the demand for food is increasing. Traditional cultural practices, such as mono-cropping, also contribute to reduce soil fertility and productivity.

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 predominately 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 of identity-preserved grain which is required for increased commercialization and transformation of sorghum and millet into value-enhanced products.

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 regional planning workshop held in Ouagadougou, Burkina Faso.

Research Progress

Genetic Enhancement: Sorghum Breeding

Ghana

Sorghum Breeding, Exotic Germplasm, and Biochemical Characterization

I. Atokple, SARI; M. Tuinstra, KSU

Germplasm collections. Collection trips to the three regions of northern Ghana and parts of Brong Ahafo region were made to farmers' fields towards the end of the seasons (October -December) when most of the sorghum had reached physiological maturity. In all, 487 accessions have been collected so far. Visually, the collections showed a wide range of seed size, color and panicle shape. The accessions collected from Lawra and Bongo districts in the two Upper regions were early maturing. As expected the yields from the two districts were quite high; Lawra accessions were 2120 – 2560 kg ha^{-1} with the exception of the line, BELUUR (DFF of 126) and Bongo accessions were 1033 – 3386 kg ha^{-1}. The days to flowering (range, 76-131) and yields (range, 368–2359 kg ha^{-1}) of the accessions from East Mamprusi District were quite variable

Screening of exotic lines and initiation of hybrid production. A total of 50 lines from INTSORMIL were planted in an observation nursery for subsequent use. Based on seed color and endosperm texture, four of theses lines (04WDRGEN-1, 04WDRGEN-2, 04WDRGEN-6, and 04WDRGEN-11) have been selected for crossing with some landraces and elite lines.

Hybrid production using A-lines from INTSORMIL and ICRISAT with 10 elite lines from SARI was initiated during the dry season, January - April 2004. The few F_1 seeds obtained were planted to test their fertility reaction and for backcrossing involving their respective recurrent parents. The F_1BC_1 progenies are being planted for backcrossing with the recurrent parents.

Biochemical characterization and DNA analysis. Twenty accessions have been selected based on plant type, seed color and texture for further biochemical characterization in determining their specific end uses in collaboration with the Food Research Institute in Accra. A complementary DNA analysis will to be carried out on the accessions in collaboration with the Crop Science Department, University of Ghana to determine the national core collection after eliminating duplications.

Mali

Sorghum Breeding and Seed Multiplication

A. Touré, S.B. Coulibaly, IER; B. Rooney, TAM; M. Tuinstra, KSU

Breeding crosses. New breeding crosses are made annually to assure the gradual improvement of new breeding materials through recombination of the best materials. During the 2004 rainy season, 128 new crosses were made at Sotuba and the F$_1$s grown during the 2004-2005 off season nursery to produce F$_2$ seeds. From the multi-location evaluation of 128 F$_2$ families in the rainy season, 31 single-plant selections were made at Cinzana, 42 at Sotuba and 28 at Finkolo. These selections will be advanced by the pedigree method. In the F$_3$ families grown in five locations (Sotuba, Cinzana, Bema, Finkolo and Kita), 62 single heads were selected at Sotuba, 100 at Cinzana, 19 at Finkolo and 113 at Kita. The F4 and F5 generations were evaluated according to the maturity group. The early and medium F4 progenies were evaluated at Sotuba, Kolombada, Cinzana and Bema. Selections were 210 panicles at Sotuba, 84 at Kolombada, 94 at Cinzana. The late F4 progenies were evaluated at Finkolo and Kita with 29 selection at Kita and 206 at Finkolo. A total of 56 lines were retained in the medium F5 progenies at Sotuba and Kolombada, 90 lines in the late F5 progenies at Kita and Finkolo, and 135 lines at Cinzana for early F5 progenies. The F5 selections move to the off-season for seed increase for entry into early yield trials the following year.

Advanced early maturity variety trials. After three years of evaluation in two locations Bema and Cinzana the average grain yield was 1605 kg ha^{-1}. One line, 01-CZ-F5P-244, was retained for grain yield and grain quality. This line produced 1662 kg ha^{-1} in 2002, 2525 kg ha^{-1} in 2003, and 2129 kg ha^{-1} in 2004 with a yield average of 2105 kg ha^{-1} compared to the local check which produced 1555 kg ha^{-1} in 2002, 1836 kg ha^{-1} in 2003, and 1559 in 2004 with an average of 1650 kg ha^{-1}. 01-CZ-F5P-244 will be in farm tests in 2005.

Advanced medium maturity variety trials. Three year evaluation of ten new improved medium maturity varieties at Sotuba and Kolombada showed significant differences among entries for grain yield. The line 01-SB-F5DT-221 with an average grain yield of 2528 kg ha^{-1} yielded 2833 kg ha^{-1} in 2002, 2709 kg ha^{-1} in 2003, and 2042 kg ha^{-1} in 2004, thus over yielding the local checks 41, 12, and 41%, respectively.

Advanced late maturity variety trials. The combined three year data from Finkolo and Kita of late maturing varieties with a grain yield average of 2156 kg ha^{-1} did not show significant differences among entries. However, three lines have shown grain yield stability during the years: two *Guinea* derivate lines (01-KI-F5T-89 and 01-KI-F5T-126) and one *Caudatum* type (01-FI-F5T-35).

On-farm trials. Six farmers were selected in each of the two localities Bema and Cinzana to compare seven new breeding early lines to their local lines. Drought and locust damage have affected severely grain yield at Bema. At Cinzana there were significant differences for grain yield, indicating that 00-BE-F5P-15 (898 kg ha^{-1}), 00-BE-F5P-135 (648 kg ha^{-1}), 00-BE-F5P-25 (546 kg ha^{-1}) showed greater grain yield than the farmer local (444 kg ha^{-1}). They also showed superior grain quality compared to the local.

For the medium maturity varieties, twelve farmers from Ouélessébougou and Bancoumana compared eight new improved new lines to the local. At Bancoumana there were no significant differences for grain yield. At Ouélessébougou there were significant differences among entries showing the local ranked first with 802 kg ha^{-1}.

For the late maturing varieties and for the second year, Kénikéba and Darrellken were compared to the local at Kita. There were significant differences for grain yield. Kénikéba ranked first with (630 kg ha^{-1}) followed by Darrellken (494 kg ha^{-1}) and the local (450 kg ha^{-1}).

Seed multiplication. Ten improved cultivars and new breeding lines are listed in Table 1. Seed was increased by the Sorghum Breeding Program in 2004 for distribution, NGO's, on-farm trials and demonstrations, and future seed increases.

Niger

Breeding sorghum for Processing Quality, Grain Yield, and Resistance to *Striga* and Midge

I. Kapran, S. Kaka, H. Kadi Kadi, INRAN;
M. Tuinstra, KSU; G. Ejeta, B. Hamaker, PU

The objective of this project is to evaluate and select local and exotic germplasms for productivity and adaptation to

Table 1: Quantity of increased seed obtained from different localities of Mali : cropping season 2004-2005.

Varieties	Localities	Weight (kg)
97-SB-F5DT-63(WASSA)	Kafara	900
97-SB-F5DT-150	Kafara	-
97-SB-F5DT-74-2	Tamala	900
98-F2-78	Kolombada, Tamala	500
CSM388	Kolombada	600
DARRELKEN	Kolombada, Kafara	1000
MALISOR-92-1	Béma	-
CSM63E	Béma	400
KENIKEBA	Kita , Kébila	300
96-CZ-F4P-98	Kita et Kébila	700
Total		6000

local conditions and biotic stresses. Activities included: 1) evaluation of experimental germplasm for drought, midge and/or *Striga* resistance, and processing quality at various INRAN stations, and 2) on-farm trials and demonstrations of elite hybrids and lines for midge resistance.

Germplasm evaluation for drought/sandy soil adaptation. This included 100 single seed derived lines from the cross between a well adapted landrace (MDK) and a breeding line (L153-5) that we described last year, as well as lines and hybrids obtained from our INTSORMIL collaborators at Purdue and Texas A&M universities. A random set of 100 SSD F8 lines from the cross MDKxL153-5 was tested in a replicated trial at the Maradi research station on sandy soil. The 2004 season at Maradi location was characterized by one of the worst end of season droughts in the past 15 years. We looked at germination, seedling vigor, anthesis, height and plot yield in the lines and in the parents which were replicated 15 times per rep. We also compared the data to that obtained from another random set of lines in the same population/same location during a better growing season (2002), when rainfall was 500 mm, rainfall was very close to the long term average at Maradi. Parental checks were replicated 26 times in the trial. Seedling vigor was good in both seasons. The most noticeable impact of drought on this population when compared to normal season seemed to be a shift towards lower grain yield, shorter plant height and earlier maturity. Lower yield in 2004 was probably also affected by a lower germination potential, but certainly premature plant death occurred under drought. These patterns were also observed in the parental lines. The dwarf early maturing parent L153-5 was apparently affected only in becoming earlier maturing under drought. The late maturing MDK with excellent seedling establishment became slightly earlier, shorter in height but lost as much as 88% of its yield as compared to normal growing conditions. We also observed a lot of leaf and plant death (half of the plots) in this otherwise well adapted landrace. Our preliminary data confirms the effects of post flowering drought on reproductive plant characters and the crucial role of early maturity for escape. An average yield of 143 g/3 m2 plot representing 55% yield loss under drought is significant indication of the potential impact of drought on farm (as occurred last season in Niger). This is also strikingly seen in the widely grown MDK which produced only 38 g/plot (127 kg ha^{-1}) as compared to 313 g/plot (1043 kg ha^{-1}) under normal conditions. Our data also indicates that MDK is probably better adapted to preflowering stress as seen in its seedling growth and vigorous vegetation including under a previous drought (1989 at Maradi). Many of these preflowering adaptation traits were visible in the progeny along with earliness from L153-5, which allowed selection of eight new lines for the breeding program. In addition a dwarf line previously selected from the same population (L28) appeared to be highly drought tolerant and may be useful to initiate the first landrace-derived A line in Niger.

Test of a promising midge resistant line SSD35. As a follow up to our selection process for midge resistance, large scale tests were conducted. In collaboration with the sorghum network, an on farm trial for a new midge resistant line SSD35 was conducted in several locations as well as an on-station demonstration. SSD35 was identified from a straight cross (MMxICSV88032) between a well adapted farmer variety (MM) which is susceptible to sorghum midge and a breeding line from ICRISAT with known resistance to midge.

For the on-station demonstration in Konni, and in outreach to local farmers working with development project PMET, large size plots of MM and SSD35 were planted on three dates over 30 days in June and July. Differences in seed set were striking (Figure 1). Based on whole plot production, it appeared that SSD35 yielded 2, 15, and 41 times more than MM from first to second and third plantings.

For on-farm testing, SSD35 was tested together with MM, F1-223 (hybrid), 90SN-7 and a local check to determine general adaptation and midge reaction at the farm level. Local extension agents monitored the trial together with three farmers at each location. The trial was affected by low rainfall but also midge damage as expected. Average yields for the locations around Konni (known for heavy midge infestation) are shown in Table 2. On-farm performance of SSD35 was very encouraging, in view of its superiority to local checks under obvious midge infestation. In this environment it appears to be even better than hybrid F1-223 known for its 3 t ha^{-1} potential and MM which is our best local check for yield stability under drought. A seed increase field for SSD35 produced nearly on ton of seed which will be used for extension efforts in 2005.

