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INTSORMIL 2007 Annual Report

John M. Yohe
INTSORMIL, jyohe1@unl.edu

Kimberly Christiansen
INTSORMIL

Joan Frederick
INTSORMIL

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Sorghum/Millet Collaborative Research Support Program (CRSP)

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

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INTSORMIL mentors from left to right: Dr. Brhane Gebrekidan (Virginia Tech, currently in Ethiopia), Dr. Gebisa Ejeta (Purdue University), Dr. Mitch Tuinstra (Kansas State University), Dr. Tesfaye Tesso (Ethiopia), and current Ph.D. student Taye Tadesse (Ethiopia)

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2007 ANNUAL REPORT

Fighting Hunger and Poverty with Research
. . . A Team Effort

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

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Report Coordinators
John M. Yohe, Program Director
Kimberly Christiansen and Joan Frederick

For additional information contact the INTSORMIL Management Entity at:

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

Telephone: (402) 472-6032
Fax: (402) 472-7978
E-Mail: SRMLCRSP@unl.edu
http://intsormil.org

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Introduction and Program Review

The 2007 INTSORMIL Six Year Report presents the progress and notable achievements by the Sorghum/Millet CRSP during the period of July 1, 2001 - June 30, 2007. These results are an outcome of partnerships between scientists at seven U.S. Land Grant Universities (Kansas State University, Mississippi State University, Ohio State University, University of Nebraska, Purdue University, Texas A&M University and West Texas A&M University), scientists of the Agricultural Research Service of the U.S. Department of Agriculture at Tifton, Georgia and the 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 but also to processors and consumers of agricultural products. Agricultural research has continuously shown that it is able to provide 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 through partnerships between 20 U.S. university scientists and scientists of the National Agricultural Research Systems (NARS), IARCs, PVOs and other CRSPs. INTSORMIL is programmatically organized for efficient and effective operation and captures most of the public research expertise on sorghum and pearl millet in the United States. ***The INTSORMIL mission is to use collaborative research as a mechanism to develop human and institutional research capabilities to overcome constraints to sorghum and millet production, marketing and utilization for the mutual benefit of the Less Developed Countries (LDCs) and the U.S.*** Collaborating scientists in NARS developing countries and the U.S. jointly plan and execute research that mutually benefits all participating countries, including the United States.

INTSORMIL takes a regional approach to sorghum and millet research in western, eastern, and southern Africa, and in Central America. INTSORMIL focuses resources in the four regions supporting the general goals of building NARS institutional capabilities and 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. In their area of adaptation, sorghum and millet have a distinctly competitive advantage to yield more grain than other cereals. 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 Central and South America. Pearl millet is also becoming an important feed source for poultry in the southeastern United States. Improved varieties and hybrids of pearl millet and improved lines of sorghum can be grown in developing countries, as well as the United States. They have great potential for processing into high-value food products which can be sold in villages and urban markets, where they compete successfully with imported wheat and rice products. In the U.S., pearl millet is sold 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 the improvement and production of sorghum and millet in the developing countries of regions in which INTSORMIL serves, population growth continues to exceed rates of increase in 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 conduct research on constraints to production, utilization and marketing of sorghum and millet.

The INTSORMIL program maintains a flexible approach to accomplishing its mission. The success of INTSORMIL 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 conduct research on sorghum and millet, development of international collaborative research networks, promoting and linking to technology transfer activities and dissemination of technologies developed from 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 with 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. INTSORMIL promotes conserving millet and sorghum germplasm,

developing resource-efficient cropping systems, developing integrated pest management strategies that conserve natural control agents, 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 in enabling economic policymakers to more intelligently consider policy options to help increase the benefits and competitiveness of sorghum and pearl millet as basic food staples and as components of value-added products.

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

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

The INTSORMIL program addresses the continuing need for development of technologies for agricultural production, processing and utilization of sorghum and pearl millet for both the developing world, especially in the semiarid tropics, and the United States. There is international recognition by the world donor community that National Agricultural Research Systems (NARS) in developing countries must assume ownership of their development problems and move toward achieving resolution of them. The INTSORMIL program is a proven model that empowers the NARS to develop the capacity to assume 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 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 the period of 2001-2007, there were 116 students from 28 different countries enrolled in an INTSORMIL advanced degree program and advised by an INTSORMIL principal investigator. Approximately 70% of these students came from countries other than the U.S. The number of students receiving 100% funding by INTSORMIL in 2001-2007 totaled 24. An additional 88 students received partial funding from INTSORMIL and the remaining four students were funded from other sources. INTSORMIL places high priority on training of women. During the period 2001-2007, 31% 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 this period of six years, seventy nine host country scientists improved their education as either postdoctoral scientists (19) or visiting scientists (60). Their research activities were in the disciplines of agronomy, food science and animal nutrition, entomology, molecular biology, and pathology. These scientists came to the United States as postdoctoral scientists or visiting scientists from Brazil, El Salvador, Egypt, Ethiopia, Ghana, Guatemala, Mali, Nicaragua, Niger and Uganda. In addition to non-degree research activities there were 3047 participants (1,753 male and 1294 female) who were supported by INTSORMIL for participation in workshops and 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 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), promotes germplasm and information exchange, and facilitates impact evaluation of new technologies.
- Develops regional research networks, short-term and degree training plans for sorghum and pearl millet scientists.

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 ICRISAT programs in east, southern and West Africa. Since 2004 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) were on making contracts between farmers' groups and the rapidly growing 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. During this six year period on-farm testing, field tours, and farm days were organized for maximal exchange with other farmers and to promote acceptance of improved cultivars by farmers. On-farm testing included on-farm evaluation of soil fertility management options for millet yield increases including use of poultry manure and microdose fertilizer applications. Improved elite sorghum hybrids, insect and *Striga* resistant lines were evaluated on-farm. Countrywide evaluation and demonstration of the marketing potential for value-added sorghum and millet products including poultry feed was accomplished. This is strengthening the linkages between production and utilization activities.

Thus, the West Africa INTSORMIL program 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. 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. A new project during this period has been in poultry nutrition aimed to encourage poultry producers to use sorghum and millet for feed.

Horn of Africa

(Ethiopia, Eritrea, Kenya, Tanzania, Uganda)

Ongoing collaborative research has progressed in each of the countries. However, activities were terminated in Eritrea in late 2005. Host country PIs in each country have taken a 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. Sorghum breeding efforts in Ethiopia have particularly gone well. 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 resistant sorghum cultivars. This collaborative activity has expanded over years and at present constitutes almost half of sorghum research activity in Ethiopia. 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. As discussed in the Horn of Africa report, these varieties are making significant impact in changing the course of sorghum production

in *Striga* infested regions of the country. Progress being made in identification of suitable hybrid cultivars in Ethiopia is also very encouraging. This activity is managed and implemented as a pilot project with supplemental funding from the Office of Foreign Disaster Assistance (OFDA) of USAID. *Striga* resistant sorghum varieties have been officially released for wide cultivation and the integrated *Striga* management pilot project has aroused interest in the technology and a community-based seed multiplication effort has been started.

Farmers participating in INTSORMIL funded research activities at one of the research sites in Tanzania produced and sold to Nile Breweries over 30 MT of sorghum grain worth > USA $ 5000 during the first rains of 2006. They have now formed a Saving and Credit Co-operative Society so as to improve production, food security and their livelihood.

In Uganda, soil fertility management practices, as well as reduced tillage, were found to be cost effective in increasing sorghum yield in predominantly smallholder agriculture where small amounts of organic fertilizer were only occasionally used. On-farm profitability and food security for sorghum production systems can be improved by use of inorganic fertilizers, manure, mucuna fallow, sorghum-cowpea rotation, and reduced tillage. This confirms that low soil fertility is a constraint to sorghum production and that the alternative strategies are effective in addressing it.

Southern Africa

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

Progress has been made in this period (2001-2007) to increase the productivity of sorghum and pearl millet and begin moving the crops from a subsistence level to a value added cash crop. The progress includes technology of use in lager beer brewing, identification and increased understanding of major disease and insect constraints and development of technology to reduce the constraints, and release of varieties and hybrids with improved productivity. However, much remains to be done. Sorghum and pearl millet are poised to make a dramatic step forward in productivity and utilization through research and a better understanding and increased employment of supply chain management strategies.

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

However, there are indications that the status of sorghum and pearl millet is improving in Southern Africa. Increasing emphasis on sorghum and pearl millet as food security crops and repeated drought induced failures of other crops is improving the outlook for sorghum and pearl millet. In collaboration with the Zambia national program, INTSORMIL has contributed to the production and distribution to NGOs of several tons of improved seed which was distributed to farmers. There is increasing recognition of the importance of developing cash generating markets for sorghum. An excellent example is the collaboration of the Zambia national program with CARE in the production of white grain sorghum (produced on tan plants) for the lager beer market. In the second year of collaboration with CARE, the number of participating farmers more than doubled. Sorghum and pearl millet should play a significant role in food security and new commercialization activities that generate cash income. The many favorable attributes of both commodities should contribute to an increased supply of high quality food available to farm families, especially those affected by HIV/AIDS.

Central America

(El Salvador, Nicaragua, Honduras)

Multi-disciplinary, multi-organization, multi-country research and technology transfer efforts were conducted between 2001 and 2007. This resulted in release and transfer of sorghum hybrids and varieties, identification and transfer of the high NUE photoperiod sensitive variety 85-SCP-805, development and release of SS-44 (INTA Forajero) with increased forage sorghum yield and quality resulting in increased dairy production, identification and integrated pest management programs for major insect and diseases and development of sorghum flour production capability and sorghum based sweet bread products. All of these activities contribute to economic growth, particularly for small farmers and processors. Institutional capabilities have been improved through collaborative research and technology transfer activities, graduate education and short-term training. Collaboration among sorghum programs, extension services, private seed companies and non-governmental agencies has increased. Extension efforts have been improved through publication of production guides and other extension bulletins. Scientific capability of collaborators has improved through publication of scientific journal articles, and participation in PCCMCA meetings. Much has been accomplished, but much remains to be done in coming years to raise all of our Central American brothers and sisters out of poverty.

Future Directions

During the past 28 years, INTSORMIL has educated more than one thousand scientists through degree programs, visiting scientist experiences, postdoctoral training, workshops, and conferences. About one-third of those trained are from the U.S. 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. Sorghum is a significant 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 semiarid tropics, and 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 increasing strength of scientific expertise in developing countries, INTSORMIL is now able to more effectively reduce constraints to production and utilization of sorghum and millet to the mutual benefit of developing countries and the United States. Advances in sorghum and millet research over INTSORMIL's 28 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 key components 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 an enhanced scientific capability on sorghum and millet, and creates technological and human capital that has a sustainable and global impact.

As the present INTSORMIL program comes to a close, a new Sorghum, Millet and Other Grains CRSP has been authorized and funded by USAID. Future strategies under this new CRSP will maintain INTSORMIL's current, highly productive momentum, build on its record of success, and work toward accomplishing a whole new set of goals. INTSORMIL's new Vision is to improve food security, enhance farm incomes, and improve economic activity in the major sorghum, millet and other grains-producing countries in Africa and Central America. The CRSP will lead efforts to promote profitable markets for sorghum, pearl millet and other grains by working with agencies that identify and expand markets, assess economics, and facilitate the evolution of a production-supply chain and expanding markets that deliver quality grain to end users. Future strategies will maintain the new CRSP's highly productive momentum, build on the old CRSPs record of success, and accomplish a new set of goals.

Sustainable Plant Protection Systems

Agroecology and Biotechnology of Stalk Rot Pathogens of Sorghum and Millet

Project KSU 210
John F. Leslie
Kansas State University

Principal Investigator

John F. Leslie, Dept of Plant Pathology, Kansas State University, Manhattan, Kansas 66506-5502

Collaborating Scientists

Dr. Ranajit Bandyopadhyay, International Institute for Tropical Agriculture, Ibadan, Nigeria
Dr. R. L. Bowden, USDA-ARS Plant Science & Entomology Research Unit, Manhattan, Kansas 66502
Drs. L. E. Claflin, L. A. Heaton, D. J. Jardine, J. Smith & M. Tuinstra, Kansas State University, Manhattan, Kansas 66502
Dr. A. E. Desjardins, NCAUR, USDA-ARS, Peoria, Illinois 61601
Dr. M. B. Dickman, University of Nebraska, Lincoln, Nebraska 68583
Dr. Mamourou Diourté, IER, Bamako, Mali
Dr. Elhamy El-Assiuty, Plant Pathology Research Institute, Agricultural Research Center, Giza, Egypt
Dr. J. Peter Esele, Sererre Agric. & Animal Production Research Institute, NARO, Soroti, Uganda
Dr. R. A. Frederiksen, Texas A&M University, College Station, Texas 77843
Dr. Laszlo Hornok, Agricultural Biotechnology Center, Godollo, Hungary
Dr. Chagema J. Kedera, Kenyan Plant Health Inspection Service, Nairobi, Kenya
Dr. Walter F. O. Marasas, South African Medical Research Council, Tygerberg, South Africa
Dr. Neal McLaren, University of the Free State, Bloemfontein, South Africa
Drs. Michael Wingfield and Brenda Wingfield, University of Pretoria, Pretoria, South Africa

Summary

Fusarium is an intermittently severe cause of grain mold, stalk rot and pokkah boeng of sorghum. The taxonomy formerly applied to many sorghum and millet isolates, especially from Africa, often is inaccurate. We used genetic and molecular criteria to describe two additional species and to identify at least six additional new species. In Egypt a detailed population study found that F. proliferatum is common on sorghum, a crop where it usually is relatively rare (~5-10% of the population). This species is almost completely absent in West Africa, and is important because it can produce fumonisins. Most *Fusarium* species found on sorghum and millet produce little or no fumonisins, but often produce moniliformin, which is quite toxic to poultry. In a collaborative study with IITA of maize, sorghum and pearl millet grown side-by-side in farmer's fields in Nigeria, the maize was more heavily contaminated with aflatoxin and fumonisins than either the sorghum or the pearl millet. In Kansas, evidence for the evolution of putative new sorghum pathogen types was found through the analysis of strains recovered from a native tallgrass prairie. Zearalenone is a well-documented mycotoxin produced by several *Fusarium* species, and often diagnosed by thin-layer chromatography. The fungi that produce this toxin are not common in hot dry areas where sorghum usually is grown. We identified another compound, 8-O-methylbostrycoidin, that comigrates with zearalenone on TLC plates and is produced by many species recovered from sorghum. Thus, more sophisticated chemical technology should be used to screen sorghum for zearalenone to ensure that grain moving in international channels is not improperly labeled as contaminated. Biological control of *Fusarium* by four mycoviruses, which might confer hypovirulence, was investigated. These mycoviruses conferred no change in morphology, other than perhaps female sterility, suggesting that they will be of little value as biological control agents.

Objectives, Production and Utilization Constraints

Objectives

- Increase collection of *Fusarium* samples from sorghum and millet, and identify the species recovered and their mycotoxigenic potential.
- Develop genetic and molecular characters, e.g., mating type and Amplified Fragment Length Polymorphisms (AFLPS), for assessing genetic variation. Use these traits to analyze fungal populations from Egypt, Mali, Tanzania, India, Uganda, South Africa, and the United States.
- Provide pure cultures of fungi to others to expedite diagnoses of fungal diseases of sorghum and millet.
- Conduct Scientific Writing, Research Ethics, and *Fusarium* Laboratory workshops.
- Prepare text for *The Fusarium Laboratory Manual*.
- Edit Proceedings of 2000 Global Sorghum and Millet Pathology Conference.

Production and Utilization Constraints

- *Fusarium* spp. associated with sorghum and millet do obvious damage as stalk rot, grain mold and pokkah boeng, resulting in intermittently heavy losses in the United States and in developing countries. Breeding for resistance to *Fusarium*-associated diseases is difficult because the strains responsible for disease often are not accurately identified and used repeatedly in field challenges. Correct identification of these fungi is essential for the design of breeding and control measures. Without a thorough understanding of the pathogen's distribution, genetic diversity and population dynamics, effective control measures are difficult to design and resistant lines may have unexpectedly brief lives.
- Mycotoxin contamination limits the uses for harvested grain, and creates health risks for both humans and domesticated animals. *Fusarium*-produced mycotoxins are common in cereal grains, yet have been little studied 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.
- Scientists in developing countries often are unfamiliar with the publication process for international journals and have little experience with contemporary research culture and laboratory practices. These problems may limit the international exposure that their work receives. The Scientific Writing, Research Integrity and Ethics, and *Fusarium* Laboratory workshops help address these needs through short-term training.

Research Findings and Project Output

Short-term training workshops. Three short-term training workshops are run through this project. *Fusarium* Laboratory workshops are taught annually by an international team of 5-7 instructors. These one-week workshops are approximately financially self-supporting from registration fees. Preparing for one of these workshops is a full-time job for two people for 3-4 months. The workshop is taught in odd years at Kansas State University and in even years at locations outside the United States (2002 - Sydney, Australia; 2004 - Pretoria, South Africa; 2006 - Bari, Italy; 2008 - Penang, Malaysia). To date, > 300 scientists have participated in one of these workshops.

Scientific Writing and Research Integrity and Ethics workshops are one day in length and require no special preparation. Costs are minimal, usually the cost of duplicating handouts and coffee breaks. These workshops are presented on request from host country scientists and include lectures and small teams working to solve sample problems. Since 2001, the Scientific Writing workshop has been taught in 12 countries with ~3000 participants. The Research Ethics workshop was developed in 2005 and has been presented in five countries for 384 participants.

Species identification and differentiation. Two new species were described, *Fusarium andiyazi*, and *Gibberella* sacchara. These species are part of the *Gibberella fujikuroi* species complex and used to be called *Fusarium moniliforme*, a name that has now been abandoned because of the confusion associated with its use. Both *F. andi-yazi* and *G. sacchara* can be distinguished on the basis of morphology, sexual cross fertility (or its lack), and differences in DNA sequences and AFLP markers. Additional species from Egypt and West Africa await description.

Egyptian *Fusarium* populations. 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 a problem on maize in Egypt and there are published cases of donkeys with leukoencephalomalacia. *Fusarium* species in the *G. fujikuroi* species complex, are widely known from maize and sorghum in Egypt, but little detailed characterization has been made. 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. Three hundred fifty-three *Fusarium* isolates in the *G. fujikuroi* species complex recovered from both maize and sorghum were identified to species with AFLP markers and sexual crosses. 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*), were recovered 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.

Mycotoxin production. We evaluated a number of *Fusarium* species for beauvericin, fusaproliferin, monili-formin, and fumonisins B1, B2 and B3 production (Table 1) of which moniliformin was synthesized most widely. Beauvericin was first identified for its antibiotic and insecticidal activities, but also is toxic to brine shrimp, and to human ematopoietic, epithelial, and fibroblastoid cells. Fusaproliferin is toxic to brine shrimp and human B-lymphocytes cell line IARC/LCL 171, and can induce teratogenic effects, e.g., cephalic dichotomy, macrocephaly and limb asymmetry, in chicken embryos. Moniliformin is extremely toxic to animals such as ducklings, rats, mice, chickens, and swine, and has been correlated with hepatitis in vervet monkeys and with a human heart condition, Keshan Disease, in China. Fumonisins B1, B2 and B3 are non-genotoxic carcinogens primarily produced by *F. verticillioides*. Dietary fumonisins are correlated with esophageal cancer in humans and can cause leukoencephalomalacia in horses, pulmonary edema in swine, and liver and kidney damage in rats. F. *concentricum* produced the most beauvericin (720 µg/g). *F. phyllophilum* produced the most moniliformin, 1,500 µg/g. *F. pseudonygamai* produced the most fusaproliferin (131 µg/g), and *F. phyllophilum* produced the most fumonisin B1 (2.5 µg/g). No culture produced fumonisin B3, and *F. bulbicola* produced none of the six mycotoxins evaluated. Several species can synthesize more than one toxin and synergistic interactions amongst these compounds need further investigation. Field samples of sorghum and millet grain from Mali contained significant levels of moniliformin.

Table 1. Production of the mycotoxins beauvericin (BEA), moniliformin (MON), fusaproliferin (FP), and fumonisins B_1, B_2 and B_3 (FB_1, FB_2 FB_3) by 15 new *Fusarium* species.

Fusarium species	Strain Number[1]	Mycotoxins BEA (μg/g)	MON (μg/g)	FP (μg/g)	FB_1 (μg/kg)	FB_2 (μg/kg)
F. acutatum	7544	6 ± 1	ND[2]	ND	147 ± 10	360± 23
F. begoniae	7542	ND	1000 ± 64	ND	66 ± 3	ND
F. brevicatenulatum	7531	ND	ND	ND	150 ± 7	ND
F. bulbicola	7534	ND	ND	ND	ND	ND
F. circinatum	7541	57 ± 2	ND	ND	ND	ND
F. concentricum	7540	720 ± 48	ND	ND	ND	ND
F. denticulatum	7538	ND	180 ± 7	ND	ND	ND
F. guttiforme	7539	72 ± 6	ND	85 ± 5	ND	ND
F. lactis	7532	ND	51 ± 3	ND	ND	ND
F. nisikadoi	7533	ND	0.6 ± 0.1	ND	ND	ND
F. phyllophilum	7543	ND	1500 ± 73	ND	2500 ± 100	T[3]
F. pseudoanthophilum	7530	2.2 ± 0.2	ND[b]	ND	ND	ND
F. pseudocircinatum	7536	ND	100 ± 16	12 ± 0.3	280 ± 3	360±30
F. pseudonygamai	7537	ND	53 ± 2	130 ± 2	ND	ND
F. ramigenum	7535	ND	46 ± 9	ND	ND	ND

[1]MRC: Medical Research Council of South Africa strain collection.
[2]ND - Not Detected.
[3]T-Trace.

Aflatoxins commonly contaminate cereals and may result in cancer, liver disease, immune suppression, retarded growth and development, and death depending on the amount and duration of toxin exposure. Maize is an introduced crop to Africa and there have been efforts for the last ~20 years to replace traditional cereal crops, e.g., sorghum and pearl millet, with maize. Maize was significantly more heavily colonized by aflatoxin-producing *Aspergillus* spp. than was either sorghum or millet and overall aflatoxin levels were correspondingly higher. Subsistence farmers in the African savannas consume locally grown maize 5.6 to 6.6 days a week. If the primary cereal were sorghum instead of maize, then the risk of aflatoxin-related problems is reduced 8-fold, and if it is pearl millet, then the risks are reduced 9-fold. Efforts to improve and maintain the traditional crops should be encouraged in areas marginal for the production of maize in Africa.

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

Zearalenone analog. Some strains produce a compound with identical migration to zearalenone on TLC plates. This compound eluted two min. before zearalenone on a C18-HPLC column. The analog also has an absorption peak at 500 nm that is not found for zearalenone. There was no evidence for zearalenone production by any of these cultures. The zearalenone analog had an elemental composition of C16H13O5N and a molecular weight of 299. It contained aromatic C–H, aliphatic C–H, C=O, CH2, C–OH, and C=CH2 based on IR, NMR, GC/MS, and ES-IMS analy-ses and was identified as 8-OMB. 8-OMB was first isolated from *Fusarium verticillioides* by Prof. Marasas's group in South Africa in 1979, as part of a search for the cause of equine leukoencephalomalacia. This group did not do any TLC analyses and failed to detect the similarity between 8-OMB and zearalenone under these simple analytical conditions. Strains of both *F. andiyazi*, which is common on sorghum, and *F. pseudonygamai*, which is common on millet, produced detectable levels of this compound. Thus, reports of zearalenone in sorghum and millet grain from hot, dry areas that are based on TLC analyses are likely to be false positives in which 8-OMB was present instead.

DsRNAs for biological control. Four *F. proliferatum* isolates contained one or more dsRNAs that might be useful as biological control agents. The dsRNAs from three strains are multipartite and mitochondrial-associated while the single dsRNA in the fourth is cytoplasmic. None of the dsRNAs alter morpho-

logical phenotypes or growth rates. None of the dsRNAs was sexually transmitted; the mitochondrial-associated dsRNAs are reliably transmitted vegetatively, but the single copy cytoplasmic dsRNA is not. These features are not conducive to the use of these dsRNAs as biological control agents for *Fusarium*.

Description of Methods of Work Used

Cultures. All cultures used are available through the KSU culture collection. Some isolates originated from other scientists but many are unique to the KSU collection. All strains were subcultured as single conidia before being accessioned in the KSU collection. Strains recovered from field samples are grown out on a medium semi-selective for *Fusarium*, and then subcultured. We have the necessary USDA-APHIS permits for working with *Fusarium* strains from around the world. Strains for morphological evaluation are grown on either Carnation Leaf Agar or Potato Dextrose Agar. Sexual crosses are made on carrot agar. Strains are maintained in long-term storage as spore suspensions in 15% glycerol frozen at -70°C.

Cultures for DNA extraction are grown in liquid Czapek's medium and DNA extracted with a CTAB protocol. AFLPs are labeled with 33P, resolved on sequencing gels, and scored manually following autoradiography. Each AFLP band is treated as a single independent locus with two alleles. Genetic similarities are calculated with the Dice coefficient. UPGMA clustering was carried out with the CLUSTER option of SAS (v 6.12). Mating type is identified following PCR amplification with degenerate primers or in crosses with strains of known mating type.

Mycotoxin production, isolation and extraction. Strains were cultured on cracked corn or maize grits for 2-4 weeks. Analytical procedures depended on the lab doing the analysis (Marasas - South Africa or Smith - KSU) with the results confirmed by comparison with authentic standards and spiked samples. Moniliformin is found in an aqueous extract and fusaproliferin and beauvericin in a methyl chloride extract. The amount of toxin present was quantified by HPLC. Fumonisins are recovered in an ethyl acetate extract and measured, after derivatization if necessary, by HPLC or LC-MS. The zearalenone analog was purified by TLC and HPLC, and structural analyses made of the HPLC-purified compound with IR (Infrared spectrometry), GC/MS (Gas Chromatography/Mass Spectrome-try), NMR (Nuclear Magnetic Resonance), and ESIMS (Electrospray Ionization Mass Spectrometry).

Networking Activities

Editorial and Committee Service

- Editor, Proceedings 3rd Global Conference on Sorghum and Millet Diseases
- Editor, Applied and Environmental Microbiology (2000-2006)
- International Society for Plant Pathology, *Fusarium* Committee (2000-2007)
- Mycoglobe Steering Committee (2003-2007)
- Senior Fulbright Scholar Review Panel (U.S./Australia/New Zealand 2003-06; chair 2005-06)

Research Investigator Exchange

Australia – November 4-11, 2000; October 10-14, 2001; January 26 – August 20, 2002; January 20 – February 1, 2003; April 10-24, 2004; August 11-26, 2006. Belgium – October 21-23, 2004. Benin – June 1-3, 2004. Burkina Faso – October 9-12, 2003. Cameroun – October 19-21, 2004. China – May 9-16, 2004; April 21-30, 2007. Egypt – April 27 - May 8, October 14-23, 2000; April 25 – May 4, 2001; July 30 – August 3, 2002; September 12-18, 2003. Ethiopia – November 9-23, 2002. Ghana – September 7-12, 2001; October 12-15, 2003; September 9-15, 2005. Hungary – November 29 – December 3, 2000. India – September 28 – October 6, 2001. Italy – September 18-26, 2003; June 4-9, 2004; May 27 – June 10, September 24-30, 2006. Kenya – November 24-25, 2002. Malaysia – November 12-18, 2000; October 7-9, 2001; January 19-25, 2002; February 1-4, 2003; April 24 – May 1, 2004; August 26 – September 2, 2006. Mozambique – October 28-31, 2001. The Netherlands – December 17-19, 2000; September 21-24, 2006. Nigeria – April 25 – May 4, October 15-25, 2003; May 24-31, October 9-18, 2004; November 22-27, 2006. South Africa – December 4-16, 2000; November 1-20, 2001; September 22 – October 11, 2002; October 31 – November 21, 2003; March 5-13, September 18 – October 2, November 2-23, 2004; October 20 – November 4, 2006. South Korea – October 14-18, 2001; February 4-9, 2003; May 2-5, 2004; September 3-6, 2006; May 1-5, 2007. Uganda – October 9-14, 2000.

Seminar, Workshop & Invited Meeting Presentations (International Locations Only)

Australia: 8th International Mycology Congress, Cairns; AustralAsian Plant Pathology Society, Mudgee; CSIRO Publishing, Melbourne; CSIRO Plant sciences, Canberra; Flinders University, Adelaide; Royal Botanic Gardens, Sydney; University of Adelaide, Adelaide; University of Melbourne, Melbourne; University of Queensland, Brisbane; University of Sydney, Sydney. Benin: International Institute of Tropical Agriculture, Cotonou. China: 15th International Plant Protection Congress, Beijing; Dalian Nationalities University, Dalian; Peking University, Beijing; Shenyang Agricultural University, Shenyang. Egypt: Egyptian National Agricultural Library, Dokki; Plant Pathology Research Institute, ARC, Giza. Ghana: Savanna Research Institute, Tamale. Hungary: Agricultural Biotechnology Center, Godollo. India: ICRISAT, Patancheru. Italy: Institute for the Science of Food Production, Bari. Malaysia: Universiti Sains Malaysia, Penang. Mexico: International Workshop on Sorghum and Millets Pa-thology, Guanjuato. Nigeria: International Institute for Tropical Agriculture, Ibadan. South Africa: Agricultural Research Council, Potchefstroom; Medical Research Council, Tygerberg; Stellenbosch University, Stellenbosch; University of the Free State, Bloemfontein; University of KwaZulu-Natal, Pietermaritzburg; University of Northwest, Potchefstroom; University of Pretoria, Pretoria. South Korea: Seoul National University, Seoul & Su-Won. Uganda: Makerere University, Kampala.

Other Collaborating Scientists (Host Country)

- Dr. Lester Burgess, Faculty of Agriculture, University of Sydney, Sydney, Australia.
- Dr. Sofia Chulze, Department of Microbiology, National University of Rio Cuarto, Rio Cuarto, Argentina.

- Drs. M. Flieger & S. Pazoutova, Institute of Microbiol., Czech Academy of Sciences, Prague, Czech Republic.
- Dr. Sandra Lamprecht, Plant Protection Institute, Agricultural Research Council, Stellenbosch, South Africa.
- Dr. Yin-Won Lee, Department of Plant Pathology, Seoul National University, Su-Won, South Korea.
- Drs. Antonio Logrieco, Antonio Moretti & Giuseppe Mulé, Inst. Sci. of Food Production, CNR, Bari, Italy.
- Dr. Anaclet S. B. Mansuetus, Dept. of Biological Sciences, University of Swaziland, Kwaluseni, Swaziland.
- Dr. Maya Piñeiro, FAO, Rome, Italy.
- Dr. Baharuddin Salleh, School of Biological Sciences, Universiti Sains Malaysia, Penang, Malaysia.
- Dr. Brett Summerell, Royal Botanic Gardens, Sydney, Australia.

Other Collaborating Scientists (U.S.)

- Drs. Charles W. Bacon and Ida Yates, USDA Russell Research Center, Athens, Georgia
- Dr. K. K. Klein, Department of Biological Sciences, Mankato State University, Mankato, Minnesota
- Dr. G. N. Odvody, Texas Agricultural Experiment Station, Corpus Christi, Texas
- Recipients of *Fusarium* cultures (other than collaborators)
- David Geiser, Pennsylvania State University, University Park, Pennsylvania
- Fungal Genetics Stock Center, University of Missouri-Kansas City, Kansas City, Missouri
- H. I. Nirenberg, Biologische Bundesantsalt für Land- und Forstwirtschaft, Berlin, Germany.
- R. D. Plattner & K. O'Donnell, Mycotoxin Research Unit, NCAUR, USDA/ARS, Peoria, IL.
- Randy C. Ploetz, Tropical Research & Education Center, Univ. of Florida, Homestead, FL.
- Amir Sharon, Department of Plant Sciences, University of Tel Aviv, Tel Aviv, Israel.
- Bettina Tudzynski, Westfaelische Wilhelms University, Muenster, Germany.
- Cees Waalwijk, DLO Institute for Plant Protection, Wageningen, The Netherlands.

Publications and Presentations (2006 and 2007)

Leslie, J. F. & B. A. Summerell. 2006. The *Fusarium* Laboratory Manual. Blackwell Professional Publishing, Ames, Iowa. 385 pp.

Leslie, J. F., R. Bandyopadhyay & A. Visconti, eds. 2007. Mycotoxins: Detection Methods, Management, Public Health and Agricultural Trade. CABI, Kew, UK.

Leslie, J. F., B. A. Summerell, S. Bullock & F. J. Doe. 2005. Description of Gibberella sacchari and neotypi-fication of its anamorph *Fusarium* sacchari. Mycologia 97: 718-724.

Leslie, J. F., K. A. Zeller, S. C. Lamprecht, J. P. Rheeder & W. F. O. Marasas. 2005. Toxicity, pathogenicity and genetic differentiation of five species of *Fusarium* from sorghum and millet. Phytopathology 95: 275-283.

Sewram, V., N. Mshicileli, G. S. Shephard, H. F. Vismer, J. P. Rheeder, Y.-W. Lee, J. F. Leslie & W. F. O. Marasas. 2005. Production of fumonisin B and C analogs by several *Fusarium* species. Journal of Agricultural and Food Chemistry 53: 4861-4866.

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Kerényi, Z., B. Oláh, A. Jeney, L. Hornok & J. F. Leslie. 2006. The homologue of het-C of Neurospora crassa lacks vegetative compatibility function in *Fusarium proliferatum*. Appl. Environ. Microbiol. 72: 6527-6532.

Leslie, J. F. & B. A. Summerell. 2006. *Fusarium* Laboratory Workshops – A recent history. Mycotoxin Re-search 22: 73-74.

Jeney, A., E. Béki, A. Keszthelyi, J. F. Leslie & L. Hornok. 2007. Inactivation of Fpmtr, an amino acid transporter gene causes communication disturbances in *Fusarium proliferatum*. J. Basic Microbiol. 47: 16-24.

Hornok, L., C. Waalwijk & J. F. Leslie. 2007. Genetic factors affecting sexual reproduction in toxigenic *Fusarium* species. (accepted).

Bandyopadhyay, R., M. Kumar & J. F. Leslie. 2007. Relative severity of aflatoxin contamination of cereal crops in West Africa. (accepted).

Leslie, J. F., L. L. Anderson, R. L. Bowden & Y.-W. Lee. 2007. Inter- and intra-specific genetic variation in *Fusarium*. (accepted).

Reynoso, M. M., S. N. Chulze, K. A. Zeller, A. M. Torres & J. F. Leslie. 2007. Genetic structure of *Gibberella moniliformis* populations isolated from maize in Argentina. (accepted).

Low Input Ecologically Defined Management Strategies for Insect Pests on Sorghum

Project MSU 205
Henry N. Pitre
Mississippi State University

Principal Investigator

Henry N. Pitre, Entomologist/Professor, Mississippi State University, Box 9775, Mississippi State, MS 39762

Collaborating Scientists

Rafael Obando Solis, Agronomist, INTA, Apdo Postal 1247, Managua, Nicaragua
Carmen Gutierrez, Entomologist, INTA, Apdo Postal 1247, Managua, Nicaragua
Yanette Gutierrez, Plant Pathologist, UNA, Managua, Nicaragua
Martha Zamora, Entomologist, UNA, Managua, Nicaragua
Sergio Pichardo Guido, Plant Pathologist, UNA, Managua, Nicaragua
Francisco Varga, Agronomist, ANPROSOR, Managua, Nicaragua
René Clará, Sorghum Breeder, CENTA, Apdo Postal 885, San Salvador, El Salvador
Jaime Ayala Moran, Entomologist, CENTA, Apdo Postal 885, San Salvador, El Salvador
Leopoldo Cervantes, Entomologist, University of El Salvador, San Salvador, El Salvador
Reina Serrano, Plant Pathologist, CENTA, Apdo Postal 885, San Salvador, El Salvador
Mario Parada, Entomologist, CENTA, Apdo Postal 885, San Salvador, El Salvador
Larry Claflin, Plant Pathologist, Kansas State Univ., Manhattan, KS 66506
Rich Baird, Plant Pathologist, Mississippi State University, Mississippi State, MS 39762

Summary

MSU-205 sorghum plant protection research and institution building activities that had been centered in Honduras for over 20 years was de-emphasized in 2001 and expanded into Nicaragua and El Salvador, with emphasis on pest management in improved cropping systems on large agricultural farms on the Pacific coastal plain, representing agricultural systems unlike the low input, subsistence farming systems in Honduras. Activities on large farms can involve a much higher level of insect and disease pest management technology with greater cost to the farmer. Initial investigations in Nicaragua and El Salvador included studies on insect biology, behavior, ecology and population dynamics of the principal insect pests. In 2003 the MSU-205 project assumed responsibility of sorghum plant pathology research activities as part of the INTSORMIL plant protection program in this ecogeographic zone. MSU 205 collaborated in research activities with the Instituto Nicaraguense de Technologia (INTA), The Universidad Nacionial Agraria (UNA), the Nicaraguan National Sorghum Producers Association (ANPOSOR) in Nicaragua, and the University of El Salvador and the Centro de Technologio de Agricola (CENTA) in El Salvador. Information from collaborative participation in research involving entomologists and plant pathologists in university, government and producer organizations was used in developing cultural, biological and chemical control tactics for implementation in insect and disease management programs for specific pests or a complex of pests. Complementary research was conducted on insect pests and diseases in the United States. Professional agricultural workshops have increased agricultural capabilities of professionals in this region of Central America. Collaborative research with scientists in host countries and host country graduate student education has been fruitful in developing greater research capacity and furthering institution building activities in the respective host countries. Popular sorghum crop management articles have been published for farmer utilization in the application of recommended crop protection technology, sorghum research papers have been presented at meetings, and scientific papers on sorghum pest management have been published in professional journals.

Objectives, Production and Utilization Constraints

Nicaragua/El Salvador

- Determine principal insect pests and diseases on sorghum, identify damage and severity levels due to specific pest situations, and develop safe, implementable and economically acceptable pest management programs.
- Study biology, ecology, seasonal occurrence and population dynamics of insect pests and host plant relationships of plant disease pathogens with sorghum plants in different cropping systems.
- Tactics for management of insect pests and diseases are evaluated and include planting date, crop variety (host plant resistance), and pesticide efficacy.
- Investigate quality of stored sorghum grain and determine the levels aflatoxin associated with storage facilities.

(ADIN) in El Salvador. Lines were selected to be carried forward to future ADIN trials. These lines were selected for tolerance to diseases and insects, size and color of the grain, length of the panicle, aspects of plant growth and yield. Sixteen sorghum lines appeared to have some levels of resistance to certain plant diseases and insects; none of the lines had resistance to stem borers.

Whiteflies were first encountered on sorghum, rice and corn in Nicaragua in 2003 by scientists at the University of El Salvador. The damage caused by this pest on these crops is lethal to young plants and later infestations reduce yield significantly. Working with scientists at the University of El Salvador, aspects of the ecology and population dynamics of this whitefly have been elucidated, as has the identity of naturally occurring beneficial insects that play a role in the dynamics of whiteflies. Populations of this pest have declined in these crop production systems since 2003. Sorghum lines have been evaluated for whitefly resistance, with some lines having some levels of tolerance. The reason(s) for the whitefly population to have become an economic problem on these crops in El Salvador is not clear. However, the explosion of this pest in these systems possibly can be related to the extended and misuse of toxic chemicals in the system, particularly on rice, with associated harmful effects on the biological organisms (predators and parasites) that previously held the whitefly population at levels that did not cause damage to these susceptible crops.

Several extension-type publications related to specific plant diseases on sorghum and the whitefly problem in El Salvador have been published by the scientists at CENTA and the University of El Salvador with INTSORMIL MSU 205 participation. Professional meetings were attended and research papers presented.

United States

The economic threshold for caterpillar pests on whorl stage sorghum was investigated in 2001 and 2002 in Mississippi. Optimum procedures were determined for infesting plants with various numbers of larvae at different times during the day to improve artificial infestation methods for scientific studies. This research is required to elucidate pest infestation levels needed to warrant the practical use of insecticides. The generally recommended economic threshold of one larvae per plant was confirmed for whorl stage 2 (5 leaves) sorghum. This threshold level was determined to be too low for subsequent whorl stage plants.

The influence of sorghum-soybean rotational cropping systems on insect pest populations and incidence of plant diseases was investigated during 2003 through 2006 crop growing seasons. This crop rotation system improves yields of the two crops over continuous cropping of individual monocrop systems and is practiced to some extent in both the United States and some areas in Central America. Research plots were too small to obtain critical information on the very mobile insect pests that move throughout the study areas. All species remained below economic threshold levels throughout the study. The most prevalent disease on sorghum was zonate spot, whereas gray leaf spot was prevalent on soybeans. Gray leaf spot, brown spot and frogeye leaf spot fungal pathogens contributed to reduced yields in continuous sorghum and continuous soybean compared with soybean-sorghum rotations or sorghum-soybean rotations.

The stinkbug complex on sorghum was investigated with emphasis on stink bug development and behavior, and ecological relationships between the most prevalent stink bug (southern green stink bug) and its host and non-crop host plants in date-of-planting crop production systems. Studies also included economic thresholds on sorghum at three stages of plant development, namely milk stage, soft-dough stage and hard-dough stage. Developmental time from nymph to adult and percent mortality was 28 days (10%) on sorghum, 29 days (14%) on soybeans, and 28 days (23%) on corn. In host plant preference studies this stink bug preferred soybeans over corn, sorghum or cotton. The adults showed no feeding preference for sorghum in prebloom, bloom or milk, hard-dough or mature seed stages. Four or five adults or 20 nymphs per panicle during the milk stage to maturity of grain development increased the number of punctures per seed and reduced seed weight and seed germination compared with panicles infested during the milk to maturity stages, but densities of 4 or 5 adults per panicle reduced seed germination when confined on panicles during hard-dough to maturity stages of seed development. This stink bug information is useful in developing effective insect pest management programs on sorghum during the reproductive plant growth stages.

Two Ph.D. students will complete their respective graduate academic and research programs and graduate from Mississippi State University in May, 2007. One will return to Nicaragua as plant pathologist at UNA and the other to El Salvador as entomologist in CENTA to become involved in teaching and agricultural research programs.

The MSU 205 principal investigator traveled to Central America in each year of the project reporting period to coordinate multidisciplinary research programs and work with collaborator scientists in developing extension-type crop protection articles for publication and distribution into agricultural communities and scientific papers for publication in respective agricultural discipline journals. Professional meetings were attended by the principal investigator of MSU 205.

Networking Activities

Networking with ANPROSOR in Nicaragua provided opportunities to conduct on-farm integrated insect pest and disease management research with cooperation from many farmers associated with this National Sorghum Producers Association. Research activities on whiteflies on multiple crops in collaboration with scientists at the University of El Salvador proved to be very important in understanding this new devastating pest situation on sorghum, rice and corn in this region of Central America.

Publications and Presentations

Journal Articles

Gutierrez, Y., M. Zamora, R. Vilchez, O. Rugama and H. Pitre. 2007. Calidad fitosanitaria y presencia de aflatoxinas en granos de sorgo (Sorghum bicolor (L.) Moench). LaCalera. Nat. Univ. Nicaragua. Managa, NI. (Accepted).

Obando, R., C. Gutierrez, M. Zamora, G. Peterson, and H. Pitre. 2007. Evaluacion de lineas de sorgo por su resistencia a la mosquita, Stenodiplosis sorghicola (Coq.) en Nicaragua. LaCalera. Nat. Univ. Nicaragua. Managua, NI. (Accepted).

Miscellaneous Publications

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Striga Biotechnology Development and Technology Transfer

Project PRF 213
Gebisa Ejeta
Purdue University

Principal Investigator

Dr. Gebisa Ejeta, Dept of Agronomy, Purdue University, West Lafayette, IN 47907

Collaborating Scientists

Dr. Patrick Rich, Research Geneticist, Purdue University, West Lafayette, IN, 47907, USA
Dr. Fasil Redda, Weed Scientist, EARO, PO Box 436, Nazret, Ethiopia
Dr. Tesfaye Tesso, Sorghum Breeder, EARO, PO Box 436, Nazret, Ethiopia
Dr. Issoufou Kapran, Sorghum Breeder, INRAN, BP 429, Niamey, Niger
Dr. Aboubacar Touré, Sorghum Breeder, IER, Station des Sotuba, BP 262, Bamako, Mali
Dr. N'Diaga Cissé, Sorghum Breeder, INERA, BP 53, Bambey, Senegal
Dr. Asmelash Abraha, Plant Protection Officer, DARE, PO Box 4627, Asmara, Eritrea
Mr. Christopher Mburu, Weed Scientist, KARI, PO Box 169, Kakamega, Kenya
Mr. Elias Latayo, Agronomist, ARI/Hombola, PO Box 299, Dodoma, Tanzania
Dr. Ambonesigwe Mbwanga, *Striga* Specialist, ARI, Private Bag Ilonga, Kilosa, Tanzania
Dr. Abebe Menkir, Maize Breeder, IITA, PMB 5320, Oyo State, Nigeria

Summary

The parasitic weed *Striga*, particularly *S. asiatica* and *S. hermonthica*, remain major biotic constraints to cereal (sorghum, millet, maize) production in Africa. Remaining largely uncontrolled, *Striga* is responsible for keeping crop productivity in many of the *Striga* endemic regions of Africa at or below subsistence level. We have made significant progress in our *Striga* research at INTSORMIL focused on genetic control of the parasite specifically in sorghum. Our approach is based on developing a better understanding of the biology of interaction between the parasite and the hosts it attacks. We hypothesized that host plant genetic resistance to *Striga* spp. can be described in terms of specific points in the parasitic life cycle that require signal exchange between the host and parasite.

Using this approach, we have identified various characters that may improve *Striga* resistance in sorghum. We are able to import *Striga* seed and grow it in the laboratory by special permit from USDA-APHIS-PPQ. Thanks in large part to the stable and continued funding provided by INTSORMIL/USAID, we maintain the only operational parasitic weed containment facility in the U.S. for *Striga* research. Using this facility, we have developed and refined laboratory techniques that allow us to observe interactions between *Striga* and sorghum from weed seed germination through attachment, establishment of vascular connections and early growth on the host root system. We have utilized the extensive network of collaboration made possible through the INTSORMIL CRSP to test and verify our laboratory findings with field performance in *Striga* prone areas and introduce germplasm to African breeders in the earliest stages of development. By combining our work and that of other scientists working on root parasitic plants, we have revised and refined our understanding of the biology of host-parasite interactions.

Objectives, Production and Utilization Constraints

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

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

- To elucidate basic mechanisms for *Striga* resistance in crop plants.
- To combine genes for different mechanisms of resistance, through traditional breeding assisted by 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 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 Findings and Project Output

We have maintained the Purdue University Parasitic Weed Containment Facility since its establishment in 2000. The facility is the only place in the US where *Striga* can be grown. It is annually inspected by USDA-APHIS-PPQ. Here we maintain our collection of *S. hermonthica* from several East and West African countries and the Carolina strain of *S. asiatica*. In addition to research, the facility is used to train African scientists in basic biological research on *Striga*.

Striga resistant sorghums developed at Purdue/INTSORMIL have been extensively tested and released for wide cultivation in a number of African countries including Niger, Ethiopia, Tanzania, Eritrea, and Eritrea.

We have developed laboratory methods that allow detailed observation on specific mechanisms of *Striga* resistance in sorghum. With these bioassays, we have been able to identify new and novel variants of sorghum with resistance to *Striga*. These include low germination stimulant production, low haustorial initiation capacity, and hypersensitive and incompatible responses to infection. Some of these *Striga*-resistance traits have come from wild sorghums.

We have effectively introgressed these traits into more productive sorghum varieties and shared this improved germplasm with collaborating breeding programs in Africa. Some have been officially released and distributed being widely grown on *Striga* prone farms under various local names ("Gubiye", "Abshir" and "Brhan" in Ethiopia; "Hakika", "Wahi" in Tanzania).

With supplemental funding from USAID/OFDA, we introduced an "Integrated *Striga* Management" (ISM) program for control of *Striga*. We first undertook this as an emergency relief effort in areas of Ethiopia and Eritrea that have been plagued by the ravages of drought, *Striga*, and subsequently famine. This project was a success as it demonstrated relief to the *Striga* problem through the combined use of *Striga* resistant sorghums, moisture conservation practice, and improved soil fertility through the use of inorganic or organic fertilizers. Yields were increased multiple-fold in many places. In Ethiopia alone, an estimated 100,000 families have benefited from the ISM technology.

Description of Methods of Work Used

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 gene products from 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 this 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. Since 2001, 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 continues 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 have developed and tested economically feasible and practicable integrated *Striga* control packages in farmers' fields in selected African countries. 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.

Networking Activities

We have held several programs and workshops in target countries, promoting the ISM package (described in the Research Findings and Project Output section) as well as training in seed multiplication and laboratory methods for *Striga* biotechnology research.

In November, 2006 we hosted a gathering of international scientists in the fields of botany, plant biology, molecular biology, plant physiology, biochemistry, plant breeding, weed science, biological control and agronomy as well as economics in Addis Ababa, Ethiopia in a conference dealing with integrating new technologies for *Striga* control. The six day conference included a discussion of future funding opportunities and plans to cooperate in a multidisciplined approach to the *Striga* problem.

In addition to the graduate students trained with the support of INTSORMIL funding, we have had visitors from India, Ethiopia, Uganda, Burkina Faso, Eritrea, Mali, Niger, and Kenya visit our *Striga* research facility at Purdue University. Some have received extensive training in *Striga* biotechnology in our laboratory.

We have also exchanged germplasm with our African collaborators. They have sent us some of their breeding materials for laboratory characterization and in turn field test ours. Our various international *Striga* resistant sorghum nurseries have been organized and distributed to a number of African national programs, who have agreed to collaborate on free will basis. We have had nursery trials in Ethiopia, Kenya, Eritrea, Niger, Mali, and Tanzania. Seed of agronomically improved *Striga* resistant sorghum lines have been filled on a request basis.

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Sustainable Management of Insect Pests

Project WTU 200
Bonnie B. Pendleton
West Texas A&M University

Principal Investigator

Bonnie B. Pendleton, Assistant Professor of IPM, Entomology, Div. of Agriculture, Box 60998, West Texas A&M Univ, Canyon TX 79016

Collaborating Scientists

Mr. Fernando M. Chitio – IIAM, P.O. Box 36, Nampula, Mozambique
Mr. Joaquim A. Mutaliano - IIAM, P.O. Box 36, Nampula, Mozambique
Dr. Johnnie van den Berg – North West University, Potchefstroom, South Africa
Dr. Hannalene du Plessis – ARC, Private Bag X1251, Potchefstroom, South Africa
Dr. D. C. Munthali – Private Bag 0027, Botswana College of Agriculture, Gabarone
Dr. Niamoye Yaro Diarisso – IER/CRRA, B.P. 258, Bamako, Mali
Dr. Yacouba O. Doumbia - IER/CRRA, B.P. 258, Bamako, Mali
Mr. Mamadou N'Diaye - IER/CRRA, B.P., 258, Bamako, Mali
Mr. Hamé Abdou Kadi Kadi – INRAN, B.P. 429, Niamey, Niger
Dr. Gary C. Peterson – Texas A&M Ag Research and Extension Ctr, Route 3, Box 219, Lubbock, TX 79401
Dr. G. J. Michels, Jr. – Texas A&M Ag Research and Extension Ctr, 6500 Amarillo Blvd. West, Amarillo, TX 79106
Dr. Roxanne A. Bowling – Texas A&M Ag Research and Extension Ctr, 6500 Amarillo Blvd. West, Amarillo, TX 79106
Dr. Michael W. Pendleton – Microscopy and Imaging Ctr, Texas A&M University, College Station, TX 77843

Summary

Collaborative research and educational activities in integrated pest management of insect pests of sorghum and pearl millet in the field and storage were done with entomologists, plant breeders, and others from government agricultural research stations and universities in nine African countries and the United States. Biological and cultural control strategies, especially resistant cultivars, were developed and evaluated. Amplified fragment length polymorphism was used to locate molecular differences among biotypes of greenbug, and the biology of greenbug biotypes was determined on wild and cultivated hosts and in relation to temperature, photoperiod, soil fertility, and soil moisture. The information was used to more accurately evaluate resistance to greenbug biotypes of 3,434 sorghum genotypes developed by sorghum breeders with the Texas Agricultural Experiment Station and commercial seed companies. Resistance to maize weevils of different genotypes of stored sorghum grain and possible causes of resistance (grain size, hardness, moisture, protein, pericarp morphology) were determined. Stored grain retained as much as 99.2% of original weight after infestation by maize weevils. Light and scanning electron microscopies showed the pericarp of the most-resistant sorghum was twice as thick as that of the most-susceptible sorghum. Hundreds of sorghum and pearl millet genotypes were evaluated for resistance and grain yield and quality against aphids, panicle bugs, sorghum midge, stalk borers, shoot fly, storage insects, termites, millet head miner, and grain mold in the field and storage in Botswana, Mali, Mozambique, Niger, and South Africa. Research was published in 62 articles and presented 111 times at farmer, extension, and professional meetings in the U.S. and at many meetings in Africa. Since 2002, one Ph.D. student from Ethiopia and nine M.S. students from Mali, Mozambique, India, and the U.S. were educated at West Texas A&M University. The students returned to research and increase institutional capacity at agricultural research centers in their countries or are earning Ph.D. degrees from other universities.

Objectives, Production and Utilization Constraints

Objectives

Africa. Support scientists from Botswana, Mali, Mozambique, Niger, South Africa, and other countries to increase yield and income through research to evaluate resistance and develop IPM strategies for managing panicle-infesting bugs; sorghum midge, *Stenodiplosis sorghicola*; sugarcane aphid, *Melanaphis sacchari*; stalk borers, and storage insects in sorghum and millet head miner, *Heliocheilus albipunctella*, in pearl millet. Educate students in IPM and entomology. United States. Study biology, ecology, and population dynamics of insects so effective management can be developed. Evaluate sorghum grain for resistance to storage insects. Collaborate with breeders, commercial seed companies, and molecular biologists to develop sorghums with greater yield potential and resistance to insects. Educate students in IPM and entomology. Advise extension and commodity organizations on managing sorghum insects. Participate in meetings to transfer insect pest management information.

Production Constraints

Africa. Panicle bugs, sorghum midge, stalk borers, sugarcane aphid, and beetles in storage are the most damaging insects that reduce yield and quality of sorghum in Africa. The worst insects of pearl millet are millet head miner and *Coniesta ignefusalis* stalk borer.

United States. Major insect pests are greenbug, Schizaphis graminum; sorghum midge; panicle bugs; and caterpillars in the field and beetles and moths in stored grain. Biology, insect-plant interactions, amount of damage, and economic and ecological costs of control need to be understood. Biological and cultural strategies such as use of plant resistance are needed to prevent damage.

Research Findings, Project Output and Description of Methods of Work Used

This project emphasized collaborative research and education. The IPM approach was used to develop strategies to manage insects. 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, cultural controls including resistant varieties, and insecticide when necessary. Information and technology from research was transferred to farmers, extension personnel, researchers, and others.

West Africa. Dr. Yaro Diarisso determined percentages of grain damage and loss by lesser grain borer, *Rhizopertha dominica*, and other storage insects from April-September 2006 in Mali. Acar and 97-SB-F5 were least damaged (0.95 and 0.5%). Most damaged (5.3%) was 04-CZ-F5P. Grain damage and loss of Acar, Malisor84-7, 04-CZ-F5P, and 97-SB-F5DT was less in metal than cloth, plastic, or polyethylene containers at Sotuba, except Darrelken was less damaged in a plastic than metal container.

Dr. Yaro Diarisso interviewed 10 farmers (seven males and three females) in each of 19 villages (four, 10, and five in Koulikoro, Ségou, and Sikasso regions) in 2007 for their perceptions of pest control on millet and sorghum. Of 190 farmers, 131 controlled pests in the field (55 used insecticide), while 36 used no control (Table 1). 79%

Sixty-eight farmers (35.8%) used local plants, especially bénéfin (*Hyptis armigera*), neem (*Azadarachta indica*), and tamarin (*Tamarindus indica*), to control storage pests in granaries in Mali (Table 2). Some farmers believed local plants were effective while others said they could not afford to use chemicals to control pests of stored grain.

Southern Africa. The PI traveled to Botswana, Mozambique, and South Africa from 6-19 March 2007 to review and discuss research with entomologists and plant breeders. Mr. Chitio planted four replications of ATX635, Macia, Malisor84-17, Sima, and Sureño sorghum on 14 January 2005 and February 2006 and 2007 at Nampula Research Station in Mozambique. Maize weevils started to appear in the field on 15 April 2005 when the grain was at the hard-dough stage. Abundance of maize weevils peaked three weeks later. Sureño and Macia were least infested by maize weevils in the field. Yields were 2.3, 2.1, 1.7, 1.1, and 0.4 tons per hectare for Sureño, Sima, Macia, Malisor84-17, and ATx635. Although Sima was most infested, it yielded well at 2.1 tons per hectare. In 2006, no maize weevils were found in sorghum where legumes had been planted the previous year.

From 2004-2006, Dr. van den Berg and students enclosed whole panicles in plastic bags and removed them from fields and used a D-Vac to vacuum panicles at 26 sites in four provinces of South Africa. A total of 23,798 (14,590 adults and 9,208 nymphs) of 43 species of herbivorous Hemiptera was collected. This is compared to 57 species of panicle-feeding Hemiptera in the world and 42 species on sorghum in Africa. Fewer than eight individuals

Table 1. Control methods for pests in fields in the Koulikoro, Ségou, and Sikasso regions of Mali in 2007

	Number of farmers using by region			
Control method	**Koulikoro**	**Ségou**	**Sikasso**	**Total**
None	10	14	12	36
Insecticide	8	37	10	55
Apron at planting		18		18
Watcher	3	9	5	17
Rhonier leaves (Borassus flabellifer var aethiopum)	5	5	2	12
Chasing birds and monkeys	4	3	2	9
Seed treatment at planting	2	3	1	6
Burning cotton residue in the field, use of fertilizer	1	1	1	3
Crop rotation		2		2
Bamboo leaves (Oxythenantera abyssinica) and baobab fruit (Adamsonia digitata)		1	1	2
Early harvesting			2	2
Burning of blister beetles in the field	1	1		2
Burning of blister beetles in the field and chasing birds		1		1
Neem jelly + soap		1		1
Neem juice			1	1
Total	**34**	**96**	**37**	**167**

Table 2. Use of local plants to control storage insects in Koulikoro, Ségou and Sikasso regions of Mali

Plant name	Scientific name	Plant part used	Number of farmers using by region			Total
			Koulikoro	Ségou	Sikasso	
Bénéfin	*Hyptis armigera*		3	20	4	27
Neem	*Azadarachta indica*	All parts		2	9	11
Tamarin	*Tamarindus indica*	Leaves	8			8
N'Tiribara	*Cochlospernum tinctorium*	Leaves	1	1		2
N'Djiro plante à serpent	*Securidata longepedonculata*	Leaves		2		2
Mougoudro		Leaves		2		2
Dimokotoli	*Cassia nigricans*	Leaves	1			
Samacara	*Swarzia madagascariensis*	Fruit	1			1
Caïcedrat	*Khaya senegalinsis*	Bark		1		1
N'Gonan	*Sclerocarya birrea*	Leaves		1		1
Piment	*Capsicum*	Fruit		1		1
Bere		Leaves		1		1
Combretum	*Guiera senegalinsis*	Leaves				
N'Binikan		Leaves				
Ash			10			10
Gasoline			1			1
Total			**25**	**31**	**13**	**68**

Dr. Yaro Diarisso found most farmers threshed and stored sorghum and millet grain in Koulikoro and Ségou regions of Mali; in Sikasso, most farmers stored the entire sorghum panicle (13.9%) or millet spike (14.5%). Clay and cement (38.3%), clay on rock (18.5%), and clay alone (14.4%) were most often used for granaries. Different kinds of granaries were used in Koulikoro and Ségou regions than in the Sikasso region.

per 100 panicles were found of most species and are not considered pests of sorghum in South Africa, but many are pests of sorghum in West Africa, North and South America, and India. Twelve to 30 bugs per 100 panicles were found of Nezara viridula, two *Eurystylus* spp., *Campylomma* sp., one *Mirid* sp., and *Nysius natalensis*. Five species of Eurystylus were most abundant at 67.9 per 100 panicles. Bugs were present from flowering until grain hardening. Damage by bugs resulted in more kernels having rotten germ. Resistance to bugs differed among sorghum varieties.

United States. Temperature affects abundance of corn leaf aphid, *Rhopalosiphum maidis*, eaten by lady beetles (family Coccinellidae) that stay to eat greenbugs and other insect pests of sorghum and other crops. M.S. student Shivakumar Bheemappa used 80 individual corn leaf aphids in clip cages on Tx399 x RTx430 sorghum at 10, 15, 20, 25, 30, and 35°C in an incubator. The aphid in the clip cage was discarded after it produced an aphid that was retained. The pre-reproductive periods per aphid were 39.9 and 4.4 days at 10 and 30°C. The reproductive periods were 31.3 and 12.2 days at 15 and 30°C. Fecundity was greatest (54.1 nymphs per aphid) at 20°C. No nymphs were produced at 35°C. Each aphid at 10 and 35°C lived 66.3 and 5.7 days. (Table 3)

Madani Telly, an M.S. student from Mali, identified insects found on mature kernels of sorghum in the field and evaluated genotypes of stored sorghum grain for resistance to maize weevil. Dead maize weevils per gram of sorghum grain at 42 days after infestation in vials ranged from 0.02 for Sureño or ICSR-939 to 0.12 for Tx7078. Total numbers of weevils were 0.22 on Tx7078 and 0.92 on 87EON366*90EON328 at 42 days after infestation. Sureño was most resistant, while ICSR-939 and 87EON366*90EON328 were least resistant.

Networking Activities

The PI, graduate students, and collaborators attended and gave three presentations at the 55th Annual Meeting of the Southwestern Branch of the Entomological Society of America and the Annual Meeting of the Society of Southwestern Entomologists, Corpus Christi, Texas, 19-22 February 2007; nine presentations at the joint conference of the National Sorghum Producers and Southern Seed Association, Santa Ana Pueblo, New Mexico, 14-16 January 2007; three posters at the 54th Annual Meeting of the Entomological Society of America, Indianapolis, Indiana, 10-13 December 2006; oral presentations at the 18th Annual Texas Plant

Table 3. Effect of different constant temperatures on corn leaf aphids on sorghum

Temperature (°C)	Pre-reproductive period (days)	Reproductive period (days)	Fecundity (nymphs)	Longevity (days)
10	36.9 ± 1.98 a	29.6 ± 2.41 a	12.5 ± 1.75 d	66.3 ± 5.10 a
15	14.4 ± 0.29 b	31.3 ± 1.42 a	46.8 ± 2.41 ab	63.4 ±2.08 a
20	7.8 ± 0.13 d	19.5 ± 0.67 b	54.1 ± 2.06 a	41.9 ± 0.99 b
25	5.2 ± 0.15 e	18.3 ± 0.72 b	38.3 ± 2.02 bc	32.7 ± 0.89 c
30	4.4 ± 0.10 e	12.2 ± 0.57 c	28.9 ± 1.65 c	18.5 ± 0.67 d
35	9.8 ± 2.46 c	0.0 ± 0.00 d	0.0 ± 0.00 d	5.7 ± 0.68 e

Means followed by the same lowercase letter are not significantly different (LSD, $P = 0.05$).

Protection Conference, 5-6 December 2006 and at the Entomology Science Conference, 24-26 October 2006, College Station, Texas; and presented an invited seminar on management of insect pests in the US and Africa for the Department of Agricultural Sciences, West Texas A&M University, Canyon, 27 September 2006. From 6-19 March 2007, the PI traveled to Botswana, Mozambique, and South Africa to discuss and view collaborative entomology research. The PI advised extension, National Sorghum Producers, and commercial seed companies on management of sorghum insect pests in the U.S. Four hundred one sorghum lines developed for resistance to biotype I greenbug were evaluated for Milo Genetics. Reference books, supplies, and/or funding were provided to Mr. Abdou Kadi Kadi in Niger, Mr. Chitio in Mozambique, Dr. Yaro Diarisso in Mali, and Dr. Munthali in Botswana.

Publications and Presentations

Journal Articles

Peterson, G.C., K. Schaefer and B.B. Pendleton. 2007. Registration of Tx2962 through Tx2978 biotype E and I greenbug-resistant sorghum germplasm lines. Crop Science 47:453-455.

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Cronholm, G., A. Knutson, R. Parker and B. Pendleton. 2007. Managing Insect and Mite Pests of Texas Sorghum. Texas Agricultural Extension Service Bulletin B-1220, College Station, TX.

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Bheemappa, S., B.B. Pendleton and G.J. Michels, Jr. 2007. Development of corn leaf aphid, Rhopalosiphum maidis (Fitch) (Hemiptera: Aphididae) at different temperatures on sorghum. Joint conference of the National Sorghum Producers and Southern Seed Association, 14-16 January 2007, Santa Ana Pueblo, NM.

Bowling, R.A., B.B. Pendleton and G.J. Michels, Jr. 2007. Managing spider mites and resistance in maize and sorghum. Joint conference of the National Sorghum Producers and Southern Seed Association, 14-16 January 2007, Santa Ana Pueblo, NM.

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Chitio, F., B.B. Pendleton and M.W. Pendleton. 2007. Resistance of sorghum grain to maize weevil. Joint conference of the National Sorghum Producers and Southern Seed Association, 14-16 January 2007, Santa Ana Pueblo, NM.

Damte, T. and B.B. Pendleton. 2007. Texas sorghum producers' perception of sorghum midge (*Diptera*: *Cecidomyiidae*). P. 36. Proceedings of the 55th Annual Meeting of the Southwestern Branch of the Entomological Society of America and the Annual Meeting of the Society of Southwestern Entomologists, 19-22 February 2007, Corpus Christi, TX.

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Damte Belete, T., B.B. Pendleton and L.K. Almas. 2007. Economic benefit of using a resistant sorghum hybrid to manage sorghum midge (*Diptera*: *Cecidomyiidae*). Joint conference of the National Sorghum Producers and Southern Seed Association, 14-16 January 2007, Santa Ana Pueblo, NM.

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Thesis

Bheemappa, S. 2007. Effect of Temperature on Growth and Development of Corn Leaf Aphid (*Hemiptera*: *Aphididae*) on Sorghum. M.S. thesis, West Texas A&M University, Canyon, TX.

Presentations

55th Annual Meeting of the Southwestern Branch of the Entomological Society of America and the Annual Meeting of the Society of Southwestern Entomologists, Corpus Christi, TX, 19-22 February 2007 – S. Bheemappa, B. Pendleton and J. Michels, *Development of corn leaf aphid, Rhopalosiphum maidis (Fitch) (Hemiptera: Aphididae)*, at different temperatures on sorghum; T. Damte and B. Pendleton, *Texas sorghum producer's perception of sorghum midge (Diptera: Cecidomyiidae)*; M. Telly and B. Pendleton, *Resistance of stored sorghum to maize weevil (Coleoptera: Curculionidae)*.

Joint conference of the National Sorghum Producers and Southern Seed Association, Santa Ana Pueblo, NM, 14-16 January 2007 – T. Damte Belete and B.B. Pendleton. *Texas sorghum producers' perceptions of sorghum midge (Diptera: Cecidomyiidae)*; T. Damte Belete, B.B. Pendleton and L.K. Almas,

Economic benefit of using a resistant sorghum hybrid to manage sorghum midge (Diptera: Cecidomyiidae); S. Bheemappa, B.B. Pendleton and G.J. Michels, Jr., *Corn leaf aphid fecundity and longevity at different constant temperatures on sorghum;* S. Bheemappa, B.B. Pendleton and G.J. Michels, Jr., *Development of corn leaf aphid, Rhopalosiphum maidis (Fitch) (Hemiptera: Aphididae) at different temperatures on sorghum*; R.A. Bowling, B. B. Pendleton and G.J. Michels, Jr., *Managing spider mites and resistance in maize and sorghum*; R.A. Bowling, B.B. Pendleton, G.J. Michels, Jr. and R. Bowling, *Alternatives to organophosphates and carbamates for managing aphids in wheat and sorghum*; F. Chitio, B.B. Pendleton and M.W. Pendleton, *Resistance of sorghum grain to maize weevil*; B.B. Pendleton, *Insect pests of sorghum.*

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18th Annual Texas Plant Protection Conference, College Station, TX, 5-6 December 2006 – B.B. Pendleton, *Managing aphids in sorghum production.*

Entomology Science Conference, College Station, TX, 24-26 October 2006 – S. Bheemappa, B. Pendleton and J. Michels, *Effect of temperature on corn leaf aphid on sorghum.*

Department of Agricultural Sciences, West Texas A&M University, Canyon, 27 September 2006 - B. Pendleton, *Management of insect pests in the U.S. and Africa.*

Sustainable Production Systems

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

Project PRF 205
John Sanders
Purdue University

Principal Investigator

John H. Sanders, Purdue University, Dept of Agricultural Economics, West Lafayette, IN 47907

Collaborators

Felix Baquedano, Apartado Postal 6149, Managua, Nicaragua
Tahirou Abdoulaye, INRAN, BP 429, Niamey, Niger
Kidane Georgis, EARO, PO Box 2003, Addis Ababa, Ethiopia
Barry I. Shapiro, ICRISAT, Patancheru AP 502 324, Hyderabad, India
Jeffrey D. Vitale, Dept of Ag Economics, Oklahoma State University, Stillwater, Oklahoma 74078
Rafael Uaiene, INIA, Caixa Postal 3658, Maputo, Mozambique
Nega Wubeneh, ILRI, BP 5689, Addis Ababa, Ethiopia
Yigezu Yigezu, ILRI, BP 5689, Addis Ababa, Ethiopia
Botorou Ouendeba, Marketing-Processing Project, Niamey, Niger
Lloyd Rooney, Texas A&M, College Station, Texas 77843
Joe Hancock, Kansas State University, Manhattan, Kansas 66502
Ababacar Ndoye, ITA, Dakar, Senegal
Aboubacar Toure, IER, Bamako, Mali
Maman Nouri, INRAN, Maradi, Niger

Summary

The Marketing-Processing Project has demonstrated in Niger that sorghum yields can be consistently raised to two to three tons and that it is very profitable for farmers to do so. In the two other countries (Mali and Senegal) improvements are being made in the basic cultivars but similar sorghum yield gains are expected. Millet yields of 1.3 to 1.9 yields are being regularly obtained in all three countries. Millet is grown on poorer soils (lower principal nutrient levels and more sandy) than sorghum so yields of 1.5 to 2 tons/ha are very respectable, whereas we expect 2.5 to 3.5 tons/ha for sorghum from improved technologies.

Two marketing strategies of improving the grain quality and selling later after the recovery from the post harvest price collapse raised prices received 10 to 37% in the 2005 crop year[1]. There are two more marketing strategies including the development of increased demand from the food and feed processing sector and convincing policy makers not to depress prices in adverse rainfall years.

In Thiare, a major millet zone in Senegal, millet food processors negotiate contracts with the farmers' groups and pay a quality premium of 20 to 30 CFA/kg. for the clean millet.The marketing activities for millet with food processors are progressing well in all three countries. There continues to be some resistance to paying a quality premium in Mali but we will be doing further extension activities to explain to food processors the importance of paying for the additional grain if they expect farmers to regularly incur the additional costs to achieve higher yields of a uniform cultivar and to reduce impurities. With ANCAR extension we will quadruple our area in Thiare in 2007-08 since both the technology and the marketing components are functioning well.

For sorghum the major potential market is to substitute for maize in the cereal for the poultry ration. Sorghum yields needs to be increased, as in Niger, so that the sorghum price can undercut that of maize. Surveys of poultry producers in three countries of the Sahel (Senegal, Burkina Faso, and Mali) are either underway (first two countries above) or being planned (Mali). Approximately 10 % of the intensive poultry producers either are mixing or plan to mix their own purchased cereals with the other feed components. This is the group targeted to buy small lots 10 to 40 tons of sorghum from the farmers' groups.

1. Normally part of these sales occur in the spring and summer of 2007 so we have to wait until the summer after the crop season to evaluate their marketing strategy.

Objectives, Production and Utilization Constraints

During the past five years we have worked in four Sahelian countries (Senegal, Mali, Niger, and Burkina Faso) to extend our research activities. The Marketing-Processing Project is a regionally supported West African AID activity. This project has the ob-

jective of getting new production technologies onto the farms of sorghum and millet producers in West Africa by providing credit for inputs to farmers' groups plus introducing marketing strategies to obtain higher prices for farmers.

From our research we had identified the importance of price collapses in discouraging farmers from higher input use (Sanders and Shapiro, 2006). The two initial, strategies are to encourage farmers to sell later after the recovery from the post harvest price collapse, to produce clean grain, and to encourage food and feed processors to pay farmers for this clean grain. A secondary component of the project is to work with food and feed processors in the four countries.

There have been two major research activities in our INTSORMIL research project. First we evaluate the farm impacts of new technologies being introduced into sorghum and millet production zones in semiarid Sub Saharan African agriculture. For example we evaluated the diffusion of and estimated the potential impact of new *Striga* resistant sorghum cultivars and associated technologies (fertilizers and water harvesting techniques) being introduced into two major states of Ethiopia, Tigray and Amhara. .

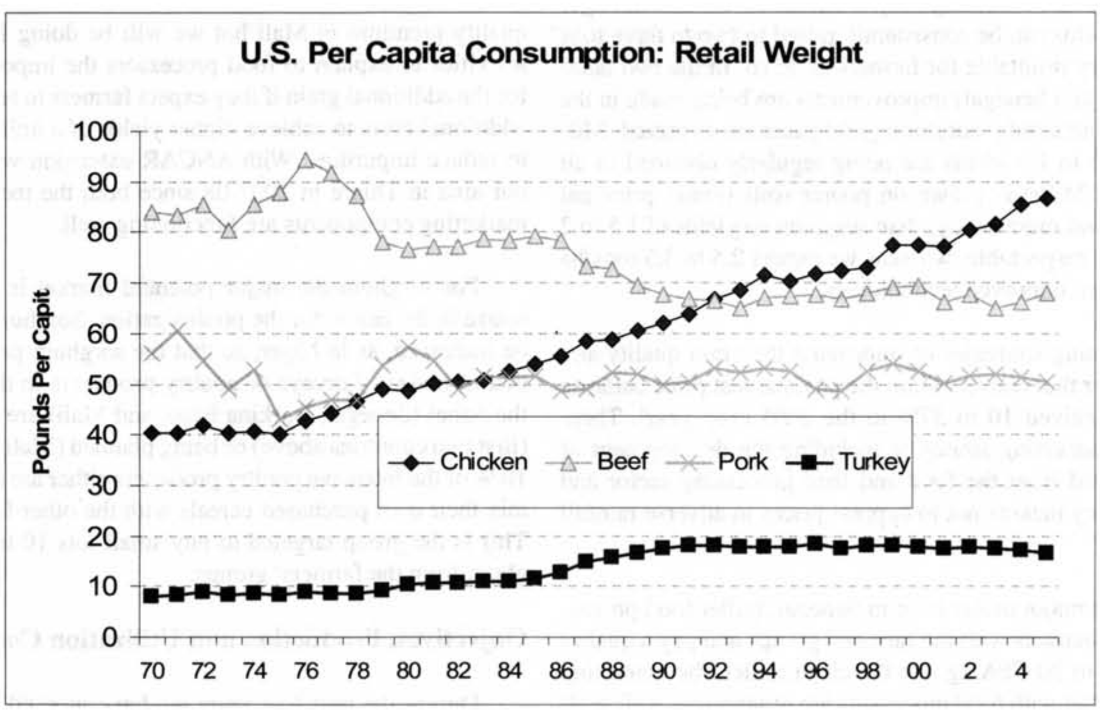
Another major activity is the research support for the Marketing-Processing Project. As part of this activity we estimate the farm level gains to new technologies and to the new marketing strategies. We also look in depth at specific policy alternatives such as evaluating Inventory Credit ("warrantage") programs.

Research Findings and Project Output

Botorou Ouendeba and John Sanders developed the Marketing-Processing Project for farmers' groups and food and feed processors of millet and sorghum. This program combines new technologies with improved marketing strategies (J. Sanders and B. Shapiro, 2006). In the first two years (2003 and 2004) this project relied on other agencies to extend sorghum and millet technologies to farmers. The contribution of the Marketing-Processing Project then was on developing new marketing strategies for farmers to increase their incentives to adopt new technologies. In 2003 and 2004 this activity was supported by INTSORMIL. Over the three years 2005- 2007 this Marketing-Processing Project has been financed by the Regional West African office of USAID. The AID funding has enabled us to support our own farmers' groups in their introduction of the new technologies of sorghum and millet.