Senegal

Sorghum Breeding

N. Cissé, ISRA; M. Tuinstra, KSU; A. Touré, IER

Fourteen genotypes and the check (F2-20) were introduced in a yield trial. Mean yields were between 421 and 3830 kg ha^{-1}. Two genotypes (ICSV 2N and KL2) out yielded F2-20 with respectively 1978 and 3830 kg ha^{-1}. The good performance of KL2 was apparently due to its better reaction to drought and its earliness. Segregating populations (F3) of elite crosses between Sorvato1, a high yielding line with good grain qualities identified from the ROCARS trials and the local varieties CE151-262, CE145-66 and 180-33 were tested. Segregating populations of these local lines with sources of earliness were also available at F3 and BC1F2. The objective is to develop early materials (about 80 days from planting to maturity) for the northern zones. Because of locust attack, seeds remaining from each main head were collected for planting in 2005.

Figure 1. Close up view of panicles of MM (left), susceptible to sorghum midge, and new resistant line SSD35 (right) in Konni (Niger), 2004.

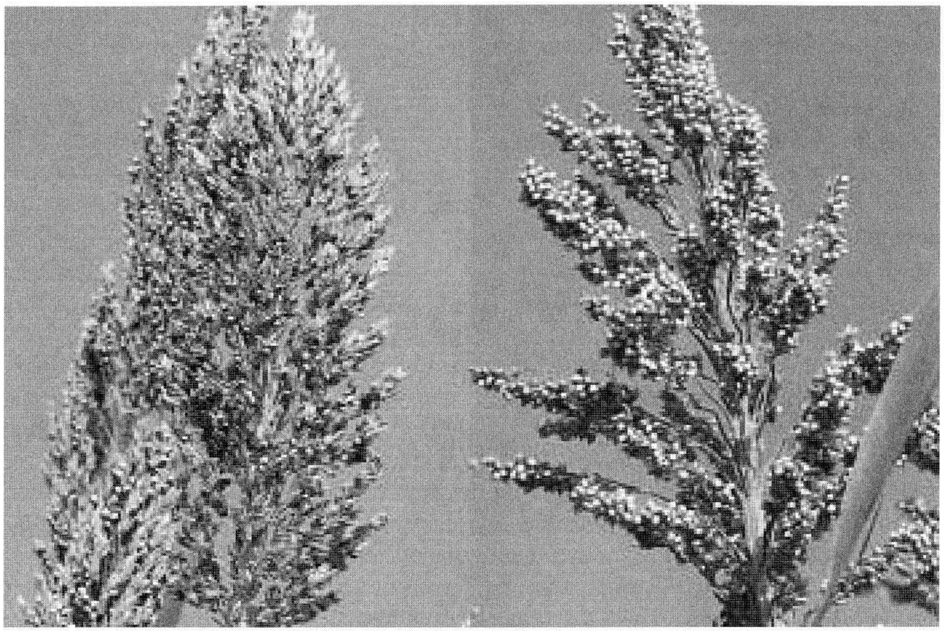

Table 2: On farm performance of SSD35 under midge infestation.

Location Entry	Konni 1	Konni 2	Boulke 1	Boulke 2	Boulke 3
		Grain yield (in % of farmer check)			
F1-223	136	111	0	18	0
90SN7	36	13	0	11	0
SSD35	185	302	323	195	162
MM	43	56	49	0	244
Farmer check	100	100	100	100	100
Yield of farmer check (kg ha^{-1})	241	117	94.6	258	44

A dwarf guinea population comprised of 143 lines and the local check (F2-20) was tested at Kolda. Plant height was between 103 and 2.74 m. Days to flowering varied between 64 and 103 days and corresponded for most lines to the cycle length sought for the zone. Segregation for plant height, sterility, grain characteristics, panicle exertion, and cycle length was observed in the population. Seventeen lines were selected for their uniformity and will be yield tested in 2005.

The entries of the 2004 yield trials were selections from previous INTSORMIL and CIRAD observational nurseries and trials. These selections were made based on agronomic performances. The trials were conducted in Bambey and Nioro. At Bambey, the test was not conducted to completion, because of locust attack. High yielding lines were observed at Nioro; 96CZFS-12, 1946.0 kg ha^{-1}; 93B1062, 1774.3 kg ha^{-1}; CE145-66, 1716.7 kg ha^{-1}; CEF439, 1562.0 kg ha^{-1}. It is noted that the new variety, 93B1062, which derived from CE145-66 through backcross, had the highest yield.

Genetic Enhancement: Millet Breeding

Mali

Millet Breeding

M. Sanago, A. Touré, IER; J. Wilson, USDA/ARS

Evaluation of the best varieties from Senegal, Niger, Nigeria and USA. An experiment was designed to test 40 millet varieties from Senegal, Niger, Nigeria and the U.S. at Cinzana. The results showed significant differences among entries for sowing, particularly 50% flowering. Differences among entries for grain yield were highly significant. The most productive varieties were NKO x TC1 and NKK with a mean yield of 2700 kg ha^{-1}. Extra early maturing varieties were less productive due to bird damages.

At maturity stage, differences in downy mildew incidence and severity were highly significant among varieties. Varieties free of downy mildew were CzSyn 00-01 and 99-72. High degree of infestation (44.75% and 43.75%) was found on the varieties TG 102 and T 99 B, respectively.

In the conditions of natural infestation, significant differences were recorded in head borer and stem borer incidences. The less infested varieties to head borer were 01 Miso NCD2-NE and 99M59043MW X 68A4R4 with 1.75% of incidence. The varieties 68 A X 08R and DMR 68 were the most affected by head borer with the incidence of 9.5% and 8.5%, respectively. The most infested varieties by stem borer were TG 102 and 01 Miso NCD2-NE with incidence of 2.25%.

Niger

Regional Evaluation of 40 of Millet Varieties in Niger

A. Issaka, INRAN; J. Wilson, USDA/ARS

The main objective is to select promising varieties for future breeding work. Traits of interest included resistance to downy mildew, *Striga*, head miner and grain yield. There was no occurrence of head miner and *Striga* during the growing season in Bengou station, but bird damage was very high leading to yield loss of up to 100%. It was generally observed that cultivars from the West African region (for example: Taram, Zongo, SOSAT C-88, SoSank, Toronio, etc) gave the highest grain yield and were free from mildew. They constitute a good starting point for line development in this breeding program. Indeed there is need to produce hybrids with local adaptation and desired types or at least where one parent is from this group.

Nigeria

Pearl Millet Breeding

I. Angarawai, B.Ndahi, Z.G.S.Turaki,
I Mohammed, LCRI; J. Wilson, USDA/ARS

Improvement of adapted A4 cytoplasm male sterile (B) lines for multi-line resistance to downy mildew. The objective is to improve the productivity and yield stability of pearl millet in the semi-arid zones of Nigeria and the region. 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 leading to backcrossing and development of two diverse A/B pairs in 2002-2003 and screening for sterility in 2003-2004. The newly constituted A-lines were each crossed to LCICDMR15 to evaluate fertility restoration in 2004 main season. Results showed that all the hybrids are fertile while the B-lines are good maintainers, since the A-lines did not revert to fertile status under selfing (except the 4B-2 series).

Genotype, environment and diseases effect on grain quality of pearl millet. A trial was made up of 40 entries of pearl millet lines evaluated at LCRI experimental station in Maiduguri during the 2004 main season. Data were collected for days to 50% flowering, DM scores, and grain yield. Results indicated that 086R could be exploited as a maintainer on male sterile (A) lines since its hybrid produced sterile heads. On the other hand, KAPIELGA and NKK are possible materials that can be explored for downy mildew resistance (0 incidence), while TG102 and T454 could used as indicators in the downy mildew screening nursery. SOSAT-c88 was the highest performer in terms of yield (800 g/plot).

Effect of population density and N-fertilizer application on growth and yield of pearl millet hybrid. To determine the optimum plant density and fertilizer requirement of newly developed hybrids. A combination of three factors: 4 intra-row spacing of 15, 30, 45 and 60 cm between stands; 4 levels of N - 0, 30, 60 and 90 kg N/ha; and three hybrid lines were applied as treatment planted on 4-row plot of 5 m long and 75 cm apart laid out in split plot design. The experiment was conducted at LCRI, Maiduguri during the 2004 main season. Data was taken for days to flower, plant height, stalk weight and grain yield. Preliminary results show that application of 60 kg N/ha at 45 cm intra-row spacing is the optimum for maximum yield since increasing the N rate to 90 kg N/ha at 30 cm intra-row spacing only lead to luxury consumption. This will be confirmed during the 2005 main season experiment.

Senegal

Millet Breeding

Fofana, ISRA; M. Sanogo, IER; J. Wilson, USDA/ARS

Varietal development. Twenty four F1 millet lines were produced during the rainy season. The objective is to develop early maturing varieties with acceptable panicle length. A yield trial was conducted collaboratively with the University of Georgia for a second year to evaluate the productivity and the grain quality of 40 millet genotypes of West Africa and USA origin and to identify parents to be included in the breeding process. Because of a massive locust attack this year, yield evaluation was not possible. However, large variations were observed between entries for days to flowering (44-70 days), the varieties Kapelga and GB 8735 being respectively the latest and earliest. Plant height varied between 90 and 94 cm, Zongo being the tallest. Panicle length was shorter with Bongo Short Head (9.6 cm) and longer with Zongo (81.2 cm). Some genotypes were highly susceptible to mildew (T99 B64, 7%), ¾ Ex Bornou (40, 2%), while others were disease-free (Sadoré local, Kapelga, Zatib, Zongo, Taram). On farm tests were conducted on varieties GB 8735, ICTP 8203, ISMI 9301, IBV 8004 in the drier northern zone of Senegal. The evaluation was not completed because of locust attack.

Seed multiplication. Seeds of the varieties ISMI 9507, ICTP 8203, and Souna 3 were increased at Sinthiou and Kolda.

The quantity of seed obtained (ISMI 9507: 16.4 kg, ICTP 8203: 12.4 kg, Souna 3: 5.5 kg) will be used in the 2005 on-farm trials.

Sustainable Plant Protection Systems: Entomology

Ghana

Resistance and IPM in Millet

P. Tanzubil, SARI; B. Pendleton, WTAMU

Multiple resistance to insects in millet. Twelve millet varieties derived largely from the millet breeding program of SARI were screened for resistance/susceptibility to the key insect pests of millet at Manga. This was a repeat of the same trial in 2002 and 2003. Records were taken on stem borer (*Coniesta ignefusalis*) incidence and damage (deadhearts, stem tunneling, larval counts), incidence of meloids (*Mylabris spp, Coryna hermanaiae*) cotton stainers (*Dysdercus volkeri*) and head miner (*Heliocheillus albipunctella*). There were no significant differences among varieties for meloids, downy mildew, cotton stainers and head miner. Smut incidence was however highest in varieties ICMV 98494, ICMV 98492 and lowest in GICKV 94135 and ICMP 96490. The local selection ARROW supported significantly higher populations of hemipteran bugs than all the other materials. From the three years of the trial, none of the materials can be described as being truly resistant to the key pests of millet. The local materials however appear to be less susceptible to the prevailing pests and diseases than the improved ones derived largely from ICRISAT.

IPM in millet. Two dates of planting (2/6/2004 and 5/7/ /2004) and five cropping patterns were studied at Manga as possible components of an IPM system for millet. There was no significant effect of cropping patterns on incidence of all the key insect pests, notably stem borers (*Coniesta ignefusa*lis*)*, meloids (*Coryna hermaniae, Mylabris spp)*, cotton stainers (*Dysdercus volkeri*) and head miner, *Heliocheillus albipunctella.* Late planting however increased infestation of the millet crop by all the key pests listed above. This confirms earlier data recorded in both 2002 and 2003. Late planting also reduced grain yield significantly, in some cases by as much as 50%. As was the case with pest infestation, cropping pattern did not affect yield significantly and interaction effects were not significant. The results once again, confirm the effectiveness of planting date manipulation as a tool for reducing pest-induced yield losses in millet. The benefits of intercropping in reducing pest incidence seem to be exaggerated, as they were not clearly manifested during the three years of testing.

Mali

Treatments and IPM to Reduce Pests

N. Diarisso, Y. Doumbia, M. N'Diaye, IER; B. Pendleton, WTAMU

The use of local plant jellies to control insect pests in the field. A susceptible head bug variety (S34) was used. The juice of a local plant was filtered and sprayed on plants at seedling stage, end of flowering, and at hard dough stage. Insects were counted a day before and a week after sprays to assess the product efficacy. At maturity stage, insect damage and grain mould were rated to assess the efficacy of the treatment. At seedling stage the number of aphids decreases after the spray. This was more remarkable on the plots treated with either doses of Neem or plots treated with Dusrban. The number of aphids on the untreated plot was about 2 fold of that in the plot treated with *C. procera.* The high doses of Neem seed extract (200 g/L and 250 g/L) seem to be more effective in controlling aphids than the small doses of Neem seed (80 g/L and 160 g/L) used in previous years. At the hard dough stage, except for the untreated plants, head bug number decreased after the plots were sprayed with either Dursban or any local plant juice or jelly. No head bugs were found on the protected panicles before and after the spray. The plot sprayed with Dursban had the least insect number (5), followed by Rt3 plants sprayed with Neem seed jelly 250g/L (7 insects), then Tt2 plants sprayed with Neem seed jelly at 200 g/L (10 insects).

The use of two local plant powders to control storage grain insect, *Rhyzopertha dominica*. The sorghum variety, Malisor 92-1, was treated with powders from 2 local plant *Calotropis procera* and *Cassia nigricans* in 4 replications. Each treatment was placed in cotton cloth bag. A monthly sampling of treated and untreated seed was done. Two months after the treatment, there was no damage of *R. dominica* on treated seeds. The infestation started on the third month after the treatments with the local plant powder. The seed lost due to damage increased over the time. The seed loss was higher on the untreated seed compare to the treated ones. The least percentage of seed lost due to *R. dominica* was found on treatments with the 6 g of Calotropis procera or Cassia nigricans for 1 kg of sorghum seed. These results confirm those of the previous year. Over the time of storage, the effectiveness of the product decreased and the number of insects increased. The two products tested at low doses do not seem to be as effective as the high doses. It would be necessary to reduce the interval of application of the products.

Millet head miner incidence. A significant difference was observed between treatments for head miner incidence at Cinzana and Banakoro. At Cinzana intercropped plot with insecticide foliar spray was less infested by millet head miner (1.67%), followed by the plot treated with Neem seed extract

(4.00%). At Banankoro, similar results were observed on head miner attack.

Millet stem borer incidence. Results obtained on stem borer incidence shown a significant difference between treatments at Sibila. In this location intercropped plots and plot treated with Apron Star were less infested (1.00%) for millet plot treated with fungicide Apron Star, intercropped plot with insecticide Dursban (1.00%) and intercropped plot with neem extract (1.33%). Check plots were most infested (3.00%) by millet stem borer. No significant differences were observed between treatments in others locations. In regard to these results, it appears that plots treated with Apron Star were less attacked by stem borer. Apron Star provided a protection from this pest damage. This season, Kondogola was more infested by stem borer (7.58%)

Niger

Screening of Pearl Millet for Resistance to Millet Head Miner in Maradi

H. Kadi Kadi, INRAN; Bonnie B. Pendleton, WTAMU

The main objective is to identify millet head miner (MHM) resistant or tolerant genotypes among millet germplasm developed at INRAN and ICRISAT Niamey. There were significant differences among the genotypes tested for the estimated mean percentages of head miner eggs hatched; for the means of large larvae developed on the panicles; and for mean yields. The highest mean percentage of eggs hatched was of 31.4% on variety ¾ HK B-78 while on genotype KBH, the mean percentage of eggs hatched was estimated to be 0.0%. The highest mean percentages of large larvae were estimated to be 11.9 and 8.3% for SOSAT-C88 and ¾ HK B-78, respectively; no large larvae developed on genotypes ICMH 2003 and KBH. The highest mean yields of 1021.7, 1133.4, 1083.4 and 1065.1 kg ha^{-1} were estimated with the genotypes TMK, 1A x TMK, ICMV IS 99001 and HKP-GMS, respectively, while the lowest estimated mean yields (< mean) of 733.4, 776.7, 628.4, 741.7, 825.0 and 850.0 kg ha^{-1} were obtained, respectively, for the genotypes ANKOUTESS, SOSAT-C 88, KBH, ICMV IS 90311, ¾ HK B-78 and ZATIB.

Some of the genotypes tested can be classified tolerant and/or resistant to MHM. The results revealed significant variability of the estimated means for variables of development of MHM stages, damage ratings and yields suggesting that it is possible to achieve a level of tolerance to MHM damage. After one year of screening the genetic materials, it was noted that some sources of resistance to MHM may be obtained from local, improved and newly developed materials that are available at the NARS and IARC institutions. Some of these materials have been tested and accepted for adaptation in the pearl millet growing zone. It should be possible to adopt an intensive screening program to explore the West African millet accessions for quick identification and development of MHM resistant genotypes.

Senegal

Control of Head Bugs

D. Badiane, ISRA; B. Pendleton, WTAMU

The efficiency of Neem extracts (manually extracted and industrial) were tested against chemical control of insects. The variety F2-20 was used as plant material. Two applications were made. Head bugs were numbered 7 days after treatment. Insect numbers were significantly less in treated plots with botanicals than in untreated. Both manual extract and industrial azadirachtine were efficient in controlling head bugs. However azadirachtine application did not improve yield compare to the untreated plots.

Sustainable Plant Protection Systems: Plant Pathology

Burkina Faso

Integrated Management of Sorghum and Pearl Millet Main Diseases in Burkina Faso

A. Neya, INERA; C. Magill, TAM; J. Leslie, KSU

Two experiments were planted at Farako-Ba Research Station: the All Disease and Insect Nurseries (ADIN) and hybrid trial. ADIN accessions were provided by D. Rosenow and A. Touré. The hybrid trial consisted of 89 hybrids assembled from Mali and Burkina Faso sorghum breeding programs. Target diseases included leaf anthracnose (*Colletotrichum sunlineolum*), sooty stripe (*Ramulispora sorghi*), grey leaf spot (*Cercospora sorghi*), zonate spot (*Gloeocercospora sorghi*), stalk red rot (*Colletotrichum graminicola*), grain mold (complex of fungi), grain anthracnose, and smuts. The two trials were planted in a plot previously planted with susceptible sorghum genotypes to leaf anthracnose and where crops residues were kept after the previous year.

During the rainy season of 2004, field screening of diverse material for multiple resistance was continued using various material including new genotypes from the breeders in Burkina, Niger, Mali, Nigeria, and U.S. All entries were infected by the target fungal diseases mentioned above. Leaf anthracnose appeared the first at about three weeks after sowing, followed by sooty stripe and gray leaf spot. While the progress of leaf anthracnose was high on susceptible entries, symptoms of gray leaf spot appear later at four to five weeks after planting on most entries. No entry showed symptoms of smuts and ergot in the two trials

ADIN trial. None of the entries was completely free from grain mold, but 15 entries showed a low severity. Three entries exhibited severity more than 5 (scale 1-9). 48 entries showed a low level of anthracnose severity. Most of entries did not show any symptoms of gray leaf spot and zonate leaf spot.

Hybrid trial. Evaluation at harvest did not show any grain mold, leaf anthracnose, or zonate leaf spot. However, two hybrids (97 SB F5DT-154 03 SB F4 PDT-107 and 97 SB F5DT 150-03 SBF5PDT-124) were free from gray leaf spot, and 34 hybrids were free from Sooty stripe. The progress of leaf anthracnose remained low during the cropping season.

Ghana

Breeding Pearl Millets for Improved Performance, Stability and Pest Resistance

S. Nutsugah, SARI; J. Wilson, USDA/ARS

Downy mildew. At soft dough stage (70 days after planting), 12 pearl millet entries showed low levels of downy mildew severity (d" 10%) while 9 entries exhibited moderate level of severity (11-22%) and 19 entries showed high level of downy mildew severity (29-100%). The yield potential for 16 entries was above what pertains in our traditional system (200-700 kg ha^{-1}); 5 of these entries gave yields above 1,000 kg ha^{-1}.

Head bug/grain mold sorghum varietal interaction trial. An on-station trial was established at Damongo in the Northern Region of Ghana to evaluate the efficacy of the minimal insecticide/fungicide technology to minimize the impact of head bugs and grain mold complex on six sorghum varieties. Four treatments were imposed; untreated, insecticide (Karate) only, fungicide (Benlate) only and insecticide/fungicide to bring to light the component that causes more damage. The experiment was laid out in a split plot design with three replications where main plots were insecticide and fungicide treatments and sub-plots were sorghum lines. The level of head bug and grain mold damage was generally low. Varietal effect was significant for cv. *Kapaala* in terms of the parameters evaluated. The insecticidal treatment resulted in reduced head bug infestation and damage and reduced mold infection and better germination. Combined treatment also showed significant reduction in both biotic stresses and good germination. Fungicide treatment on grain mold damage was significant and to a lesser extent in reduced head bug infestation and slightly good germination. In untreated plots, poor germination was observed. Insecticide treatment on head bug damage showed good level of efficacy. The effect was also significant on grain mold score, thus partially confirming the critical role played by head bugs as factors aggravating mold infection.

Mali

Anthracnose-Resistant Sorghum Lines, Plant-Based Pesticide Control, and Downy Mildew Control

M. Diourte, IER; C. Magill, TAM; J. Leslie, KSU

Anthracnose screening nurseries. Results from preliminary screening indicated that 38.9% of the 95 breeding accessions tested scored no more than 5% of foliar disease severity at physiological maturity and produced more than one ton per hectare. Compared to the susceptible varieties, almost all the 95 accessions could be considered fairly resistant. Results from the advanced screening plots indicated that 45.3% of the 86 breeding accessions and 23.3% of the West African varieties scored no more than 5% of foliar disease severity at physiological maturity and had more than one ton per hectare. The best varieties were 02-cz-f5p-96 (2 tons) and 02-cz-f5p-100 (1.8 tons).

Evaluation of some of the best lines of sorghum under the conditions of high and low pressure of the anthracnose. Disease intensity was lower at Katibougou compared to Sotuba, on almost all the varieties tested except on 99-SB-F5DT-170-1, 96-CZ-F4P-99 AND 99-BE-F5P-66. In addition, the grain yields per hectare were higher at Katibougou than Sotuba with a differences of 222 kg ha^{-1} for the susceptible variety IS18442 to 1344 kg ha^{-1} for the resistant variety 98-SB-F5DT-8. Resistant varieties such AS 99-SB-F5DT-170-1, 96-CZ-F4P-99 AND 99-BE-F5P-66 are then available and ready for an integrated approach to controlling anthracnose in Mali.

Development and diffusion of a plant based pesticides for the control of sorghum pests including *Striga* and covered smut (Sporisorium sorghi). At Kolokani, compared to the farmer's practice, the greatest variations of yield observed were 350 kg ha^{-1} with the variety 98-BE-F5-P84 treated with Apron star or the Diro+Guo+Néré formula. The differences in yield of the variety 98-SB-F2-78 treated compared to the untreated were not negligible. At Cinzana, the incidence of diseases, insects and *Striga* was also low and the interpretation of the results was limited to the yield obtained. The greatest variations were 522.25 kg ha^{-1} with Darrel ken treated with the Diro+Guo+Néré formula and 422.75 kg ha^{-1} with Wassa treated with Apron star. The differences in yield of the same varieties treated compared to the untreated were also not negligible. At least 15 farmers in the zones where the tests were conducted relatively adopted this technique of seed treatment.