The market focus of this program is on the rapidly expanding millet food processing sector in urban Sahel[2] and the substitution of sorghum for maize in the ration for intensive broiler and egg production. With increasing incomes there is a structural change in diets in developing countries to more meat, milk, cheese, fruits and vegetables. One of the main beneficiaries of this process across countries is broilers. A long run process of falling broiler prices relative to other meats converts chicken from a luxury food to a middle class and then even lower class principal meat source. These falling costs result from intensive poultry producers learning how to reduce their costs by gaining experience and on the consumption side from increasing vertical integration and economies of size. This process of the shift in consumption to chicken is

Figure 1. Source: USDA data provided by Chris Hurt, Department of Agricultural Economics, Purdue University.



2. Even though millet is the preferred grain for the food processors they have bought sorghum from our project farmers in all three countries to mix with the millet flour.

Table 1. Farmers and areas in new sorghum and millet technologies in Mali, Niger and Senegal, summer of 2006

Country and locations	Sorghum area	Sorghum farmers	Millet area	Millet farmers
Mali				
Koutiala	50	41	-	-
Kafara	62.5	48	-	-
Tingoni	-	-	50	50
Niger				
Gabi	60	118	-	-
Maraka	40	134	-	-
Doutchi	-	-	50	50
Senegal				
Diobene Talene	25	25	-	-
Mbodiene	20	20	-	-
Ndianda	20	20	-	-
Thiare	-	-	50	50
Dianke Souf	20	9		
Nganda	5	4		
TOTAL:	**302.5**	**399**	**150**	**150**

Source: J. H. Sanders and B. Ouendeba, Annual Report 2006: Marketing-Processing Project, preliminary draft., 8 pages.

illustrated in Figure 1 for the U.S. experience. But this same process of the substitution of chicken for other meats is accelerating in a number of African countries including Senegal.

What is the potential of sorghum to substitute for maize in the cereal component of the ration? According to nutritional evidence non-tannin sorghum[3] has approximately 95 to 97% (J. Hancock, correspondence) of the feed value of maize. So sorghum yields need to increase sufficiently so that it can be profitably sold for less than 95% of the maize price. Sorghum has an advantage in the Sahel over maize from being less susceptible to drought and low soil fertility. Moreover, unlike maize sorghum does not allow mico-toxin development in the field.

In Table 1 we report the number of farmers and cultivated area adopting technologies in the Marketing-Processing project. The summer of 2006 was the second year of intensive on-farm activities. The outstanding success story is in Gabi and Maraka, Niger. There farmers doubled to tripled yields of sorghum for the second year by following program recommendations. The new cultivar Sepon 82 has been very popular with Nigerien farmers. Many farmers in the surrounding region and even from Nigeria have been buying the grain for seed. The principal buyer from these sorghum producers has been Harouna Labo, the largest egg producer in Niger. Mme Cisse, a millet food processor, has historically been the most important buyer of millet from our farmer producer groups and she has been purchasing sorghum from the program farmers in 2006.

The program successes in doubling to tripling sorghum yields have been encouraging us to rapidly expand the program. In Senegal, Mali, and Niger we are expanding the number of farmers and the cultivated areas in the regions where farmers are following the technology and marketing recommendations as well as developing their own farmer organizations. These more successful zones are Thiare (millet) in Senegal, Kafara (sorghum) and Tingoni (millet) in Mali, Gabi, Maraka, and Doutchi in Niger. In other regions the inorganic fertilizer ended up on other crops besides the sorghum and/or the new technologies were planted late and on the poorer soils.

There has been useful feedback to the breeders in both Mali and Senegal from the program. In Mali a shorter, sturdier cultivar is being demanded by farmers. Farmers appreciate one of the new cultivars with these characteristics observed in regional trials of Aboubacar Toure of IER in Mali. In Senegal the lack of sorghum improvement programs in the last two decades means that there are not many non-tannin sorghum cultivars available. The Senegalese sorghum breeder of ISRA, Ndiaga Cisse, is presently trying to remedy this situation. More advance work needs to be done to convince farmers that with higher yields and prices sorghum can be competitive with cotton and maize in profitability terms.

Marketing recommendations have been critical in increasing the profitability of these technology innovations especially by encouraging farmers to sell later than at the post harvest price collapse. Secondly, the program provides "baches" (tarps) to keep the threshing off the ground. Clean grain not only saves processors a cleaning cost but also provides 10% to 20% more grain by eliminating the dirt, sand and rocks from doing threshing on the ground. A second marketing strategy is to press food and feed processors to pay a quality premium for both the savings in cleaning costs but also the increased quantity of grain. Table 2 summarizes the price gains obtained by farmers in the different regions, which can be principally attributed to the two marketing strategies above. These price gains make a substantial difference in raising the profitability of the new technology components. These technology components

3. In a recent bulletin of the Marketing-Processing project (Abdoulaye et al, 2006) it was demonstrated that it is now a myth that all sorghum cultivars have tannin. In all four countries of the Sahel there are now many non and low tannin cultivars of sorghum available.

Table 3. Household incomes (in dollars) for different technology and marketing strategy for the different states of nature (model results), Niger.

	Without New Technologies	With New Technologies	New technologies and inventory credit	New technologies with less government intervention in bad years	New technologies and only moderate price collapse in good and very good years
Adverse	459 (159)	529 (244)	528 (246)	775 (478)	530 (249)
Normal	583 (278)	794 (504)	827 (543)	849 (574)	792 (511)
Good	647 (334)	914 (623)	955 (670)	1018 (736)	11146 (865)
Very good	640 (322)	977 (684)	1016 (731)	1107 (826)	1559 (1278)
Expected income	587 (279)	805 (515)	835 (550)	914 (633)	939 (657)

Source: Abdoulaye, T. and J.H. Sanders, 2006. "New technologies, marketing strategies and public policy for traditional food crops: Millet in Niger," Agricultural Systems, 90: p. 288.
Numbers in parentheses are crop incomes and outside of the parenthesis are whole farm incomes. Both are in dollars.

include improved cultivars, moderate levels of inorganic fertilizer, and improved agronomy.

Then in our research we complement the extension activity by evaluating the income effects of different marketing strategies. In the US and other developed countries there are both insurance programs (federally subsidized for drought regions) and disaster assistance to aid farmers in drought regions during adverse rainfall years. In West Africa there are public programs for the worst years, the major drought years, which occur approximately once a decade. However, for poor rainfall years governments often intervene to drive down consumer prices of the basic staples. This public sector behavior makes it more difficult for farmers to make money and then invest in annual inputs and in fixed investments. Table 3 demonstrates that a public policy program to convince governments not to intervene in bad rainfall years could result in substantial benefits to farmers waiting to sell after harvest. This type of non-intervention by government in bad years[4] by allowing the food staple prices to go up then would serve some of the same purposes as risk insurance and disaster assistance in the US of raising farmers' incomes in adverse rainfall years.

One major problem with the principal food staples is that in normal and good rainfall years there is an abundant supply but consumers can only eat so much. Once consumers with income have their food requirements, there are few other uses hence prices of food staples collapse. To moderate this good weather price collapse one strategy is to facilitate the evolution of the food and feed processing sector. This provides an alternative market thus setting a floor on prices primarily for good rainfall years. In the last column of table 3 the impact of this market evolution in moderating the price decline in good and very good years is estimated. With this development of the food and feed sector farmers' incomes are increased by 16%.

Another study, also a spin-off from the Marketing-Processing Project, was an examination of Inventory Credit Programs. These programs enable farmers to obtain cash at harvest for the many pressing expenditures incurred at this time. In improved Inventory Credit programs farmers retain ownership of their grains so they can then sell them later in the season. Farmers repay the credit plus interest and storage costs once they have sold their grain. The farmers' group holds the grain as an assurance of repayment but the farmers make the decisions on when and where to sell. As presently implemented in the Sahel these Inventory Credit programs tend to make profits for the producers' groups but give few incentives to farmers. Farmers turn their grains over to the farmers' groups and receive the harvest time prices. The farmers' groups make the profits from the seasonal price increase and use the profits to purchase fertilizers for the group for next season with quantity discounts from larger purchases. Returning the control of the grain to the farmers rather than the producers' groups increases farmers' expected income by 8% (Baquedano and Sanders, 2006, p. 307).

4. Prices for sorghum and millet are in the 90 to 110 FCFA/ kg range in normal years. As the prices go to 200 FCFA/kg governments normally intervene with food aid or imports to drive down these prices. If the national governments waited until the price were 240 FCFA before intervening to drive down prices, farmers would be substantially benefited as indicated in Table 3.

Description of Methods of Work Used

In the Marketing-Processing Project there is an extension approach to getting technology and marketing strategies used by farmers. We are also engaged with food and feed processors in developing better ties and higher prices for the farmers' groups. We provide feedback to the plant breeders researchers on how the technologies are functioning. Moreover, this project helps identify many research issues. Some of these applied issues are handled within the project such as surveys on the importance of tannin in West African sorghum cultivars. We have also been interviewing millet processors about the purchasing decisions especially the premium for higher quality millet. We interview poultry producers about their decision to mix their own feeds and to substitute sorghum for maize in the ration. This extension project helps us identify issues for further in depth analysis in our INTSORMIL funded research program.

In our research we rely on survey data of farmers and do modeling from that to answer a series of policy related questions about technology introduction and marketing. For example with Tahirou Abdoulaye we have estimated the income effects of four of the marketing strategies being introduced. With Felix Baquedano we

have investigated the effects of improvements in the types of Inventory Credit Programs being introduced in West Africa. A major activity has always been estimating the impacts of new technology introduction. This research is based upon farmer surveys though in Mali a sector model was developed by Vitale to more accurately predict national effects.

Networking Activity

With the Marketing-Processing Project there are a large number of systematic ties to other agencies. The most important of these are to the national agricultural research organizations (IER in Mali, INRAN in Niger, INERA in Burkina Faso, and ISRA in Senegal) and to the extension agencies, either the national extension service, (ANCAR in Senegal) or to NGOs working at the village level (Catholic Relief Services in Niger, Global 2000 and AHMED in Mali). With the national agricultural research agencies we identify the technologies and obtain the seed of the new cultivars. Then the extension groups work with us in getting the technologies to farmers' groups and in providing technical services to these farmers to support the introduction of the technologies and the marketing strategies. We also involve the millet processors, intensive poultry producers and feed mixers in our activities tying them where possible to the farmers' groups. As part of this networking we hold an annual workshop to explain what we are doing and to get feedback from the agencies, firms and farmers involved.

Publications and Presentations

Journal Articles

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

Project UNL 213
Stephen C. Mason
University of Nebraska

Principal Investigators

Dr. Stephen C. Mason, University of Nebraska, Dept of Agronomy, Lincoln, NE 68583
Dr. Samba Traoré, Cinzana Research Station, IER, BP 214, Segou, Mali
Dr. Nouri Maman, INTARNA Research Station, BP 429, Maradi, Niger
Dr. Minamba Bagayoko, IER, Niono, Mali
Dr. Taonda Sibiri Jean Baptiste, INERA, Koudougou, Burkina Faso
Mr. Seyni Sirifi, INRAN, Kollo, Niger
Mr. Sìebou Pale, INERA, Koudougou, Burkina Faso
Mr. Maximo Hernández Valle, CENTA, San Salvador, El Salvador
Mr. Orlando Téllez Obregón, INTA, Somoto, Nicaragua
Mr. Leonardo García Centeno, UNA, Managua, Nicaragua

Collaborating Scientists

Ing. René Clará Valencía, Central America Regional Coordinator, San Salvador, El Salvador
Dr. Bruce Hamaker, Food Scientist, Purdue University, West Lafayette, IN 47907
Dr. Jeff Wilson, Millet Breeder, USDA-ARS, Tifton, GA 31793
Dr. Issoufou Kapran, Sorghum Breeder, INRAN, Niamey, Niger
Dr. Charles Wortmann, Soil Scientist, University of Nebraska, Lincoln, NE 68583
Dr. Martha Mamo, Soil Scientist, University of Nebraska, Lincoln, NE 68583
Dr. David Jackson, Food Scientist, University of Nebraska, Lincoln, NE 68583
Boniface Bougouma, Food Scientist, IRSAT/DTA, Ouagadougou, Burkina Faso
Prof. R. Klein, Agronomist, West Central Res. & Ext. Center, Univ. of Nebraska, North Platte, NE 69101
Dr. Roger Elmore, Agronomist, University of Nebraska, Lincoln, NE 68583
Dr. Drew Lyon, Agronomist, Panhandle Res. & Ext. Center, Univ. of Nebraska, Scottsbluff, NE 69361
Dr. Alex Martin, Weed Scientist, University of Nebraska, Lincoln, NE 68583
Dr. Lloyd Rooney, Food Scientist, Texas A & M University, College Station, TX 77843
Ing. Vilma Ruth Calderon, Food Scientist, CENTA, San Salvador, El Salvador
Ing. Quirino Argueta Portillo, Soil Scientist, CENTA, San Salvador, El Salvador
Ing. Rafael Obando Solis, Plant Breeder, CNIA/INTA, Managua, Nicaragua
Mr. Nanga Mady Kaye, Agronomist, Moundou, Chad
Dr. Gerrit Hoogenboom, Agronomist, University of Georgia (SANREM) CRSP

Summary

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 average pearl millet and sorghum grain yield across four years and three West African countries by 372 kg ha^{-1} (67%) and stover yield by 838 kg ha^{-1} (51%). Microdose application resulted in similar net nutrient removal as the zero fertilizer control. Over 30 kg N ha^{-1} and approximately 10 kg P ha^{-1} were required to eliminate mining of nutrients from the soil. The highest grain and stover yields required 20 kg P ha^{-1} and 30 kg N ha^{-1}. 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 N ha^{-1} application increased grain yield by approximately 800 kg ha^{-1} (26%) over the local check without N application. These results were validated on-farm, and transfer has occurred in the Department of Cabañas in El Salvador with economic benefits of several miilion dollars. Transfer activities are starting in the Department of Chalatenango and in Honduras In studies on N use

efficiency (NUE), yields of photoperiod insensitive lines ranged from 1.8 to 3.0 Mg ha^{-1} in El Salvador, but only ICSVLM-90520 produced a higher yield than the best control variety of Soberano and had high NUE. In Nicaragua, 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 the check variety Pinolero. ICSCVM-93076 was N responsive while still producing high yields without N application. These lines have been incorporated into public plant breeding programs.

In El Salvador, average grain yield of photoperiod insensitive varieties 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%), documenting the importance of N fertilizer use to increase grain sorghum yields.

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 and hardness were increased for sorghum rotated with non-nodulating and nodulating soybean. This study along with research on environment influence on grain quality of food-grade sorghum have shown that production practices have a large impact on grain quality, and should be considered in production of value-added grain for human food, livestock feed and industrial uses.

Project principal investigators have incorporated research results into extension bulletins (production guides) in El Salvador and Nicaragua.

INTSORMIL Project UNL-213 has emphasized capacity development through graduate education and short-term training, Graduate degrees have been earned by students from Burkina Faso, Chad, Niger and the U.S.

Objectives

Production and Utilization Constraints

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 and Central America, but a source of N and/or P often is more critical. Nutrient and water use efficiencies are closely interwoven with higher yields possible with improved cropping systems utilizing improved cultivars. Another important constraint to production and utilization of pearl millet and grain sorghum is the limited human capital for research and extension activities.

Objectives

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

Conduct research on mechanized (i.e., animal traction) zaï production system for pearl millet and crop/soil management for traditional sorghum beer production in Burkina Faso, weed control interactions with fertilizer in Mali, and poultry manure use for pearl millet production in Niger.

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

Determine environment interactions with food-grade sorghum hybrids for grain yield and quality.

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 and grain sorghum are important crops through graduate education, short-term training and through mentoring former students upon return to their home country.

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

Domestic (Nebraska) Research Activities

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-noduating soybean with different fertilizer applications (zero, 90 kg ha^{-1} N to sorghum and 45 kg ha^{-1} N to soybean, and annual feedlot manure) was studied to separate N and non-N effects of crop rotation.

Research Results

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}, stover yields by 1.5 to 1.8 Mg ha^{-1}, and soil NO3-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 NO3-N at vegetative growth stage. Biologically fixed N accounted for only 35 to 41% of enhanced sorghum yield due to crop rotation with soybean. On average grain N concentrations were increased by 0.5 to 1.0, 2.5 to 5.0 and 3.3 to 4.7 g kg^{-1} for N application to continuous sorghum and sorghum rotated with non-nodulating and nodulating soybean, respectively. Cropping sequences influenced grain hardness to a lesser extent. Irregardless of cropping sequence, manured plots produced the highest grain and stover yields, grain N concentration, and grain hardness. TADD removal indicated that continuous sorghum without manure or N application produced the softest grain with 43 to 44% TADD removal, and sorghum rotated with nodulating soybean with manure application produced the hardest grain with 22 to 27% TADD removal. Cropping sequence and soil amendment choices are important to assure optimal sorghum grain yield and quality important for food and livestock feed uses.

Environment effect on White Sorghum Hybrid Grain Yield and Quality (Joni Griess, M.S. Thesis)

Research Methods

Eight commercial food-grade commercial grain sorghum hybrids, one food-grade variety check (Macia), three experimental food-grade hybrids along with six commercial check hybrids were planted in randomized complete block designed experiments in six environments in 2004 (east central and central Nebraska locations with and without irrigation) and seven environments in 2005.

Research Results

Grain yields and kernel weights varied greatly across environments. Harder kernels were produced in 2005 environments than in 2004 environments, with Orleans 2005 having the lowest TADD removal. Low N environments had the lowest protein concentrations in both years and the highest starch concentration in 2005. Dryland environments in 2005 with hard kernels had high starch setback viscosities as a result fo high final viscosities and moderate holding viscosities, indicating that products made from grain produced in these environments would have similar qualities. Commercial check hybrids produced higher yields and heavier kernel weights than food-grade hybrids. Hybrid differences for bulk and true density were small, while TADD removal differences were larger. The food-grade check Macia had the lowest TADD removal of 21% which was similar to Asgrow Orbit and UNL N252AX1038R. Starch cooking properties of NC+7W92, Kelly Green Seed KG6902, Asgrow Eclipse and Fontanelle $W^{-1}000$ had high peak viscosities, dispersed starch molecules during shear thinning, and high final and setback viscosities. The opposite was true for Macia, UNL 03H21203, UNL N252AX1038R, Asgrow Orbit and NK1486 desirable for many food uses. Kelly Green Seed KG6902, Fontanelle $W^{-1}000$ and NC+7W92 had lower protein and higher starch concentrations and softer kernels, indicating likely usefulness for brewing and ethanol production.

Water Supply on Pearl Millet and Sorghum Yield and Water Use Efficiency (Nouri Maman, Ph.D. Thesis)

Research Methods

The experiment was conducted on a Keith silt loam under a linear move irrigation system with drop nozzles in western Nebraska (semi-arid environment) in 2000 and 2001. The experiment was conducted using a randomized complete block design with a factorial (2 x 4) treatment arrangement and three replications. Factor 1 was the pearl millet hybrid (68Ax 086R) and one grain sorghum hybrid (DK 28E). Factor 2 was composed of four different water regimes. The water regimes consisted of; (i) Control, rainfed; (ii) Full water supply at all growth stages; (iii) water supply at boot stage, and (iv) water supply at grain fill stage. Environments were considered to by year, location and water regime combinations.

Research Results

Pearl millet grain yields were 60 to 80% that of grain sorghum. Average grain yields in eastern Nebraska were 5.1 Mg ha^{-1} for pearl millet and 6.1 Mg ha^{-1} for grain sorghum. In western Nebraska, average pearl millet yields were 1.9 to 3.9 Mg ha^{-1} for pearl millet, and 4.1 to 5.0 Mg ha^{-1} for grain sorghum. Both crops used similar amounts of water and responded to irrigation with a linear increase in grain yield as water use increased. Sorghum had a greater water use efficiency than pearl millet (12.4 to 13.4 vs 5.1 to 10.4 kg grain ha^{-1} mm-1). Correlation and path analysis direct effects indicated that the number of kernels per panicle and kernel weight were associated with grain for both crops. However for sorghum, kernel weight was more highly associated with grain yield than kernels per panicle. Pearl millet had lower and less stable yields than sorghum, thus is not a viable substitute for sorghum in Nebraska.

Nitrogen Response of Pearl Millet (Nouri Maman, Ph.D. Thesis)

Research Methods

The pearl millet hybrids 68Ax086R and 293x086R were planted in randomized complete block experiments with N fertilizer rates of zero, 45, 90 and 135 kg ha^{-1} and four replications in 2000 to 2002. The study was conducted in Sidney, NE on a silt loam soil and in Mead, NE on a silty clay loam soil.

Research Results

Hybrids had similar yield, N uptake and nitrogen use efficiencies (NUE) responses. In western Nebraska in 2000, pearl millet yield response to N rate was linear, but the yield increase was on 354 kg ha^{-1} to 135 kg N ha^{-1}. In eastern Nebraska, pearl millet response to N rate was quadratic with maximum grain yields of 4040 Mg ha^{-1} in 2001 and 4890 Mg ha^{-1} in 2002 attained with 90 kg N ha^{-1}. The optimum N rate for pearl millet was 90 kg N ha^{-1} for eastern Nebraska. For western Nebraska, drought may often limit pearl millet response to N fertilizer.

Planting Date and Row Spacing of Pearl Millet (Siébou Palé, M.S. Thesis)

Research Methods

Studies were conducted between 1995 and 2001 to determine recommended planting date and row spacing for pearl millet hybrids was conducted on a silty clay loam and sandy soil site in Mead, NE (east), a loam soil in Sidney, NE (west), and a sandy soil site in Ogallala, NE (west-central). Sidney has low rainfall, short growing season. and efforts are being made to intensify wheat-fallow production systems by incorporating pearl millet as a summer annual crop in this region. The pearl millet hybrids 68A X 086R responses to planting date, and narrow (38 to 50 cm) and wide (76 cm) row spacing were compared to the grain sorghum check DK28.

Research Results

Optimum pearl millet planting times were 399 air heat unites or 410 soil heat units after April 1 for the silty clay loam soil, and 406 soil heat units for the sandy soil. The optimal sorghum planting time was 308 air heat units or 307 soil heat units after April 1 for the silty clay loam soil and 402 air heat units after April 1 for the sandy soil. Both crops had large planting time windows, allowing flexibility in planting time. Sorghum outyielded pearl millet for May and early June planting dates by 0.57 to 2.32 Mg ha^{-1}while pearl millet had higher yields by 0.95 to 1.20 Mg ha^{-1} for late June and July planting times. Sorghum produced greater yields than pearl millet for most planting times while pearl millet produced greater yields for very late planting times.

Row spacing response was similar across locations, planting dates and the two crops. Narrowing rows from 76 to 38 cm increased the yield of both crops by 8 to 14%. Pearl millet and early-season sorghum producers should plant these crops in narrow rows to optimize grain yield production.

Grain Sorghum - Maize Hybrid Comparisons in Dryland and Irrigated Environments

Research Methods

A three-year study was conducted to determine the basis for shift in dryland sorghum to maize production in eastern Nebraska. Best hybrids were identified from the 1950s, 1970s and 1990s as the best performing hybrids in the University of Nebraska Performance Tests and they were produced in three environments each year. The environments were sandy loam and silty clay loam soil types, and irrigated and dryland water regimes on the silty clay loam soil. Regression analysis was conducted to relate year of hybrid release to yield with the objective to determine if a difference in rate of yield increase was present between maize and grain sorghum for different production environments.

Research Results

Maize yields were higher than grain sorghum for all production environments and hybrids. On the high water holding capacity silty clay loam soil, irrigation increased maize grain yield but not for grain sorghum. The rate of yield increase was similar for maize in the sandy loam soils, and grain sorghum in all production environments with the rate of increase being 0.05 ± 0.004 Mg ha^{-1} yr^{-1}. The rate of increase for irrigated maize was 0.0282 Mg ha^{-1} (28 kg ha^{-1}) and 0.0501 Mg ha^{-1} (50 kg ha^{-1}) for dryland maize produced in the high water holding capacity silty clay loam soil. These rates of maize yield increase, except for the dryland, high soil water holding capacity soil, are considerably lower than the 57 to 89 kg ha^{-1} yr-1 reported in the literature for dryland production in central Iowa (Duvick and Cassman. 1999. Crop Sci.39:1622 - 1630). This suggests that the ability to tolerate intermediate stress likely to occur in dryland production on high water holding capacity soils has been the major contribution of plant breeding to maize yield improvement in eastern Nebraska during the past 50 years. These rates of sorghum yield increase due to hybrid improvement are also less than the 23 kg ha^{-1} yr-1 reported in the literature for Bushland, Texas (Unger and Baumhardt. 1999. Agron. J. 91: 870-875). The higher yields and higher rate of yield improvement of maize on dryland, high soil water holding capacity soils partially explain the replacement of dryland grain sorghum with dryland maize in the western corn belt during the last 10 years.

International Research Activities

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

Research Methods

Four-year 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 P ha^{-1}, microdose + 40 kg P ha^{-1}, microdose + 30 kg N ha^{-1}, microdose + 60 kg N ha^{-1}, microdose + 20 kg P ha^{-1} + 30 kg N ha^{-1}, and microdose + 40 kg P ha^{-1} + 60 kg N ha^{-1}. Satellite studies were conducted on farms using zero and microdose; zero, microdose, and 20 kg ha^{-1} P; zero, microdose and microdose + 20 kg P ha^{-1} + 30 kg N ha^{-1} treatments depending upon location.

Research Results

Analysis of variance indicated that grain and stover yields responses to fertilizer treatments varied by country and year. On average, microdose fertilizer application increased on-station pearl millet grain yield by 113% (225 to 479 kg ha^{-1}) in Niger, by 81% (351 to 637 kg ha^{-1}) in Burkina Faso, by 30% (764 to 1046 kg ha^{-1}) on sandy soil in Mali, and by 33% (1069 to 1417 kg ha^{-1}) on a heavy soil in Mali. Sorghum yield increase was 117% 885 to 1924 kg ha^{-1}) greater on the heavy soil in Mali. Grain yields were further increased by 20 to 83% with application of N and P fertilizer on sandy soils, and by 10 to 13% on heavy soils in Mali. On-farm pearl millet yield responses were similar, with grain yield increases of 76% (328 to 577 kg ha^{-1}) in Niger, by 180% (197 to 552 kg ha^{-1}) in Burkina Faso, and 27% (1108 to 1448 kg ha^{-1}) in Mali. Stover is important as a livestock feed, construction material

and for soil maintenance/improvement. Stover yields increased 61% (1566 to 2626 kg ha^{-1}) in Niger, by 72% (929 to 1597 kg ha^{-1}) in Burkina Faso, and 66% (1545 to 2561 kg ha^{-1}) on a sandy soil in Mali, and by 50% (2500 to 3750 kg ha^{-1}) on a heavy soil in Mali. Additional N and P fertilizer further increased stover yield by 20 to 50%. Microdose application is a low cost investment that has a high probability to increase grain and stover yields across the West Africa pearl millet (and sorghum) production area, but estimated N and P removals are negative and similar to zero application and thus does not alleviate soil nutrient mining concerns. Blank tests to determine the residual benefits of different fertilizer treatments indicated no differences in Niger and Mali, while all fertilizer treatments led to increased yield over the zero treatment in Burkina Faso. Applications of microdose plus 30 kg N ha^{-1} and 10 kg P ha^{-1} are required to reverse soil mining in production systems with both grain and stover removed from the field.

Mechanized Zaï (animal traction) and Other Tillage/Fertilizer Treatments Influence on Grain Sorghum Yield (Taonda Jean Baptiste - Burkina Faso)

Research Methods

The traditional zaï system composed of planting pearl millet seed in a small hole with a small amount of manure application which increases water infiltration in some soils and results in increased yield, but requires much hand labor. Scientists have developed a mechanized zaï using animal traction. The objective of this study was to determine the effectiveness of the mechanized zaï (with 300 g compost per hill) to the traditional zaï (with 300 g compost per hill) and a flat-planted control (without compost) across six different soil types in Burkina Faso. The study was conducted on 12 farms in a 800 mm yr-1 rainfall zone. The soil types present on the farms were sandy (2 farms), sandy loam (5 farms), sandy clay (5 farms), clay (2 farms), gravelly clay (4 farms) and gravelly (6 farms). On-farm research was conducted as a followup to studies on 5 farms with diverse soils in 2004. Treatments were no fertilizer, no tillage (farmer practice), zaï with compost 300 g compost hill-1, and animal traction zaï with 300 g compost hill-1.

Research Results

Pearl millet grain yields varied across soil types with control yields ranging from 246 to 686 kg ha^{-1}. The use of the manual or mechanized zaï consistently increased yields, with the yield increase being greatest on the gravelly soil. Pearl millet stover yield was increased by a similar magnitude. The combination of tillage, creation of a micro-catchment to increase water infiltration, and compost application increased crop yield, and the human labor savings of approximately 278 man-hours ha^{-1} indicated that this is an improved technology for Burkina Faso production situations. On-farm studies indicated that the manual 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 to 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. This is a component of a concerted effort by INERA to promote adoption of animal traction zaï combined with compost application.

Sorghum Production Practices for Dolo (Beer) Production in Burkina Faso (Siébou Palé)

Research Methods

Previous research has shown that the sorghum varieties IRAT 9 and ICSV 1001(Framida) to be superior for dolo (traditional beer) production. Studies were initiated in 2003 to develop production practice recommendations for grain yield and dolo quality. These included studies on production practices to optimize grain production, crop/soil management influence on grain composition and biochemical parameters relevant to malting and brewing (grain protein, tannin, total sugar and reducing sugar), surveys of malt producers, dolo producers, dolo and malt marketers, and dolo consumers, and economic analysis. The crop/soil management study was conducted in a randomized complete block design with split plot treatment arrangement. The whole plot is water management (shallow cultivation control, tied ridges, manual zaï, mechanized (animal traction zaï, and dry soil tillage) and split plots of fertilizer levels (zero, micodose with 4g of 15-15-15 per hill, recommended rate of 75 kg ha^{-1} of 15-15-15 plus 50 kg ha^{-1} urea, and microdose plus 20 kg P ha^{-1} and 30 kg N ha^{-1}). The grain yield study is completed and laboratory quality tests associated with dolo production are being conducted. Surveys are completed and being analyzed, and economic analysis will be completed following completion of the other studies.

Research Results

For Framida (ICSV1001), averaged over three years, tied ridges increased yield over the control by 241 kg ha^{-1}. All fertilizer treatments except for microdose application produced higher grain yields in 2003, but the largest grain yield increases of 420 to 756 kg ha^{-1} occurred when applying microdose + 20 kg P ha^{-1} + 30 kg N ha^{-1}. For IRAT9, all water treatments produced higher grain yield in 2005. All fertilizer treatments except the control produced higher grain yields in 2005. Microdose + P + N increased grain yield by 812 to 1346 kg ha^{-1}. Combination of microdose + P + N with tied ridges increased grain yield by 1462 kg ha^{-1} . The best cropping system to optimize grain yield of Framida and IRAT9 was combining tied ridges and microdose + P + N application.

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 to 2004. Pearl millet was planted on ridges after fertilizer application. 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} of diamonium phosphate broadcast applied after emergence. Mechanical weed control treatments consisted of complete control, weeding of ridges only, and no weeding.

Research Results

Analysis of variance indicated that yield differences were due to year X weed control and year X fertilizer treatments. 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 kg ha^{-1} 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} diamonium 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 and N and P produced the highest grain and stover yields, except in the dry 2001 season.

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 9 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}).

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 average rate of application by farmer was 1 t ha^{-1}. All farmers agreed that the manure increased yield and improved soil fertility, and only one producer indicated that application labor was a major constraint to use of poultry manure.

Three-year on-farm research found that poultry manure increased pearl millet grain and stover yield by 57% (461 to 721 kg ha^{-1}) and stover yield by 54% (1466 to 2250 kg ha^{-1}). When 40 kg ha^{-1} 15-15-15 fertilizer was applied, grain yield further increased to 999 kg ha^{-1} and stover yield to 2834 kg ha^{-1}. The on-station study showed that maximum pearl millet grain yield 2 t ha^{-1} poultry manure combined with 10 kg P ha^{-1}. Variable cost ratios indicated that more than a five-fold increase in economic income was associated with the use of poultry manure alone (5.63) or in combination with 10 kg P ha^{-1} (5.47).

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

Research Methods

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 with and without N in a randomized complete block design with four replications, and only the 16 superior lines being carried forward to the following years study.

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 5 for stover yield, and within the top 6 for grain NUE. It was recommended that the Plant Breeding program utilize this line, and that the other lines be dropped. 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, 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 program. Application of N fertilizer increased the average grain yield from 3.1 to 3.9 Mg ha^{-1} (26%).

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 extension service and 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 the department of Cabañas 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.

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 ha^{-1}. 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. Widespread transfer of the 85-SCP-805 and 86-EO-226 varieties has occurred in collaboration with extension services and NGOs in 2004 through 2007.

Simulation Modeling of Growth and Yield of Pearl Millet in Nebraska and Niger (Dr. Gerit Hoogenboom, SANREM CRSP, University of Georgia, Griffin, GA)

Methods

The CSM-CERES-Millet model of the DSSAT Version 4.0 was calibrated for conditions in Nebraska, USA and Sadoré, Niger. The observed data for calibration were obtained from two experiments conducted at the University of Nebraska under rainfall conditions on a silty clay loam in 1995 and 1996. Daily weather records were obtained from an automated weather station located at Mead, Nebraska (latitude 41.25; longitude 96.58; elevation 366 m). The experiment included three pearl millet hybrids, i.e., 59022A x 89-083, 1011A x 086R and 1361M x 6Rm and two nitrogen fertilizer levels, i.e., a control with no N and 78 kg ha^{-1} of N. For Sadoré, Niger, two experiments were conducted in 1995 and 1996. The soil was sandy and the daily weather records were obtained from ICRISAT, Sadoré, Niger (latitude 13.23; longitude 2.28; elevation 210 m). These two experiments consisted of three varieties, i.e., Heini Kirey, Zatib and 3/4HK and two N fertilizer levels (zero N and 23 kg N ha^{-1}).

The CSM-CERES-Millet model includes seven cultivar-specific coefficients that require modification for new cultivars that have not been previously used with the crop model. The specific cultivar coefficients adjusted for millet were for phenological development followed by crop growth parameters during the calibration process. The cultivar coefficients were determined in sequence, starting with the phenological development parameters, followed by the crop growth parameters. Emergence, flowering, and maturity dates, growth analysis data and yield were used to calibrate the performance of the CSM-CERES-Millet model. The combination of coefficients that resulted in the smallest RMSE and the highest d value were selected as final cultivar coefficients.

Results

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

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

Networking Activities (2006 - 2007)

Workshops: American Society of Agronomy Annual Meetings, Nov. 2006, Indianapolis, IN.

Research Investigator Exchange: Visited INTSORMIL research efforts in El Salvador and Nicaragua in March and May 2007.

Research Information Exchange: Funds passed through to Burkina Faso, Mali and Niger to assist with collaborative research.

Publications and Presentations

Abstracts

Griess, J., S.C. Mason, D.J. Jackson and R.E. Elmore. 2006. Environmental influence on grain quality of white sorghum. Amer. Soc. Agron. Annual Meetings, Indianapolis, IN, published online.

Abunyewa, A., R. Ferguson, S. Mason and C. Wortmann. 2006. Skip-row configuration and plant density for rainfed grain sorghum in Nebraska. Amer. Soc. Agron. Annual Meetings, Indianapolis, IN, published online.

Journal Articles

Kaye, N.M., S.C. Mason, D.J. Jackson and T.D. Galusha. 2007. Crop rotation and soil amendment influences sorghum grain quality. Crop Sci. 47: 722 - 729.

Kaye, N.M., S.C. Mason, T.D. Galusha and M. Mamo. 2007. Nodulating and non-nodulating soybean rotation influence on soil nitrate-nitrogen and water, and sorghum yield. Agron. J. 99: 599 - 606.

García Centeno, L., O. Tellez Obregon and S.C. Mason. 2007. Uso eficiente del nitrogeno por 16 lineas de sorgo en Nicaragua. Agronomia Mesoamericana 18(2): (In Press).

García Centeno, L. and S.C. Mason. 2007. Uso del clorofilometro (SPAD-502) para diagnosticar deficiencia de nitrogeno en sorgo. *La Calera* (In Press).

Proceedings

Feoli, C. J.D. Hancock, M.C. Herrera, G.M. Herrera, M. Ríos, F. Vargas and S.C. Mason. 2007. Nutritional value of corn versus sorghum when ground through different screen sizes and used in diets for broiler chicks. Proc. SICNA Meeting, Albuquerque, New Mexico.

Theses

Griess, J. 2007. Environment and hybrid influence on food-grade sorghum grain yield and quality. M.S. thesis, University of Nebraska, Lincoln, NE.

Extension Publications

García Centeno, L. 2006. Uso de Abono Verdes en Cultivos Agrícolas. Guía Técnica No. 10, Universidad Nacional Agraria, Managua, Nicaragua.

Obando, R., C. Gutiérrez, O. Téllez, L. García, Y. Gutiérrez and M. Zamora. 2007. Cultivo de Sorgo. Guía Técnica No. 5. INTA, UNA, INTSORMIL. Managua, Nicaragua.

Obando, R., M. Mena, O. Téllez and C. Gutiérrez. 2007. Guía Tecnologica del sorgo millon. INTA, INTSORMIL, Managua, Nicaragua (In Press).

Obando, R. et al. 2007. Guía de Sorgo Forrajero. INTA, INTSORMIL, Managua, Nicaragua (In Press).

Zeledón, H.S., M.A. Hernández, J.E. Ayala Morán, R.F. Guzmán de Serrano, C.A. Borja, M. Alvarado de Torres and V.R. Calderón. 2007. Guía Técnica del Sorgo. CENTA, INTSORMIL, San Andres, El Salvador.