Downy mildew incidence. Variability of downy mildew incidence has been observed in all locations. A significant difference was observed among treatments at Cinzana, Banankoro, Yolo and Boussin. At Sibila and Kondogola, no difference was observed between treatments. The lowest incidence has been shown in intercropped plot (millet: cowpea), except at Cinzana where the lowest incidence was observed in treated plot with fungicide Apron Star. The highest incidence at seedling stage was shown at Yolo (4.58 %) and the lowest at Cinzana and Kondogola (1.08 %). At Cinzana, the millet monocrop plot treated with the fungicide Apron Star (1.33 %) and the one treated with neem extract (2.67%) were less damaged by downy mildew. This result was similar to this observed last year. At Yolo, the lowest incidences were observed in the intercropped plot (4.58%) and neem extract plot and the plot treated with insecticide Dursban. The plot treated with fungicide Apron Star was less infested by downy mildew. The untreated plot was highly infested by the patho-

Table 3. Evaluation of 21 sorghum lines under INTSORMIL WASDON for resistance to foliar anthracnose at Samaru, 2004 cropping season.

Entry	Anthracnose severity	Reaction class	Grain weight (g/5 panicles)
98-F2-82	1.7	MR	91.1
97-SB-F5-DT-154	4.7	S	90.7
SAMSORG 40	5.1	S	145.9
SAMSORG 14	1.8	MR	110.1
A 2267-2	1.0	R	111.1
98-FA-EART-101	1.3	MR	125.5
F2-78	2.0	MR	129.8
90 L19178	1.0	R	79.1
SC 326-6	1.0	R	99.3
FOULATIEBA	3.0	MR	140.0
98-SB-F5-DT-59	2.4	MR	99.0
SARIASSO-01	1.8	MR	206.6
9G 4092	1.0	R	129.3
VG 153	2.5	MR	100.5
97-SB-F5-DT-150	2.8	MR	64.3
98-SB-F5-DT-4	2.1	MR	116.0
SARIASSO-02	1.0	R	181.5
98-K1-F5-T-45	1.4	MR	115.7
SURENO	2.2	MR	77.3
97-SB-F5-DT-160	2.1	MR	98.1
98-SB-F5-DT-25	1.9	MR	107.1

gen *Sclerospora graminicola.* These results show the variability of the pathogen into the Ségou millet production area.

Nigeria

Anthracnose Screening
P.S. Marley, A. B. Zarafi, IAR; D. Rosenow, C. Magill, TAM

Screening for anthracnose resistance. In the 2004 cropping season, 21 lines were sown in Samaru under the INTSORMIL West Africa Sorghum Disease Observation Nursery (WASDON). Data on Table 3 show that five lines (A 2267-2, 90L 19178, SC 326-6, 9GW092 and Sariasso-02 maintained their high resistance to foliar anthracnose.

Senegal

Mildew and Ergot Resistance
M. Wade, ISRA; C. Magill, TAM

Millet. The 40 entries of the regional trial were observed for mildew and ergot at maturity. Twenty-five out of the 40 showed a high level of resistance to mildew: Toronio, HKP, CIVT, ICMV IS 89305, Synthétic 1-2000, NKO x TC1, Guéfoué 16, Indiana 05, NKK, Bongo Short Head, Manga Nara, Arrow, Gwagawa, LCIC 9702, GB 8735, 99-72 (L), T454 (L), 68A x 086R (H), 99M59043Mw x 68A4R4 (H), SOSANT C88, ¾ Souna, DMR 15, DMR 68, TG102 (H), and 01Miso NCD2-NE). Five of the genotypes were susceptible to mildew.

Thirty-seven of genotypes tested were resistant to ergot and three (TG 102 (H), T99B (L), 01Miso NCD2-NE) were tolerant. Variations on the level of resistance were observed. Genotypes resistant to both mildew and ergot were observed in the group. These were: Toronio, HKP, CIVT, ICMV IS 89305, Synthétic1-2000, NKO x TC1, Guéfoué 16, Indiana 05, NKK, Bongo Short Head, Manga Nara, Arrow, Gwagawa, LCIC 9702, GB 8735, 99-72 (L), T454 (L), 68A x 086R (H), 99M59043Mw x 68A4R4 (H), SOSANT C88, ¾ Souna, DMR 15, DMR 68, TG102 (H), 01Miso NCD2-NE.

Sustainable Plant Protection Systems: Striga

Burkina Faso

Resistance and Control of *Striga* Hermontica
H. Traore, INERA; G. Ejeta, PU; J. Wilson, USDA/ARS

Regional trial of medium cycle sorghum for *Striga Hermontica* resistance. The trial was conducted at the experimental research station of Kouaré (11°95'03" N and 0°30'58" E) in the eastern Sudan-Savannah region of Burkina Faso in a natural infested field by *S. hermonthica.* Twenty-two sorghum varieties (seven from Nigeria, eight from Mali and seven from Burkina Faso) were compared for their resistance to *S. hermonthica.* Mineral fertilizer of 100 kg ha^{-1} of NPK and 50 kg ha^{-1} of urea was applied. *Striga* emerged 50 days after sowing in KL-3 from Nigeria. Only two varieties, both from Mali were free of *Striga* during the season (Wassa

& CMDT-38) and *Striga* infestation was generally low. The five most infested varieties in decreasing order were: CEF 322/53-1-1 from Burkina, Twin Secdeel from Nigeria, Kamo Farafara from Nigeria, EP II-2002-8 from Burkina and SSV 200123 from Nigeria. Yields were low because of late sowing and the cycle (medium or long) of 13 varieties. The highest yield was recorded with the short cycle variety Gaden Kurciya from Nigeria (306 kg ha^{-1}). This trial should be conducted for a second year and all varieties will be screened in vitro by using Agar gel and Roll paper techniques. It will also be desirable to screen sorghum genotypes and landraces from Burkina Faso in order to find new sources of *Striga*-resistance which can be used in breeding programs.

Evaluation of sorghum cultivars for *Striga Hermontica* resistance in eastern Burkina Faso. The trial was conducted in 2004 at the experimental research station of Kouaré (11°95'03" N and 0°30'58" E) in the eastern Sudan-Savannah region of Burkina Faso in a natural infested field by *S. hermonthica.* Sixteen sorghum varieties (10 from Purdue University, Indiana, U.S. and six from the National Program of Burkina Faso) were compared for their resistance to *S. hermonthica.* No significant difference among the 16 varieties was shown. Low *Striga* infestation may be the result of late planting and the abrupt stop of rainfall in mid-September. Planting early next rain season will allow having a better idea on the potential yield of the varieties, particularly Purdue's varieties and their behavior *vis-à-vis Striga.*

Integrated *Striga* management using water conservation, varietal tolerance, fertilizer to control *Striga* in sorghum in the eastern Burkina Faso. This trial was carried out in 2004 at the experimental research station of Kouaré (11°95'03" N and 0°30'58" E) in the eastern Sudan-Savannah region of Burkina Faso in a natural infested field by *S. Hermonthica.* Treatments were as follows: water conservation (three treatments) - no soil preparation, soil preparation, and soil preparation + tie ridging; varieties (three treatments) - F 2-20 (a tolerant cultivar to *S. hermonthica*), CEF 322/35-1-2 (a tolerant cultivar to *S. hermonthica*), and a susceptible check (S29); and fertilizer (four treatments) - no fertilizer, manure (3 t ha^{-1}), mineral fertilizer (100 kg ha^{-1} NPK + 50 kg ha^{-1} urea), and manure (3 t ha^{-1}) + mineral fertilizer (100 kg ha^{-1} NPK + 50 kg ha^{-1} urea).

Number of sorghum harvested plants was influenced by tillage, fertilization, varieties and interaction the interaction tillage*fertilization. Furthermore, fertilization and interaction fertilization*varieties influenced sorghum grain weight, whereas varieties influenced sorghum grains weight and 1000 grains weight. Neither the date to *Striga* emergence, nor the numbers of emerged *Striga* (at different dates) were influenced by tillage, fertilization, varieties and their interactions. The two *Striga* tolerant varieties (F2-20 and CEF 322/35-1-2) yielded more than the *Striga* susceptible variety S29.

Mali

Striga Control
B. Dembébé, M. Kayentao, IER; G. Ejeta, PU

Analysis on number of *Striga* emerged on plots showed a significant difference between treatments at Yolo, where the intercropped plot presented less *Striga* number (three and four respectively for neem extract treatment and insecticide treatment). In other locations, no difference was observed between treatments. Analysis of mean number of *Striga* emerged indicated that Boussin was less infested (1.25 %) this season contrary to last season where this location was the most infested by *Striga.* The most infested location was Sibila (4.83) Banakoro (4.37) and Yolo (4.33).

Niger

Introgression of Genes for *Striga* Resistance into Landrace El Mota
I. Kapran, INRAN; G. Ejeta, PU

The objective is to introduce *Striga* resistance into an otherwise adapted landrace preferred by Nigerian farmers. We report third year data on an advanced backcross population of a cross "El Mota x SRN39' genotyped at Purdue University and field tested for *Striga* resistance in Niger. In Niger, agronomic and *Striga* related data were recorded at the Konni station under uniform *Striga* infestation where plots were deliberately seeded with known quantity of *Striga* seed. There were significant variation for agronomic and *Striga* related traits. Genotypes with good level of *Striga* resistance and high resemblance of phenotype with the local landrace were recovered in the BC2F3 progeny. The same progenies were also examined and contrasted with parental lines in the laboratory at Purdue University for specific *Striga* resistance mechanisms introgressed. For germination induction, it appeared that all the progenies were rather highly stimulant-inducing lines, while SRN39 has low stimulant production. This suggests that the field resistance found among these lines is not a result of lack of germination stimulant production. Five progenies seem to have an incompatible response kind of resistance since *Striga* did not develop once attached.

This laboratory assay provided a very fast and inexpensive tool to screen for mechanisms of resistance. As expression of resistance in the field may be confounded with other factors, lab assay allows more control of the environmental variance and, therefore, gives a more reliable estimate of resistance. The following lines were selected based on field and laboratory data and will be tested on farm in 2005 in integrated *Striga* resistance packages: B4-33, B4-8, B2-3, B5-5, B1-13.

Striga outreach included invited presentations:

Kapran, I., S. Issoufou, C. Grenier, and G. Ejeta. 2004. Introgression of Genes for *Striga* Resistance into African Landraces of Sorghum. McKnight Foundation Workshop on Millet and Sorghum-Based Systems in West Africa. January 27-30, 2004. Niamey, Niger

Kapran Issoufou, Magagi Abdou, Soumana Souley, and Leland R. House. Sorghum Hybrid Project in Niger: Challenges and Opportunities for Private Seed Production. (Poster). McKnight Foundation Workshop on Millet and Sorghum-Based Systems in West Africa. January 27-30, 2004. Niamey, Niger

Research supervision included:

Abdou, Magagi 2004. Effect of Nitrogen and plant spacing on sorghum hybrid seed production at Maradi, Niger Republic. In partial fulfillment of the requirements for the award of Bachelor of Agricultural technology of Abubakar Tafawa Balewa University, Bauchi, Nigeria

Maman, Soulé. 2004. Evaluation des besoins en eau et capacité de production des rejets chez trios variétés de sorgho (*Evaluation of water uptake and tillering capacity in three sorghum varieties)*. Mémoire de fin d'études pour l'obtention du diplôme de maîtrise es Sciences Agronomiques. Université Abdou Moumouni/Faculté d'Agronomie/INRAN/AGRHYMET

Nigeria

Striga Screening

P.S. Marley, A. B. Zarafi, IAR;
D. Rosenow, C. Magill, TAM

Screening for *Striga* resistance. The INTSORMIL *Striga* control nursery was repeated in the 2004 cropping season. Among the 14 lines evaluated, lines SRN 39, MALISOR 84-1, MALISOR 92-1, 97-SB-F5-DT-64 AND CE-151-202-A1 maintained low *Striga* infestation and also had low numbers of plants infested with *Striga*. Lines CMDT 38, CMDT 39 and CMDT 45 had medium *Striga* infestation while SAMSORG 14 had the highest *Striga* infestation, but gave the highest yield in the last two years of testing.

Sustainable Crop Production Systems: Agronomy

Burkina Faso

Microdose Fertilizer and Practices for Dolo Production

T. Jean-Baptiste, P. Siebou, INERA; S. Mason, UNL

Microdose fertilizer. Three-year central studies were initiated on-station in Burkina Faso (pearl millet). 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. 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.

Analysis of variance indicated that grain and stover yields to fertilizer treatments varied by year (Table 4). However, on the average, microdose fertilizer application increased grain and stover. The microdose application is a low cost investment that has a high probability to increase grain yields in Burkina. 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.

Table 4. Fertilizer treatment influence on pearl millet, grain and stover yield (averaged over 4 years and 4 replications; Saria, 2001-2004).

Fertilizer treatment	Grain yield	Stover yield
	--------- kg ha^{-1}	------
No treatment	351	929
Microdose	638	1597
Microdose + 20 kg ha^{-1} de P	781	1836
Microdose + 40 kg ha^{-1} de P	847	1847
Microdose + 30 kg ha^{-1} de N	625	1493
Microdose + 60 kg ha^{-1} de N	696	1622
Microdose + 20 kg ha^{-1} de P + 30 kg ha^{-1} de N	880	2098
Microdose + 40 kg ha^{-1} de P + 60 kg ha^{-1} de N	1035	2248
Year 2001	749	2240
Year 2002	772	1243
Year 2003	804	2056
Year 2004	602	1296

Sorghum production practices for *dolo* (traditional beer) production in Burkina Faso. Previous research has shown 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 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 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 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.

Ghana

P and N Fertilization and Crop Residue Removal

S. Buah, SARI; S. Mason, UNL

Comparative response of sorghum to phosphorus fertilizer in the savanna zone. Permanent plots were established in 1999 in Wa for rotating grain sorghum and cowpea through a two year growing cycle. Sorghum (cv. *Kapaala*) and cowpea (cv. *IT87D-1951*) were grown on adjacent plots each year during the rainy season. Major objectives of this long-term experiment were to determine if fertilizer phosphorus (P) rates applied to one crop (direct for current crop and residual for succeeding crop) or to both crops (cumulative) would enhance soil P availability enough to maintain both sorghum and cowpea yields when grown in rotation. Data have been collected for 2000 through the 2004 cropping seasons. Over the years, frequency of P application did not interact significantly with P rates. On average, sorghum grain yield responses to frequency of P application were significant (Table 5) with fresh (direct and cumulative) application of P to sorghum obtaining higher and similar yields compared with residual P effects. Grain yields with fresh P applications were significantly increased by an average of 21% (or 392 kg ha^{-1} more) in 2004. The slope of the yield response to applied P decreased with each increase in the P level. Consistently, sorghum yields were not increased significantly beyond the 60 kg P/ha level in 2004. Grain yields of sorghum grown on the 30, 60, and 90 kg P/ha treatments averaged 48, 62 and 80%, respectively, of the 0 kg P/ha treatment. Also, grain yield was more associated with seed number (r = 0.84) than seed size (r =0.77).

Table 5. Sorghum grain yield and yield components as affected by added fertilizer P, 2004.

Frequency of P application	100-seed weight	Kernels m^{-2}	Stover yield at maturity	Grain yield
	g	no	kg ha^{-1}	kg ha^{-1}
Cumulative	2.10	7095	2071	1843
Direct	2.08	7616	1928	1928
Residual	1.94	6313	1711	1494
LSD (0.05)	NS	1023	317	274
P rate kg/ha)				
0	1.86	5174	1692	1188
30	2.01	7163	1776	1761
60	2.11	7525	2154	1928
90	2.18	8170	1990	2142
P linear	*	**	*	**
P quadratic	NS	NS	NS	NS
CV %	14.9	25.1	28.7	28.9

*, **, and NS = significant at 1 and 5% probability levels and not significant, respectively.

Previous-crop effects on grain sorghum response to N fertilizer. Permanent sorghum, cowpea, groundnut, and soybean plots were established under dryland conditions in Wa beginning in 2000. Additionally, sorghum was established on an adjacent plot. Thereafter, sorghum and the rotation crops were alternated on the two sets of plots, establishing a 2-yr rotation between sorghum and each legume, along with continuous sorghum. Improved early sorghum, cowpea, soybean, and groundnut varieties planted each year were *Kapaala, IT87D-1951, Salintuya 1,* and *Chinese*, respectively. All plots received a uniform application of 30 kg P/ha.

In 2004, apart from grain production, agronomic and physiological traits of sorghum measured or calculated in the experiment were not influenced by the previous crops. On average, sorghum following a grain legume tended to have numerically greater kernels and therefore had significantly greater grain yields than a when it followed a previous crop of sorghum. Averaging over previous crops, grain production was significantly increased by N application for 40 kg N/ha with no further increase at higher N rates.

Effect of crop residue removal and fertilizer use on crop yield in the savanna zone. An on-station experiment was initiated in Wa in 2000 to evaluate the combined effects of fertilizer use and crop residue management on sorghum production in the savanna zone. Treatments were: 1) control (no fertilizer or crop residue), 2) fertilizer only, 3) 50% stover return rate only, 4) 50% stover return rate and the use of fertilizer, 5) 100% stover return rate only, and 6) 100% stover return rate and the use of fertilizer. Fertilizer rate was 64-38-38 kg ha^{-1} (as N, P_20_5 and K_2O) + 2.5 bags of sulphate of ammonia. Crop residue return rate did not influence parameters measured or calculated for sorghum over the years. When averaged across residue return rates, fertilized sorghum flowered three days earlier than did unfertilized sorghum. Fertilized sorghum plants had higher chlorophyll concentration (greener leaves) on a leaf area basis than unfertilized plants. Added fertilizer increased stover, kernel numbers and ultimate grain yields. On average, a yield advantage of 32% (248 kg ha^{-1} more) was obtained from fertilized sorghum when compared with unfertilized plants. Grain yield increases were a function of seed number rather than seed size. The results obtained for the three seasons reveal that fertilizer application would increase sorghum and maize grain yields on a savanna soil low in plant available nutrients.

Mali

Crop Management, Acid Soils, and Fertilization

M. Bagayoko, M. Doumbia, A. Toure,
S. Traore, IER; S. Mason, UNL

Assessing crop management strategies in Mali._ An experiment was designed to determine the best rotation technique between that based on rows in intercropping, and that based on the pure crops using mucuna and sorghum, rock phosphate and urea. Sorghum grain yield recorded in intercropping with sorghum and mucuna (335 kg ha^{-1} in average) was less by a rotation based on rows compared to the one of plot basis 1030 kg ha^{-1}. In intercropping, late planting of mucuna compared to sorghum did not significantly affect sorghum grain yield with 391 kg ha^{-1} of grain for the former and 280 kg ha^{-1} for the latter. In intercropping with sorghum and mucuna, delaying planting date of mucuna did not significantly affect sorghum stover yield; with 2725 kg ha^{-1} for the former and 2583 kg ha^{-1} for the latter. In pure sorghum, mucuna as previous crop did significantly affect stover yields. Compared to sorghum alone as previous crop, the positive effect of mucuna was about 36%. In sorghum and mucuna intercropping with a rotation based on their respective rows, recorded sorghum stover yields (2654 kg ha^{-1} in average) were less than with a rotation based on the all plots (8576 kg ha^{-1}). In sorghum and mucuna intercropping with a rotation based on their respective rows, recorded mucuna biomass yields (2015 kg ha^{-1} in average) were less than a rotation based on the all plots (3480 kg ha^{-1}), when the planting date of mucuna was 15 days delayed to that of sorghum. When simultaneously planted, the rotation rows basis of mucuna and sorghum was not significantly different from that of the all plot basis. In sorghum and mucuna intercropping, delaying mucuna planting date for 15 days (2015 kg ha^{-1}) compared to sorghum (2810 kg ha^{-1}) led to a decrease of mucuna biomass production.

Mali acid soil sorghum. Phosphorus deficiency and Al toxicity are major factors contributing to poor growth and yield in acid soils of Mali as well as those of other regions of West Africa. Several sorghum exotic genotypes, breeding lines, local cultivars, and improved varieties were tested for tolerance and performance in contrasting properties of the above soils. Seventy-five percent of production is based on local cultivars. Local/cz produced 259 kg ha^{-1} under these soils. In fact, local cultivars are well adapted to low rainfall and soil stresses (nutrient deficiencies and toxicities). Improved and released genotypes such as N'Tenimissa failed completely to bring to maturity any of its germinated plants. When soil conditions were improved with lime, N, P, and K amendments (NuMaSS model), N'Tenimissa counted at harvest 95% of germinated plants and produced 1487 kg per ha. The local produced 1100 kg ha^{-1}.

Emerging genotypes from breeding programs, such as Darrell-ken, 01-Cz-F5P-263, 03-BE-F5P-225, showed a very poor tolerance to soils stresses. These genotypes brought to maturity an average of 9% of their plant population for grain yields ranging from 29 to 91 kg ha^{-1}. Under optimum soil conditions, they produced about 1600 kg ha^{-1} from about 98% of germinated plants. Analysis of collected soil and plant samples (leaves, shoots and grains) would give some indication on mechanisms of tolerance/susceptibility of the different genotypes tested.

Performance of microdoses of chemical fertilizers application on millet production. A trial was conducted on a leached sandy soil at Cinzana to evaluate the performance of microdose with and without complementary fertilizer application on millet grain and straw production. Millet grain yields were low in general due to water shortage from the blooming stage to physiological maturity. All the treatments produced more grain and more straw than the control. This indicates that the soil used in the experiment had a low fertility level. The application of microdose + 20 kg ha^{-1} of P + 30 kg ha^{-1} of N or microdose + 40 kg ha^{-1} of P + 60 kg ha^{-1} of N did not significantly increase pearl millet grain yield. However, straw production was significantly increased by the addition of complementary P and N to microdose. The application of complementary P alone resulted in greater millet grain production compare to the application of complementary N alone. In heavy soil, millet grain yields were low in general due to water shortage from the blooming stage to physiological maturity. Any significant difference was observed among the treatments for both millet grain and straw production. The effect of water deficit was more important on heavy soils compare to sandy soils. This phenomenon did not allow millet plants to fully express their yield potential as the result of complementary fertilizers application.

Effects of fertilizer application techniques and weeding strategies on millet production. A trial was conducted on a leached sandy soil at Cinzana to evaluate the effects of three fertilizer application techniques and three weeding strategies on millet grain and straw production. Millet grain yields were low in general due to water shortage from the blooming stage to physiological maturity. No fertilizer application technique x weeding strategy interaction was observed for panicle yield, grain and straw production. The main effect of fertilizer application strategies was highly significant ($p < 0.01$) for straw, panicle and pearl millet grain production. The application of microdose at the rate of 2 g per hill of DAP and 6 g per hill of cereal complex (15-15-15) produced lesser grain and straw than the organo-mineral fertilizer treatment. The 2 g of DAP had more negative effect on millet plant at emergence probably due to its concentration in ammonium. It was noticed that lower moisture conditions were detrimental to plant germination when DAP based microdose was used. The different weeding strategies used had different effects on pearl millet straw, panicle and grain production. The complete weeding had the highest panicle weight, grain and straw production. The no weeding treatment had the lowest panicle weight, grain and straw production.