Soil and Water Management for Improving Sorghum Production in Eastern Africa

Project UNL 219

Charles Wortmann and Martha Mamo
University of Nebraska

Principal Investigators

Charles Wortmann & Martha Mamo, Dept of Agronomy & Horticulture, Univ of Nebraska, Lincoln, NE 68583-0915

Collaborating Scientists

Gebisa Ejeta, Purdue University, Dept of Agronomy, Purdue University, Lilly Bldg State Street, West Lafayette IN 47907-1150.
Steve Mason, University of Nebraska, Dept of Agronomy and Horticulture, 279 Plant Science, Lincoln, NE 68583-0915
Kidane Georgis- EARO-Addis Ababa, P.O. Box 2003, Addis Ababa, Ethiopia.
Amare Belay and Gebreyesus Brhane, Mekele Agricultural Research Center (ARC), P.O. Box 492, Mekelle, Ethiopia
Girma Abebe and Tewodros Mesfin, EARO-Melkassa ARC, P.O.Box 436, Nazareth, Ethiopia
Kaizzi Kayuki and John Byalabeka, KARI-NARO, P.O. Box 7061, Kampala, Uganda.
Soares Xerinda, INIA, Av. das FPLM, P.O. Box 3658, Maputo, Mozambique
Elias Letayo, Hombola ARC, Hombolo, Tanzania
Christopher Mburu, Kenya Agricultural Research Organization, Regional Research Center, Kakamega, Kenya

Summary

This project focused on soil and water management for improving sorghum production in eastern Africa, with some activities in southern Africa. Enhancement of research and extension capacity in host countries was of high priority and included partial or full support enabling six graduate students from Ethiopia, Mozambique, Latin America, and the U.S. to earn M.Sc. or Ph.D. degrees. A researcher from Ghana is continuing with Ph.D. studies at UNL. Four collaborators from Africa attended an IFDC-organized short course on integrated soil fertility management. On-going technical support to collaborators was an important part of enhancing institutional capacity.

Increasing yield as a means to promote economic growth and improve human nutrition in semi-arid areas has been the objective of research and extension activities. In Ethiopia, tie-ridging resulted in 45% more available water; grain yield with traditional practices was 45 and 62% of the yield with the best tie-ridging practice. In another study, sorghum yield with tie-ridge tillage was the same as flat planting where 3 Mg ha^{-1} of crop residue had been applied as ground cover and 75% more than flat planting with no ground cover. In a third study, highland pulse yield was increased by a mean of 70% with tie-ridging compared with flat planting. Oxen drawn implements for tie-ridging and row planting were verified with farmers as suitable for tie-ridge systems. Extension efforts to promote tie-ridging were enhanced. Evaluation of skip-row planting as a means to improve water availability during grain-fill is underway. In Uganda, several soil fertility management and tillage practices were found to be economical for resource poor farmers through a process of farmer participatory research; extension efforts to promote soil fertility management options were established while evaluation of sustainability issues associated with these management practices continues. In Mozambique, research on integrated soil fertility management was initiated. In central Tanzania, research addresses tillage options to conserve water and enable more timely planting. Information was compiled for five countries in eastern and southern Africa (ESA) and published "The Atlas of Sorghum Production in Five Countries of Eastern Africa". An analysis of sorghum production constraints was done.

In Nebraska, several studies addressed opportunities to improve the profitability of grain sorghum production. The use of starter fertilizer and row cleaning under no-till conditions was not profitable. An N use recommendation for the sorghum-soybean rotation was developed that considers expected yield and the prices for N and grain. One-time tillage of no-till reduced nutrient stratification and the potential for dissolved P runoff with no negative effect on soil organic C content, soil physical properties, microbial communities, or yield. Skip-row planting of sorghum was found to have a yield advantage at 2 of 4 western Nebraska sites and no yield disadvantage at the other 2 sites.

Objectives, Production and Utilization Constraints

Each of the four major objectives of INTSORMIL have been addressed, i.e., promote economic growth, improve nutrition, increase yield, and improve institutional capacity. The main sorghum production constraints addressed were soil water deficits, nutrient deficiencies, and *Striga*.

Ethiopia

- Fine-tune tie-ridge tillage technology for sorghum production systems.
- Partially support M.Sc. education of two EIAR researchers at

Alemaya University and host them to UNL as visiting scientists.

- Conduct training for field extension staff and support their promotion of tie-ridging.
- Evaluate skip-row planting as a means to increase water availability during grain-fill.

Uganda

- Develop soil fertility management and reduced tillage practices for small scale farmers in eastern Uganda, using participatory research approaches.
- Evaluate sustainability of some soil fertility management practices over eight seasons.
- Facilitate extension activities to promote soil fertility management practices.
- Evaluate *Striga* tolerant varieties in eastern Uganda.

Mozambique

- Develop integrated soil fertility options for sorghum production systems.

Tanzania

- Evaluate reduced and water conserving tillage options in Central Tanzania

U.S.

- Develop an N response function for sorghum following soybeans.
- Evaluate the use of starter fertilizer and row-cleaning for no-till sorghum.
- Mentor five students for graduate degrees at UNL with at least partial INTSORMIL support.
- Evaluate occasional one-time tillage of no-till systems as a means for improving productivity, C sequestration, and soil aggregation while reducing potential for P runoff.
- Evaluate skip-row planting as a means for conserving water for the reproductive stage of sorghum in western Nebraska.

Africa and U.S.

- Collect sorghum yield response and nutrient uptake data for evaluation of the QUEFTS concepts in estimation of nutrient needs.
- Compile a geo-referenced data base and publish an atlas of sorghum production in eastern and southern Africa (ESA).
- Determine soil properties affecting P sorption for soils of ESA.
- Strengthen research and extension capacity by technical support to collaborating researchers.

Research Findings and Project Output

Ethiopia. The effectiveness of tie-ridge tillage was evaluated as a means to improve soil water availability through reduced runoff for increased grain and stover yield. Tied-ridging before or at planting resulted in the best soil water status throughout the season and the best crop performance, especially when planting was in-furrow (Table 1; Brhane et al., 2006). Mean soil water content with the most effective tie-ridge treatment was 45% more than with traditional practices. Grain yield with traditional practices was 45% and 62% of the yield with the best tie-ridging practice. In a study of tillage and ground cover interactions, yield with tie-ridge tillage was the same as flat planting with the ground covered with 3 Mg ha^{-1} of crop residues and 75% more than flat planting with no ground cover (Mesfin, 2004). In subsequent research, highland pulse grain yield and nodulation were greatest with tie-ridging at the first weeding after planting with grain yield increases of 79, 31, and 96% for faba bean, lentil, and field pea, respectively, compared with flat planting. Oxen-drawn implements developed at Melkassa ARC for tie-ridging and row planting were evaluated with farmers in Wolencheti and Miesso. Responses were favorable with opportunities, problems and likely improvements identified (Mesfin et al., 2004). Extension staff were trained at Melkassa ARC and Mekele ARC on water conserving technology, use of row planting and tie-ridging equipment, and extension methods to promote tie-ridging. A decision guide to selection of fields appropriate for

Table 1. Grain yield as affected by tillage treatments in northern Ethiopia†

Treatments	Grain yield Mg ha^{-1} 2003	2004
Flat plant‡	1.48	0.79
TR–4WAPIF	2.87	2.50
TR–4WAPOR	2.38	2.00
TROWAPIF	2.52	2.16
TROWAPOR	2.16	1.70
Shilshalo	1.78	1.30
TR4WAP	2.12	1.70
LSD 0.05	0.725	0.056

† Adapted from Brhane et al. (2006).
‡ Flat plant = planting with a flat soil surface, a traditional practice. 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.

tie-ridging was developed and provided to extension (Brhane et al., 2005). Researchers have worked with extension to demonstrate tie-ridge technology.

Uganda. Researchers worked with farmers to evaluate alternative low-input practices for soil fertility management in sorghum-based cropping systems. Four studies, comprised of 148 on-farm trials, were conducted at three locations over three years in semi-arid areas of eastern Uganda. The mean mucuna dry biomass yield was 7 Mg ha^{-1} containing 160 kg N ha-1 (Kaizzi et al., 2007; this publication was singled out for special recognition and promotion by the American Society of Agronomy). Application of fertilizer N and P, and of manure, was found to be profitable, even for the most resource-poor farmers (Table 2). The increase in sorghum grain yield in response to 30 kg N ha-1 alone, to a mucuna fallow, and to a rotation with cowpea was 1.15, 1.55 and 0.82 Mg ha^{-1}, respectively. Extension activities are underway and expanding including participatory extension with farmers who participated in the research and collaboration with USAID-APEP and TEDDO and their extension field staff.

Mozambique. Adoption of no-till farming was assessed in Manica province where it had been promoted and subsidized for >5 years after which support was discontinued. The results showed negligible adoption largely due to the cost and/or unavailability of herbicides. Concurrent with the survey, field trials were conducted at three locations to determine main and interaction effects of tillage and soil fertility management practices. Results of the adoption study caused a re-thinking of priorities with a decision to focus on integrated soil fertility management.

African regional activities. Soil properties have been related to P sorption for diverse soils of Ethiopia, Uganda and Mozambique (Mamo et al., 2004). Soil clay content was a major determinant of P sorption with increased sorption due to termite impact on sandy soils.

The importance of 43 biotic and abiotic constraints to sorghum yield were evaluated for Ethiopia, Kenya, Uganda, Tanzania and Mozambique (Wortmann et al., 2006). Total potential production losses for these five countries due to major constraints were 1.8, 1.0, 1.0, and 0.9 million Mg ha^{-1} due to soil water deficits, N deficiency, the stalk borer complex, other weeds, and Striga, respectively (Table 3). Quelea, shoot fly and P deficiency were each found to cause losses of >500,000 Mg yr-1. Approximately 30% of sorghum production area is intercropped (Fig.1).

Nebraska. Twelve trials on the use of starter fertilizer, and another six trials on starter fertilizer and row-cleaning, were conducted for no-till sorghum (Soares et al., 2004; Soares, 2005; Wortmann et al., 2006). Starter fertilizer use and row cleaning resulted in increased early growth but no gain in grain yield. Similar research was conducted for maize using other funding (Wortmann et al., 2006). An extension publication was updated (Hergert et al., 2006). These results were used to develop a lesson for certified crop advisors (Crops and Soils 40:20-24).

Twenty five trials were conducted and an alternative recommendation for N use was developed that considers expected yield and the prices for N and grain; when the value of one bushel of corn is less than the cost of 9 lb of N, the recommendation results in less fertilizer application than the previous recommendation

Table 2. Increase in sorghum grain yield (Mg ha-1) compared with the traditional practice of no input application, and net returns and benefit:cost ratios for minimum acceptable rate of returns of money of 25, 50, and 75% due to application of fertilizer or manure in eastern Uganda.†

Treatment kg ha^{-1}	Increase in grain yield Mg ha^{-1}	Net returns to input use‡ '000 UgSh ha^{-1}			Benefit/cost ratio UgSh UgSh^{-1}		
		25%	50%	75%	25%	50%	75%
30 N + 10 P	1.30	88.2	63.7	39.2	1.72	1.43	1.23
30 N + 2500 manure§	1.47	65.7	41.2	16.7	1.38	1.21	1.08
30 N	0.77	53.0	38.6	24.3	1.73	1.45	1.24
2500 manure	1.06	121.7	121.7	121.7	3.43	3.43	3.43

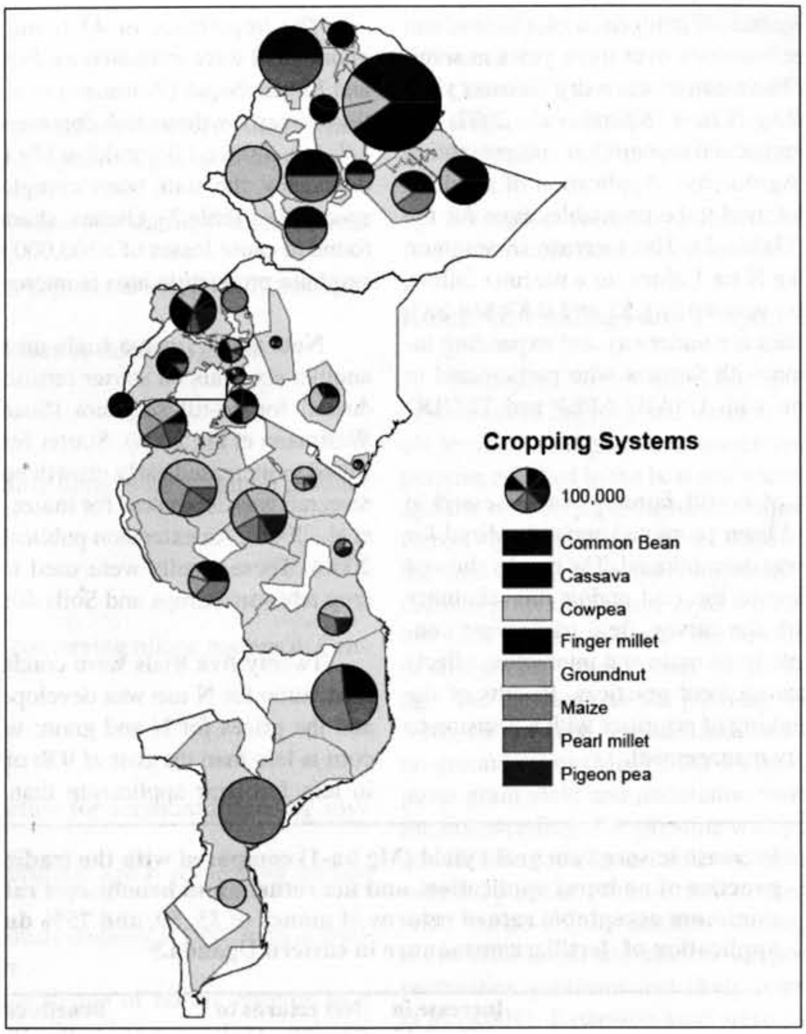
† Adapted from Kaizzi et al., 2007.
‡ Conversion rate of 1800 Uganda shillings (UgSh) per US dollar.
§ The cost of obtaining and applying the manure was estimated to be UgSh 20,000 Mg-1.

Table 3. Estimated losses of grain sorghum production due to the 10 most important constraints in five countries of eastern Africa ('000 Mg yr-1).†

Constraint	Overall	Ethiopia	Kenya	Uganda	Tanzania	Mozambique
Water deficits	1831	718	38	126	283	666
Stem borers	1181	749	46	130	170	86
N deficiency	1025	338	44	81	288	274
Weeds	957	412	24	100	243	178
Striga	927	560	40	118	205	4
Quelea	840	526	47	61	202	4
Shootfly	553	361	31	76	41	44
P deficiency	535	126	25	45	159	180

† Adapted from Wortmann et al., 2006.

Figure 1. The relative importance of associated crops in intercrop production of grain sorghum in eastern Africa. Pie chart diameter varies according to the number of sorghum hectares annually in each production area. Approximately 30% of sorghum area is in intercrop association.



(Wortmann et al., 2006; Wortmann et al, 2007).

In a study of one-time tillage of no-till, nutrient stratification and P runoff potential were reduced with a tendency to higher yield. There was no effect on soil C and an inconsistent effect on rate of water infiltration (Quincke et al, 2007; Quincke, 2006; Quincke et al., 2007). Mycorrhyzal colonization of the roots was reduced by tillage with delayed recovery, probably due to increased root P concentration with tillage (Garcia, 2005; Garcia et al., 2007). The longer-term effects of one-time tillage on C sequestration, yield, and soil properties are being assessed.

Skip-row planting is being evaluated as a means of improving soil water availability during grainfill in a rainfall transect across southern Nebraska. There was not a yield advantage with skip-row planting in the higher rainfall part of the transect, but yield was increased in 2 of 4 trials in the drier western part of the transect with no yield change in the remaining trials (Akwasi et al., 2006). Crops matured earlier with skip-row planting, reducing the risk of frost damage, an important consideration for high plains sorghum production.

Improved institutional capacity. Mr. Brhane and Mr. Mesfin completed their M.S. degrees at Alemaya University with partial funding and advisory support from this project; they visited UNL and presented research findings at ASA annual meeting. Mr. Xerinda from Mozambique completed his M.S. degree at UNL with full INTSORMIL support. A. Quincke (Ph.D.) from Uruguay, J.P. Garcia (M.S.) from Columbia, and G. Miller (M.S.) for the U.S. completed their graduate degrees with INTSORMIL support for their research. A. Abunyewa continues Ph.D. studies at UNL. S. Xerinda, G. Brhane, T. Mesfin and E. Letayo were sponsored to an IFDC-conducted short-course on integrated soil fertility management. Dr. Kaizzi was hosted to UNL as a visiting scientist and presented two papers at an ASA annual meeting. The atlas of sorghum production (Wortmann et al., 2006) and a GIS-referenced database were created to facilitate regional networking. Advisory support

was provided to collaborators in Ethiopia, Uganda, Tanzania, and Mozambique.

Description of Methods of Work Used

Most field research was conducted on-station or on-farm over years and/or locations. In Uganda, Dr. Kaizzi used a farmer participatory research approach where farmers were involved in identification of problems and possible solutions, managing on-farm trials, and interpretation of the results. A participatory approach was used in Ethiopia to evaluate oxen-drawn implements. Adoption of no-till technology in Mozambique was assessed using survey results. Data collection, analysis and interpretation for the sorghum atlas was have been described in "The Atlas of Sorghum Production in Five Countries of Eastern Africa".

Networking Activities

Geo-referenced data was compiled and "The Atlas of Sorghum Production in Five Countries of Eastern Africa" was published to meet information needs of researchers, extension and rural development specialists, policy makers, and emergency relief personnel (Wortmann et al., 2006). Numerous researchers and others knowledgeable of sorghum in their respective countries contributed information and expert opinions to develop the Atlas. The Atlas presents information in maps and tables for 30 sorghum production areas in five countries addressing production constraints, cropping systems, management, uses of grain and stover, phenotype preferences, gender roles, and marketing.

Publications And Reports (2006-2007)

Journal Articles

Garcia, J.P., C.S. Wortmann, M. Mamo, R. A. Drijber, J.A. Quincke, and D. Tarkalson. 2007. One-time tillage of no-till: effects on nutrients, mycorrhizae, and phosphorus uptake. Agron. J. In Press.

Kaizzi, C.K., J. Byalebeka, C.S. Wortmann, and M. Mamo. 2007. Low input approaches for soil fertility management in semiarid eastern Uganda. Agron. J. 99:847-853.

Mamo, M., C. Wortmann, and S. Brubaker. 2007. Manure P fractions: Analytical methods and the effect of manure types. Comm. Soil Plant Anal. 38:935-947.

Quincke, J.A., C.S. Wortmann, M. Mamo, T.G. Franti, R.A. Drijber, and J.P. Garcia. 2007. One-time tillage of no-till systems: soil physical properties, phosphorus runoff, and crop yield. Agron. J. In Press.

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Thesis

Andres Quincke, Ph.D. Dissertation. 2006. Occasional tillage of no-till systems to improve crop yield, soil quality and carbon sequestration. Univ. of Nebraska, Dept. of Agronomy and Horticulture.

Miscellaneous Publications

Hergert, G.W., and C.S. Wortmann, 2006. Using starter fertilizer for corn, grain sorghum and soybeans. NebGuide G361. University of Nebraska-Lincoln.

Wortmann, C.S., M. Mamo, G. Abebe, K. Kaizzi, C. Mburu, E. Letayo, and S. Xerinda. 2006. An Atlas of Sorghum Production in Eastern Africa. http://intsormil.org.

Wortmann, C.S., A.R. Dobermann, R.B. Ferguson, G.W. Hergert, C.A. Shapiro, and D. Tarkalson. 2006. Fertilizer suggestions for grain sorghum. NebGuide G1669, University of Nebraska-Lincoln.

Germplasm Enhancement and Conservation

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

Project ARS 206
Jeffrey P. Wilson
USDA-ARS

Principal Investigator

Jeffrey P. Wilson, USDA-ARS Crop Genetics and Breeding Research Unit, University of Georgia, Tifton, GA 31793-0748

Collaborating Scientists

Issaka Ahmadou, INRAN, B.P. 429, Niamey, Niger
Ignatius Angarawai, Lake Chad Research Institute, KM 6 Gamboru Ngala Rd., P.M.B. 1293, Maiduguri, Nigeria
Simon Awala, Ministry of Agriculture, Water and Forestry, Omahenene Research Station, P.O. Box 646, Namibia
Amadou Fofana, CRZ, Insitut Senegalais de Recherches Agricoles, BP 53, Kolda, Senegal
Ferdinand Muuka, Kaoma Research Station, PO Box 940084, Kaoma, Zambia
Stephen Nutsugah, Savannah Agricultural Research Institute, P.O. Box 52, Tamale, Ghana
Moussa Sanogo, IER, Cinzana Agricultural Research Station, BP 214, Ségou, Mali
Hamidou Traore, INERA, CREAF de Kamboinse, B.P. 476, Ouagadougou, Burkina Faso
Scott Bean, USDA-ARS Grain Marketing and Production Research Center, Manhattan, KS 66502
Nick Dale, Dept of Poultry Science, University of Georgia, Athens, GA 30602
Peng Chee, Dept of Crop and Soil Sciences, University of Georgia, Tifton, GA 31793
Patricia Timper, USDA-ARS Crop Protection and Management Research Unit, University of Georgia, Tifton, GA, 31793
Andrew J. McAloon, Crop Conversion Science and Engineering Research Unit, USDA-ARS, Wyndmoor, PA 19038
John McKinney, Identity Preserved Grain Laboratory, Illinois Crop Improvement Association, Champaign, IL 61826
Donghai Wang, Dept of Biological and Agricultural Engineering, Kansas State University, Manhattan KS 66506

Summary

The goals of project ARS 206 have been to increase diversity of pearl millet germplasm available to breeders and researchers, identify sources of disease and pest resistance for pearl millet improvement, develop pearl millet with high yield, disease resistance, and superior grain quality for diverse uses, and expand markets for pearl millet.

Greater collaboration among researchers was fostered. Linkages and germplasm exchanges were established among relatively isolated pearl millet breeding programs within and across the West and Southern African regions. Simon Awala (Namibia) participated in short-term training with USDA-ARS, and Ferdinand Muuka (Zambia), Issaka Ahmadou (Niger), and Isaac Mbaiwa (Botswana) participated in the "International Training Course on Pearl Millet Improvement and Seed Production" at Patancheru, India.

Pearl millets Gwagwa and ICMV IS 89305 were high yielding and resistant to downy mildew across multilocation trials in West and Southern Africa. These and other distributed germplasm have been used as parents to introduce new traits into locally-adapted varieties. In similar evaluations for combining ability in hybrid combination, SoSank and SoSat C-88 tended to produce the highest-yielding hybrids.

Advances in breeding for resistances to other pests were made. Among diverse pearl millets from West Africa, SoSat C-88 was among the most resistant to the root-knot nematodes. Resistant progeny lines were produced from SoSat, Zongo, Gwagwa, and P3Kollo to develop nematode-resistant versions of these popular varieties. Wild pearl millets with resistance to *Striga hermonthica* were genetically diverse and may represent distinct sources for resistance breeding.

Tolerance to drought and improved nitrogen utilization is associated with stay-green. A non-destructive method for quantifying staygreen in pearl millet was developed. Staygreen was expressed as a dominant or overdominant trait, which will simplify its use in hybrid production.

Promising new hybrids for the U.S. were identified through multocation trials in Georgia. Hybrids (506 x 2304) and (606 x 2304) had yields ranging from 17 to 38% greater yield than the commercial standard Tifgrain 102. Increased yield will improve grower profit and expand cultivation.

Expanding markets will stabilize prices for grain. Pearl millet was shown to be a viable supplemental feedstock for ethanol production using standard maize-to-ethanol processes. Pearl millet ferments 30% faster than maize, and the net value of the products has the potential to result in greater economic value than maize feedstocks.

Significant advances have been made in developing collaborative research networks, identifying pearl millets with stable yield and downy mildew resistance across diverse locations, advancing the development of resistance or tolerance to biotic and abiotic

stresses, and improving profitability and developing new uses for U.S. growers.

Objectives, Production and Utilization Constraints

Research Objectives

Increase yield and economic growth through:

- Increasing diversity of pearl millet germplasm available to breeders and researchers
- Identifying sources of disease and pest resistance for pearl millet improvement
- Developing pearl millet with resistance to multiple diseases, high yield, and superior grain quality for diverse uses
- Expanding market opportunities for pearl millet by identifying new uses

Production and Utilization Constraints

New pearl millet genotypes must be an acceptable type for cultural practices in their target production areas. The concept of desirable plant type differs dramatically between African and U.S. production systems. Yet, in both systems the production of high-quality pearl millet grain and forage is a result of the interaction between plant variety, diseases and pests, and environmental production constraints. The effects of these factors must be assessed when developing new germplasm and varieties. Developing the commercial potential of pearl millet requires an understanding of the needs of and constraints faced by producers, providing a consistent product that meets market standards, and identifying uses in which pearl millet has a competitive advantage compared to alternatives.

Research Findings and Project Output

Improve Institutional Capacity

Linking and Building Capacity in African Pearl Millet Breeding Programs

Linkages were developed for more effective research, dissemination of advances from individual research programs, and institutional capacity building. Samples of 86 pearl millets were acquired from breeding programs in West and Southern Africa. These represent new cultivars and advanced breeding lines with high grain quality, fertility restoration for specific cytoplasms, resistance to diseases or pests, or superior agronomic traits. Forty of these germplasms were distributed to collaborators in West Africa (Senegal, Mali, Burkina Faso, Ghana, Niger, and Nigeria) and Southern Africa (Zambia, Namibia, South Africa, and Botswana).

Through this network new germplasm was widely disseminated across essentially isolated pearl millet breeding programs throughout Africa. Linkages between the West and Southern Regions were fostered. These germplasms have been used by the breeders to introduce new traits into their programs, and will lead to varieties with improved yield and adaptation.

Simon Awala (Namibia) participated in a short-term training opportunity with USDA-ARS, and Ferdinand Muuka (Zambia), Issaka Ahmadou (Niger), and Isaac Mbaiwa (Botswana) participated in the "International Training Course on Pearl Millet Improvement and Seed Production" at Patancheru, India.

Increase Yield

Pearl Millet Germplasms with High and Stable Yield and Disease Resistance

Multi-location evaluations can quickly identify genotypes with superior grain yield and quality, and resistance to diseases and pests. Collaborative, trails were established throughout West and Southern Africa to characterize selected pearl millets for high and stable yield over a range of production environments. Trials were conducted in 2003 and 2004 in Burkina Faso, Ghana, Mali, Niger, Nigeria, Senegal, Zambia, and South Africa.

Grain yield across locations was greatest for varieties CIVT, ICMV IS 89305, SoSat C-88, Gwagwa, SoSank, NKK, and GB 8735. Across locations, the most downy mildew resistant accessions were Gwagwa, ICMV IS 89305, ICMV IS 90311, Synthetic 1-2000, Zatib, ¾ ExBornu, and ¾ Souna. Grain yield was correlated with days to flowering, plant height, and panicle length. Grain yield was negatively correlated with downy mildew incidence. High-yielding varieties within locations varied, and germplasm introduced from other programs was frequently ranked among the top-yielding varieties.

Combining Ability for Grain Yield and Pest Resistance in Pearl Millet

Determining combining ability is valuable to identify prospective parents for hybrid production. Pearl millets were assessed for general and specific combining ability for yield and resistance to diseases in multilocation evaluations. Varieties that had superior performance across multilocation trials in 2003, or superior performance within each test location were crossed in a half-diallel design and grown in Burkina Faso, Ghana, Mali, Niger, Nigeria, Senegal, and Zambia for evaluation in 2005. This network of researchers characterized the germplasm to assess yield, agronomic characteristics and superior resistance to pests and diseases.

Across all locations, (SoSank x SoSat C-88) was the top-yielding hybrid combination, followed by (SoSat C-88 x Indiana 05), (SoSank x ICMV IS 89305), (SoSank x Gwagawa), and (SoSat C-88 x GB 8735). Yields were lowest for (Manga Nara x SoSat C-88), (GB 8735 x CIVT), (Gwagawa x CIVT), (Manga Nara x GB 8735), and (CIVT x ICMV IS 89305). Yield was correlated with days to flowering, plant height, and panicle length. Grain yield was negatively correlated with downy mildew incidence.

Downy mildew incidence was recorded in all locations except Burkina Faso and Zambia. Downy mildew was greatest in Mali, and least in Nigeria. Over all locations, the most resistant hybrids were (Indiana 05 x ICMV IS 89305), (Gwagawa x SoSat C-88), (SoSank x Indiana 05), (SoSank x ICMV IS 89305), and (SoSank

x Gwagawa). The most susceptible hybrids were (Manga Nara x SoSat C-88), (GB 8735 x ICMV IS 89305), (GB 8735 x CIVT), (Manga Nara x GB 8735), and (HKP (GMS) x GB 8735).

Striga was observed only in Niger and Nigeria, and infestation was greater in Niger. In these environments, SoSat C-88 and (SoSank x SoSat C-88) were more susceptible, and HKP (GMS) and Indiana 05 were the most resistant entries. Smut was recorded only in Ghana. All entries had some level of smut, but (GB 8735 x CIVT) was most susceptible. Grain mold data were recorded only in Zambia. All genotypes had some level of grain molds. GB 8735, (SoSat C-88 x Indiana 05), (Gwagawa x GB 8735), (GB 8735 x Indiana 05), and (CIVT x Indiana 05) were more susceptible to grain mold.

A1 and A4 Restorers for African Pearl Millet Hybrids

Suitable fertility restorer inbreds are required for the development of pearl millet hybrids for African production systems. Crosses were made between diverse African pearl millet cultivars and Tift 454 (cms A1 restorer) or 99-70 (cms A4 restorer). Head-to-row selections were made in Tifton GA from 2003 to 2005. From these selections, 82 promising F4 lines were grown at Nigeria and Ghana in 2006 to assess days to flowering, downy mildew, panicle length, and grain yield.

Of the progeny with Tift 454 parentage, derivatives of (SoSat C-88 x Tift 454) had greater downy mildew resistance coupled with higher yield. Derivatives from Zongo tended to be most susceptible to downy mildew. Of the progeny with 99-70 parentage, derivatives from SoSat and Ankoutess had greater downy mildew resistance and higher yield. Downy mildew resistance in (SoSat x 99-70) progeny were greater than the counterparts derived from Tift 454. Progeny derived from 99-70 probably acquired some resistance from this ICRISAT-developed inbred. Selections (SoSat x Tift 454) F4-9, (SoSat x 99-70) F4-2 and F4-7, and (Ankoutess x 99-70) F4-5 and F4-4 are good candidates to use as parents for further development of downy mildew resistant A1 and A4 restorer inbreds for African hybrids.

Root Knot Nematode Resistance in African Pearl Millets

Root knot nematodes can reduce yield of pearl millet and of peanut and cowpea, which are often intercropped with millet. Seventeen diverse pearl millet varieties from Africa were evaluated for resistance to Meloidogyne incognita in greenhouse experiments. Plants were inoculated with eggs of *M. incognita*, and reproduction of the nematode was determined

Reactions within each African variety varied from resistance to extreme susceptibility. SoSat C-88 was among the most resistant varieties, Zongo and Gwagwa were intermediate, and P3Kollo was among the most susceptible. Patterns of apparent segregation of resistance varied among S1 progeny. Discreet resistant and susceptible phenotypes were identified in Zongo, and it was estimated that two dominant genes for resistance segregated in this variety. Reproduction of *M. incognita* on S2 progeny tended to confirm results from S1 progeny. Heritability of resistance determined by parent-offspring regression was 0.54. Realized heritability determined by divergent selection was 0.87. Selected progeny lines from these experiments will allow reconstitution of nematode-resistant versions of these popular varieties.

Genetic Variability of Wild Pearl Millets with Striga Resistance

Wild pearl millets (*P. glaucum* subsp. *monodii*) have been identified as potential sources of resistance to the hemi-parasitic weed, *Striga hermonthica*. Eighty wild pearl millet accessions, 9 U.S. inbreds and 7 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 evaluated with EST and SSR primers. PCR fragments were scored for presence or absence of DNA fragments in each genotype. Dendograms were constructed the pearl millets grouped in distinct clusters. Cluster analysis was conducted and level of genetic diversity within and between populations was calculated.

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 7 West African varieties were grouped in one cluster, and the U.S. accessions were clustered in two groups. The wild accessions were grouped independently from the U.S. and African cultivated varieties. *Striga*-resistant accessions PS 202, PS 637, PS 639 and PS 727 tended to be located in different clusters, suggesting they are unrelated and may possess different resistances.

Expression and Segregation of Stay-green in Pearl Millet

Delayed senescence, or "stay-green" is a mechanism of drought tolerance characterized by the retention of green leaf area at crop maturity. Based upon information from the sorghum model, stay-green should have multiple benefits in pearl millet improvement. The chlorophyll content of a stay-green and normal senescent pearl millet were quantitatively compared over time, and preliminary information on the inheritance of stay-green was obtained through segregation in an F2 population.

Stay-green pearl millet 02F266-4 was crossed with a normal senescent line Tift 454. Relative chlorophyll content of 02F266-4, Tift 454 and their F1was measured on the top three leaves of the main tiller with a SPAD 502 Chlorophyll Meter. Data were collected at 7 d intervals for a total of 5 ratings. Segregation of stay-green was assessed in 02F266-4, Tift 454, and their F1 and F2. Using the SPAD meter, relative chlorophyll measurements were taken on the second uppermost leaf of the main tiller. A stay-green value was calculated which reflected the magnitude and duration of the relative chlorophyll content.

Minor differences in SPAD ratings among genotypes were observed at stigma emergence, but over time the upper leaves of 02F266-4 and the F1 maintained greater levels of chlorophyll than Tift 454. SPAD ratings of 02F266-4 were similar to the F1, but greater than Tift 454 in weeks 1 and 2. In weeks 3 and 4, SPAD rating of the F1 was greater than 02F266-4, and ratings of both

genotypes were greater than Tift 454. The expression of relative chlorophyll content in the F1 indicates stay-green is a dominant or over-dominant trait with degree of dominance = 1.46. Stay-green in the F2 was skewed toward normal senescent types. Use of the SPAD meter to measure relative chlorophyll content provided a quantitative assessment of the stay-green trait. The data confirmed that 02F266-4 expressed stay-green characteristics. Trait expression was greatest in leaf 2. Using SPAD ratings, a stay-green value could be calculated as a measure of the magnitude and retention of chlorophyll content over time to assess segregation within populations.

Promising New Pearl Millet Hybrids for the U.S.

Pearl millet for grain is making inroads as a new-use crop for the U.S. but higher yield will improve returns to growers. Seven experimental hybrids and a pollinator were compared to the commercial standard Tifgrain 102 (TG102) in four locations in Georgia (Moultrie, Tifton, Watkinsville, and Newton) to identify superior yielding varieties under minimal inputs. No-till production practices were compared to conventional tillage in Watkinsville, GA with the goal of lowering production costs. Grain yield, 100 grain weight, protein, fat, starch, and fermentation efficiency were assessed.

Experimental hybrid (606 x 2304) was among the top yielding hybrids at all locations and had 17% higher yield than TG102. (606 x 2304) had 40% higher 100 grain weight, 7% lower protein content, similar fat, 50% greater starch, and 14% greater fermentation efficiency compared to TG102. In the no-till experiments in Watkinsville, experimental hybrid (506 x 2304) was among the top yielding hybrids and had a 38% greater yield than TG102. Over all treatments, (506 x 2304) had 10% higher 100 grain weight, similar protein and fat, 1% greater starch, and 1% lower fermentation efficiency compared to TG102. Hybrid (606 x 2304) had 30% greater yield than TG102. Over all treatments, (606 x 2304) had 17% higher 100 grain weight, 6% higher protein content, similar fat, 1% greater starch, and 1% lower fermentation efficiency compared to TG102. Yields were greatest in conventional tillage plots, which had better stand establishment than no-till plots. Grain from no-till plots had greater 100 grain weights, greater protein content, similar fat, lower starch, and greater fermentation efficiency. Hybrids (506 x 2304) and (606 x 2304) appear promising for additional testing. No-till has the potential to reduce production costs, but techniques to improve stand establishment must be identified.

Pearl Millet as a Feedstock for Ethanol Production

Grower profit can be improved by identifying applications in which pearl millet has advantages compared to alternatives. It is a superior grain in game bird rations and for broiler production, but diversified market options will stabilize grain prices. The development of the ethanol industry in the southeastern U.S. is limited by the amount of feedstocks produced in the region. Biological and economic information is needed on the value of pearl millet as a potential feedstock for this market.

Two fermentation evaluations were conducted. The first at KSU used four pearl millet varieties. The second at ICIA compared experimental variety "2304" to maize. Samples were evaluated using standard corn-to-ethanol protocols. The economic feasibility of using pearl millet as a feedstock was compared to maize by using the Superpro Designer Dry Grind model. This analysis simulates costs associated with the production of ethanol, as affected by the composition of raw materials entering the process. Other variables used in the model include the sizing of equipment, utility consumption, operating costs, capital costs required for a facility with a 40 million gallon per year capacity.

Ethanol yield from pearl millet was 8% less than from maize. Pearl millet fermented more quickly and reached 85% fermentation 12 hr earlier than maize. Fermentation efficiencies of pearl millet, on a starch basis, were comparable to those of maize. DDGS from pearl millet had 6% lower moisture compared to DDGS from maize. On a dry basis, the DDGS from pearl millet had 16% greater protein, 53% greater fat, 45% higher ash, 19% lower crude fiber, and 20% lower nitrogen-free extract content compared to DDGS from maize.

The protein content of pearl millet would result in a 13% greater DDGS value compared to maize DDGS. The analysis suggests that even with a 10% premium on the cost of pearl millet, the net cost of ethanol production is $0.06 per gallon less than production using maize. Total net profit from a facility using pearl millet as the sole feedstock was estimated as $25,175,000 per year compared to $23,758,000 for maize feedstocks, a $1.4 million advantage. Two additional sources of savings not captured in the analysis are the lower energy requirements to grind pearl millet, and a potentially faster batch processing allowed by the faster fermentation rate. Grinding rate of pearl millet is 53% faster and requires 40% less energy to grind than maize. For grain quantities indicated by the process and cost analysis, electricity costs can be reduced an additional $20,200 because of the lower energy requirements for grinding. The economic benefit of the faster fermentation rate could be significant, but may be difficult to capture if pearl millet is used as a supplement, rather than a principal feedstock. If used as a sole feedstock, faster fermentation could increase gross returns by 25%. Biologically and economically, pearl millet is a feasible supplemental feedstock for dry-grind maize-to-ethanol facilities. Pearl millet should benefit the economies in the southeast that must import feedstock for ethanol production.

Networking Activities

Seed of superior Ghanaian pearl millet varieties were provided back to the Savannah Agricultural Research Institute after problems with storage facilities resulted in the loss of SARI's elite pearl millet germplasm repository.

Seed of forage pearl millet populations with brown midrib and staygreen traits was sent to René Clará Valencia, CENTA, El Salvador for evaluation and selection.

Experimental pearl millet hybrids were provided to Pronaca, Ecuador for evaluation in agronomic production and poultry feeding trials.