Millet grain yields were low in general. The application of the two types of microdoses (two grams of DAP and 6 grams of cereal complex per hill) had similar effects on millet plant height, plant population and number of panicles at harvest. The combined application of farm manure at the rate of four tons ha $^{-1}$ and DAP at the rate of 50 kg ha $^{-1}$ resulted in greater millet plant height, plant population and number of panicles at harvest than the microdoses application.

Niger

Millet Organic and Inorganic Fertilization

N. Maman, S. Sirifi, INRAN; S. Mason, UNL

Pearl millet grain yield improvement via combination of poultry manure and inorganic fertilizer. The objectives are to: 1) characterize poultry manure produced by the poultry industry, and establishment of their fertilizer equivalence values, 2) understand farmers' practice with poultry manure, 3) develop improved crop and soil management methods based on the combination of the organic residues from the poultry industry and inorganic P fertilizer to improve pearl millet yield and quality, generate profit, and reduce soil degradation in sorghum and pearl millet based cropping systems in Niger, 4) find the best combination of the organic residues from the poultry industry and inorganic fertilizer to improve pearl millet and grain sorghum yield and quality, and 5) make economical analysis.

In a farm survey, data was collected on quantity, time and method of manure application, grain and stover production and constraints related to poultry manure utilization.

Manure analysis indicated that poultry manure contains more N, P, and K than cattle manure, and that in contrary to our hypothesis it is higher in phosphorus than N (1.3-3.9-0.3). This shows that to have the recommended 18 kg P_2O_5 ha^{-1} one will need nearly 500 kg of poultry manure. Results of the survey indicate that farmers apply poultry manure on all dryland crops: pearl millet, grain sorghum, groundnut, and cowpea, at a high rate of more than 1,000 kg ha^{-1} (equivalent to 13 kg N and 39 kg P_2O_5 ha^{-1}). This is free manure for farmers working at the poultry plant but they indicate their willingness to buy and apply lower rates of the same manure. Farmers understand the need to incorporate the manure to have better results even though it requires extra labor. Inorganic fertilizers are used only on cash crops like vegetables and cotton. On-farm, the impact of poultry manure alone or in combination with NPK fertilizer (15-15-150) on millet yield was tested with 10 farmers using their own plant management practices including plant population, weeding, thinning on millet local cultivar. Yields obtained for all the treatments were higher than the 2004 yield average of the area (480 kg ha^{-1}). Using poultry manure increased grain and stover yield and inorganic fertilizer significantly increased yield. Also, in economic terms, this management is profitable for the producers.

In conclusion, farmers are conscious that poultry manure is an important source of nutrients that can be used to improve soil fertility for high pearl millet grain and stover yield. They apply it at rates of 2300 kg ha^{-1} broadcast and 1600 kg ha^{-1} when hill placed. In the latter case manure is incorporated later during weeding, a strategy to avoid burning effects during water stress and to cover more area. According to test results, this type of manure contains more nutrients, N, P, and K, than cattle manure. This type of manure will contribute a lot to improving and sustaining soil quality as it is beneficial agronomically and economically. However, according to the test results our experiment should be based on adding only N fertilizer, as the amount of P is high.

Pearl millet microdose study. The main objective is to understand the effects of microdose rates of NPK fertilizer on pearl millet agronomic performance. The study should lead to information on the best combination of nutrients to significantly increase pearl millet yield. Average grain yields varied from 48 kg ha^{-1} (check) to 682 kg ha^{-1} for treatment that included microdose, 20 units of P and 30 units of N. For stover yield the same tendency was obtained. Over a four year period of this trial, microdose + 20 units of P + 30 units of N (treatment 7) always gave the highest grain yield average. It was followed by treatment 8 (microdose + 40 units of P + 60 units of N). In conclusion, despite seasonal variation our results show that microdose improved millet stands and vigor; adding 20 units of P and 30 units of N to microdose increased millet grain yield even on very poor soils used for the trial.

Utilization and Marketing: Cereal Technology and Processing

Burkina Faso

Malting and Brewing, Lactic Acid Bacteria Starters

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H., B. Diawara, IRSAT; B. Hamaker, PU

Optimization of malting and brewing processes. The study of the conservation at room temperature of *dolo* without preliminary treatment of preservative by using hermetically closing polyethylene barrels was undertaken. The study showed that conservation could be increased up to four days instead of one day, that the pH did not vary (P d” 0.5) around 3.5, and that temperature stabilizes at 27 °C after two days of conservation. The decrease of total sugars tends to stabilize after three days (from 42,67 ± 5.05 g/l to 17,40 ± 1.40 g/l), whereas reducing sugars decrease continuously until 8th day from 30,81 ± 3,69 g/l to 11,40 ± 2,23 g/l. from 4th day acidity increases from 9,66 ± 1,14 g/l up to 12,02 ± 2,77 g/l. The density dropped gradually from 1,018 ± 0,006 to 1,007 ± 0,002. On the microbiological level, coliform were not present. After 3 - 4 days of conservation there is a handing-over from the suspension of yeasts to lactic acid bacteria. The increase of acidity from the 4th days is correlated with a development of the lactic acid bacteria which cause a deterioration of the organoleptic quality of *dolo*. The pressure exerted by the gaseous emission during the conservation did not have a significant influence on the various analyzed parameters of *dolo* conservation (P d" 0.5).

Beng-Salga (fermented porridge) process optimization by using functional lactic bacteria starters. *Lactobacillus plantarum* A6, a strain isolated in the Congo, known for its strong amylolytic potential was used as starter culture in the fermentation of gelatinized starch suspension of millet to improve the fermentation conditions and the energy density of fermented porridges. These tests were carried out and compared to a porridge obtained by natural fermentation of a noncooked starch suspension of millet. Fermentation lasted 24 h with a follow-up of the evolution of pH and population of lactic bacteria. At the end of the fermentation, porridges containing variable dry matter concentration were prepared and consistency was measured at 45°C. The results showed that the acidification was faster with the crude starch suspensions than with the gelatinized starch suspensions. With equal consistency (120 mm/30s; 1 Step) that was easily accepted by the children, the porridges obtained by fermentation of the gelatinized starch suspensions by Lb A6 of were higher energy density (56.16± 0.77 Is Kcal/100 ml 14.04± 0.77 % G MS/100 G of porridge) that those by natural fermentation (23.16± 0.70 Is Kcal/100 ml 5.91± 0.70 G MS/100 G of porridge), which highlights the capacity of Lb A6 to hydrolyze the gelatinized starch of millet and to increase the energy value of the porridges.

Survey on traditional malting and brewing processes in Burkina Faso. The survey was conducted in three regions of Burkina Faso: south, west and north. The investigation revealed the various processes of malting and brewing, the equipment used and the constraints of each activity. On the level of malting there are two types of steeping - normal steeping and alternate steeping. The duration of these two types of malting varies from 18 to 36 hours. Germination is carried out in earthenware jar or on surface and lasts from 2 to 4 days. Germination is sometimes in two stages, low temperature germination (30-40 °C) followed by high temperature germination (60-70 °C). During low temperature germination, the green malt is sprinkled, sometimes washed, but seldom turned over. High temperature germination is made in a heap or in bags or containers. Final drying lasts from one to two days. The brewing processes were the same in the regions. Specificities are due on the sorghum malt quantities and qualities or on the lactic fermentation of whole or part of the mash tub. *Dolo* preparation takes place during 24 h (1 day), 42 h (2 days) or 66 h (3 days). *Fo* the *dolo* are filtered in Burkina Faso, but there are also sorghum opaque beers, like light porridge and that containing particles of malt flour suspension (*bourou bourou*). This investigation showed that the activities of malting, brewing and sale of *dolo* are, for the majority of the areas, exerted by the same women, particularly in rural medium. In the cities one notices a specialization of the participants for the malting of sorghum, the brewing, and the sale of dolo. The principal constraints are the rise in the price of the sorghum following the rainy season.

Mali

Screening of Breeding Lines and Porridge Quality

F. Cisse, IER; L. Rooney, TAM; B. Hamaker, PU

Grains from improved breeding lines (early, medium and late maturing groups) were evaluated for physico-chemical properties and food traits. Several entries showed similar decortication yield percentage to local Guinea checks (more than (80%). The lowest decortication yield was 45%. Most of the lines had good flotation scores indicating dense and vitreous grains. Almost all of the lines evaluated showed good *tô* consistency and acceptable color. The lines showed a 1000 seed weight that varied between 8.14 and 44.5 g g.

In effort to diversify sorghum end-use activities, flours varying in pH were studied for eight months conservation. The results showed significant differences for all parameters used such odor, color and taste. For acid-treated flour products such as porridge (*moni mugu*), the study showed that the odor, color rancid taste were not appreciated by people. Floor treated with potassium showed insect (tribolium) infestation, while acid-treated flour (*moni mugu*) did not.

Niger

Cereal Quality and Utilization

S. Kaka, M. Moustapha, S. Ramatou, I. Kapran, A. Tahirou, INRAN; B. Hamaker, PU

The objective of this project is processing and commercialization of value-added sorghum and millet products with particular emphasis on utilization of locally and regionally fabricated food processing equipment.

Support contractual agreements between farmers and processors. Contracts were made to initiate reliable and sustainable supply of quality grains for production of high quality sorghum/millet foods. Conducted jointly with the West and Central African Sorghum Research Network (WCASRN), two contractual agreements between farmers and the INRAN food technology laboratory were implemented for 10 tons of high quality sorghum grains (five tons of SEPON 82 and five tons of MDK). One metric ton of MDK grains so far been processed into quality *couscous*. The decortication yield or extraction rate varied from 47 to 62%, and the couscous obtained was from 38 to 51% from each 100 kg bag.

Monitor product stability. Stability was monitored using different packaging materials and shelf life determined for both couscous and flour. This activity is on-going.

Expand marketing study of sorghum couscous. The market survey of the couscous is to be conducted in two cities of Niger: Maradi and Niamey. The activity is just starting through: i) alternative marketing: compare couscous acceptance through neighborhood stores and supermarkets (via a private cereal processor) and ii) commercialization test using 450 kg of couscous to document the price, rate of sale, and packaging quality of couscous in the two cities of Maradi and Niamey. Linear models of profitability for a food processing unit will be constructed to determine the viability of processing technology.

Quality screening of new lines. Evaluation of physical, chemical and technological characteristics of 24 new sorghum varieties was conducted. There were three groups: i) group 1 - more than 65% of grains of size between 2.5 and 3.15 mm, ii) group 2 - more than 65% of grains of size superior to 3.15 mm, and iii) group 3 - less than 65% of grains of size between 2.5 and 3.15 mm or superior to 3.15 mm. Other screening activities included: i) determination of flour and couscous yield, ii) sensory evaluation of products obtained from the 24 sorghum new varieties samples, and iii) characterization of 76 millet new varieties from INRAN (Niger) and LCRI (Nigeria).

Nigeria

Physical, Chemical, Rheological, Nutritional and Sensory Aspects of Sorghum and Millet

I. Nkama, M. Badau, S. Modu, A. Jato, C. Uga, J.U. Igwebuike, I.D. Mohamed, University of Maiduguri; I. Angarawai, LCRI; B. Hamaker, PU

The major sorghum and millet production and utilization constraints include lack of improved varieties and lack of adoption of new production and utilization technologies by farmers and processors. An important use of sorghum and millet for food in Nigeria is in the preparation of *tuwo, kunu, ogi, ndaleyi, masa, sinasin, fura and dakuwa* among others. Grain and flour properties that contribute to the production of acceptable food products need to be defined. Also improvement of traditional food products and revolutionary change of sorghum and millet to new shelf stable foods and industrial products is needed to encourage increased production of grain. Sorghum has fared better than millet in Nigeria because additional industrial uses are now available in areas of beer brewing, malt drinks, biscuits and animal feeds.