Collaborated with Compatible Technology International (MN), Hampshire College (MA), and Bicycling Empowerment Network Namibia, in developing a prototype for a manually oper-

ated pearl millet thresher suitable for African village settings. F. Muuka (Zambia), I. Mbaiwa (Botswana), and A. Issaka (Niger) contributed to design specifications, and a prototype has been evaluated with pearl millet panicles sent to CTI and Hampshire College.

Collaborated with USDA-NRCS and the Smithsonian Institute to rectify incorrect information for pearl millet in the USDA-NRCS Plants Database. Pearl millet had been previously listed with incorrect taxonomic information and was classified as a noxious weed in this internet database used by NRCS field offices nationwide for making recommendations to growers.

Organized and discussed pearl millet field demonstrations at the Sunbelt Ag Expo in Moultrie, GA. (July 11, 2006), and Pearl Millet Field Day at Newton, GA (October 10, 2006).

Discussed pearl millet production and markets at demonstration plots at the Alternative Crops Workshop, Western Illinois University, Macomb, IL (July 20, 2006).

Presented "Biological and economic feasibility of pearl millet as a feedstock for ethanol production" at the 6th New Crops Symposium, Association for the Advancement of Industrial Crops. San Diego, CA October 14-18, 2006.

Presented "Pearl Millet: New Opportunities for Georgia Agriculture and Agri-Tourism" at Emanuel County Ethanol Producers, East Dublin GA (August 18, 2006), Sigma Xi Seminar, Tifton, GA (October 12, 2006), Johnson County Georgia Young Farmers Association, Wrightsville, GA (November 28, 2006), and Workshop for Small, Beginning, and Limited Resource Farmers, Heart of Georgia Technical College, Dublin, GA (December 14, 2006).

Hosted visit by Tom Hash, Principal Scientist (Molecular Breeding, Pearl Millet), International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru 502 324, Andhra Pradesh, India; December 15, 2006.

Hosted visit by Stephen Nutsugah, Savannah Agricultural Research Institute, Ghana, in complementary project, "Identifying sources of resistance to grain molds and mycotoxins in pearl millet", funded by USDA-FAS.

Collaborated with Bettina Haussmann, ICRISAT Niger, in development of complementing proposal, "Introgressing resistance to *Striga* hermonthica from wild to cultivated pearl millet", funded by USAID Initiative on Development of Linkages with the International Agricultural Research Centers.

Publications and Presentations

Journal Articles

Bean, S.R., Tilley, M., and Wilson, J.P. 2006. Separation of pearl millet proteins by high-performance capillary electrophoresis. International Sorghum and Millets Newsletter 47:167-169.

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Books, Book Chapters, and Proceedings

Wilson, J.P., Timper, P., Truman, C.C., Dale, N.M., Batal, A.B., Ni, X., Gitaitis, R., McAloon, A.J., Shumaker, G., Dowling, G. Brown, J. Webster, T., and Maas, A. 2006. Economics-driven research and incentives for pearl millet production in the United States. Proceedings of International Pearl Millet Breeding and Seed Production Workshop. ICRISAT, Hyderabad, India. (CD-ROM)

Abstracts

Wilson, J.P., McAloon, A.J., Yee, W., McKinney, J., Wang, D., and Bean, S.R. 2006. Biological and economic feasibility of pearl millet as a feedstock for ethanol production. Abstracts of the 6th New Crops Symposium, p. 47, Association for the Advancement of Industrial Crops.

Gulia, S.K., Wilson, J.P., Singh, B.P., and Carter, J. 2006. Progress in grain pearl millet research and market development. Abstracts of the 6th New Crops Symposium, p. 48, Association for the Advancement of Industrial Crops.

Breeding Grain Mold Resistance in High Digestibility Sorghum Varieties

Project TAM 230
Dirk B. Hays
Texas A&M University

Principal Investigator

Dr. Dirk B. Hays, Cereal Grain Development and Food Quality Genetics, Dept of Soil and Crop Sciences, Texas A&M University, College Station, TX 77843, USA.

Cooperators

Dr. Ralph D. Waniska, Food Science and Technology, Texas A&M University, Dept of Soil and Crop Sciences, College .Station, TX 77843-2474

Dr. Monica Menz, Director, Laboratory of Plant Genome Technology (LPGT), Texas A&M University, Dept of Soil and Crop Sciences, College Station, TX 77843-2474

Collaborating Scientists

Dr. Scott Bean, Cereal Chemist, USDA,ARS,GMPRC, Manhattan, Kansas 66502

Dr. Sergio Capareda, Biological and Agricultural Engineering, Texas A&M University, College Station, TX 77843

Dr. Gary C. Peterson, Sorghum Breeding and Genetics, Texas Agricultural Experiment Station, Lubbock, TX 79403

Dr. Louis K. Prom, Sorghum Pathology, USDA-REEE-ARS-SOA-SCR Lab CGR, College Station, TX 77845

Dr. Lloyd W. Rooney, Food Science/Technology, Texas A&M Univ, Dept of Soil/Crop Sciences, College Station, TX 77843

Dr. William L. Rooney, Sorghum Breeding/Genetics, Texas A&M Univ, Dept of Soil/Crop Sciences, College Station, TX 77843

Dr. John R. N. Taylor, Grain Quality, Professor/Head, Dept of Food Science Univ of Pretoria, Pretoria 0002 Republic of South Africa

Summary

The goal of this proposal is to combine the improved nutritional grain quality sorghum (i.e., high protein digestibility HD) with high levels of grain mold resistance. Sorghum grain mold, which is vectored by over 40 fungal species, is a primary constraint to sorghum production worldwide. The HD trait derives from a modified grain endosperm mutant possessing irregular and invaginated kafirin protein bodies. The HD grain confers a gain in function in human protein bioavailability and increased lysine amino acid content. Our project goal is to commercialize designer sorghums that combine disease and environmental stress resistance with grain possessing enhanced malting, fuel, and human and animal nutrition quality via the HD and waxy grain endosperm traits. To accomplish this goal we teamed with Southern African and Central American scientists and students and U.S. University and USDA, ARS scientists. The PI leveraged the $178,500 in funds from INTSORMIL with $120,000 in research and $212,700 in graduate fellowship funds obtained from competitive Federal and State programs during the 3-year funding period to accomplish the goals of this project. The fellowship funds supported two graduate students from Central America and two from the U.S.

In the past 2+ years we have developed molecular markers linked to single genetic loci for grain mold resistance to the two predominant vectors of the grain mold disease, Fusarium thapsinum and Curvularia lunata. The individual loci for resistance to the two pathogens are unlinked to each other and are independent of plant height, grain color, and grain hardness (Figure 1). These are critical and important new result the PI and graduate students obtained in terms of changing grain mold resistance breeding strategies and increasing grain yield. We are currently using marker-assisted-selection (MAS) in conjunction with Texas A&M sorghum breeders to combine resistance to these two pathogens into new inbred and hybrid lines. The mapping of genetic loci for the HD trait will be complete by summer 2007 and will be used to combine grain mold resistance with the HD trait.

The PI and graduate students also completed a genotype x environment (G x E) study to determine the other predominant pathogens vectoring sorghum grain mold, and the viability of HD germplasm in humid grain mold prone environments. Several HD lines were identified that were as resistant as normal endosperm lines to grain mold. No statistical correlations between assays for the HD trait and grain mold susceptibility were found. This means that grain mold resistant high nutritive HD sorghum hybrids and inbred cultivars can be developed for humid environments in Africa and Central America. Other predominant grain mold pathogens species that impact grain germination and grain quality were also identified. New resistance loci and linked molecular markers for these pathogens will be developed by the PI if refunded and combined with the resistance to *F. thapsinum* and *C. lunata* using MAS.

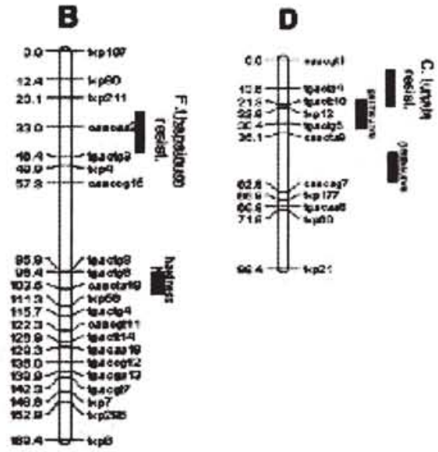

Figure 1. Framework genetic map of sorghum linkage group B and D of the inbred RIL population derived from *Sorghum bicolor* RTx430 and Sureño highlighting the locations of genetic loci for resistance to *C. lunata* and *F. thapsinum.*

The PI, graduate students and collaborators in the Texas A&M Department of Biological and Agricultural Engineering have also demonstrated the utility of the HD sorghum trait for the bio-ethanol market. We have shown that the HD trait yields 15 to 20% more ethanol with lower energy input than normal endosperm sorghums and corn. We are now using MAS to combine the HD and high waxy endosperm traits to improve on this result with a target for the bio-ethanol and brewery industry in Africa and the U.S.

Objectives, Production and Utilization Constraints

Objectives

The objectives for the 3-year funding period were as follows:

- Determine 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 the mold resistance for future utilization in genetically engineering improved resistance to grain mold.
- Test the physical and functional properties of highly digestibility sorghums in fuel, brewery, food and feed products.

Sorghum and Millet Production or Utilization Constraints Addressed

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 high grain protein digestibility (HD) trait that is also associated with high lysine content is one such attribute that may spur increased utilization of sorghum. However, for the HD 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 HD varieties with optimal endosperm characteristics and viable levels of grain mold resistance. The HD lines have also been analyzed for their improved performance in the growing African brewery and biofuels industry

Research Findings and Project Output

Grain mold and other disease resistance breeding: The PI (Hays,TAM230) in conjunction with other INTSORMIL CRSP projects (William Rooney, TAM 220c, and Gary Peterson, TAM 223) have developed molecular markers and mapped loci linked to resistance to two prominent grain mold pathogens, namely *Fusarium thapsinum* and *Curvularia lunata* (Figure 1). The genetic loci for resistance to these two pathogens were identified using control inoculations at anthesis of the individual pathogens in a set of 'Tx430' x 'Sureño' white grain recombinant inbred lines. Resistance was based on the presence or absence of ¼ PDA mycoflora colonies of the inoculated pathogen from surface sterilized grains. The loci for resistance to the individual pathogens are unlinked to each other (Figure 1). As well, they are unlinked to previously suspected phenotypic modes of resistance such as grain hardness, plant height, or plant color (not shown). It is also important to note that mycroflora resistance was poorly correlated with visual resistance scoring, but was highly correlated to controlled grain weathering by the same pathogen (i.e., dry mature grain maintained in a wetted condition). This indicates that while appearing resistant, grains can still harbor fungal mycelium that can, under the right condition, contribute to grain weathering or storage damage to grain quality. The identified markers for resistant loci are suitable for MAS. MAS and other fast breeding techniques discussed below are being used to pyramid grain mold resistant loci to *F. thapsinum* and *C. lunata* with the high value HD and waxy endosperm traits.

We have also conducted a genotype x environment (G x E) study in Texas to determine other key vectors of grain molds, and the viability of HD germplasm in a humid grain mold prone environment. Several HD lines were identified that were as resistant as normal endosperm lines based on visual and mycoflora scores. No statistical correlations between assays for the HD trait and grain mold susceptibility were found. This means that grain mold resistant high nutritive HD sorghum hybrids and inbred cultivars can be developed for humid environments in Africa and Central America. The prominent vectors of grain mold found in this study were *C. lunata*, *F. thapsinum*, *F. semitectum*, *Rhizopus mucor*, *Bipolaris*, *Alternaria*, *Phoma*, *Penicillium*, and *Aspergillus*. Some pathogens have serious correlative detrimental impacts on grain quality and germination (i.e., *Fusariums*, *Curvularia*, and *Alternaria*), while others appear to be passive pathogens with little correlative impact on grain quality and germination (i.e., *Penicillium*). Resistance loci and linked molecular markers to those individual pathogens that appear to have negative impacts on grain quality and germination are being developed in the same RIL population described above and in new RIL populations derived from novel sources of grain mold resistance. These will be used for MAS and mapped based cloning. Use of these tools, MAS and other fast breeding techniques will be trained and disseminated to collaborators in Africa and Central America. Efforts are being made to develop and provide hemizygous PCR marker pairs for simple scoring resistant and susceptible individuals in breeding populations.

The G x E study also revealed interesting antagonistic relationships between groups of grain mold pathogens. For instance *Alternaria* and *Penicillium* conferred no detrimental impacts on grain quality, had a positive impact on grain germination and were negatively associated with more pathogenic fungal pathogens such as *F. thapsinum* and *C. lunata* (not shown). This result opens some tantalizing possibilities for domesticating casual grain mold agents such as *Penicillium* as biological controls against more pathogenic grain mold agents.

High value high digestibility (HD) and waxy sorghum breeding. The PIs in conjunction with other INTSORMIL CRSP projects (William Rooney, TAM 220c, and Gary Peterson, TAM 223, Lloyd Rooney, TAM 226) have breed, and developed fast breeding technologies for the HD and high amylopectin waxy endosperm traits. These include MAS and near-infrared spectroscopy (NIR) early and late generation grain selection and sorting technologies for separating HD, waxy and HD-waxy grains with a hard flinty endosperm texture in segregating populations (being developed collaboratively with Drs. Floyd Dowel, Scott Bean, Michael Tilley, Cereal Chemist USDA,ARS,GMPRC). We have identified hard flinty, HD sorghum lines with no protein highways surrounding the starch granules. Similar lines have been identified by Bruce Hamaker (Tesso et al., 2006). The PIs have also worked collaboratively with cereal chemists and agricultural engineers from South Africa (John Taylor) and (Sergio Capareda, Texas A&M) to demonstrate the positive gain in function obtained from HD sorghums for malting and bio-ethanol systems (Figure 2). While only one HD sorghum line has been tested for bioethanol conversion to date, this one line conferred a 15-20% greater ethanol conversion rate versus corn or normal endosperm sorghums (Figure 2). Based on starch gelatinization data, we have identified additional HD lines which will confer an even higher increase in ethanol conversion rate versus normal sorghum or corn. These lines are currently being tested. Similar results have been reported for waxy sorghums (Moheno-Perez et al., 1999; Moquel et al., 2001; Urias Lugo et al., 2005). The (HD) sorghum genotypes have a modified endosperm matrices with invaginated kafirin protein bodies that do not surround the starch granules and restrict hydration. As such, the grain

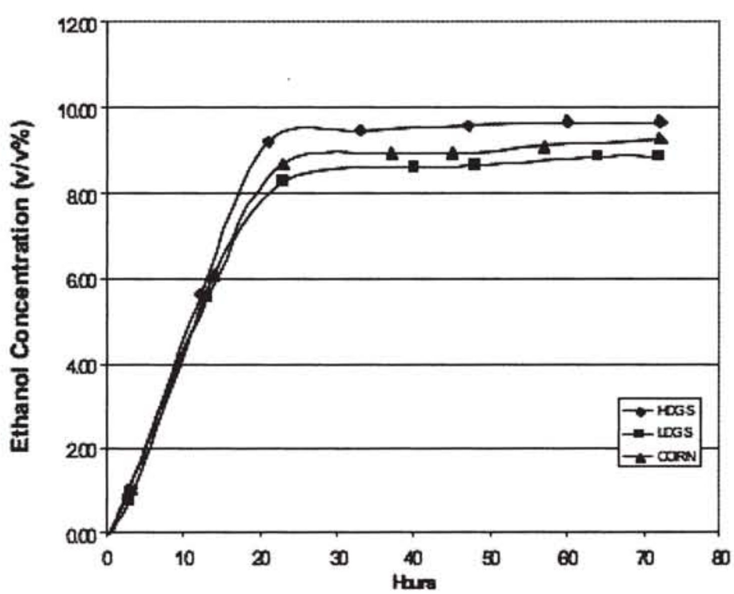

Figure 2. Change in ethanol level during 72 hrs of simultaneous hydrolysis and ethanol fermentation of high digestible grain sorghum (HDGS) (TX635/P850029), low digestible grain sorghum siblings (LDGS) (TX635/P850029) and Corn.

starch gelatinizes at lower temperatures, in less time, and produces significantly more ethanol (Capareda, D. Hays, W. Rooney, Figure 2). Second, the proteins present have improved feed value with higher bioavailability and 60% more lysine, similar to high lysine corn lines (Weaver et al., 1998). Waxy sorghum genotypes and cultivars exist with little or no linear starch (amylase) and a highly-branched amylopectin starch content. Waxy sorghums and their counterparts in other cereals require significantly less energy input for gelatinization and have improved malting (Moheno-Perez et al., 1999; Moquel et al., 2001; Urias Lugo et al., 2005) and feed quality properties. We have found similar significant reductions in gelatinization temperatures in HD protein endosperm lines (not shown). Due to the similar and complementary properties that the HD and waxy endosperm traits confer, the PI and collaborators in the U.S. and Africa (J. Taylor, Cereal Chemist, University of Pretoria, South Africa) believe combining both traits into a single sorghum cultivar will have ideal end-use attributes for malting & bio-ethanol conversion and high value grain distillers feed products with improved nutritional value coming from the high HD lysine content. We believe HD-waxy sorghums will also have added marketability in terms of improved nutritional value for traditional and fast cook sorghum based food and snack products. Crosses between advanced HD and waxy lines have been made and segregating lines will be screened for lines possessing both the HD and waxy endosperm traits combined or only the HD or waxy traits using MAS and NIR sorting technologies. These lines will be advanced along with low digestible siblings for bio-ethanol analysis in the near future

Networking Activities

D. 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, fuel, and brewery products that could be developed from the modified endosperm HD lines. The PI has maintained regular phone contact with John Taylor and supplied HD lines to him for analysis of brewing functionality. The PI also meets regularly with the William Rooney (TAM-220c) to discuss priorities for breeding HD -waxy sorghums, screening germplasm for the HD and waxy traits using MAS and protease assays, and increasing advanced lines for bio-ethanol, and food and feed product research studies in collaboration with Dr. Sergio Capareda (Dept. of Biological and Agricultural Engineering, Texas A&M University) and Lloyd Rooney (TAM-226).

Publications and Presentations

Workshops Meetings/Invited Presentations

Hays DB, Portillo O, Finlayson S, Cepeda S, Rooney WL. 2007. Designer sorghums: Analysis of sorghum genotypes with modified endosperm matrices for optimized low energy input ethanol production. National Sorghum Producers and Southern Seed Trade Association. Santa Ana Pueblo, New Mexico. presentation.

Robbins A, Hays DB. 2005 Expression Quantitative Trait Loci Mapping Grain Mold Resistance in Sorghum. American Society of Agronomy, Salt Lake City, Utah. Presentation.

Dirk B Hays. 2004. Sorghum Biotechnology: Combinability of high grain digestibility with grain mold resistance, USA-AID-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

Gebisa Ejeta
Purdue University

Principal Investigator

Dr. Gebisa Ejeta, Dept of Agronomy, Purdue University, West Lafayette, IN 47907

Collaborating Scientists

Dr. Aberra Deressa, Agronomist, EARO, Melkassa Research Station, Nazret, Ethiopia
Dr. Tesfaye Tesso, Sorghum Breeder, EARO, Melkassa Research Station, Nazret, Ethiopia.
Dr. Issoufou Kapran, Sorghum Breeder, INRAN, Niamey, Niger
Dr. Aboubacar Touré, Sorghum Breeder, IER, Bamako, Mali
Mr. C.K. Kamau, Sorghum Breeder, KARI, Kenya
Dr. Peter Esele, Plant Pathologist, NARO, Uganda
Dr. Hamis Sadaan, Sorghum Breeder, Department of Crops, Tanzania
Mr. Tesfamichael Abraha, Agronomist, DARE, Eritrea
Dr. Mitchell Tuinstra, Dept of Agronomy, Kansas State University, Manhattan, KS 66506
Dr. Darrell Rosenow, Texas A&M Ag Research Center, Route 3, Lubbock, TX 79403
Dr. Kay Porter, Pioneer HiBred International, Plainview, TX 79072
Dr. Bruce Hamaker, Cereal Chemist, Dept of Food Science, Purdue University, W. Lafayette, IN 47907
Dr. Peter Goldsbrough, Geneticist, Dept of Horticulture, Purdue University, W. Lafayette, IN 47907
Dr. Layia Adeola, Animal Nutritionist, Dept of Animal Sciences, Purdue University, W. Lafayette, IN 47907
Dr. Wilfred Vermerris, Physiological Biochemist, Purdue University, W. Lafayette, IN 47907
Dr. Abdel Latif Nour, Sorghum Breeder, ARC Sudan
Dr. Mohamed El Hilu Omer, Sorghum Pathologist, ARC, Soudan
Dr. Oudeba Botorou, Millet Breeder, INRAN, Niamey, Niger
Dr. Aberra Debelo, Sorghum Breeder, EARO, Ethiopia
Dr. Ketema Belet, Pearl Millet Breeder, EARO, Ethiopia
Mr. Zenbaba Gutema, Sorghum Breeder, EARO, Ethiopia

Summary

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

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

Major Achievements

Promote Economic Growth

Within the six-year life of this project we have learnt more about the inheritance and individual mechanisms of resistance to grain mold and tolerance to drought. A number of lines, populations, and hybrids will be made available for public release and distribution. Several seed parents were developed and scheduled for release to the US seed industry in 2002.

Improved hybrids and varieties developed in this project have been distributed for testing at various locations in collaboration with a number of NARS. These cultivars have been widely tested in several agroecologies and show excellent adaptation and promise. The potential benefits from these cultivars and others that are now in the pipeline should be substantial.

The activities of this project and the overall INTSORMIL efforts in Sudan have demonstrated that sustained support and focused research efforts would produce tangible and useful results. A similar deliberate effort has begun in Ethiopia and may be ex-

panded to Eritrea and Kenya as well. We have shown that effective utilization of research-generated technologies would in return bring due recognition to scientists and research programs, and generate increased national support for agricultural research.

Benefits arising from germplasm are often tangible and easy to recognize. Figures on acreage, volume of seed distribution, and number of farmers using improved germplasm can tell the success story sufficiently well.

Improve Nutrition

We conducted experiments that provided key understanding for the basis of improved digestibility in sorghum and utilized this information towards the development of high digestible sorghum lines. High digestible sorghum variants associated in progenies derived from the high lysine-breeding program are being developed for food.

We more recently started evaluation of hybrids derived from sorghum-inbred lines with improved agronomic characteristics but with the brown midrib trait that exhibits increased forage digestibility.

Increase Yield

We assessed genetic variation and relationships among seedling vigor traits in sorghum. Estimates of heritability and the significant additive genetic variances obtained indicated that selection for vigor and stand establishment would be effective as long as superior sources of the trait are available.

We evaluated the role of various phenolic compounds in sorghum kernels on early season seedling vigor and showed that effective selection for seedling vigor can be done by selecting sorghum kernels with high concentration of certain phenols.

We conducted specific studies in attempting to understand the genetic and physiological basis of drought tolerance using a mix of both traditional and molecular approaches.

We also conducted several studies in elucidating the basis of grain mold resistance in low and high tannin sorghums. Specific studies were undertaken in determining the role of physical and chemical kernel properties associated with mold resistance, and in assessing the nature of specific phenolic compounds that contribute to grain mold resistance.

We conducted observations relative to identification and characterization of sorghum genetic variants in glycinebetaine accumulation and their role in tolerance to drought and salinity stresses. We discovered GB protects cellular components from injury caused by dehydration. We established that GB accumulation in sorghum is inherited as a single recessive gene.

We employed molecular marker assisted selection to introgress the excellent cold tolerance observed in Chinese sorghums with the agronomic adaptation of our standard cultivars.

Improve Institutional Capacity

We provided graduate and non-graduate education of U.S. and LDC scientists in the area of plant breeding and genetics. We also contribute to human capital development by providing training opportunities and sponsoring program visits and international conferences for some LDC partners. We developed liaison and facilitate effective collaboration between LDC and U.S. sorghum and millet scientists. We worked towards developing interdisciplinary research teams with clearly defined research agenda with NARS scientists in selected countries. We have encouraged and facilitated positive institutional changes in research, extension and seed programs of collaborating countries involved in sorghum and millet research and development. We promoted the value of agricultural research as a catalyst for change and development, the recognition of improved seed as an essential input and the role of the private sector entrepreneurial approach to seed production and distribution

Objectives, Production and Utilization Constraints

- To identify and characterize traits associated with nutritional quality improvement and with increased levels of drought and grain mold resistance in sorghum.
- To assess the physiological role of the staygreen trait in sorghum.
- To elucidate mechanisms of resistance to drought and grain mold.
- To study the inheritance of phenotypic, physiological, chemical, and molecular traits associated with nutritional quality and resistance to early season cold, drought and grain mold.
- To devise breeding approaches and methods for effective exploitation of useful traits for effecting improved nutrition, cold and drought tolerance and grain mold resistance in sorghum.
- To characterize genomic differences among botanical races and germplasm pools of sorghum.
- To extensively evaluate hybrid combinations developed from sorghum inbred lines with the brown midrib trait.
- To develop sorghum varieties and hybrids with improved yield potential and broader environmental adaptation.
- To diversify the germplasm base of improved grain sorghum cultivars through introductions.
- To introgress useful traits found in landrace and wild sorghum germplasm into adapted cultivars.
- To maintain a strong seed parent breeding program (elite and diverse food-type seed parents) for both US and LDC collaborators.
- To generate and release populations, varieties, and hybrids with high yield, resistance to diseases, grain quality attributes, and increased forage digestibitibility and biofuel conversions characteristics for public and private seed programs.
- To assemble unique sorghum germplasm, and to encourage and facilitate free exchange of germplasm between US 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.

Research Findings and Project Output

We developed a better understanding of drought stress in sorghum by identifying and characterizing associated traits that contribute to stress tolerance. We employed this approach in the study of the role of osmoregulatory compounds such as glycine-betaine (GB) in drought stress and salinity tolerance. We discovered that GB protects cellular components from injury caused by dehydration. We established that GB accumulation in sorghum is inherited as a single recessive gene. We demonstrated the value of well-structured genetic populations for phenotypic and genotypic characterization leading to mapping of molecular markers associated with the important loci conditioning drought tolerance in sorghum.

We have generated an array of sorghum germplasm populations to study the genetics of drought tolerance in sorghum. We have evaluated drought tolerance of recombinant inbred lines under different moisture levels in dryland in Mexico. We identified putative molecular markers associated with drought tolerance.

Upon large-scale screening we found that sorghums from China exhibit excellent level of seedling cold tolerance. From our permanent recombinant inbred lines generated from a cross between a Chinese kaoliang and an African caudatum we identified key molecular markers associated with seedling cold tolerance. We employed molecular marker assisted selection to incorporate the excellent cold tolerance observed in Chinese sorghums with the agronomic adaptation of our standard cultivars. Introgression of seedling cold tolerance from Chinese landraces into high yielding lines using molecular markers was initiated. Key markers were identified and validated. Two new populations of sorghum were synthesized for the purpose of verification.

Newly derived mold resistant breeding lines will be evaluated at several locations to provide essential data to support release. Hybrids with mold resistant seed parents have been generated and new mold resistant parental lines will be released upon supportive evaluation data evaluated in two years. Data collected will be analyzed to support planned. Mold resistant seed parents and new sets of early maturing lines were available for release in 2002.

We conducted experiments that provided key understanding for the basis of improved digestibility in sorghum and utilized this information towards the development of high digestible sorghum lines. New and improved high digestible sorghum lines generated via longterm breeding and selection in cooperation with Dr. Bruce Hamaker will be further evaluated both for agronomic characteristics as well as for in vitro digestibility. High digestible sorghum variants associated in progenies derived from the high lysine-breeding program are being developed for food. Brown midrib mutants with reduced lignin have been introgressed into improved sorghum cultivars for commercial exploitation.

New sorghum inbred lines with improved agronomic characteristics but with the brown midrib trait that exhibits increased forage digestibility and biofuel conversion characteristics will be extensively evaluated in hybrid combinations.

We have developed a large array of food grain seed parents (A&B) lines in the last few years. These seed parents are currently under evaluation in test crosses that have been distributed to Niger, Mali, Sudan and Ethiopia. Seed increase of entries in this set has been completed and their release was planned before the 2002 crop season.

Several nurseries on drought, mold, and food grain experimental hybrids will be distributed for evaluation in cooperating NARS and the performance of these material will be assessed. This has been an on-going project that will continue as long as support is available. It has been an effective way for distribution and sharing of improved germplasm.

A study on introgression of useful genes from elite landraces into improved temperate lines has been initiated through a modified conversion program. The procedure utilizes conventional backcrossing into an improved food-grain population accelerating the rate in which useful genetic stocks are obtained in diverse genomic background. We extracted and selfed progenies which were evaluated for per se performance and for combining ability. Diverse germplasm generated from this project will be released for wide distribution.

We considered the possible role of DNA fingerprinting technology in discerning genomic similarity among and within races of sorghum. We thus conducted major studies on assessing genetic diversity using both phenotypic characters and molecular markers. In a collaborative study we analyzed genetic diversity among sorghums from Sudan.

We have also embarked on DNA marker assisted introgression of landraces and wild relatives to increase efficiency of transferring genes of value from exotic to improved sorghum lines. This is a longer-term project on increasing efficiency of breeding methods.

We are collaborators on a study that is currently underway to assess potential gene flow between and among sorghum species under natural conditions in native environments of sorghum in Africa.

Characterization of germplasm for drought, cold tolerance and grain mold resistance, as well as identification of QTL associated with these traits continues to be undertaken as major research efforts in the program.

Array of elite food-grain type seed parents with excellent food quality and yield potential and others with improved maturity and disease resistance have been developed and will be released. Drought resistant inbred lines developed from intercrossing germplasm selected in Sudan and Niger into U.S. germplasm will be released. Genetic stocks of unique gene sources will also be shared with LDC and U.S. users on a regular basis. Stay green lines developed in a seed parent background that combines excellent food grain characteristics with enhanced productivity and drought tolerance will also be available for distribution.

Description of Methods of Work Used

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 Hi-Bred and DeKalb Genetics

The training, networking and institutional development efforts of PRF-207 have been provided through graduate education, organization of special workshops and symposia as well as direct and closer interaction with research scientists and program leaders of NARS and associated programs. Much of the effort in this area has been primarily in Sudan and Niger, with limited activity in Mali and some in Southern Africa through SADC/ICRISAT.

Networking Activities

We continue to provide an array of sorghum germplasm from our breeding program to NARS 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 seven countries in 2000-01. Three new *Striga* resistant varieties of sorghum from our program in 2001 were recommended for commercial cultivation to two African countries, one in Tanzania, and two in Ethiopia. Germplasm was distributed to cooperators in 20 countries in 2002. Sorghum germplasm from our program was sent to Ethiopia, Kenya, Tanzania, Eritrea, Niger, and Mali in 2003. Germplasm was distributed to cooperators in 10 countries in 2004.

Technical assistance was provided to sorghum and millet research programs in Sudan, Kenya, Uganda, Eritrea and Ethiopia, Tanzania (Horn of Africa) on a regular basis, and to Niger and Mali in West Africa on a request basis. PI additional effort will be placed on firming up plans for operating a regional network for INTSORMIL in the Horn of Africa in association with ICRISAT and ASARECA.

Two U. S. students are currently supported by PI and are in the middle of their graduate degree programs. An Ethiopian student from EARO has just started a graduate program, and before the end of the year, a student each from Tanzania and Nigeria will start graduate program in the project. PI also hosts a Fulbright fellow from Burkina Faso and anticipates short-term training for scientists from Eritrea, Ethiopia, Sudan and Tanzania with support from other agencies. Effort will be made to assist in the procurement of support for collaborators from other donors.

Major linkages with several NARS have been established. Effective collaborative linkages have been put in place both with U.S. and LDC partners. DNA marker studies for drought tolerance as well as for germplasm classification have been accomplished in collaboration with Dr. Peter Goldsbrough (Purdue, Horticulture dept.). The germplasm development effort will continue to be in cooperation with programs in Ethiopia, Eritrea, Uganda, Kenya, Sudan as well as Niger and Mali. The pool of germplasm in PRF-107 has shown good adaptation in both West and East Africa. Sorghum breeders in each of the above countries have been partners in both the make up of synthesized populations as well as the evaluation and collection of data. This project has a good record of joint publications with both LDC and U.S. collaborators. In addition, germplasm is freely exchanged among collaborating partners and others. The PI has excellent ties with the sorghum breeders in Niger, Sudan, and Mali and recently formalized linkages with sorghum breeders in Ethiopia and Kenya.

Effective interdisciplinary teams have been put in place in Ethiopia, Eritrea, Kenya, Uganda, and Sudan. Specific research agendas engaging teams of scientist in each country or prime site will be developed in consultation with host country collaborators.

With the revival of ECARSAM as a regional network for sorghum and millet scientists in the Eastern and Central African countries, we hope to channel all our regional networking efforts through this network. Experience in the use of hybrids with successful production and distribution of hybrid seeds will be shared with neighboring countries. We hope to develop regional nurseries of drought tolerant lines and hybrids from germplasm thoroughly evaluated in Sudan and Ethiopia which will most likely be useful in other Horn of Africa countries. Germplasm, sufficiently tested in NARS experiment stations, will be made available to participating NGO and PVO to enable wider testing and demonstration in farmers' fields. Collaborative interdisciplinary projects involving agronomists, breeders, and plant protection scientists will be established.

Techniques in breeding for drought tolerance which have resulted in unique drought tolerant genotypes will be promoted and transferred. Parental lines and hybrids tested for stability and productivity will be made available. The PI will work closely with national program scientists to obtain resources for on-farm demonstration and extension of improved germplasm and package of technologies deriving from collaborative research efforts. The assistance of NGOs and PVOs will be solicited when possible.

Publications and Presentations

Refereed Papers

Knoll J.E., N. Gunaratna and G. Ejeta. 2007. QTL analysis of early-season cold tolerance in sorghum. Theor Appl Genet. (in press).

Knoll J.E. and G. Ejeta. 2007. Marker-assisted selection for early-season cold tolerance in sorghum: QTL validation across populations and environments. Theor Appl Genet (in press).

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Tesso, T., G. Ejeta, A. Chandrashekar, C.-P. Huang, A. Tandjung, M. Lewamy, J.D. Axtell and B.R. Hamaker. 2006. A novel modified endosperm texture in a mutant high-protein digestibility/high-lysine grain sorghum (Sorghum bicolor (L.) Moench). Cereal Chemistry 83(2): 194-201.

Book Chapters

Joel, D.M., Y. Hershenhorn, H. Eizenberg, R. Aly, G. Ejeta, P.J. Rich, J.K. Ransom, J. Sauerborn and D. Rubiales. 2007. Biology and management of weedy root parasites. in: J. Janick (ed.) Horticultural Reviews, Vol. 33. John Wiley & Sons, Inc. Hoboken, NJ. pp. 267-350.

Invited Presentations

Knoll, J. and G. Ejeta. 2005. Identification and validation of QTL for early-season cold tolerance in sorghum. Invited graduate student poster presented at American Seed Trade Association meeting, Chicago, IL, USA, 7-9 December, 2005.

Tesso, T., I. Kapran, C. Grenier, A. Snow, P. Sweeney, D. Marx, J. Pedersen, G. Bothma and G. Ejeta. 2005. Potential of crop-to-wild gene flow in sorghum in Ethiopia and Niger: A geographic survey. Poster presented at NCWSS/Crop Gene Flow meeting. Kansas City, MO, USA, 14-15 December, 2005.

Saballos, A., G. Ejeta and W. Vermerris. 2006. Development of brown midrib sweet sorghum as a biomass crop. Oral presentation (1b-04) given at Symposium on Biotechnology for Fuels and Chemicals hosted by the Oak Ridge National Laboratory, Nashville, TN, USA, 30 April to 3 May, 2006.

Saballos Espinal, A., W. Vermerris and G. Ejeta. 2006. Genetic enhancement of sorghum for biomass conversion. Oral presentation (#57-1) given at ASA-CSSA-SSSA International Meetings, Indianapolis, IN, USA, 12-16 November, 2006.

Gutema, Z.W., J. Knoll, J. Santini and G. Ejeta. 2006. Genetic analysis of early season cold tolerance in sorghum. Oral presentation (#57-3) given at ASA-CSSA-SSSA International Meetings, Indianapolis, IN, USA, 12-16 November, 2006.

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

Projects
KSU 220A - Mitchell Tuinstra, Kansas State University
KSU 220 B- Joe Hancock, Kansas State University
TAM 220C - William Rooney, Texas A&M University
TAM 220D - Clint Magill, Texas A&M University

Principle Investigators

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

Collaborating Scientists

Dr. Issoufou Kapran, Plant Breeding, INRAN Rainfed Crops Program, INRAN, BP 429, Niamey, Niger
Dr. Salissou Issa, Head of Animal Husbandry, INRAN Rainfed Crops Program, INRAN, BP 429, Niamey, Niger
Dr. Aboubacar Touré, Sorghum Breeding, IER/Sotuba Research Station, BP 262, Bamako Mali
Dr. Medson Chisi, PB 7, Mt. Makulu Research Station, Chilanga, Zambia
Ing. René Clará, Centro Nacional de Technologia, Agricola de El Salvador, San Salvador, El Salvador
Dr. Carlos Campabadahl, Professor Emeritus of Animal Nutrition, Centro de Investigaciones en Nutricion Animal, Universidad de Costa Rica, San Jose, Costa Rica
Dr. Scott Bean, USDA-ARS Grain Marketing and Production Research Center, Manhattan, Kansas
Dr. Mamorourou Diourté, Pathology, IER/CRRA de Sotuba, Bamako, Mali
Dr. Paul Marley, Pathology, Institute for Agricultural Research, Samru, Zaria, Nigeria
Dr. Adama Neya, Pathology, INERA, Faroko-BA Station, Bobo Dioulasso, Burkina Faso
Dr. Paco Sereme, Director General, INERA, 01 B.P. 476, Ouagadougou, Burkina Faso
Dr. Dale Hess, ICRISAT, PB 320 Bamako, Mali
Dr. Louis Prom, USDA, College Station, Texas
Drs. Fred and Eva Weltzien Rattunde, ICRISAT, P.B. 320 Bamako, Mali

Summary

The marketing and utilization of sorghum grain often has been limited by lower grain quality and feeding value compared to other cereals. Our 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.

Improve Nutrition and Increase Yield

One objective of our project was to develop sorghum varieties and hybrids with enhanced grain quality characteristics. Large-seeded sorghum genotypes with enhanced feed-value and grain-quality characteristics were identified via animal feeding trials. The genes for improved nutritional value were incorporated into local and improved genetic backgrounds. These varieties are being evaluated for adaptation and production characteristics through collaboration with colleagues in Western and Southern Africa and Central America.

Additionally, much of the historical effort in development of food-grade sorghum varieties has focused on selecting for improved grain mold resistance. Grain mold resistance is so important that molecular markers are being developed to more efficiently manipulate this trait in breeding populations. Questions have emerged that ask whether selection of genotypes that produce grains resistant to microbial and fungal attack may inadvertently have reduced digestibility by enzymes of the digestive tracts in livestock and humans. Poultry feeding trials were conducted to compare the nutritional value of grain produced from mold resistant and susceptible genotypes in different environments. These trials demonstrated that selection for mold resistance had minimal and inconsistent effects on the nutritional value of sorghum grain for broiler chicks.

Improve Institutional Capacity

The focus of our training program was to build human capital among research institutions in developing countries. In West

Africa, technology transfer efforts were initiated through interaction with Dr. Salissou Issa, Head of the Animal Husbandry Unit at the INRAN Rainfed Crops Program in NIGER. These efforts included farm visits and feeding trials to demonstrate the relative feeding value of local and improved sorghum varieties in comparison to traditional corn-based feed rations. After completion of a Poultry Field Day and formation of the Nigerien Poultry Growers Association, Salissou transferred to Kansas State to pursue a Ph.D. degree. His program included course work and some research experience in the U.S. with much of his research efforts designed to demonstrate the feeding value of sorghum grain via well designed experiments "on-site", back at his research institute in Niamey. Other graduate students and visiting scientists with interest in crop improvement, crop utilization, and molecular biology were hosted for short-term and graduate training at Kansas State University and Texas A&M University. The research projects of these student were strongly multidisciplinary and provided opportunities for collaboration with investigators from other departments and universities. Finally, our U.S. investigators presented seminars to feed manufacturers, poultry producer groups, and research scientists in Niamey, Burkina Faso, and Senegal to promote the use of sorghum grain in animal feeds.

In Central America, our training program was focused on the transfer of technology to allow development and utilization of improved sorghum and pearl millet cultivars for animal feeding and human food. A key component of our technical assistance efforts was a series of seminars given to livestock and poultry producers in El Salvador and Nicaragua on the use of sorghum grain as animal feed. Additionally, efforts in Central America included development of human capital via collaboration on an research project at the agricultural university of Nicaragua in Managua (UNA). For this project, ties were formed with the Feed Plant Manager (Francisco Baltodano) and Director of Livestock Operations (Miguel Rios) at the university and the Executive Director (Francisco Vargas) of the National Sorghum Growers Association (AMPROSOR). The university facilities were renovated to allow conduct of chick feeding experiments that demonstrated the excellent feeding characteristics of sorghum grain (when properly milled) compared to imported corn. Of equal importance was that these experiments were used as the Senior Project for four undergraduate students in the Department of Animal Science at UNA. On another front, participation in the LANCE/RAPCO Short Courses for Animal Nutrition and Feed Manufacturing was a vital component of our technology efforts in Central America.. This week-long short course was held each year in Costa Rica and included participants (professionals in nutrition, feed plant management, quality control, and ingredient procurement) from Mexico, Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica, Panama, the Dominican Republic, Columbia, Venezuela, Peru, and Ecuador. In the course, attention was given to issues (real and perceived) that limit expanded use of sorghum as a feedstuff for animal producers throughout Latin America.

Promote Economic Growth

Past breeding efforts have significantly enhanced yield potential of sorghum in semi-arid regions of the world. However, 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 and will undoubtedly increase the value of sorghum as a human foodstuff. As for feed value, poultry and egg production is rapidly increasing throughout the developing world. These industries are providing increased market opportunities for sale of grain not consumed by humans. In many semi-arid environments, sorghum is the logical cereal grain for use in manufacturing feed. However, sorghum is not always considered the feedstuff of choice because of fear about tannins that decreased feed intake (and, this growth rate) and nutrient digestibility. Numerous laboratory and animal feeding experiments were conducted in the United States, West Africa, and Central America to demonstrate and quantify the value of local and improved sorghum grains for use in feed manufacturing. Of particular importance was demonstration of the impacts of various manufacturing processes (such as fine-grinding) on feed value of the grain for layers and broilers. These experiments conclusively demonstrated that when properly milled, sorghum grain was similar to corn as a feedstuff in diets for broilers and layers used for meat and egg production.

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 local adaptation characteristics by conventional plant breeding and marker-assisted selection technologies
- Provide technology transfer and technical assistance in promoting the use of improved sorghums and millet in poultry feeding in the developing regions of Africa and Central America.

Production and Utilization Constraints

New entrepreneurial opportunities for production of animal feeds, meat, and eggs in developing countries are needed to move sorghum and millet from subsistence crops to value-added commodities. Thus, our research efforts were focused to address food quality and feed efficiency traits that would make sorghum the cereal of choice in diets for humans and livestock.

Components of feed quality are usually defined in terms of animal performance or metabolizable energy value. Thus, in our project we integrated laboratory assays for feeding quality, traditional plant breeding, and biotechnology techniques to develop elite hybrids and cultivars with improved nutritional and grain quality traits. These genetic resources were transferred to developing countries with modern poultry production practices to facilitate development of new markets for sorghum and millet. Recognition of the true nutritional value of grain sorghum by animal producers lead to greater poultry production and productivity in regions of the world where hunger and poverty are major issues.

Research Findings and Project Output

Use of Sorghum for Poultry Feed

Maize-based feed is common in many areas of Africa and Central America because the grain is cheap and readily available. In semi-arid environments, sorghum represents a more logical choice for use in manufacturing feed. However, animal producers generally will not feed sorghum-based diets because of misconceptions about the feed value and tannin content of the grain. In most cases, these concerns are unfounded because improved sorghum cultivars are low in tannin and have feed-value nearly equal to maize. Thus, to demonstrate the nutritional value of sorghums, chick growth and metabolism assays were conducted and the nutritional quality of sorghum was determined and compared to that of maize.

Our first objective was to compare sorghum genotypes with different grain morphologies and compositional characteristics to determine how these traits were related to variation in poultry feed quality. Extensive testing indicated that large seeded sorghum genotypes such as KS115, with their greater protein and fat content, had greater nutritional value and higher yield potential (Kriegshauser et al., 2006). At the time of this writing, KS115 was being used in combinations with locally adapted landrace varieties from West and Central Africa to produce lines and hybrids having large seed size and good local adaptation.

An additional consideration is that feed manufactures in Africa are likely to use grains of landrace varieties as well as improved sorghum cultivars for production of poultry feed. Many landrace sorghum varieties produce grain with a pigmented testa that has condensed tannins. Although tannins are known anti-nutritional factors that can depress growth performance in chicks, pigs, and rats, it is not known how much tannin can be tolerated in the diet before animal performance suffers. Furthermore, it is known that tannins from different origins (tea, grapes, coco) have different potencies leaving the possibility that some sorghums might contain tannins of little or no nutritional consequence. So, sorghum treatments were created by mixing decorticated endosperm from a non-tannin sorghum with blends of bran from tannin and non-tannin sorghum varieties. A broiler chick feeding trial indicated a 20% decrease in average daily gain as tannin bran (from Shanqui Red) in the diet was increased. In subsequent experiments, tannin and non-tannin brans were blended to produce tannin concentrations ranging from 0 to 5.44% CE (where % CE = catechin equivalents/100 mg of grain DM). Rate of gain was decreased by 8% as tannin concentration was increased from 0 to 5.44% CE. However, the responses were mostly quadratic and suggested that some tannin (up to 1.35% CE) was tolerated by growing broiler chicks without loss in growth performance and/or nutrient utilization.

To further investigate the possible variability in the negative effects of tannins, broiler and layer trials were conducted in Niger. The control diet had corn that was imported from Nigeria (a common practice among Nigerien poultry producers) with fishmeal and peanut cake used as the primary protein supplements. Sorghum was used to replace the corn on a wt/wt basis so that treatments were: 1) corn-based control; 2) a locally adapted sorghum landrace (Mota Galmi) with a pigmented testa and 0.3 mg % CE; and 3) an improved (white-seeded, food-grade) sorghum variety (IRAT204) with no detectable tannins. In the broiler feeding trial, ADG and ADFI were greater ($P < 0.001$) for chicks fed corn than the sorghums but carcass weight, carcass yield, and carcass fat were not different ($P > 0.35$) among the various treatments. However, more close scrutiny of the data indicated that the locally-adapted landrace was superior in nutritional value to the improved food-grade sorghum and comparable in nutritional value to imported corn. In a second experiment, Harco layers were evaluated for 18-months to determine the effects of the sorghum varieties on egg production. No differences in growth rate were detected among birds fed the corn and sorghum treatments in the first 126 days of the experiment. However, birds fed the sorghum-based diets took fewer days to come into production ($P < 0.007$), ate more feed ($P < 0.02$), and produced more eggs ($P < 0.001$) than birds fed the corn-based diet There were no differences in egg weight and egg:feed ratio among birds fed corn and the sorghums. In summary of these experiments, it can be argued that some sorghums are equal or superior to corn as a feedstuff in diets for broilers and layers reared in West Africa.

A final need for chick feeding experiments resulted from questions concerning the effects of selection for mold resistance in sorghum grain without concern for whether resistance to microbial/fungal attack might also cause resistance to attack by digestive enzymes. A chick experiment was designed with diets based on grain produced from mold resistant and susceptible genotypes grown in different environments. Analyses of the data indicated no consistent differences among locations and sorghum type for growth performance or nutrient utilization. Thus, selection for mold resistance had minimal and inconsistent effects on the nutritional value of sorghum grain for broiler chicks. Our data demonstrated that sorghum breeders should continue with current efforts to improve mold resistance in sorghum without fear of reducing nutritional value of the resulting grain.

Marker Assisted Selection for Grain Mold Resistance

In previous work, five quantitative trait loci (QTL) were detected for grain mold resistance from Sureño in the recombinant inbred line progeny from the cross of RTx430 x Sureño. In recognition of these findings, a critical component of the KSU220 project was to determine the efficacy of marker assisted selection (MAS) when used to improve grain mold resistance in sorghum.

Five sorghum populations were developed. In each population, Sureño was used as the grain mold resistant parent with one of five elite parental lines (Tx430, Tx436, Tx2903, Tx635, and Tx631). From each cross, F2 progeny were selected based on maturity and short plant height. Molecular markers associated with QTL for grain mold resistance originating in Sureño were then used to determine if their presence enhanced selection for grain mold resistance in these populations. The QTL genotypes of the 87 F4 lines were determined using simple sequence repeats (SSR) and amplified fragment length polymorphism (AFLP) markers. The F4:5 lines also were evaluated for grain mold resistance in replicated trials in eight diverse environments in South and Central Texas during the summer of 2002. The effects of each allele from Sureño were determined across and within all five populations, within individual environments, and in each population x environ-

ment combination. The results indicated that while these alleles confer additional grain mold resistance in the progenies derived from RTx430 x Sureno, their applicability beyond the mapping population is limited. This fact reduces their potential usefulness in applied sorghum breeding programs and suggests that additional molecular characterization of this trait is needed.

Other efforts at MAS for improved grain quality focused on development of robust, easily-scored markers for known genes and QTL involved in grain mold resistance. Several sorghum defense response genes that are activated in immature florets were identified in response to inoculation with Curvularia lunata and Fusarium thapsinum. The timing and level of mRNA induction was detected using real-time PCR to identify genes with optimal regulation characteristics.

A gene that confers resistance to anthracnose (*Colletotrichum gramincola*) in sorghum cultivar SC748 was tagged with flanking PCR-based markers. These markers permit the efficient incorporation of the gene into otherwise high yielding cultivars that lack resistance, even in the absence of high disease pressure. As other anthracnose resistance genes are tagged, it also will be possible to combine or "stack" multiple genes for resistance based on the easily detected DNA-based markers. Gene stacking is expected to provide much more durable resistance to pathogens, but is virtually impossible without the use of marker assisted selection. Another anthracnose resistance gene present in cultivar SC155 has been tagged with two AFLP markers that also show polymorphism in the mapping parents, allowing the marker to be pinpointed to a location on sorghum linkage group "B". Nearby SSR markers are being evaluated to identify those suitable for use in marker-assisted selection.

Enhancing Protein Digestibility

Sorghum breeding and utilization programs have identified several sorghum variants that possess unique and in some cases desirable grain quality traits. One such trait is enhanced protein digestibility which allows greater utilization of both protein and starch in the grain. This characteristic has obvious benefits for an array of end uses; however, if varieties with these mutations are to be grown, they must possess suitable levels of grain mold resistance. Two accessions with enhanced protein digestibility were evaluated in South Texas and Central America and grain mold susceptibility in these lines were increased compared to locally produced checks. To determine if susceptibility was because of increased protein digestibility or other grain based factors, these lines were crossed to grain mold resistant lines and progeny were selected for grain mold resistance. In cooperation with TAM230, these lines were screened to determine if any possessed increased digestibility. Within the group of 25 lines, six had greater protein digestibility. To determine if grain mold resistance was better in these lines, they, along with comparable lines with normal digestibility were grown in multi-location trials in 2005 and 2006. Comparisons indicated that enhanced protein digestibility can be selected in genotypes with improved levels of grain mold resistance (when compared to the original accessions). These improvements seemed to result from changes in pericarp, mesocarp, and endosperm characteristics that likely serve to protect the endosperm from degradation. None of the lines were highly resistant and it is not known if commercially acceptable levels of resistance could be developed in these materials. These populations do provide the basis for further study and development.

Striga Resistance

Researchers attending the 2004 and 2006 West Africa Regional Workshop in Burkina Faso indicated that *Striga* infestations were one of the most important regional constraints to sorghum production. It has been estimated that 3.5 million ha of agricultural lands in West Africa are infested by *Striga*. Thus, we developed a new low-biotech strategy for managing *Striga* infestations in sorghum.

Seeds from an experimental sorghum hybrid (ATx623 x Tailwind) with resistance to acetolactate synthase (ALS) inhibiting herbicides were treated with varying rates of imazapyr (0.018, 0.037, 0.075 mg ai seed-1) and metsulfuron (0.003, 0.006, 0.012 ai seed-1). These treatments were compared to an untreated control group in field trials in Cinzania, Mali and Konni, Niger in 2005 and 2006. *Striga* infestation was variable in Mali and no significant differences were detected among treatments. However, in Niger significant differences were detected among herbicide treatments. *Striga* emergence was delayed by up to 20 days in plots produced from herbicide treated seeds with eight-fold reductions in *Striga* infestation in herbicide treated plots compared to the control. These studies suggested that herbicide seed treatments may provide another tool for suppressing or delaying *Striga* parasitism in sorghum. Improved food- and feed-grade sorghum varieties that integrate this low-biotech approach with host-plant resistance to *Striga* are being developed for evaluation in integrated *Striga* management (ISM) crop production systems.

Products and/or Impacts

Poultry Production in West Africa

Numerous laboratory and production trials were conducted in the United States, West Africa, and Central America to demonstrate and quantify the value of local and improved sorghum grains for use in animal feed. Feed manufacturing technologies such as fine-grinding were evaluated as tools to further improve the feed value of grain for meat and egg production. Poultry producers from each region were invited to participate in a review of these research projects. In Niger, this dialogue led to the formation of the Nigerien Poultry Producers Cooperative.

Sorghum Variety and Hybrid Development

Kansas State University developed and distributed seven new parent lines and 19 germplasm lines to seven commercial seed companies in the United States and other countries. These lines are being evaluated in commercial breeding programs and one parent currently is being used in commercial hybrid seed production. Additionally, Texas A&M University released two sets of sorghum germplasm (Tx2912-2920 and Tx2921-Tx2928) that were made available to sorghum improvement programs throughout the world.

From 2001 to 2004, the PIs in our project coordinated the United States Tan Plant Hybrid Trial that was designed to evaluate commercially available tan plant sorghum hybrids for agronomic adaptation and grain quality parameters. The test was grown at multiple locations in Kansas and Texas. These trials indicated that commercial food-grade hybrids are now available in all maturity groups. These hybrids are high-yielding and well-adapted to dryland and limited-irrigation environments.

Germplasm exchange activities included distribution of elite parent lines, testcross hybrids, high-feed value breeding lines, and forage sorghums. These materials were distributed to national program scientists for evaluation in Niger, Mali, Ghana, Senegal, Zambia, and Nicaragua.

Herbicide Seed Treatments: A New Tool for Striga Management in Sorghum

As explained earlier in this report, a low-biotech strategy was developed for managing *Striga* infestations in sorghum. This strategy involves use of low-dose ALS-inhibiting herbicide seed coating applied to ALS-herbicide tolerant sorghum varieties. This tolerance trait is being incorporated into sorghum varieties and hybrids adapted for production in different regions of Africa in combination with host-plant resistance genes for *Striga*. Kansas State University is working with the agricultural chemical industry to register one or more herbicides for this use.

Description of Methods of Work Used

Collaborative research efforts in Africa and Central America were supported through short and long-term training programs, germplasm exchange and evaluation, and basic research support activities. These research efforts were 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 utilized elite varieties and cultivars that were adapted to each of the regions. The lines used to create these populations were selected through evaluation of elite U.S. and host-country germplasm in the targeted region. This material was evaluated in the target region in conference with collaborating plant breeders. Improvement efforts in Western and Southern Africa were focused on development of early-maturing, drought-tolerant cultivars and hybrids that incorporate *Striga* resistance. Efforts in Central America were on improved food-type and Macio Criollos cultivars. These efforts were focused on development of photoperiod sensitive hybrids using Ma5 and Ma6.

The underlying objective for research to identify and map genes related to grain quality was to develop a better understanding of the genetic control of important quality traits. This greater understanding then would allow us to generate genetic markers to be used by sorghum improvement programs in the immediate future. Combining these traits into one genotype will be a significant challenge that can be facilitated by use of molecular technology. Development of these technologies should enhance the efficiency of combining grain quality factors (e.g., feed quality characteristics and grain mold resistance) into varieties with high yield potential. Mapping populations were developed and characterized in cooperation with collaborators at domestic and international sites. These populations were genotyped in laboratories in the U.S. using various of genetic markers.

Technical assistance and technology transfer efforts in poultry production and nutrition were facilitated through workshop and short course activities as well as feeding trials and demonstrations. The feeding trials specifically were designed to compare feed value of corn- and sorghum-based poultry diets in West Africa and Central America. Replicated trials to evaluate performance of broiler and/or layer chickens were conducted in Niger and Nicaragua from 2003-2007.

Networking Activities

Workshops, conferences, and meetings to support extensions services, NGOs, regional networks, international agencies, USAID missions and others

INTSORMIL Principal Investigators (PI) Conference, Addis Ababa, Ethiopia – 2002

ASA-CSSA-SSSA – 2002, 2003, 2004

Cursos Regionales en Produccion Animal (RAPCO Short Courses), Costa Rica – 2003, 2004, 2005, 2006, 2007

Sorghum Improvement Conference of North America (SICNA) – 2003, 2005, 2007

USDA Sorghum Germplasm Committee – 2003, 2004, 2005, 2006, 2007

American Seed Trade Association (ASTA) – 2003, 2004, 2005, 2006

INTSORMIL Western Africa Regional PI Workshop, Ouagadougou, Burkina Faso – 2004, 2006

INTSORMIL Central American Regional Workshop – 2002

United States Great Plains Sorghum Conference – 2004, 2005, 2006

NSF Sorghum Genomics Workshop –2004

INTA/CINA/INTSORMIL Sorghum Utilization Conference, Managua, Nicaragua - 2005

Integrating New Technologies for *Striga* Control: Towards Ending the Witchhunt, Addis Ababa Ethiopia – 2006

USAID/INTSORMIL West Africa Sorghum in Poultry Diets Conference, Saly, Senegal -2007

West African Workshop on Hybrid Sorghum and Millet, ICRISAT, Samanko, Mali – 2007

Germplasm and Research Information Exchange

Kansas State University developed and distributed seven new parent lines and 19 germplasm lines to seven commercial seed companies in the United States and other countries. Texas A&M University released two sets of sorghum germplasm (Tx2912-2920 and Tx2921-Tx2928) in 2002. These germplasms were made available to sorghum improvement programs throughout the world.

The PIs were active members of the USDA Sorghum Germplasm Committee (SGC) from 2002 to 2007. The SGC funds and coordinates public and private germplasm research in the United

States including evaluation and seed increase of all photoperiod insensitive sorghum lines from the U.S. collection and development, seed increases, and characterization of a sorghum association panel (300 genotypes) for use in gene association studies.

Elite parent lines, testcross hybrids, high-feed value breeding nurseries, *Striga* resistant varieties, and forage sorghums were distributed to national program scientists for evaluation in Niger, Mali, Ghana, Senegal, Zambia, El Salvador, and Nicaragua in each year from 2003 to 2007.

The PIs coordinated the United States Tan Plant Hybrid Trial. This project was designed to evaluate commercially available tan plant sorghum hybrids for agronomic adaptation and grain quality parameters from 2001-2004. The test was grown at multiple locations in Kansas and Texas.

Assistance given to collaborating scientists with research equipment, supplies, and/or other support.

The PIs supported the development and/or expansion of sorghum breeding and poultry production research in West Africa, Southern Africa, and Central America. Support for these programs included direct financial support from this project as needed (e.g., pollinating bags, cameras, computers and other equipment, graduate training, purchases of chicks and feed ingredients, etc). Additionally, PIs from this project participated and presented in numerous workshops (sponsored by INTSORMIL, USAID, UNA, INRAN, INTA, CINA, ICRISAT, et al.) in each region.

An e-mail interactive group of scientists interested in the use of biotechnology has been established. These scientists participate from national laboratories in Mali, Burkina Faso, Nigeria, Ghana, and Senegal. Small equipment items required for DNA extraction, PCR amplification, and gel separation have been provided for the use of IER associates in Mali. Pass through funds have been provided for use in Burkina Faso and Nigeria, primarily for permitting disease surveys to be made and for providing samples for use in DNA comparisons.

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

Project TAM 223
Gary C. Peterson
Texas A&M University

Principal Investigator

Gary C. Peterson, Professor, Sorghum Breeding & Genetics, Texas Agricultural Experiment Station, Lubbock, TX 79403

Collaborating Scientists

Dr. Medson Chisi, Sorghum Breeding, Golden Valley Research Station, Box 54, Fringila, Zambia
Dr. Neal McLaren, Plant Pathology, Dept of Plant Sciences, University of the Free State, Bloemfontein, Orange Free State, South Africa
Dr. Hannalene du Plessis, Entomology, ARC - Grain Crops Institute, Private Bag X1251, Potchefstroom 2520, Republic of South Africa
Ing. Rafael Obando, Sorghum Breeding, Instituto Nicaragense de Tecnolog, Edificio Mar, Apdo.1247, Managua, Nicaragua
Ing. Rene Clara, Sorghum Breeding, CENTA, Apartado Postal 885, San Salvador, El Salvador
Dr. David Munthali, Entomology, Botswana College of Agriculture, Private Bag 0027, Gaborone, Botswana
Mr. Niaba Teme, Sorghum Breeding, IER Sotuba, B.P. 438, Bamako, Mali
Ms. Phoebe Ditshipi, Plant Pathology, Dept of Agricultural Research, Private Bag 0033, Gaborone, Botswana
Mr. Godwin Kaula, Plant Pathology, Ministry of Agriculture and Cooperatives, Mt. Makulu Research Station, Private Bag 7, Chilanga, Zambia
Dr. Bonnie B. Pendleton, Entomology, Division of Agriculture, West Texas A&M University, Canyon, TX 79016
Dr. W.L. Rooney, Sorghum Breeding, Dept of Soil and Crop Sciences, Texas A&M University, College Station, TX 77843
Dr. Lloyd Rooney, Cereal Chemistry, Dept of Soil and Crop Sciences, Texas A&M University, College Station, TX 77843

Summary

Increase Yield

To develop new genetics for cultivars and hybrids a number of sorghum lines were evaluated for resistance to several abiotic and biotic stresses. The objective was to identify, characterize, and utilize the genetic diversity of sorghum to develop sorghum germplasm, parental lines, or varieties with resistance to multiple stresses including insects, disease, and drought. Primary insect pests are the greenbug (*Schizaphis graminum*), sorghum midge (*Stenodiplosis sorghicola*), and sugarcane aphid (*Melanaphis sacchari*). Concurrent selection is practiced for the following diseases: sorghum downy mildew (caused by *Peronosclerospora sorghi* (Westan and Uppal) Shaw), head smut (caused by (*Sphacelotheca reiliana* (Kuhn) Clinton), anthracnose (caused by *Colletotrichum graminicola* (Cesati) Wilson), 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). Selections were made to incorporate the stress resistance into food type sorghum with improved grain mold/weathering resistance.

Promote Economic Growth and Improve Nutrition

Sorghum varieties or hybrids with multiple stress resistance increase the potential to produce a consistent supply of high quality grain for household or off-farm end-use industry. Parental lines A/BTx642 through A/BTx645 contain several valuable traits including stay-green, lodging resistance, and grain mold/weathering resistance. Seventeen biotype E greenbug/disease resistant germplasms and 17 biotype E/I greenbug resistant germplasms were approved for release. The lines are tan plant with wide adaptation and contain genes for resistance to several diseases. 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. Forty-nine converted exotic cultivars broaden the genetic base of temperately adapted germplasm available to sorghum breeders. Tx3301 through Tx3360 possess a high level of resistance to sorghum downy mildew. The lines can be used as hybrid parents or as a source of useful genes to develop food type sorghums.

Improve Institutional Capacity

Served as co-chair of one U.S. Ph.D. student in the Texas A&M University Department of Entomology and as co-chair of one Mali Ph.D. student at Texas Tech University. Served on the

M.S. and Ph.D. committees of a Mali student and two M.S. international students at Texas A&M University.

Objectives, Production and Utilization Constraints

Project Objectives

- Obtain and evaluate germplasm for resistance to arthropod pests and other abiotic or biotic stresses including drought and selected diseases.
- Develop and release high grain yield, 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

Sorghum production is constrained by less than desired yield, and biotic (insect pests and disease pathogens) and abiotic (primarily pre- and post-flowering drought) stresses that reduce yield, grain and forage quality, lower value and amount of grain or forage available to cash markets, and government policy. Sorghum with genetic resistance to stress will increase ecological fitness and reduce pesticide use while increasing productivity and profitability. Grain weathering reduces grain quality, marketability and utilization. Grain with traits suitable for end-use processing will improve marketability, profitability, and increase demand for grain. As new technologies that render solutions to existing problems are deployed new biotic stresses and production constraints may occur.

Improved plant genetics for adaptation, stress resistance, and quality are needed to meet the demands of increased food production and provide high quality grain for commercial end-uses. Integrated cropping systems with improved plant genetics should be easy to implement, economically profitable, and environmentally sustainable. Plant stress occurs as concurrent multiple events, and while research can be conducted on individual stresses hybrids or cultivars must have resistance to multiple stress(es). Development of multiple stress resistant crops is a continual effort in response to a dynamic evolving cropping agro-ecosystem.

Research Methods, Findings and Project Output

Research Methods

Crop improvement programs requires a knowledge of plant genetics, field nurseries with the capability of providing adequate selection pressure to evaluate populations for important traits, and a multi-disciplinary team to research multiple traits. Pedigree breeding supplemented with backcrossing for specific traits can efficiently incorporate desired genes into new lines. Field nurseries replicated over locations and years expose segregating populations to multiple environments and lead to identification of those genotypes with the best combination of genes for the trait(s) of interest. For combining ability evaluation advanced selections are crossed to A-line testers (for R-lines) or sterilized (A1 cytoplasm) and then crossed to R-line testers (for B-lines).

Host country research is supported through short-term training, graduate education, germplasm exchange and evaluation, site visits, and research in Texas, Southern Africa, and Central America. Southern Africa activity is focused on incorporating sugarcane aphid resistance, disease resistance, adaptation, and improved grain end-use traits into new cultivars. Central America research in Nicaragua in for with sorghum midge resistance, drought resistance, disease resistance, adaptation, and end-use traits. In the U.S. important traits include biotic (disease, insect, grain mold/weathering) and abiotic (drought) stress resistance, and increased yield. Collaboration with other projects facilitates studies on inheritance, resistance mechanisms, molecular mapping, and marker-assisted selection.

Germplasm is evaluated for resistance to insects in field nurseries or greenhouse facilities. Suitable germplasm from other programs, exotic lines, and converted exotic sorghum lines is crossed to elite resistant germplasm or to germplasm with superior traits. The goal is to develop a multiple stress resistant 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 sub-tropical South Texas. The germplasm is provided to host country collaborators in replicated trials for insect resistance and agronomic evaluation under the local production system.

Research Findings and Project Output

Five sets of germplasm were released. Parental lines A/BTx642 through A/BTx645 (A1 cytoplasm) have with purple plant color. A/BTx642 (originally A/B35) has excellent stay-green, charcoal rot, and lodging resistance. A/BTx643 (B35 derivative) has higher grain yield potential but a lower level of stay-green. A/BTx644 has excellent pre-flowering drought tolerance and a low level of stay-green and lodging resistance. A/BTx645 has excellent grain mold/weathering resistance and produces hybrids with high test-weight grain. Tx2945 through Tx2961 are tan plant types with excellent resistance to biotype E greenbug and several diseases including grain mold/weathering. Tx2962 through Tx2978 are resistant to biotype E and I greenbug. Several lines possess a high level of disease resistance. Forty-nine converted exotic cultivars broaden the genetic base of temperately adapted germplasm available. Tx3301 through Tx3360 possess a high level of resistance to sorghum downy mildew.

A Ph.D. problem compared the efficiency of marker-assisted selection versus traditional selection methodology for greenbug (*Schizaphis graminum* (L.) Rondani) resistance and post-flowering drought tolerance (stay-green). Ninety-eight recombinant inbred line populations (RILs) were derived from a cross between BTx642, a post-flowering drought resistant but pre-flowering drought susceptible line, and Tx7000, a post-flowering drought susceptible but pre-flowering drought resistant line. Two hundred and seventy four restriction fragment length polymorphic (RFLP) markers were used to identify the main-effect and epistatic QTLs. Highly significant ($P<0.05$) differences were detected between the parents and among the RILs for grain yield, drought susceptibil-

Table 1. Sugarcane aphid damage rating, grain yield, and grain mold rating of selected entries in the sugarcane aphid test at Potchefstroom and Burgershall, South Africa and Mt. Makulu, Zambia

PEDIGREE	Potchefstroom†	Burgershall†	Greenhouse‡	Grain Yield Potchchefstroom	Grain Yield Mt. Makulu	Grain Mold§
				–kg/ha--	- -kg/ha--	
(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-C CBK-LBK	3.0	2.3	1.0	4260	5503	3.2
((6BRON126/87BH8606-6*GR107-90 M46)*CE151)-LG2-CG1-BG2-BG1-C G1-CABK	3.7	2.7	1.7	4030	4977	4.0
(Town*EPSON2-40/E#15/SADC)-LG 1-BGBK-CCBK-LBK	3.3	2.3	1.3	4020	1936	4.5
(SDSL89426*6OB124/GR134B-)-LG 5-CCBK-CCBK-LBK	2.7	2.3	1.7	4000	4651	3.8
(EPSON2-40/E#15/SADC*A964)-CG 3-BGBK-CCBK-LBK	3.7	2.7	5.0	3870	2747	3.3
(CE151*TAM428)-LG15-LG1-BG1-B GBK-LBK	2.3	2.3	1.3	3760	4644	3.8
(EPSON2-40/E#15/SADC*A964)-LG 2-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)-HG5 4)*CE151)-LG1-BGBK-CCBK-LBK	1.3	1.0	1.0	3250	5435	3.8
(Marupantse*TAM428)-HM7*CA1-C G1-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/(80 C2241*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.

ity index, grain yield loss percentage, and grain yield geometric mean. Low drought susceptibility index did not always indicate higher grain yield but generally indicated lower grain yield loss percentage. The MAPMAKER/QTL analysis detected 11 main-effect QTLs for grain yield under water stress and non-stress conditions with 7 on linkage groups A and F. Three main-effect QTLs collectively explained 48.2% of the phenotypic variation in grain yield. Linkage group A contained a QTL (Gya.2) strongly associated (21.0%) with sorghum grain yield under one stress environment. Among the QTLs identified under non-stress environments, 1 QTL (Gyf.2) located on linkage group F was consistent across locations.

Table 2. Grain yield, midge damage rating, and days to 50% anthesis, for selected entries in the Midge Line Test at Santa Rosa, Nicaragua, and Corpus Christi and Lubbock, TX

Designation	Yield	Midge Damage Rating	Days to 50% Anthesis		Plant Height		
	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.

Performance of BC2 to BC4 generations from introgressing stay-green into greenbug resistant lines was evaluated in 217 back-cross lines from 9 populations. No progeny or parental line was as stay-green as the resistant check and only four lines were classified as stay-green. The populations generally produced more grain

than the parental lines. Most progeny were resistant to biotype E greenbug and slightly resistant to susceptible to biotype I. In general, lines with a combination of multiple QTLs were resistant to moderately resistant to both greenbug biotypes. QTL9 was more linked to resistance to both greenbug biotypes than QTL2, which was found linked to biotype E.

The performance of backcross generations from introgressing stay-green QTLs into elite sorghum lines was evaluated in 150 BC2 to BC4 progenies from 5 populations. Only one line could be classified as stay-green as the resistant check. There was no relationship between stay-green QTL analysis and field phenotypic ratings. Some progenies with stay-green QTLs were considered stay-green susceptible based on the field reaction.

A Ph.D. study was conducted to determine if grain yield of an adapted line can be increased by introgressing exotic cultivar genes. A BC2 derived line (DLs) population between a recurrent parent (Tx2783) and an exotic donor parent (SC170-14E) was developed. One hundred forty two DL pollinators were used to create derived line hybrids (DLHs). Grain yield (GY) and yield component analysis indicated highly significant differences among DLs and DLHs within and across environments. Several DLs and DLHs produced significantly higher GY than their parental lines, parental line hybrids and the commercial check. Grain yield was poorly correlated with later maturity while taller genotypes increased grain yield. Genetic analysis of GY and its components revealed 62 QTLs: grain yield (14), maturity (9), plant height (11), panicle exsertion (10), panicle length (9), stand after emergence (3), panicles harvested per plant (3) and 1000 seed weight (3). DLs and DLHs had 7 common QTLs for GY across environments. Fourteen QTLs positively affected GY: 3 were from DP and 11 from the RP.

The sugarcane aphid is a sorghum insect pest throughout Southern Africa. Resistance sources including TAM428, CE151, WM#177, Sima (IS23250), SDSL89426, FGYQ336 were crossed to locally adapted cultivars and to elite Texas lines. Segregating populations were selected in semi-tropical South Texas for plant height, foliar disease resistance, head smut resistance, grain yield potential, and lodging resistance. Evaluation for pest resistance and local adaptation was conducted at the ARC-GCI in Potchefstroom and the Burgershall Station near Hazyview, South Africa or Gaborone, Botswana. The test was evaluated at Mt. Makulu, Zambia for grain mold resistance. Segaolane (local susceptible check) was rated at 4.3 and TAM428 (resistant check) was rated at 1.3 (Table 1). Forty-seven entries and 36 entries respectively at Potshefstroom and Burgershall were highly resistant (one or two). In a greenhouse seedling stage trial 67 entries were highly resistant (rated at one or two). Data analysis led to the conclusion that many express seedling stage resistance and consistent resistance over locations.

The Potchefstroom and Mt. Makulu trials were harvested for grain yield. Sixty entries produced more grain than the mean. Eleven experimental entries with the highest grain yield produced more grain than the best local check (Kuyuma). Of the 60 entries that produced more grain than the mean, 26 are highly resistant to sugarcane aphid in field (rating 2.3 or less) and greenhouse (rating 1.7 or less) trials. The three entries with the highest grain yield also possess excellent resistance to sugarcane aphid. At Mt. Makulu forty-three entries produced more grain yield than the test mean (3689 kg/ha). Genotype x environment interaction was apparent with only a few entries ranking high for grain yield at both locations.

Sorghum midge is the most ubiquitous insect of sorghum and poses a production risk in many areas. Genetic resistance can provide a low cost, stable, and durable measure of control. Primary research emphasis is to develop varieties for host country cropping systems with tan plant color, white grain, disease resistance, drought tolerance, 1.5 meters in height with a moderate level of sorghum midge resistance. Primary collaboration is with the Nicaragua INTA program. Partial results from a grown at Corpus Christi and Lubbock, Texas and Santa Rosa, Nicaragua are shown in Table 2. 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 and the yield (kg/ha^{-1}) is a good indication of performance 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. Data analysis led to the conclusion that it is possible to select for a moderate level of sorghum midge resistance with moderate to high grain yield potential. Several of the lines were selected for continued evaluation.

Networking Activities

Germplasm exchange

- Germplasm was distributed as requested to private companies and to countries including but not limited to: Mali, Senegal, Ghana, Nicaragua, El Salvador, Guatemala, South Africa, Botswana, Zimbabwe, Zambia and Mozambique. The All Disease and Insect Nursery (ADIN) was evaluated domestically and internationally.
- Germplasm previously developed and released by this project is used by private seed companies.

Technology transfer

Assisted the Zambia national program to develop and publish a AProduction Guide for Sorghum and Pearl Millet in Zambia@.

Other Cooperators

Ing. Rene Clara, Sorghum Breeding, CENTA, Apartado Postal 885, San Salvador, El Salvador

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. John Taylor, Cereal Quality, Department of Food Science, University of Pretoria, Pretoria 0002, South Africa

Dr. D.T. Rosenow (retired), Sorghum Breeding, Texas Agricultural Experiment Station, TAMU-AREC, 1102 E FM 1294, Lubbock, TX 79403-6603

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

Publications and Presentations

Refereed Journal

Peterson, G.C. 2007. Registration of A/B Tx639, A/B Tx640 and A/B Tx641 midge-resistant sorghum inbred lines. Crop Sci. 47:458-459.

Peterson, G.C., K. Schaefer and B.B. Pendleton. 2007. Registration of Tx2962 through Tx2978 biotype E and I greenbug resistant sorghum germplasm lines. Crop Sci. 47:453-455.

Dissertations and Thesis

Teme, N. 2007. Molecular marker analysis of quantitative trait loci in BC2 derived population influencing heterosis in grain sorghum. Ph.D. dissertation. Texas Tech University, Lubbock, TX.