Millet and sorghum grain samples grown by Lake Chad Research Institute, Maiduguri and local cultivars were analyzed for physical, chemical, rheological and sensory properties. Various food products (weaning foods, *tuwo, ogi (akamu), ndaleyi, fura, kunu, dakuwa* and animal feeds) were prepared to test the quality of the grain samples. Some of the findings are summarized below.

Sorghum grain and food quality. Five simple methods reported by Taylor (2001) were used to determine the end-use quality of some Nigerian sorghum varieties (Masakwa tumbuna, Chakalari red, Chakalari white, Dan Bauchi, ICSV, Jigari, Kaura, Masakwa burku, Masakwa ajaama and masakwa bulwalana). These included the detection of tannin by bleach test, classification of sorghum grain according to color by visual observation, determination of sorghum grain hardness by cutting the grain into two equal halves, determination of germinative energy and determination of total defects. The Masakwa tumbuna and Masakwa bulwalana varieties had the lowest germination while the Jigari, Chakalari red and Chalari white, had the highest germination after 24 h. Germination after 72 h ranged from 11.5 to 100%. Masakwa ajaama, Masakwa tumbuna, kaura, Chakalari white, Chakalari red and Chakalari white had the highest hardness among the varieties. The sorghum color determination showed that three varieties were white and seven colored. The percentage total defect ranged from 13.75to 26.0%. Masakwa tumbuna, Masakwa burku and Jigari were rated as high tannin sorghum varieties; Chakalari white, Masakwa ajaama and Masakwa bulwalana were considered as low tannin sorghum varieties, while Chakalari red, Da bauchi, ICSV, and Kaura were classified as non tannin sorghum. These simple tests can be used to determine the end-use quality of sorghum in Nigeria by farmers.

Malting characteristics of 10 pearl millet cultivars. Studies on the malting characteristics of 10 pearl millet cultivars with negligible tannin content, low mould count and good germinative properties were continued. Pearl millet cultivars were germinated along with one sorghum cultivar for 96 hr. Germination significantly reduced phytic acid content of the grains and improved the quality of the minerals by reducing the quantity of the pearl millet cultivars needed to be consumed before meeting the RDI (recommended daily intake) values. The grains are good sources of Fe and Zn followed by calcium. Pearl millet is not a good source of P, I, and Ca.

Papers published and in press

Badau, M. H., Nkama, I., and Jideani, I. A. (2005). Phytic acid content and hydrochloric acid extractability of minerals in pearl millet as affected by germination time and cultivar. *Food Chemistry*, 92 (3), 425-435.

Badau, M. H., Nkama, I., and Jideani, I. A. (2005). Steep-out moisture, malting loss and diastatic power of pearl millet and sorghum as affected by germination time and cultivar. *International Journal of Food Properties* (in press).

Badau, M. H., Nkama, I., and Jideani, I. A. (2005). Water adsorption characteristics of various pearl millet cultivars grwon in Northern Nigeria. *Journal of Food Process Engineering* (in press).

Badau, M. H., Nkama, I., and Jideani, I. A. (2005). Production, acceptability and microbiological evaluation of weaning food formulations. Journal of Tropical Pediatrics (in press).

Badau, M. H., Nkama, I., and Jideani, I. A. (2005). Sugar contents of pearl millet as diverse among cultivars and affected

by germination. Journal of Applied Glycoscience (in press)

Senegal

Cereal Technology Project
A. N'Doye, ITA; B. Hamaker, PU

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.

Utilization and Marketing: Poultry

Niger

Use of Sorghum in Poultry Nutrition
S. Issa, K. Saley, I. Kapran, INRAN; J. Hancock, and M. Tuinstra, KSU

The objectives of this project are: 1) to promote sorghum use as poultry feed in Niger and West Africa, 2) to compare the performance of maize and sorghum based-feed layers and broilers, and 3) to evaluate the carcasses and the carcass output of maize and sorghum-based feed broilers.

A test of maize substitution with sorghum in broiler and layer rations was carried out at the public poultry station of Goudel (Niamey, Niger). One day old chicks (320) of ABRO broilers weighing 34 ± 3 g were distributed in eight pens of 40 chicks and 600 of one day old HARCO layers weighing 25 ± 2 g were distributed in 12 pens of 50 chicks. The chickens were fed four different rations: maize coarsely milled (traditional milling), maize finely milled (1500 µm), improved sorghum IRAT204 finely milled (1500µm), landrace sorghum Mota Galmi finely milled (1500 µm). All the chicks were vaccinated (HB1, Lasota and Gumboro) and dewormed. Curative treatment for respiratory intestine affections was done on the chicks. The following data were collected: i) weight of layers and broilers at the beginning of test and every two weeks until the end of the experiments; ii) daily measurements of distributed feeds and the refuse; iii) daily egg production and egg weight; iv) chemical compositions, digestibility, and feed values of rations and the ingredients, digestibility, and parameters for the carcass were evaluated; and v) all input costs were collected for economic analysis.

After eight weeks, mean broiler weights were 1.76 kg for IRAT 204, 1.85 kg for Mota Galmi, 1.87 kg maize-based fed broilers, and 1.92 kg for the control (traditional milling). Carcass weights recorded at 60 days were 73.0% for IRAT 204, 75.3% for Mota Galmi, 75.1% for maize and, 74.7% for the control. Maize fed and sorghum fed layers did not differ statistically for whole weight or egg weight (P=0, 05). After 56 days, whole chick weight averaged 585 g for IRAT 204 sorghum, 562 g for Mota Galmi sorghum, 592 g for maize, and of 565 g for the control. It was noted that sorghum fed chicks started laying eggs one week before those fed on maize, and laying rates were higher for sorghum fed chicks (Table 6). Although egg weight was statistically the same for maize and sorghum, egg laying rate and consumption index were better for sorghum fed layers.

These results demonstrate the nutritional merits of sorghum and establish the essentiality of proper milling when using sorghum-based diets for the production of poultry. This study confirms Kansas State University results suggesting that proper milling is even more important in sorghum-based than corn-based diets. We believe that the INTSOMIL program will stimulate the development of a thriving poultry industry in Niger that should serve to create demand for domestically

Table 6. Maize and sorghum based-diets laying rate (Harco hens) at Niamey.

	Laying rate (%)			
Month	**Control**	**Maize**	**IRAT 2004**	**MOTA GALMI**
Number	135	135	135	135
February (*)	15.6 ± 9.7	13.1 ± 9.8	20.6 ± 12.1	15.0 ± 10.4
March	47.0 ± 10.9	38.2 ±10.4	51.3 ±9.7	48.9 ± 7.4
April	45.6 ± 11.6	36.3 ± 10.5	45.2 ±10.4	42.7 ± 9.1
May	42.0 ± 11.3	33.9 ± 12.4	42.3 ±11.1	43.0 ± 12.2
Mean	40.1 ± 16.0	31.4 ± 14.5	41.9 ± 15.3	40.6 ± 16.5

produced sorghum.

Research Supervision

Brah, Nouri. 2004. Substitution du maïs par le sorgho dans les rations des poulets de chair et de ponte. Mémoire de fin d'études en vue de l'obtention du diplôme d'ingénieur des techniques agricoles Option : production animales. Université Abdou Moumouni/Faculté d'Agronomie/INRAN

Networking

INTSORMIL is supporting the NARS of West Africa through strengthening their research capability. Most of the NARS have a few well trained highly skilled scientists working on millet and sorghum. Projects are initiated through discussion of commonly identified constraints by these NARS and US scientists who are often major professors of the former at one point. The meeting in Ouagadougou was an excellent opportunity for such an exercise and it can be argued that a regional approach has become consensus among all the PIs. In addition, there exist regional initiatives and organizations dealing with the same crops/issues including networks (WCASRN, ROCAFREMI), research forums (CORAF, INSAH) as well as international organizations like ICRISAT, which are excellent collaborators of the program. Interaction with these various groups insures optimal use of resources and good focus on key issues.

Examples of networking in the region

Technologies developed in Mali on sorghum are transferable to most countries in West Africa particularly in where head bug, 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 increased use of NGOs, farm organizations, and extension in on-farm trials, seed increased and distribution is a key activity of networking. 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.

Recently, more than 30 farmers were invited to a field day on sorghum use as poultry feed, which was useful for the farmers to discuss the issue of tannin content in sorghum and for them to indicate their priorities in terms of nutrition for layers.

Training local university students is also used as an approach to improve human resources in the country and collaborate with other institutions. The Agrometeorology Research Center of the Sahelian countries (AGRHYMET-Niamey) and the School of Agronomy in the University of Niamey are collaborating on INTSORMIL projects to train students in evaluation of sorghum water needs or use of sorghum in animal nutrition.

In Nigeria, the first commercial millet hybrid appreciated by farmers and will soon be released by the LCRI breeders. Also seeds of newly developed millet hybrid from LC0475A-3/LC0375B-3 and SOSAT-A/SOSAT-B were sent to Dr Iro Nkama for nutritional quality evaluation at University of Maiduguri. Grains from 40 pearl millet lines evaluated during the 2004 main season at L.C.R.I. Maiduguri were sent to Kaka Saley INRAN Niamey, Niger for grain quality analysis. This is a good example of collaboration among NARS scientists which was initiated through INTSORMIL projects.

Educational Activties

Year 26 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, 62 students from 23 different countries were enrolled in an INTSORMIL advanced degree program. Approximately 69% of these students come from countries other than the U.S. which shows the emphasis placed on host country institutional development (Figure 1).

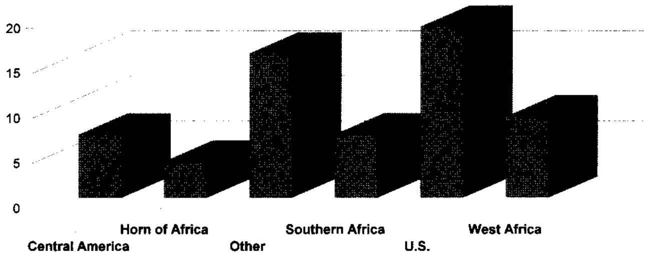

Figure 1. Degree Participants by Region.

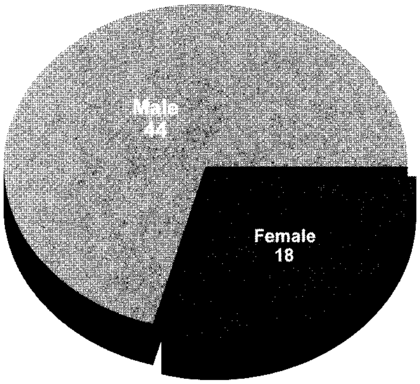

Figure 2. Degree Participants by Gender.

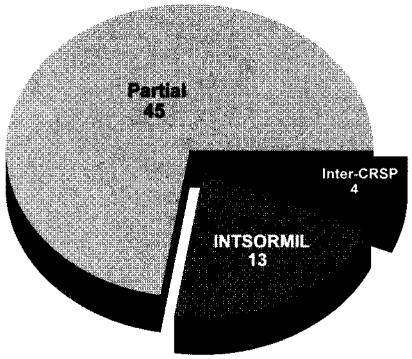

Figure 3. Degree Participants Funding.

INTSORMIL also places a high priority on training women which is reflected in Figure 2. In 2004-2005, 29% of all INTSORMIL graduate participants were female. Thirteen of the total 62 students received full INTSORMIL scholarships. An additional 45 students received partial INTSORMIL funding and the remaining four students were funded from other sources as shown in Figure 3.