Miscellaneous Publications

Damte, T., B.B. Pendleton, L.K. Almas, and G.C. Peterson. 2006. Farm-level return on use of midge-resistant sorghum hybrid. International Sorghum and Millets Newsletter 47:101-102.

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Crop Utilization and Marketing

An Evaluation of New Market Development and Marketing Strategies on Sorghum and Millet Farmers' Income in Tanzania and Zambia

Project OSU 200
Donald Larson and J. Mark Erbaugh
Ohio State University

Prinicipal Investigator

Donald Larson, Ohio State University, CMPS/3064 Smith Lab/174 Eighteenth Ave, Columbus, OH 43210
J. Mark Erbaugh, Ohio State University, IPIA/113 Ag Admin Building/2120 Fyffe Road, Columbus, OH 43210

Collaborating Scientists

Emmanuel Mbiha, Sokoine University of Agriculture, Morogoro, Tanzania
Fredy Kilima, Sokoine University of Agriculture, Morogoro, Tanzania
Gelson Tembo, University of Zambia, Lusaka, Zambia
Priscilla Hamukwala, University of Zambia, Lusaka, Zambia

Summary

The present marketing research on sorghum and millet in Tanzania and Zambia contributes to the four INTSORMIL project objectives: promoting economic growth, improving nutrition, increasing yields, and improving institutional capacity. The main objective of this marketing project was to evaluate the effects of new market developments and new technology adoption on economic growth, productivity, and smallholder incomes. One of the keys to economic growth is increasing productivity though new technology. Linking farmers to markets is fundamental to the adoption of new technology that can increase farm output, productivity and income.

Four market developments for sorghum and millet offer opportunities to increase farmers' income: (1) the agro-food industry, especially food processing, (2) feed concentrates, (3) clear beer brewing, and (4) energy markets. Some of these markets such as sorghum based clear beer brewing and feed concentrates can be expected to grow rapidly (10 to 15 percent or more per year) in the near future while others such as fortified foods may grow more slowly. If small farmers are to take advantage of these new market developments they will need to be better integrated into commercial supply chains.

Closer coordination between producers and commercial end-users on supply chain management has begun with clear beer brewing in each country. Beer brewers have developed a sorghum based clear beer called Eagle Lager brand. Eagle Lager was introduced in Zambia in 2005 and in Tanzania in 2007. Early results in Zambia indicate that sales are exceeding expectations and that clear beer brewing has developed as a new market opportunity for sorghum producers. Lack of a market is no longer the main supply chain constraint. Rather, sorghum supply has become the main constraint. Based on interviews with key participants in the supply chain the major constraints are adequate quantities, reliable supply, high quality product and reasonable prices.

A comparison of crop budgets between farmers using traditional and new technology is presented in Tables 1 and 2 for Tanzania and Tables 3 and 4 for Zambia. The traditional technology is based on what most farmers are using at the present time in the study areas. The new technology is based on recommendations by INTSORMIL and host country research institutes. These new technologies include improved seeds, manure/fertilizer, and ridge tilling/basins to conserve moisture. Crop yields, gross returns, variable costs, profits and profit per man day all increase with the new technology package. In most cases the increases are dramatic. A large gap exists between the traditional and new technology results. The new technology returns are higher; however, the risks (e.g., market, production, and financial) are also higher which may explain the gap between use of the traditional and adopting the new technology. Farmers will examine the risk to return ratio when choosing to adopt new technology. Finding ways to lower the risk relative to the return will increase technology adoption. Linking farmers to dependable markets is key to reducing the risk to return ratio.

Quantitative analyses of survey data generally concur with past findings from research on the adoption of agricultural technologies. A combination of human capital (education) and economic assets (farm size, farm income and dwelling index) and background characteristics (sex) influence access to new information and affect the ability to adopt new technologies. In general, adopters appear to be those who are willing and able to accept the risks associated with adoption of new technologies. Thus, interventions to promote adoption of new sorghum and millet technologies need to invest in programs that reduce perceptions of risk such as educational programs and risk-reduction strategies such as provision of credit.

The present research has contributed to strengthening the administrative and research capacities of the collaborating universi-

ties. The sub-contracts provided very important resources to facilitate applied research on major crops in each country. The faculty and students have gained valuable understanding of sorghum and millet marketing, agribusinesses such as food processors, and the management of all aspects of a field research project. In addition, the interaction among the researchers has produced capacity building benefits to the faculty and students from SUA and UNZA as well as to the U.S. based researchers.

Objectives, Production, and Utilization Constraints

The main objective of this marketing economics research project at The Ohio State University was to evaluate the effects of new technology and marketing strategies on sorghum and millet farmers' income in Tanzania and Zambia. Past agricultural research and development experience indicates that adoption of improved technologies in the absence of cash markets is rare. Thus for the purposes of our study it was assumed that new markets for sorghum and millet would drive the adoption of new technologies and lead to enhanced output, farmer incomes, and improved rural livelihoods. The second year close out project objectives were: (1) to conduct further analyses of the farm level data that was collected in year one and, (2) to conduct an in-depth study of the entire value added supply chain for one of three potential valued added markets for sorghum and millet. We selected the sorghum based clear beer supply chain for study in the second year of the project because of its new and dynamic characteristics and because this value chain is emerging simultaneously in both countries.

The main production constraints addressed were low technology adoption, low productivity, low profitability, low income, and household food insecurity. The main utilization constraints addressed were perceived lack of reliable markets, linking small farmers to markets, erratic supply, poor rural infrastructure, and high costs and poor quality in the sorghum supply chain.

Description of Methods of Work Used

This marketing research project was carried out in cooperation with the Department of Agricultural Economics and Agribusiness, Sokoine University of Agriculture (SUA), Faculty of Agriculture, Morogoro, Tanzania and the Department of Agricultural Economics and Extension Education, the University of Zambia (UNZA), School of Agricultural Sciences, Lusaka, Zambia. A questionnaire was developed with host country collaborators to survey farmers in a major sorghum and millet producing area in each country (Dodoma in Tanzania and Siavonga in Zambia). It was assumed that some of the farmers in each area would be using new technologies and others would be using traditional technologies for producing sorghum and millet. Usable questionnaires were completed with over 100 farmers in each country. Additional interviews were completed with key informants in the private and public sectors in each country to obtain valuable insights about new markets and the adoption and profitability of new sorghum production and marketing technology. Key informants included farmers, input supply firms, sorghum buyers, processors, and wholesalers in the sorghum beer brewing and food processing value chain. Public sector interviews included USAID/Tanzania, USAID/Zambia, sorghum and millet researchers (e.g., INTSORMIL), government policy makers, statistical agencies, TechnoServe, CARE, and others such as the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT).

The sorghum based clear beer market was selected for additional supply chain analysis because of its high growth potential. A small number of surveys were completed with retailers, wholesalers, brewers, warehouses, transporters, local buyers, farmers, and others engaged in the clear beer supply chain. All aspects of information flows (e.g., prices, qualities, varieties), promotion flows, ownership flows, product flows, payment flows, and constraints in the supply chain were examined. A diagnostic report examining the problems and constraints of the supply chain is being prepared.

Research Findings and Project Output

New Market Opportunities for Sorghum and Millet: Four market developments offer opportunities to increase farmers' income: (1) the agro-food industry, especially food processing, (2) feed concentrates, (3) clear beer brewing, and (4) energy markets. Some of these markets such as a sorghum-based clear beer brewing and feed concentrates can be expected to grow rapidly (10 to 15 percent or more per year) in the near future while others such as fortified foods may grow more slowly. The energy market for sorghum is a longer term development that may grow rapidly but also carries higher risk because of volatile world energy markets.

Survey Results of Sorghum and Millet Farmers: In general, the households surveyed (130 in Dodoma Region, Tanzania; 116 in Siavonga Region, Zambia) have little education, small farms, low crop yields, and low incomes. Low levels of household education (6.6 years) slow the dissemination and adoption of new technologies and participation in new market opportunities. Average farm size including fallow and virgin land was 2.6 hectares in Tanzania and 2.99 in Zambia. Household income from all sources averaged about U.S. $430 in Tanzania and $260 in Zambia. Most households had several sources of income with farm income being more important than off-farm income in Zambia but the reverse in Tanzania. Average yields per hectare were 280-430 kg/ha for maize; 330-360 for sorghum; and 305-320 for millet. Overall, crop yields were very low. Most growers of maize (76%); sorghum (79%); and millet (95%), were net-buyers, indicating that food security was a major problem.

Adoption of New Technologies: The use of inorganic fertilizers and other agro-chemicals such as herbicides in agriculture was not common. However, 17 % of the farmers applied manure on maize, 30% on sorghum, and 52% on millet. Use of improved varieties varied by country with 59% of respondents in Tanzania and 30% in Zambia growing improved sorghum varieties; and 33% in Tanzania and 6% in Zambia using improved millet varieties. Tanzanian farmers indicated that they preferred the quality of local sorghum varieties, and drought tolerance and early maturity of improved sorghum varieties. The most commonly used improved sorghum varieties were Kuyuma and Sima in Zambia, and Pato, Tegemo, and Mesia in Tanzania. Most farmers used their own seed which is replanted year after year. The most important tillage practices were animal draft (Zambia) and hand hoe and zero tillage (Tanzania). Using deep tillage, planting basins and ripping to conserve soil moisture was used by very few farmers. Except

for the use of improved sorghum varieties in Tanzania, the use of improved technologies was very low.

Crop budgets using traditional and new cropping technologies were estimated for maize, sorghum and millet for surveyed households in Dodoma Region, Tanzania, and Siavonga Region, Zambia. Crop budgets for Tanzania are provided in Tables 1 and 2. The results indicate that yields and profits are low. Millet was the most profitable crop followed by sorghum and maize. The net profit for millet was 46% and 44% higher than sorghum and maize, respectively; whereas that of sorghum was 0.75% higher than maize. The profit per man day is very low, ranging from US$ 0.30 to 0.60 daily. New technology adoption increases daily profits from US$ 0.50 to 1.70 depending on the crop. Crop budgets for the Siavonga Region of Zambia are provided in Tables 3 and 4. The analysis shows that sorghum was the most profitable crop followed by millet and maize. The net profit for sorghum was 246 % higher than maize and 19 % higher than millet. However, the profit per man day is very low-ranging from a loss in maize to about US$ 0.25 daily for millet. New technology adoption increases profits from US$ 1.13 to 1.62 depending on the crop.

Analyses of factors that influence adoption of improved technologies generally concur with past findings from research on the adoption of agricultural technologies. A combination of human capital (education) and economic assets (farm size, farm income and dwelling index) and background characteristics (sex) influence access to new information and affect the ability to adopt new technologies. In general, adopters appear to be those who are willing and able to accept the risks associated with adoption of new technologies. Thus, interventions to promote adoption of new sorghum and millet technologies need to invest in programs that reduce perceptions of risk such as educational programs and risk-reduction strategies such as provision of credit.

Clear Beer Marketing and Supply Chain: Eagle Lager was successfully launched on the Zambian market in 2005 and in Tanzania in 2007. The product created a supply chain which has benefited the people and firms involved in the supply chain. Among the beneficiaries are sorghum farmers, sorghum traders, processors (breweries), beer distributors, retailers and Eagle Lager consumers. Farmers have a new commercial market for their sorghum crop. The supply chain members benefit from having more sorghum to buy, transport and sell. Brewers have a new product to market and a new source of sorghum supply. Beer distributors and retailers have another product to sell. Consumers have more choice in the selection of clear beer products to purchase. The supply chain developed by Eagle Lager can be used as a model to study value added markets for other sorghum and millet based products.

Marketing and Supply Chain Problems: Major weaknesses in the production of sorghum and millet were low productivity at the farm level resulting from poor agronomic practices, unreliable rainfall, infrastructural problems that limit competition in grain procurement, and lack of support services to enhance efficiency in production and marketing systems. Marketing problems identified by farmers in the survey were unreliable markets, low producer prices, grain damage due to storage pests, lack of price information and lack of good transportation infrastructure. Detailed analysis of market services available in villages indicates that only 9 percent of respondents received professional advice on marketing from government departments, private firms, NGO projects, or other farmers. This reveals an apparent imbalance between promoting agricultural production services and marketing services. Whereas increasing production was highly encouraged there was no similar effort to enhance marketing. Major problems in supplying sorghum and millet to commercial channels were inadequate and erratic supply, quality problems, and lack of smallholder access to commercial markets.

Policy constraints: The main thrust of government agricultural policy in both countries has been on maize, the main staple, almost to the exclusion of other grains such as sorghum and millet. Some of the policy incentives enjoyed by the maize sub-sector include output price supports, fertilizer subsidies, and other marketing institutional measures that adversely affect farmer incentives to produce sorghum and millet even in areas where the latter have a comparative advantage.

Project Outputs: The main project outputs from 2005 to 2007 were developing and implementing a farm household survey that included questionnaire design, field testing the questionnaire; training six undergraduate and graduate students plus a supervisor in each country to conduct survey work, completion of 116 and 130 farm household questionnaires in Zambia and Tanzania respectively, and tabulating, analyzing and writing up results; interviewing key public and private sector decision makers in the clear beer supply chain; presenting four seminar papers; writing two case studies; writing six reports and papers; supporting one Tanzanian PhD student on a cost share basis to complete his field research work on the clear beer supply chain; and establishing a successful collaboration with faculty colleagues in Tanzania and Zambia.

Networking Activities

This research has collaborated with INTSORMIL researchers Gary Peterson (Texas A&M), Gebisa Ejeta (Purdue), Medson Chisi (Golden Valley, Zambia), and John Sanders, (Purdue); and other researchers including Mike Weber (Michigan State University), scientists at the Ilonga Research Institute, Tanzania, and faculty at host country institutions. Networking activities included USAID/ Tanzania and Zambia, government policy makers, statistical agencies, CARE, TechnoServe and others such as ICRISAT.

Publications and Presentations

Erbaugh, J.M., D.W. Larson, E.R. Mbiha, F.T.M. Kilima, P.Hamukwala, & G.Tembo. 2007. Evaluation of New Market Development and Marketing Strategies on Sorghum and Millet Farmers' Income in Tanzania and Zambia. Presented at International Sorghum and Millet Conference, University of Pretoria, South Africa, April 25-27, 2007.

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Larson, D.W., J. M.Erbaugh, E.R. Mbiha, F.T.M. Kilima, P.Hamukwala, & G.Tembo. 2006. An Evaluation of New Market Development and Marketing Strategies on Sorghum and Millet Farmers' Income in Tanzania and Zambia. Final Report, Year One, Prepared for INTSORMIL University of Nebraska, Agreement Number 25-6805-0003-089, Under USAID Grant no. LAG-G-00-96-90009-00, OSURF Proj. No: 60004926. September 30, 2006, Columbus, Ohio.

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Tembo, G., P.P. Hamukwala, D.W. Larson, J. M. Erbaugh, and T.H. Kalinda. 2007. Adoption of improved agricultural technologies by smallholder maize, sorghum and millet farmers in southern Zambia. Paper prepared for INTSORMIL University of Nebraska, Agreement Number 25-6805-0003-089, Under USAID Grant no. LAG-G-00-96-90009-00, OSURF Proj. No: 60004926. May, 2007, Columbus, Ohio.

Table 1. Maize, sorghum and millet crop budgets with current technology adoption in surveyed districts of Dodoma-Tanzania for 2005-2006 agricultural season

		Crop	
Variable	**Maize**	**Sorghum**	**Millet**
Average yield per hectare (kg)	433.05	338.75	321.05
Average farm price (Tshs/kg.)1	169.25	200.00	369.31
Average gross return per hectare (Tshs)	74,462	67,753	118,565
Average variable cost per hectare (Tshs)	15,285	9,135	12,167
Average profit per hectare (Tshs)2	58,180	58,615	106,397
Average man days per hectare	134.9	168.45	164.58
Profit per man day (Tshs)	31.23	314.37	646.55

Source: Survey Data, 2006 Exchange rate equals Tshs 1,100/US$.

Table 2. Maize, sorghum and millet crop budgets with new technology adoption in surveyed districts of Dodoma-Tanzania for 2005-2006 agricultural season

		Crop	
Variable	**Maize**	**Sorghum**	**Millet**
Average yield per hectare (kg)	5,000	3,500	2,500
Average farm price (Tshs/kg.)	169.25	200.00	369.31
Average gross return per hectare (Tshs)	846,250	700,000	923,275
Average variable cost per hectare (Tshs)	750,410	535,885	538,917
Average profit per hectare (Tshs)	95,480	164,112	384,357
Average man days per hectare	193.53	232.57	205.75
Profit per man day (Tshs)	495.24	705.64	1,868.08

Source: Survey Data, 2006 Exchange rate equals Tshs 1,100/US$.

Two crop budgets for each of the three cereal crops – maize, millet and sorghum – for Tanzania's smallholder agriculture are presented. For each crop, one budget assumes potential input use and yield levels whereas the other uses actual input use and yield levels. The potential budget is drawn from conditions recommended by researchers for this level of management. These new technologies include improved seeds, manure/fertilizer, and ridge tilling/basins to conserve moisture. The actual budget is drawn from actual survey data from farmers in Dodoma region in January, 2006.

Table 3. Maize, sorghum and millet crop budgets with current technology adoption in surveyed districts of Siavonga region-Zambia for 2006-2007 agricultural season.

		Crop	
Variable	**Maize**	**Sorghum**	**Millet**
Average yield per hectare (kg)	279.78	362.19	306.61
Average farm price (ZMK/kg)	760.00	960.00	960.00
Average gross return per ha (ZMK)	212,633	347,702	294,346
Total variable cost per hectare (ZMK)	418,846	336,000	216,000
Average profit per hectare (ZMK)3	-206,213	11,702	78,346
Average man days per hectare	106.00	112.00	72.00
Profit per man days (ZMK)	-1,945	105	1,088

Source: Survey Data, 2006 Exchange rate equals Zambian Kwacha (ZMK) 4,100/US$.

[1] Kariakoo is the largest consumer market in Tanzania located in Dar es Salaam, grains traded in this market come from all regions and its prices are arguably a good reflection of commodity prices in Tanzania. The farm prices were adjusted for transportation cost between Dodoma and Dar es Salaam.

[2] Average profit per acre is the average gross return minus the variable costs of production. The average profit per acre is the return to the fixed costs of production such as land and management.

[3] Average profit per acre is the average gross return minus the variable costs of production. The average profit per acre is the return to the fixed costs of production such as land and management.

Table 4. Maize, sorghum and millet crop budgets with new technology adoption in surveyed districts of Siavonga region-Zambia for 2006-2007 agricultural season.

		Crop	
Variable	**Maize**	**Sorghum**	**Millet**
Average yield per hectare (kg)	1,550	800.00	700.00
Average farm price (ZMK/kg)	760	960	960
Average gross return per ha (ZMK)	1,178,000	768,000	672,000
Total variable cost per hectare (ZMK)	852,550	303,500	323,912
Average profit per hectare (ZMK)	325,450	464,500	348,087
Average man days per hectare	70	70	70
Profit per man days (ZMK)	4,649	6,636	4,973

Source: Survey Data, 2006 Exchange rate equals Zambian Kwacha (ZMK) 4,100/US$.

Two crop budgets for each of the three cereal crops – maize, millet and sorghum – for Zambia's smallholder agriculture are presented. For each crop, one budget assumes potential input use and yield levels whereas the other uses actual input use and yield levels. The potential budget is drawn from conditions recommended by researchers for this level of management. These new technologies include improved seeds, manure/fertilizer, and ridge tilling/basins to conserve moisture. The actual budget is drawn from actual survey data from farmers in Siavonga district in November, 2005. Prevailing market prices, as reported in the Ministry of Agriculture and Cooperatives crop budgets, were used in the computations. Maize input and output estimates were obtained from the Ministry of Agriculture and Cooperatives crop budgets. The potential yields for sorghum and millet were obtained from FAO (2003).

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

Project PRF 212
Bruce R. Hamaker
Purdue University

Principal Investigator

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

Collaborating Scientists

Mr. Kaka Saley, Cereal Scientist; Mr. Moustapha Moussa, Cereal Technologist; Ms. Ramatou Seydou, Chemist; Dr. Issoufou Kapran, Sorghum Breeder; INRAN B.P. 429, Niamey, Niger
Ms. Senayit Yetneberk, Cereal Scientist, 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
Dr. Iro Nkama, Professor, University of Maiduguri, P.O. Box 1069, Maiduguri, Nigeria
Mr. Boniface Bougouma, Cereal Scientist, IRSAT/DTA, B.P. 7047, Ouagadougou, Burkina Faso
Dr. John Taylor, Cereal Chemist, University of Pretoria, Food Technology Dept, Pretoria 0002, South Africa
Dr. Adam Aboubacar, Assistant Professor, University of Wisconsin-Stout, P.O. Box 790, Menomonie, WI 54751
Dr. Arun Chandrashekar, Cereal Chemist, CFTRI, Dept of Food Microbiology, Mysore 570013, India
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

This project has focused on improvement of nutritional and grain quality of sorghum and millet, and their processing to competitive products for the West Africa Sahelian marketplace. The overall aim of the research is to make sorghum and millet more competitive grains for human and animal nutrition and for enhanced utilization in traditional and processed foods. In the period 2001 to 2007, major advances for PRF-212 were in five areas involving grain quality improvement and processing: 1) a mechanistic understanding of the basis of the comparably lower raw and cooked starch digestibility of sorghum grain and strategies to improve it, 2) grain quality improvement of the high protein digestibility, high-lysine sorghum mutant (collaboration with G. Ejeta), 3) an understanding of the relationship between starch amylopectin fine structure and its retrogradation property and a strategy to improve staling quality of sorghum and millet, 4) discovery of how to make non-wheat cereal storage prolamin proteins behave as wheat gluten to make yeast-leavened products, and 5) development of new pre-gelatinized sorghum thin and thick porridge flours that were preferred in sensory trials in Niger over traditionally-processed porridges. This project PI has a number of collaborations with PIs in West Africa associated with improving or developing new sorghum and millet-based products for sale to urban consumers. These are summarized both in this and the West Africa regional reports. A number of students and post-doctoral research associates were trained in this period including Betty Bugusu, a Kenyan doctoral student who worked on the sorghum starch digestibility problem, and Moustapha Moussa, a Nigerien master's student who developed the pre-gelatinized "instant" porridge flours.

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 criti-

cally 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, and their competitiveness, through a better understanding of the structural and chemical components of the grain that affect quality. This knowledge is 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

Pregelatinized Sorghum Flour Products

In a completed study, M. Moussa (INRAN/Niger) and in collaboration with Dr. LiFu Chen of Purdue's Food Science Department, developed a procedure to produce pregelatinized sorghum or millet flours using a high shear, low pressure mixer for possible commercialization as instant thin or thick porridges. It has clear advantages over traditional processes of having the advantage of using a low-moisture feed stock to produce a dry product similar, but of lower cost, than an extruder, and of higher quality than a drum-dried product. Consumer testing in Niger in four urban and rural sites showed both instant thin and thick porridges were statistically preferred over same flour-prepared traditional porridges (Figure 1). Such high quality instant porridge flours appear to have good potential in urban markets where mid-level consumers are able and wanting to buy more convenience foods. Moreover, pregelatinized flours have good potential for long term storage and low susceptibility to microbial spoilage. This is one project in our effort to find ways to enhance sorghum and millet markets in West Africa.

Analysis of the physicochemical properties of various optimized instant sorghum porridge flours were conducted and related to sensory acceptability results. Analysis of dynamic oscillation measurements on thick porridge samples via frequency sweep revealed that all instant thick porridges were found to form stronger viscoelastic gels than the local traditionally prepared sorghum MR732 cultivar. As well, analysis of viscosities of thin porridge samples via flow curves measurement show that, at a maximum shear stress of 100Pa, the conventionally cooked MR732 thin porridge had the highest viscosity, while all instant thin porridges were characterized by lower viscosities. Molecular weight distributions of starch molecules showed significant fragmentation of amylopectin in the instant flours, a property thought to confer a smoother, creamier texture to the porridges.

High Quality Couscous and Flour Processing

Over the period, we have continued collaborative efforts to produce high quality sorghum and millet agglomerated products (couscous and other sized products) and flours at INRAN/Niger with a regional strategy and collaborations to commercialize sorghum and millet products. A group of food scientists/technologists from each of the six INTSORMIL-collaborating West Africa countries, and B. Hamaker, have met a number of times to draw up a regional strategy and concept note under the leadership based principally on the institution, Institut de Technologie Alimentaire (ITA) in Dakar, Senegal and PI A. N'Doye.

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

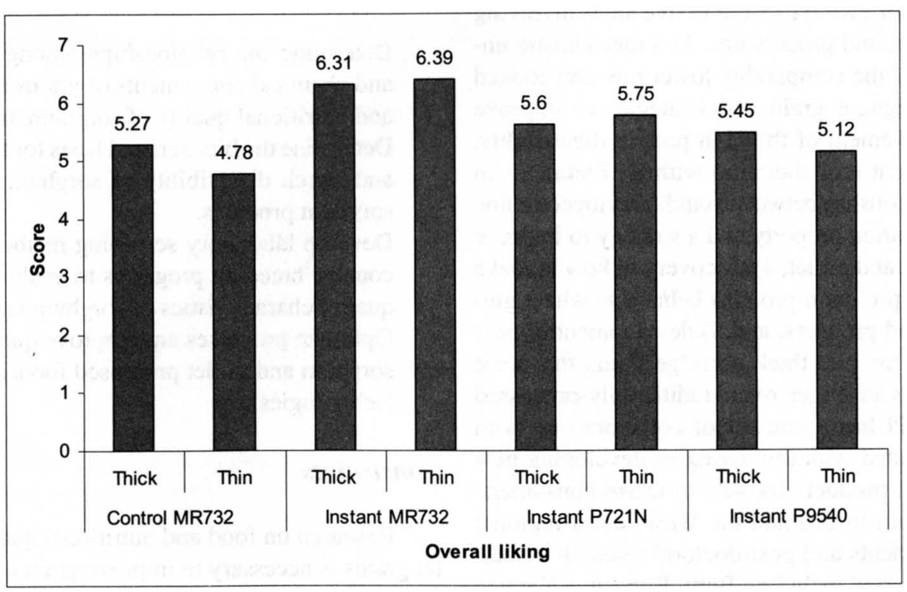

Figure 1. Combined overall liking scores for new instant thin and thick porridges compared to the traditionally processed control porridges

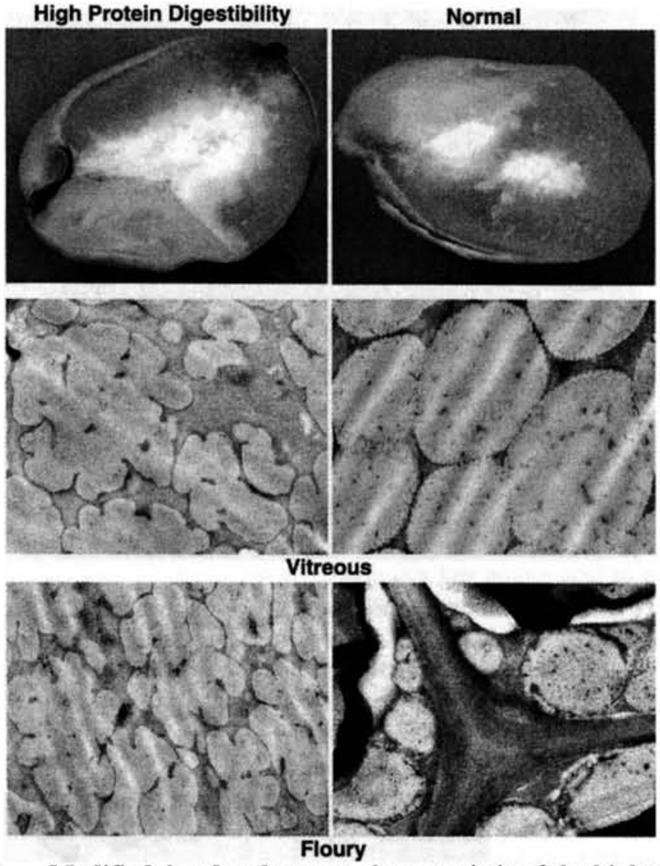

Figure 2. Modified, hard endosperm characteristic of the high protein digestibility/high lysine sorghum mutant (left) with altered protein bodies compared to a related normal, hard kernel line (right)

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. This project collaborates with J. Sanders and O. Botorou and their efforts towards contracting farmers to provide a pure, clean grain source for processed products. This is critical to make consistent, acceptable products.

Nutritional Quality Improvements in Sorghum

We continued work in this period on sorghum nutritional quality improvement with two areas of focus: 1) grain quality (hardness) improvement of Purdue's previously identified high protein digestibility/high lysine sorghum mutant lines [collaborative previously with J. Axtell (deceased) and now with G. Ejeta], and 2) understanding the basis of the comparably poor starch digestibility property of cooked and raw sorghum foods and feed. As described in reports and publications prior to this project period, 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.

High Protein Digestibility/High Lysine Sorghum Mutant

Figure 2 notably shows that the nutritionally enhanced mutant can be combined with hard endosperm trait, even though its packing is fundamentally different from that of a normal hard sorghum kernel (i.e., the former has starch packed in a discontinous protein matrix). This modified hard endosperm sorghum mutant is not yet consistent among all panicle kernels, and studies are continuing on this track.

Sorghum Starch Digestibility

Our research findings on manipulations of sorghum starch digestibility showed that, during the cooking process, sorghum proteins form web- and sheet-like structures that constrain gelatinizing starch granules. Thus, cooked sorghum porridge, for example, has a preponderance of protein-starch associated complexes (Figure 3) that appear to restrict starch digestion rate leading to lower starch digestibility. These extended protein structures are formed due to intermolecular disulfide-bonding that creates large polymers, and their rupture improved digestibility. Normal sorghum grain apparently contains a third component that acts to promote protein polymerization that affects starch, as well as protein, digestibility and its identification could lead to more (or less) digestible grains. In the area of animal feed use, starch granule properties were shown

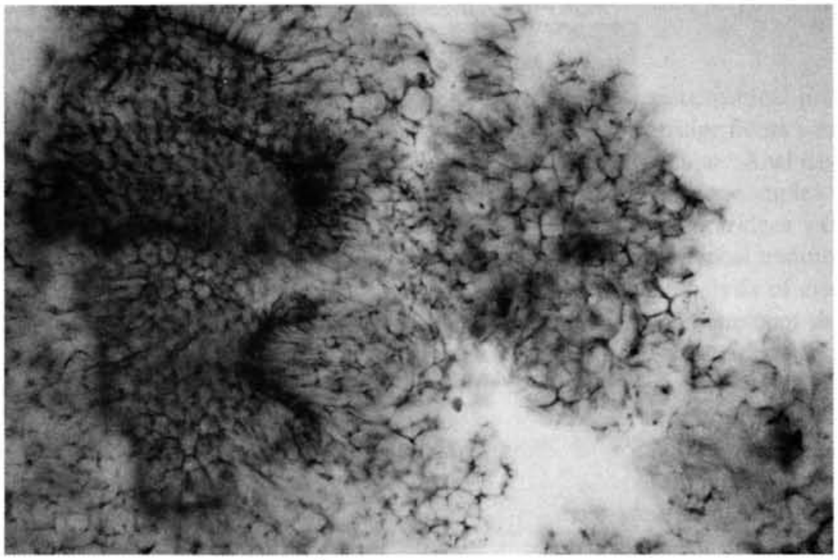

Figure 3. Light micrograph of cooked sorghum flour (1:10 w/v flour-to-water, 20 min at 100°C) stained for starch (pink) and proteins (blue). Gelatinized starch entrapped in protein webs is the last to be digested by α-amylase (Venkatachalam and Hamaker, unpublished)

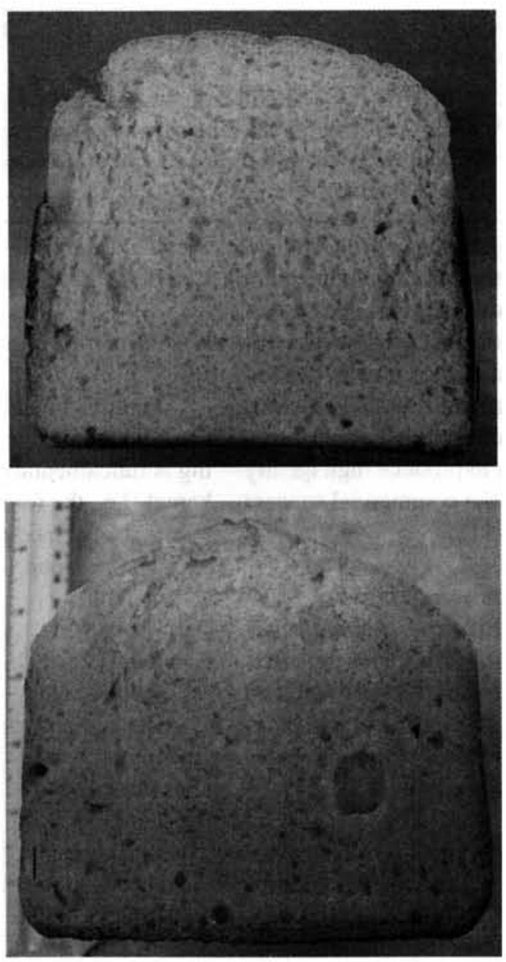

Figure 4. Yeast-leavened breads made from wheat flour (top) and a maize zein-starch model system (gluten-free) (bottom)

to affect raw starch digestibility rates and strategies were discussed to improve this property.

Starch Structure and Keeping Quality of Sorghum

A study on fundamental factors that affect sorghum flour pasting properties showed that starch amylopectin fine structure (lengths and proportions of linear chains), and specifically proportion of the longest chains, was highly correlated (r=0.92) to retrogradation (starch reassociation) tendency during storage. This relates starch structure to staling property and may relate to the comparably poor shelf life of some sorghum products (e.g., injera). Noted variability in this property among different sorghum cultivars provides a strategy to improve sorghum product storability through varietal selection.

Making Sorghum and Millet Storage Proteins Behave Like Wheat Gluten?

This study shows that maize prolamin storage protein (zein) can function similarly to gluten, and is the first report of a non-gluten protein yielding a leavened bread-type product. Maize zeins were used as model proteins due to their availability in a relatively pure form. Sorghum and millet prolamins are analogous to zeins. Prolamins were shown to increase in their β-sheet secondary structure similar to wheat gluten when made to be viscoelastic. We found a means to stabilize this increase in β-sheet structure and, when doing so, showed that these proteins could be made to behave similar to wheat gluten in a bread making system to yield yeast leavened bread (Figure 4). This work provides a new opportunity to develop gluten-free products and perhaps ultimately sorghum or millet grains with bread making property.

Networking Activities (2006-2007)

In January 2007, B. Hamaker traveled to Niger, Mali, and Senegal for PRF-212 activities in Niger to promote pre-gelatinized thin and thick sorghum porridge flours to donor groups, and in his West Africa regional coordination role. In April 2007, he traveled to Ouagadougou, Burkina Faso to participate in a regional planning meeting for the new CRSP project.

Publications

Journal Articles

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Thesis

Moussa, Moustapha. 2007. Effect of High Shear, Low Pressure Continuous Processor Technology and Sorghum Cultivars on the Properties of Pregelatinized Sorghum Foods. M.S.

Food and Nutritional Quality of Sorghum and Millet

Project TAM 226
L.W. Rooney
Texas A&M University

Principal Investigator

Lloyd W. Rooney, Professor, Food Science & Agronomy, Cereal Quality Lab, Soil & Crop Sciences Dept, Texas A&M University, College Station, Texas 77843
Cooperator: Ralph D. Waniska, Professor, Food Science, Cereal Quality Lab, Texas A&M University, College Station, Texas 77843

Collaborating Scientists

Dr. A. Touré, Sorghum Breeder, Institute Economic Rurale, Bamako, Mali
Dr. G. Peterson, Texas A&M Ag Research and Extension Center, Lubbock, TX 79401
Drs. W.L. Rooney and D. Hays, Texas A&M University, Soil & Crop Sciences, College Station, TXs 77843-2474
Drs. Mitch Tuinstra Dept of Agronomy, and Joe Hancock, Dept. of Animal Sciences and Industry, Kansas State University, Man hattan, KS 66506-5506
Dr. Sergio Serna-Saldivar, Professor and Head, Food Science, ITESM de Monterrey, Monterrey, Mexico
Professor John R.N. Taylor, Head, Food Technology Dept, University of Pretoria, Pretoria 0002, South Africa
Ms. Ruth Vilma Calderon, Food Technologist, and Ing. René Clará, Sorghum Breeder, CENTA, Km 331/2 Carretera a Santa Ana, San Andrés, La Libertad, El Salvador
Ms. Eliette Palacio, Seed Technologist, INTA, Managua, Nicaragua
Dr. Javier Bueso, Associate Professor, Escuela Agricola Panamericano, Zamarano, Honduras
Dr. John Sanders, Professor, Agriculture Economics, Purdue University, W. Lafayette, IN 47907-2056

Summary

Special sorghums have excellent levels of bioactive compounds that are unique with promising positive effects on colon and breast cancer in addition to producing bran with high antioxidant power equal to blueberries. Other positive health benefits relate to slower digestion that has applications in type II diabetes. Supply chain management systems are improving the profitability and acceptance of sorghum/millet based convenience foods for urban markets in Africa, Central America and USA. New, more-efficient, higher-yielding white tan varieties and hybrids have excellent properties for food processing. In West Africa, demand for sorghum and millet products is increasing and contracting among supply chain components is increasing. In El Salvador, small farmers have vertically integrated; they sell their white tan sorghums in the form of baked products. The principle of supply chain management from seed to food products is being implemented. United States value-enhanced white food sorghums developed in part by INTSORMIL, and promoted by the U.S. Grains Council continued to be used in Japanese foods. Several small mills in the US are producing sorghum flour for food markets, especially for celiac-sprue and ethnic groups. Anheuser Busch Redbridge™ lager beer based on sorghum is nationally marketed for celiacs. Tannin and other special sorghums have excellent levels of antioxidant power, high dietary fiber, and impart attractive dark natural color to baked products. They were incorporated into a wide variety of products including BONGOS (a whole grain snack), VITA-BREAD and gluten-free products. Workshops and seminars on food and special tannin sorghums as health foods were presented in South Africa, Mexico, Central America, Mali and Senegal. The project graduated 11 M.S., 4 Ph.D., 9 short-term trainee students, and produced more than 127 publications. Presentations included international conferences, workshops, commercial companies, and sorghum conferences in Nicaragua, Mexico, El Salvador, Guatemala, Brazil, Japan, Australia and USA.