All 62 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 the loss of U.S. principal investigators. In 1993-94 there were 25 U.S. PIs with the program and in 2004-2005 there were 19.

Graduate degree programs and short-term training programs have been designed and implemented on a case by case basis to suit the needs of host country scientists. One post doctoral scientist and 10 visiting host country scientists were provided the opportunity to upgrade their skills in this fashion during 2004-2005.

Figure 4 is a compilation of all INTSORMIL training activities by discipline for the period July 1, 2004 through June 30, 2005.

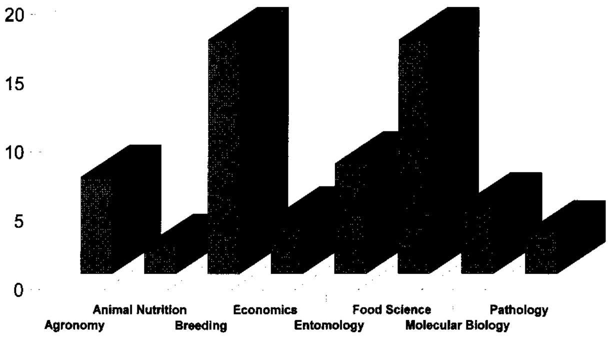

Figure 4. Degree Participants by Discipline.

Year 26 INTSORMIL Degree Training Participants July 1, 2004 - June 30, 2005

Name	Country	Univ.	Discipline	Advisor	Degree	Gender	Funding
Garcia, Juan Pablo	Colombia	UNL	Agronomy	Wortmann/Mamo	MSC	M	P
Griess, Joni	U.S.	UNL	Agronomy	Mason	MSC	F	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
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
Monge, Cynthia	Costa Rica	KSU	Animal Nutrition	Hancock	MSC	F	P
Amusan, Idris	Nigeria	PRF	Breeding	Ejeta	MSC	M	P
Kaufman, Rhett	U.S.	KSU	Breeding	Tuinstra	MSC	M	P
Kuhlman, Les	U.S.	TAM	Breeding	W. Rooney	MSC	M	P
Mpofu, Leo	Zimbabwe	TAM	Breeding	W. Rooney	MSC	M	P
Mutaliano, Joaquim	Mozambique	TAM	Breeding	W. Rooney	MSC	M	IC
Pandravada, S.	U.S.	KSU	Breeding	Tuinstra	MSC	M	P
Ridder, Dunstan	U.S.	KSU	Breeding	Tuinstra	MSC	M	P
Soumana, Souley	Niger	KSU	Breeding	Tuinstra	MSC	M	I
Teme, Niaba	Mali	TTU	Breeding	Peterson	MSC	M	P
Bading, Ryan	U.S.	TAM	Breeding	W. Rooney	PHD	M	P
Gonzalez-Cruz, G.	Mexico	KSU	Breeding	Tuinstra	PHD	M	P
Knoll, Joseph	U.S.	PRF	Breeding	Ejeta	PHD	M	I
Krishnamorthy, G.	India	TAM	Breeding	W. Rooney	PHD	M	P
Mateo, Rafael	Honduras	TAM	Breeding	W. Rooney	PHD	M	I
Saballos, Ana	Nicaragua	PRF	Breeding	Ejeta	PHD	F	P
Teme, Niaba	Mali	TTU	Breeding	Peterson	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
Bheemappa, S.	India	WTU	Entomology	Pendleton	MSC	M	P
Chitio, Fernando	Mozambique	WTU	Entomology	Pendleton	MSC	M	IC
Telly, Madani	Mali	WTU	Entomology	Pendleton	MSC	M	P
Traore, Tiecoura	Mali	WTU	Entomology	Pendleton	MSC	M	I
Belete, Tebkew D.	Ethiopia	WTU	Entomology	Pendleton	PHD	M	P
Parado Jaco, Mario	El Salvador	MSU	Entomology	Pitre	PHD	M	I
Pichard, Sergio	Nicaragua	MSU	Entomology	Pitre	PHD	M	P
Boldt, Clayton	U.S.	TAM	Food Science	L. Rooney	BSC	M	P
Pope, Kim	U.S.	TAM	Food Science	L. Rooney	BSC	F	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
Calderon, Vilma	El Salvador	TAM	Food Science	L. Rooney	MSC	F	I
Cedillo, Guisselle	Mexico	TAM	Food Science	L. Rooney	MSC	F	P
de Castro, Angelina	Mexico	TAM	Food Science	L. Rooney	MSC	F	P
Guajardo, David	Mexico	TAM	Food Science	L. Rooney	MSC	M	P
Hines-Wortham, L.	U.S.	TAM	Food Science	L. Rooney	MSC	F	P
Moussa, Moustapha	Niger	PRF	Food Science	Hamaker	MSC	M	I
Perez, Alejandro	Mexico	TAM	Food Science	L. Rooney	MSC	M	P
Xu, Lisha	China	TAM	Food Science	L. Rooney	MSC	F	P
Yeung, Hway Seen	U.S.	TAM	Food Science	L. Rooney/R. Waniska	MSC	F	P
Angarawai, Ignatius	Nigeria	PRF	Food Science	Hamaker	PHD	M	P
Dykes, Linda	U.S.	TAM	Food Science	L. Rooney/R. Waniska	PHD	F	P
Guajardo, Sara	Mexico	TAM	Food Science	L. Rooney	PHD	F	P
Ngwenya Dlamini, N.	Zimbabwe	TAM	Food Science	L. Rooney/J. Taylor	PHD	F	P
Burns, Frederick	U.S.	TAM	Molecular Biology	Magill	MSC	M	P
Cho, Jae-Min	S. Korea	TAM	Molecular Biology	Magill	PHD	M	P
Katile, Seriba	Mali	TAM	Molecular Biology	Magill	PHD	M	I
Mason, Esten	U.S.	TAM	Molecular Biology	Hayes	PHD	F	I
Robbins, Adriana	Mexico	TAM	Molecular Biology	Hayes	PHD	F	P
Ditshipi, Phoebe	Botswana	UFS	Pathology	McLaren/Swart	PHD	F	I
Frank, Erin	U.S.	KSU	Pathology	Leslie	PHD	F	P
Lee, Jin-Kwan	S. Korea	KSU	Pathology	Leslie	PHD	M	P

I = Completely funded by INTSORMIL **P = Partially funded by INTSORMIL** **IC = InterCRSP funding**
KSU = Kansas State Univ. **TAM = Texas A&M Univ.** **USDA = Tifton, Georgia**
MSU = Mississippi State Univ. **TTU = Texas Tech Univ.** **WTU = W. Texas A&M Univ.**
PRF = Purdue Univ. **UNL = Univ. of Nebraska, Lincoln**

Year 26 INTSORMIL Non-Degree Training Participants July 1, 2004 - June 30, 2005

Name	Country	Univ.	Discipline	Advisor	Activity	Gender	Funding
Mesfin-Abebe, Tewodros	Ethiopia	UNL	Agronomy	Wortmann/Mamo	VS	M	I
Issa, Salissou	Niger	KSU	Animal Nutrition	Hancock	VS	M	P
Awala, Simon	Namibia	USDA	Breeding	Wilson	VS	M	I
de Jesus Morales, Manuel	Nicaragua	TAMU	Breeding	Rooney, W.	VS	M	I
Zeledon-Gonzalez, H.	El Salvador	TAMU	Breeding	Rooney, W.	VS	M	I
Abdoulaye, Tahirou	Niger	PRF	Economics	Sanders	VS	M	P
Aboubacar, Adam	Niger	PRF	Food Science	Hamaker	VS	M	I
Benmoussa, M.	Morocco	PRF	Food Science	Hamaker	PD	M	P
Gayin, Joseph	Ghana	TAMU	Food Science	Rooney, L.	VS	M	P
Koreissi, Yara	Mali	TAMU	Food Science	Rooney, L.	VS	M	P
Sandoval, Luis	El Salvador	TAMU	Food Science	Rooney, L.	VS	M	P

VS = Visiting Scientist PD = Post Doctoral

Year 26 INTSORMIL Conference/Workshop Activities July 1, 2004 - June 30, 2005

			Participants		
Name	Location	Date	Male	Female	Total
Belete, Tebkew Damte	Bushland, Texas	August 31, 2004	1		1
Bheemappa, Shivakumara	Bushland, Texas	August 31, 2004	1		1
Morales, Manual	Bushland, Texas	August 31, 2004	1		1
Traore, Tiecoura	Bushland, Texas	August 31, 2004	1		1
Zeledon, Salvador	Bushland, Texas	August 31, 2004	1		1
Diourte, Mamourou	Ethiopia	Sept. 18 - Oct. 20, 2004	1		1
Population Genetics Workshop	Univ. of Pretoria, South Africa	Sept. 22-24, 2004	27	20	47
Fusarium Laboratory Workshop	Univ. of Pretoria, South Africa	Sept. 26-Oct.1, 2004	18	22	40
South Africa White Sorghum Workshop	Univ. of Pretoria, South Africa	October 21-22, 2004	10	2	12
Marketing & Processing for Dryland Crops in West Africa	Bamako, Mali	Nov. 16 - 18, 2004	38	10	48
Perumal, Ramasamy	Reno, Nevada	Feb. 20-23, 2005	1		1
Belete, Tebkew Damte	Albuquerque, New Mexico	Feb. 28-Mar. 3, 2005	1		1
Bheemappa, Shivakumara	Albuquerque, New Mexico	Feb. 28-Mar. 3, 2005	1		1
Traore, Tiecoura	Albuquerque, New Mexico	Feb. 28-Mar. 3, 2005	1		1
Snack Food Processing Workshop	Texas A&M University	March, 2005	30	15	45
IFDC: Soil Fertility Management	Accra, Ghana	April 11-14, 2005	7		7
PCCMCA Annual Meeting	Panama	May 1-5, 2005	5		5
Sorghum Utilization Workshop	Managua, Nicaragua	May 18-19, 2005	50	10	60
Bheemappa, Shivakumara	Stratford, Texas	May 25, 2005	1		1
Traore, Tiecoura	Stratford, Texas	May 25, 2005	1		1
Neya, Adama	Michigan State University	June 18 - 30, 2005	1		1
Fusarium Laboratory Workshop	KSU	June 26 - 30, 2005	30	27	57
TOTAL			**228**	**106**	**334**

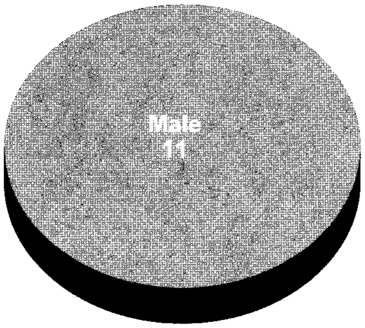

Figure 5. Total Non-Degree Participants by Gender

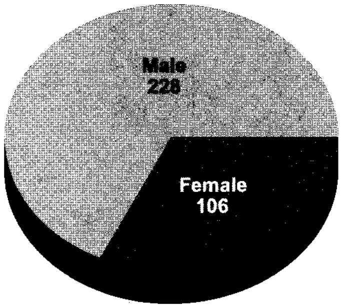

Figure 6. Total Conference/Workshop Participants by Gender

Appendices

INTSORMIL Sponsored and Co-Sponsored Workshops 1979 - 2005

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 A1 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
53. South Africa White Sorghum Workshop	Univ. of Pretoria, South Africa	09/04
54. Marketing & Processing for Dryland Crops in West Africa	Bamako, Mali	11/04

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

Participants attending the Marketing & Processing for Dryland Crops in West Africa Workshop in Bamako, Mali from November 16-18, 2004.

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