Objectives, Production, and Utilization Constraints

Objectives

- Develop urban convenience food products from sorghum and millet and assist in developing supply chains to secure a consistent supply of grain for profitable processing
- 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

This project relates quality to measurable characteristics that are used to select sorghum and millets with good 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 finds more efficient ways of processing sorghums and millets into new foods with better acceptability that can generate income for farmers and entrepreneurs.

Research Findings and Project Output

Research Findings

More people understand the need to develop supply chain management schemes to secure grain for processing. Many small entrepreneurs demanding improved quality grain are paying 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.

Products and/or Impacts Produced from Projects

Supply chain management is the way to improve adoption of new technologies from cultivars to management practices, provided there is a profitable market for the grain produced. Successful development of this system requires patience and practical programs to educate key managers, farmers and processors. J. Sanders' project on marketing has demonstrated this concept and profitable millet/sorghum foods are being marketed in West African countries.

Similar findings in Central America demonstrated that good quality sorghum produces convenience foods with good taste, appearance and consistent quality at competitive prices. In El Salvador, sorghum flours from improved white tan plant varieties like Sureño, Soberano, and Dorado are used in small bakeries to produce pan dulce, muffins, bread, rosquettes, rosquillos and other variations of these products. The ability to identity preserve food sorghums for processing is necessary for consistent success.

Some producers process their own sorghum into flour and sell baked products in local village markets. These operators plant, harvest, store and process Dorado grain into baked products for sale in local villages. There is significant interest in the larger formal baking industry in San Salvador to use white sorghum flour. Ms. Vilma R. Calderon, Food Technologist, CENTA, worked with a rice miller to process white food sorghum into excellent flour and decorticated products which are acceptable to bakers in San Salvador. The bland flavor of sorghum flour has advantages over corn flour as a wheat flour substitute, and in producing certain types of snacks, i.e., extruded fried potato sticks.

Extrusion processing. Several graduate students demonstrated that whole grain, cracked whole grain and decorticated grain of waxy, heterowaxy and nonwaxy sorghums had significantly different extrusion properties when producing ready-to-eat breakfast cereals and snacks 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. Extrusion processing caused significantly reduced levels of extractible tannins, and reduced antioxidants in sorghum products. The success of commercially extruded Japanese snacks substantiate that sorghum can be easily processed into a wide variety of products.

Bioactive components and health benefits of sorghums. Tannin, black and other special sorghums have relatively large amounts of unique compounds that have significantly positive effects on human health ranging from type II diabetes control to anticancer activities. The bioactive compounds are concentrated in the outer areas of the kernel, and can be easily concentrated by abrasive milling and other processes. They contain powerful antioxidants effective in stabilizing ground meat patties, and have in vitro antioxidant levels similar to many fruits and vegetables. In addition, some have high levels of 3-deoxyanthocyanins which are pH-stable colorants. These compounds have anticancer activities in human cell culture tests. The condensed tannins of sorghum provide strong antioxidant activities; their availability is affected by different processing methods.

Health foods from special sorghums. Our graduate student product development teams won first prize in three consecutive years in the American Association of Cereal Chemistry International Conference for producing BONGOS, "Vita Bread" and CRUNCHCHIPS containing sorghum whole grain and bran. 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. A bread that contains high tannin sorghums as a source of antioxidants is currently being sold by a commercial bakery in the USA.

Gluten-free breads for celiacs. A gluten-free bread for gluten intolerant people based on a blend of starches, xanthan gum, tannin sorghum bran, inulin and flax seed 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. Sorghum is sold in a wide variety of celiac foods.

Tan plant food-type hybrid performance and quality trials. Environment and hybrids significantly affect composition, physical and processing properties of sorghums. 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 has a thin pericarp particularly suited to whole grain extrusion.

Networking Activities

Southern Africa

INTSORMIL interaction with Professor Taylor and his colleagues at the University of Pretoria informed many future African food industry leaders of the potential role of sorghum and millets as food and industrial ingredients. Three Ph.D. students graduated and returned to Mozambique, Ethiopia and Zimbabwe. Martin

Kebakile (Ph.D. student, Botswana), Stephen Barrion and Luke Mugode (M.S. students), Food Science Department, University of Pretoria, continued their studies with partial support from INTSORMIL. Workshops were held to demonstrate the use of sorghums in food and feeds for Southern Africa.

Sorghum use in decorticated meals for porridges is increasing in spite of a 14% value-added tax on sorghum in South Africa. The currently strong interest in white sorghums by South African breweries has stimulated interest in improved sorghum cultivars for Southern Africa.

Professor Taylor's research program is optimizing processes using local equipment for sorghum and millet. For example, Mr. Kebakile compared traditional and modern dry milling methods for 10 varieties of sorghum which suggests a roller mill was summarized in Cereal Foods World in 2007. Mr. Barrion, University of Namibia, is completing a M.S. on milling of pearl millet and its food quality. Mr. Mugode's work on sorghum brewing in Zambia continues.

Dr. Leda Hugo, Head, Agronomy Department, Eduardo Mondlane University, Mozambique, received her Ph.D. from University of Pretoria with partial support from INTSORMIL.

Central America, Mexico and South America

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 and healthy foods, i.e., anticancer activities. Dr. Serna-Saldivar has provided assistance to our projects in El Salvador and Nicaragua, and was a key speaker in the Nicaraguan white sorghum utilization workshop.

Dr. L.W. Rooney made several trips to El Salvador, Nicaragua and Mexico to develop collaborative research plans and to participate in workshops on utilization of sorghum for human and animals which were jointly sponsored by CENTA, INTA, AMPROCESSORS and INTSORMIL. Myths about sorghum tannins were discussed. We graduated five graduate students from Central America and Mexico who were partially funded on TAM-226. Ms. Vilma Ruth Calderon, Food Technologist, CENTA, will return to El Salvador in September 2007 with her M.S. degree. We hosted three EAP, Zamorano, Honduras food science visiting scholars for the spring semester of 2005-2007.

West Africa

Ms. Yara Koreissi, Food Scientist, IER, Mali, and Mr. Joseph Gayin, Assistant Research Scientist and Borlaug Fellow, Food Research Institute, CSIR, Accra, Ghana, received short-term training in our laboratory. Lloyd Rooney participated in workshops in Mali and Senegal on marketing of sorghum and millet feed and food products.

North America

Numerous papers were presented at the American Association of Cereal Chemists conferences (37), the Institute of Food Technologists conferences (8), commercial food companies and to other groups. For example, a special seminar and demonstrations of gluten-free products from white sorghum was presented to 52 Disney World chefs.

More than 255 participants from all over the world enrolled in the annual 1-week short course on practical snack food production for private industry in which sorghum utilization was part of the program. A book, Snack Foods Processing, co-edited by Lloyd Rooney, contained information on food sorghum.

Training, Education and Human Resource Development

Eleven M.S. degree and four Ph.D. students graduated; nine visiting scholars were provided short-term training. Our collaboration with Dr. Serna-Saldivar, Head, Food Science Dept., ITESM, Monterrey, Mexico has led to completion of six or more M.S. degrees. These scientists have positions in the Mexican food industry which transfers technology directly to industry.

Collaboration with University of Pretoria has educated three Ph.D. students, and one Ph.D. and two M.S. students continue.

Publications and Presentations

(In 6 years, 127 publications, excluding proceedings: 29 journal articles, 10 book chapters, 10 theses, 1 non-thesis opt, 4 dissertations, 73 abstracts)

Journal Articles

Dykes, L. and L.W. Rooney. 2007. Phenolic compounds in cereal grains and their health benefits. Cereal Foods World 52:105-111.

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Dykes, L. and L.W. Rooney. 2006. Sorghum and millet phenols and antioxidants. J. of Cereal Science 44:236-251.

Rodriguez-Herrera, R., R.D. Waniska, W.L. Rooney, C.N. Aguilar, and J.C. Contreras-Esquivel. 2006. Antifungal Proteins during Sorghum Grain Development and Grain Mold Resistance. J. Phytopathology 154:565-571.

Books, Book Chapters and Proceedings

Rooney, L.W. 2007. Mycotoxins in grains. Supply Chain Management of Millets for Processing into Feeds and Foods, Dakar, Senegal, May 16, 2007, Dakar, Senegal.

Rooney, L.W. 2006. Phenols, antioxidants and bioactives of sorghum food. Brazilian National Corn and Sorghum Conference, August 30, Belo Horizonte, Brazil.

Rooney, L.W. 2006. Sorghum and nutraceutical food applications. American Seed Trade Association (ASTA) 61st Corn, Sorghum and Soybean Seed Research Conference, December 6-8, Chicago, IL.

Dissertations and Theses

Barron, M.E. May 2007. MS Thesis. The effect of flaxseed hulls on expanded corn meal snacks. Texas A&M University, College Station, TX. 123 pp.

Dlamini, N.R.N. May 2007. Effect of sorghum type and processing on the antioxidant properties of sorghum [Sorghum bicolor (L.) Moench] based foods. PhD Dissertation. Texas A&M University, College Station, Texas. 130 pp.

Hines, L.W. May 2007. Development of specialty breads as nutraceutical products. MS Thesis. Texas A&M University, College Station, TX. 111 pp.

Abstracts

Austin, D.L., L.W. Rooney, and C.M. McDonough. 2007. The effects of sorghum bran substitution and whole grain flours on starch digestibility and Estimated Glycemic Index (EGI) of porridges. Texas A&M University Student Research Week, College Station, TX.

Calderon, V.R., L.W. Rooney. C.M. McDonough. 2007. Developing quick methods to cook sorghum for different food applications. Texas A&M University Student Research Week, College Station, TX.

Calderon, V. 2007. Sorghum cooking quality and effect of pretreatment on physical properties of sorghum kernels. (Spanish ppt) Program Cooperativo CentroAmerica de Cultivos y Animales (PCCMCA), Guatemela City.

Cardenas-Hinojosa, A.P., D. Guajardo-Flores, L. Dykes, C.M. McDonough, and L.W. Rooney. 2007. Analysis of phenols, tannins, and antioxidant activity of grain legumes compared with different whole grain cereals. Texas A&M University Student Research Week, College Station, TX.

Guajardo-Flores, D., A.P. Cardenas-Hinojosa, L. Dykes, C.M. McDonough, and L.W. Rooney. 2007. Comparison of total phenol, antioxidant activity and tannin content in different grains. Texas A&M University Student Research Week, College Station, TX.

Austin, D.L., L.W. Rooney, and C.M. McDonough. 2006. The effect of cooking on starch digestibility of corn and sorghum porridges. American Association of Cereal Chemists (AACC), San Francisco, CA, http://www.wgsummit.org/program/posters.cfm #212

Calderón, V.R., L. Sandoval, L.W. Rooney, and S. Mason. 2006. Grain quality analysis of sorghum samples from El Salvador. American Association of Cereal Chemists (AACC), San Francisco, CA, http://www.wgsummit.org/program/posters.cfm #304

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Cardenas-Hinojosa, A.P., D. Guajardo-Flores, L. Dykes, C.M. McDonough, and L.W. Rooney. 2006. Analysis of phenols, tannins, and antioxidant activity of grain legumes compared with different whole grain cereals. American Association of Cereal Chemists (AACC), San Francisco, CA, http://www.wgsummit.org/program/posters.cfm #224

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McDonough, C.M., L. Dykes, R.J. Carroll, L.W. Rooney, and N.D. Turner. 2006. Antioxidant activity in sorghum bran diets and their effect on colon carcinogenesis. American Association of Cereal Chemists (AACC), San Francisco, CA, http://www.wg-summit.org/program/posters.cfm #271

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

Project UNL 220

David S. Jackson
University of Nebraska – Lincoln

Principle Investigator

Dr. David S. Jackson, Univ of Nebraska, Dept of Food Science & Technology, 256 Food Industry Bldg, Lincoln, NE 68583

Collaborating Scientists

Ms. Jill Gifford, University of Nebraska, Food Processing Center, Lincoln, NE 68583
Dr. Joseph J. Mpagalile, Sokoine Univ of Ag, Dept of Food Science and Technology, P. O. Box 3006, Morogoro, Tanzania
Ms. Joan Scheel, University of Nebraska, Food Processing Center, Lincoln, NE 68583
Dr. Curt Weller, University of Nebraska, Dept of Biological Systems Engineering, Lincoln, NE 68583

Summary

Since this project's inception in March 2005, we have established, primarily in Tanzania, an active educational and small-business assistance infrastructure designed to support entrepreneurial businesses developing sorghum and millet food products. This assistance program has provided information to over 140 business groups and farmers. The program uses a model from the University of Nebraska's Food Processing Center. The Food Processing Center model is based on the realization that for food businesses to be successful there must be a strong linkage between services provided in business, marketing, supply chain management, and the technological/scientific aspects of foods. The assistance program involves: (i) training current or potential food processors starting and running a sorghum and pearl millet based business, (ii) practical hands-on training on how to process/prepare different sorghum-based food products, (iii) a one-on-one follow up of every processor at their place of work. During the project period our clients have developed a wide range of sorghum and millet-based food products, including: weaning foods, sorghum flours, popped sorghum, porridges, composite flours, sorghum breads, rolls, cakes, chapatti, pilau, and hospital-grade nutrient flour mixes. In addition, several businesses and women's groups now offer dehulling and sorghum/millet grinding services available to entire towns. Farmer training has focused on grain quality, cleaning, and storage techniques to achieve high-quality marketable grain for food and industrial uses.

Objectives, Production and Utilization Constraints

Development of successful entrepreneurial businesses that adds value to sorghum and millet such that:

- Farmers have an established outlet for cash sales of high-quality sorghum and millet.
- Small businesses or cooperatives develop processing capabilities enabling the incorporation of sorghum and millet into a wide variety of food products.
- Markets and market channels for sorghum and millet-based products develop.

Further develop research, extension and marketing expertise of National Agricultural Research program scientists and professionals so that they can:

- Offer business and technical assistance to processors and small businesses in order to speed development of sorghum and millet food products.
- Advise producers on which grain type(s) are ideally suited for particular processors, including both very small entrepreneurs, regional-village level millers, and larger multinational brewers (among others).

Research Findings and Project Output

Note: Not all clients or project types are listed; multiple similar situations are omitted.

Initial Client Status	Current Status as of May 2007
• Producing weaning food without using sorghum	• Tested different sorghum based weaning food formulations • Received on site assistance with food development • Developed different sorghum processed products (sorghum flour and popped sorghum) • Project team assisted in developing simple packages and labels
• Was not using sorghum (was using other cereals) in formulation of nutritious flour (*Lishe*).	• Received on site assistance with food development and labeling. • Producing and packaging popped sorghum.
Processed per month: • 100 kg per month of *Lishe* flour using other cereals but was interested in processing sorghum • 100 pieces of bread (made without sorghum) per week	• Secured orders for sorghum based foods (cakes, flour and bread) • Has opened her own vending shop. • Processes 60 kg of sorghum per month for *lishe*, cakes, flour and bread (in addition to 100 kg of other flours). • Provides sorghum porridge to construction workers who are working near her office.
• Processes 40 kg of *Lishe* per month without sorghum • Processes about 15 kg of soya per month	• Processing about 100 kg of sorghum flour per month • Produces 3 different sorghum products i.e. sorghum flour, sorghum bites and sorghum based composite flour*s*. • Developed a bankable business plan for sorghum based products • Trained 3 other womens groups (of approximately 10 members each) on processing different sorghum products.
• Processes 10 kg of Soya and *Lishe* per month respectively • Processes 4 kg of sorghum per month	• Producing 10 kg of popped-sorghum for primary school children • Processes about 80 kg of sorghum flour per month • Has incorporated sorghum in all her processed *lishe* flour. • Developed a bankable business plan for sorghum based products
• Processes 60 bottles of jam per month • Processes about 20 kg of sorghum per month for mixing in Lishe	• From knowledge gained during the workshop they are now commercially cooking sorghum *Pilau* and selling popped sorghum • Processing sorghum buns (*maandazi*) for school pupils • Processed about 200 kg of sorghum that is included in different sorghum products (buns, sorghum flour, *chapatti, pilau*, and *lishe*). • Has opened their own vending shop near Yombo Vituka primary school • They have registered their group as partnership business.
• Processes 50 kg, 20 kg and 30 kg of *Lishe*, soya and finger millet per month respectively.	• Processed 90 kg of pearl millet per month and is selling it to people with special food requirements (diabetics) • Has trained more than 55 farmers on processing different sorghum and pearl millet products • Is selling pearl millet flour to women who cook morning porridge for street vendors
• Processes 200 kg of *Lishe* *u*sing other cereals, and 30 kg of sorghum per month	• Processing 350 kg of sorghum per month • Trained more than 8 processor groups (of approximately 15 members each) in Dar es Salaam and Mtwara region

Initial Client Status	Current Status as of May 2007
	• Trained about 150 sorghum farmers in Mtwara region • Produced 6 different sorghum products (sorghum flour, sorghum based composite flour, buns, bread, cakes and *chapatti*) • Developed a bankable business plan for sorghum based products • Attended different trade fairs in Tanzania, Uganda and Kenya • Their duhulling machine has dehulled sorghum from more than 1,000 households located in their Mbagala division. Also they supplied dehulled sorghum to other processors located in Dar es Saalam.
• Producing *Lishe* flour and using about 5kg of sorghum per month.	• Processing about 120 kg of sorghum based flour per month • Processed 3 sorghum based products (sorghum flour and sorghum based composite flour '*lishe'*) and cake. • Secured orders from local super markets for sorghum flour and sorghum cake.
• Had used sorghum on trial basis	• Processing about 60 kg of sorghum per month. • Processes sorghum flour and sorghum based composite flour and supplies the flours to local shops. • Contacts with sorghum farmers for her grain.
• Just started processing food products after graduation from Sokoine University of Agriculture (SUA).	• Processing 150 kg of sorghum per month. • He has specialized in incorporating sorghum in his composite flour.
• Processed 150 kg of Lishe per month without using sorghum • Has a mini processing factory TOTOMIX with maize dehuller, dryers, and grain silos and milling machines.	• Processing about 400 Kg of sorghum for his Lishe formulation "TOTOMIX'. • Supplies Turiani Hospital child feeding program with sorghum based Lishe • Supplies local markets with sorghum based products • Developed packaging and label with assistance from project staff at SUA. • Operating a sorghum dehulling machine which serves more than 2,500 households in Bwagala village.
• Process nutritious foods targeting people leaving with HIV/AIDS	• Processing about 150 kg of sorghum per month • Produced 2 different sorghum products (sorghum flour and sorghum based composite flour and) • Developed a bankable business plan for sorghum based products • Serves orphans living in their orphanage centre with sorghum based products • The have received orders of sorghum flour from other missionary charity organizations in Dodoma
• Miller (milling only maize) • Supplies Dodoma prisons with maize flour	• Secured a loan from CRDB bank to establish a medium scale sorghum processing milling machine. • He has ordered industrial scale dehulling and milling machine with high capacity from South Africa • He is expecting to open his small processing industry in the near future

Initial Client Status	Current Status as of May 2007
• Produces nutritional flour without sorghum. • Supplies CARE international program with *Lishe*	• Operating 6.6 HP Improved disc sorghum dehulling machine which serve more than 3,000 households in area D, Dodoma region. • Processing 350 kg of sorghum per month • Producing 3 different sorghum products (sorghum flour, sorghum based composite flour and *chapatti*) • Developed a bankable business plan for sorghum based products
• Mills maize flour but showed interest in starting to mill sorghum and sell flour to consumers around the village.	• Involved in dehulling sorghum to about 500 sorghum consumer and processors
• Co-ordinate diocese of central Tanganyika feeding programme under CARE international	• Trained more than 50 farmers on utilization of sorghum through processing different sorghum products i.e. sorghum flour, incorporation of sorghum in composite flour, cooking of *pilau*, cakes, buns and *chapatti*
• Produces wheat based breads (600-700 loaves a day).	• Now producing in excess of 1,000 loaves a day, using a 80% wheat and 20% sorghum flour mixture in Dar es Salaam.

Description of Methods of Work Used

The project uses a systematic procedure for assisting clients. Clients interested in using sorghum or millet in food products for their existing business or those wishing to start new entrepreneurial businesses, attend a 1-day workshop focusing on the basics of creating and marketing food products in East Africa. These workshops have been held in three regions within Tanzania. The workshop content was made specific to East Africa by translating and adapting educational materials created at the University of Nebraska. After attending the first workshop, smaller processors attend a second (hands-on) workshop that focuses on practical uses of sorghum and millet in food products, and the limitations these ingredients have for certain uses. Clients wishing to continue (and those with existing businesses) receive direct one-to-one assistance in product / process or market development assistance from Food Science & Technology staff at Sokoine University of Agriculture. In certain cases, Women's Groups that have attended the workshop series have gone on to train their own clients and/or other villagers on basic sorghum-food processing and milling techniques. SUA scientists have also facilitated the availability of higher quality sorghum and millet grain by conducting farmer training workshops that focus on appropriate sorghum/millet grain handling techniques.

Host Country Program Enhancement

Central America
(El Salvador, Honduras, Nicaragua)

Stephen C. Mason
University of Nebraska

Coordinators:

Ing. René Clará Valencia, Plant Breeder,CENTA, Apdo. Postal 885, San Salvador, El Salvador [Central America Regional Host Coordinator, El Salvador Country Coordinator]
Ing. Rafael Obando Solis, Agronomist, CNIA/INTA, Apdo. 1247, Managua, Nicaragua [Nicaragua Country Coordinator]
Dr. Stephen C. Mason, 229 Keim Hall, Dept of Agronomy, University of Nebraska, Lincoln, NE 68583-0915 [Central America Regional Coordinator]

Collaborating Scientists:

Mr. Francisco Vargas, Agronomist, ANPROSOR, Nicaraguan Grain Sorghum Producers Association, Managua, Nicaragua
Mr. Sergio Pichardo Guido, Plant Pathologist, UNA, Managua, Nicaragua
Ms. Yanet Guitiérez Gaitán, Plant Pathologist, UNA, Managua, Nicaragua
Ms. Martha Zamora, Entomologist, UNA, Managua, Nicaraqua
Ing. Reina Flor Guzmán de Serrano, Plant Pathologist, CENTA, San Andrés, El Salvador
Ing. Carlos Armando Borja Melara, Plant Pathologist, CENTA, San Andrés, El Salvador
Ing. Mario Parada Jaco, CENTA, San Andrés, El Salvador
Ing. Jaime Ayala, Entomologist, CENTA, San Andrés, El Salvador
Mr. Leopoldo Serrano Cervantes, Entomologist, Universidad de El Salvador, San Salvador, El Salvador
Ing. Carmen Gutiérrez D., Entomologist, INTA, Managua, Nicaragua
Ing. Humberto Salvador Zeledón, Plant Breeder, CENTA, San Andrés, El Salvador
Ing. Maximo Hernández Valle, Agronomist, CENTA, San Andrés, El Salvador
Ing. Quirino Argueta Portillo, Agronomist, CENTA, San Andrés, El Salvador
Ing. Orlando Téllez Obregón, Soil & Water Scientist, Posoltega, INTA, Nicaragua
Mr. Leonardo García Centeno, Agronomist, UNA, Managua, Nicaragua
Ms. Vilma Ruth Calderón, Food Scientist, CENTA, San Andrés, El Salvador, El Salvador
Mr. Guillermo Bonilla, Food Scientist, UJMD, San Salvador, El Salvador
Dr. Henry Pitre, Dept of Entomology/Plant Pathology, Mississippi State University, Mississippi State, MS 39762
Dr. Lloyd Rooney, Cereal Quality Lab, Dept of Soil and Crop Sciences, Texas A & M University, College Station, TX 77843
Dr. Gary Peterson, Texas A & M University Ag Research and Extension Center, Rt. 3 Box 219, Lubbock, TX 79401-9803
Dr. Larry Claflin, Dept of Plant Pathology, Kansas State University, Manhattan, KS 66506-5502
Dr. W.L. Rooney, Dept of Soil and Crop Sciences, Texas A & M University, College Station, TX 77843
Dr. Darrell T. Rosenow, Texas A & M University Ag Research and Extension Center, Rt. 3 Box 219, Lubbock, TX 79401-9803
Dr. John Sanders, Dept of Ag Economics, Purdue University, West Lafayette, IN 47097-1145
Dr. Sergio O. Serna-Saldivar, Instituto Tecnologico y de Estudios Superiores, Monterrey, Mexico

Summary

Multi-disciplinary, multi-organization, multi-country research and technology transfer efforts were conducted between 2001 and 2007. These efforts resulted in release of grain and forage hybrids/ varieties resulting in increased grain yields and dairy production. The photoperiod sensitive variety 85-SCP-805 was identified as a high yielding, high nitrogen use efficient and nitrogen fertilizer response variety which has been transferred in Cabañas (poorest department, most sorghum production area, and lowest sorghum yields) with over 35% adoption shown in surveys which corresponds to several millions of dollars economic benefit to small farmers. Integrated pest management programs for fall armyworm and midge have been developed and transferred to farmers and extension agents. The most common insect and disease of sorghum have been identified. Resistance or tolerance has been identified for *Cercospora*, *Gloeocercospora*, rust, *Heminthosporium*, downy mildew and anthracnose, and are being incorporated into improved varieties in breeding programs. Research has shown that aflatoxin is not present in stored sorghum grain, and that sorghum when ground with 4 mm screens, has equal feeding value to maize grain. Sorghum production guides and extension bulletins have been published and distributed widely, and scientific journal articles published *La Calera* and *Agronomia Mesoamericana*. Five collaborators have received graduate education, intensive short-term training delivered to more than 25 collaborators, and workshops sponsored on sorghum grain utilization, sorghum as a poultry feed and forage sorghums. Collaboration among government institutions, universities, NGOs and private sector organizations has been widely developed. The efforts have benefitted sorghum producers

and processors in Central America, and helped prepare national research programs to respond to future needs related to sorghum production and utilization.

Research Objectives

Production and Utilization Constraints

Objective

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."

Sorghum Production/Utilization Constraints

Grain sorghum is the third most important grain crop in Central America (El Salvador, Guatemala, Honduras, and Nicaragua) after maize and beans. The area devoted to grain sorghum in 2005 was 225,000 ha-1 with an average grain yield of 1.6 Mg ha-1 (FAO, 2007). During the last decade sorghum grain yield in Central America increased due to improved varieties and production practices, while the production area has declined. The dominant cropping system is maize intercropped with photoperiod sensitive sorghum (called maicillos criollos or millón) planted on approximately 67% of the grain sorghum area. Improved seed and fertilizer are available from public and private sources, but supply is inadequate and cost high for small farmers. Poultry and swine feed are the major uses of sorghum grain, and forage is a major use of sorghum as silage, green cut and through utilization of stover. Alternative uses for sorghum grain need to be developed to encourage sustainable economic growth in semi-arid areas in Central America, but lack of milling equipment for production of grain sorghum flour limits adoption of the use of grain sorghum flour for baked products. Limited investment by governments in research and technology transfer, and inadequate training of many scientists limit potential for progress.

Education and Training Output

Workshops

Five workshops were sponsored between 2001 and 2007. Utilization workshops were held in 2002 and 2005 in Nicaragua, livestock feeding of sorghum grain in 2003 in El Salvador and Nicaragua, and forage sorghum workshop in 2005 in El Salvador. Approximately 500 scientists, public officials and private industry personnel participated, and proceedings was published on CD or in the journal *La Calera*, and widely distributed throughout Central America.

Programa Cooperativo Centroamericano para el Mejoramiento de Cultivos y Animales (PCCMCA) [Cooperative Central American Program for Crop and Animal Improvement] Annual Meetings

Regional and U.S. scientists participated regularly in these professional meetings, and presented nearly 100 papers in the sorghum section. This contributed to networking, improving professional capability and dissemination of research results.

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 in Central America universities. Between 2001 and 2007 more than 30 students completed undergraduate theses on grain sorghum at the Universidad Nacional Agraría in Nicaragua, and the University of San Salvador and the University of José Matías Delgado in El Salvador.

Graduate Education and Short-Term Training

Between 2001 and 2007, five students from El Salvador and Nicaragua have completed Ph.D. degrees (two in entomology, one in plant pathology, one in food science, one in plant breeding) and one M.S. degree (food science). INTSORML provided short-term training to 12 collaborators in plant breeding, agronomy, plant protection, food science and impact assessment. In addition, a one-week training session on experimental design, statistics and technical writing was provided to 25 collaborators.

Plant Breeding

The plant breeding programs in El Salvador and Nicaragua have strived to identify and develop adapted grain sorghum varieties with good agronomic and utilization characteristics for photoperiod-sensitive (for intercropping systems with maize)varieties, insensitive varieties for grain production, dual-use for grain and forage, and forage (silage, green-cut). Between 2001 and 2007, the following varieties were released for public use:

- CENTA S-3 is the Honduran variety Sureño which in El Salvador is being adopted as a dual-use grain/forage variety.
- CENTA SS-44 (ICSA275xTX2784), INTA Forajero as a forage hybrid for green chop use in intensive dairy production. This forage sorghum hybrid has high palatability, digestibility and nutritional quality, has been shown to increase milk production 25% over previously used forage sorghum varieties, and is being widely adopted by dairies in El Salvador. This hybrid has been widely adopted by dairy producers in El Salvador, and validation tests in Honduras and Nicaragua have shown its value and it is currently being transferred to dairy producers.
- The El Salvador Dairyman Association (PROLECHE) has transferred the use of the sorghum variety RCV for silage to maintain milk production during the dry summer season.

- INTA Trinidad, INTA Ligero are white-grained, early maturity varieties adapted to low rainfall areas with less than 800 mm per year.
- INTA CNIA is a white-grained variety for higher rainfall areas with over 800 mm per year.
- Two varieties developed by CENTA (Oro Blanco and Diamante) have been marketed through the region by PROSEMILLAS, and germplasm shared with Cristiani Burkard for use in their breeding program.

Photoperiod sensitive varieties are not formally released as there is no seed industry incentive to produce and sell seed. The improved photoperiod sensitive varieties 85-SCP-805 and ES-790 were transferred through artesianal seed producers, extension agents and non-governmental agencies to producers in Cabañas which is the department with the largest sorghum production area, lowest yields and economically poor). The variety 85-SCP-805 has high nitrogen use efficiency, and impact studies showed high adoption rates of over 35% in the department of Cabañas with over a million dollars economic benefit, largely to small farmers. Transfer efforts are at present focused on the department of Chalatenango, and this variety is being validated in Honduras for transfer starting in 2007.

Breeding programs continue developing white grain, tan plant and red grain sorghums varieties, and sorghum hybrids in Nicaragua. The following lines are expected to be released in the near future as varieties:

- The hybrid ESHG-3 (ICSA613 X 86EO361) with high yield potential, excellent grain quality and good disease resistance will be released in Nicaragua and El Salvador pending development of seed production procedures. This hybrid has produced the highest yields in regional PCCMCA hybrid performance trials in 2005 and 2006.
- In Nicaragua, release of SR-16 and SR-17 (red-grained varieties); Africana (Macia) and Macia X Dorado (white-grained varieites), CENTA RCV and CENTA Soberano (white grained varieties developed in El Salvador), and varieties with tolerance of sorghum midge and low soil N are possible. Two or three of the photoperiod sensitive varieties ES-790, ES-86-226, EIME 119, 99 PREEIMME 119 and 99 PREEIME 116 will be released. All have performed well, but only the best will be released.
- In El Salvador, the white-grained photoperiod sensitive varieties 99 ZAM 686-2, 99 ZAM 911-3, and 99 ZAM 676-1are in the process of validation and release.

Regional PCCMCA trials were coordinated and conducted annually for sorghum hybrid entries from the private companies Cristiani Burkard, Monsanto, Pioneer and PROSEMILLAS, and public breeding programs at CENTA and INTA along with a common check hybrid and a local check hybrid at multiple locations in El Salvador, Guatemala, Honduras and Nicaragua. The provides producers information about the yield, tannin content, agronomic performance and insect/disease tolerance of commercial sorghum hybrids. It also provides public breeding programs a test for comparison of experimental hybrids to commercially available hybrids.

The booklet "La Androestrilidad en el mejoramiento genético del sorgo" (René Clará Valencia and Nora E. D'Croz-Mason, 2007) was published to assist sorghum breeders with the use of male sterility in their breeding programs.

Sorghum seed production in the region has been improved by training artesenal farmer producers of photoperiod sensitive varieties, and providing technical assistance to farmer-producers of certified varieties and hybrids, and consultation with regional private seed companies PROSEMILLAS and Cristiani Burkard.

Plant Protection Research

Efforts were made to identify the major disease and insect pests of sorghum in Central America, then develop integrated pest management programs. The major insect pests identified were fall army worm, midge, chinch bugs, stalk borers and white grubs. Research studied life cyles, damage, and cultural and chemical control strategies. Previously developed integrated pest management of fall army worm in Honduras was disseminated in Nicaragua and El Salvador, and an integrated pest management program developed for sorghum midge, published in an INTA extension bulletin and scientific journal articles. A white fly infestation problem evolved in 2003 spurring research on the insect. Several naturally occurring insects were found to reduce infestations, and several sorghum lines were identified with some tolerance. Incidence of white fly infestations has naturally been reduced below economic threshold levels in recent years. Insecticide and barrier crop research was conducted to evaluate control options. It was found 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, and that the natural insecticide Dipel plus season-long weed control was effective for fall army worm control. Barrier crops were not effective in controlling insect pests.

The most prevalent diseases found on sorghum in El Salvador were rust (*Puccinia* species), *Helminthosporium*, zonal spot (*Gloeocercospora sorghi*,) ergot (*Clavcep*), fuscarium and gray leaf spot (*Cercospora*). In Nicaragua, anthracnose (*Colletotrichum graminicola*) and gray leaf spot (*Cercospora sorghi*) were most common. Starting in 2004, infestations of downy mildew (*Peronosclerospora sorghi*) were identified in Nicaragua. Efforts have been made to identify sorghum lines with broad and specific resistance to these common diseases, and assist breeding programs develop resistant/tolerant varieties. Fungicide trials were conducted and found that at 10 to 20% infection levels a single application three weeks after planting could be used for integrated pest management of fungal diseases.

Stored sorghum grain was found to have very low levels of aflatoxin, well below the 20 ppb considered safe for human and livestock consumption. The most common insect pests of stored sorghum grain were found to be grain borer (*Rhizopertha dominica*), rice weevil (*Sitophillus oryzae*), and flat grain beetle (*Cryptolestes* sp.), while the fungi *Fusarium* and *Helminthosporium* and the bacteria *Pseudomonas syringae* and *Bacillus megaterium* were the most common diseases.

Sorghum entries (50) in the All Disease and Insect Nursery were evaluated in Nicaragua for resistance to insect pests and diseases in multiple years to identify sources of resistance for breeding programs. All sorghum entries were infested with fall armyworm larvae, with only three were found to be tolerant. Six sorghum lines were classified 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. Six of the seven sorghum varieties with highest yield were considered tolerant to fall armyworm, but susceptible to one or more diseases.

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. 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. Similar results were found in El Salvador, which also evaluated photoperiod sensitive sorghum varieties, with the variety Indio Macartus having a high level of resistance to diseases.

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 determining best sorghum flour replacement for wheat flour for product quality, shelf-life studies, market surveys, and exploration and development of locally available decortication and milling making sorghum flour available to bakers in rural and suburban areas.

Research has found that 100% sorghum flour can be used for some sweet breads, cold drinks (horchatas, refescos), and hot drinks (atoles). Most sweet and French bread products produce good quality products with up to 25% sorghum flour mixed with wheat flour. Shelf life of sorghum products ranges from 7 days (pastelito de leche, pastelito de piña) to 35 days (novia and pichardine). Market surveys show that sorghum flour substitutes with wheat flour have desirable texture, consistency, color, smell and taste. Interest is high among suburban bakeries due to the lower cost of locally produced sorghum than imported wheat.

A student at the University of José Matías Delgado in El Salvador developed a machine to decorticate sorghum grain as part of his undergraduate thesis, and the rice mill Suzuki MT-99 was found to be the best locally available mill for producing sorghum flour. Research with the private company GUMARSAL found that decortification reduced flour yield by 16%, losing about 2% of weight in the germ and another 2% in endosperm attached to the pericarp. This increases the shelf life of the flour, while reducing the nutritional value slightly. Adequate supply of sorghum flour continues to be the biggest problem for expansion of the use of sorghum flour as a wheat flour substitute.

Past research has focused on grain quality of sorghum insensitive varieties and improved photoperiod sensitive varieties. In 2004 and 2005 photoperiod sensitive varieties used by small farmers were evaluated for nutritional and flour quality traits. The varieties De Leche, Enanon and Peruano Blanco had the highest nutritional quality, and had predominately floury endosperm. De Leche and Enanon contained no tannins, and the variety de leche had the smallest flour particle size with 75% passing through a 0.5 mm screen. Wide variation in quality was found, thus opportunity exists to develop improved quality photoperiod sensitive varieties.

Agronomy Research

A series of studies were conducted between 2001 and 2004 with the objective to determine if high nitrogen use efficient (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. In general, differences in NUE among photoperiod insensitive varieties were small. However, in El Salvador, ICSVLM-90520 was identified with the best grain yield, one of the best for stover yield, and grain nitrogen use efficiency. In Nicaragua, the line ICSCVLM-93076 and the local check variety Pinolero 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. These two varieties are now being used in breeding programs. In El Salvador, 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}, an increase in yield of 46% with a marginal return of 44 kg ha^{-1} grain production for each kg N ha^{-1}. In Nicaragua, the average grain yield increase from nitrogen fertilizer was from 3.1 to 3.9 Mg ha^{-1} (26% increase). Increased application of N fertilizer to sorghum would greatly increase grain yields.

Research on photoperiod insensitive varieties found large differences in NUE in El Salvador. The variety 85-SCP-805 was found to be high yielding, have high NUE and be responsive to fertilizer application. These results have been confirmed in on-farm validation trials (over a 1000 trials), and widespread effort to disseminate this variety to small farmers in poorest department of Cabañas was conducted in 2004 and to other departments in 2005 to 2007. This effort has involved a number of NGOs, the extension service and CENTA, both with artesenal seed producers and local farmers. In Cabañas, economic impact surveys show a 35% adoption rate in communities where transfer was attempted, and the potential for several million dollars economic benefit, mostly by small farmers.

Validation of the improved SS-44 (INTA Forrajero) sorghum hybrid were conducted, and it was found that it produced more forage dry matter for each harvest date, had higher energy and crude protein content. These result contributed to the release of this hybrid in El Salvador and Nicaragua for use by intensive dairy producers.

Networking

Institutions/Organizations

INTSORMIL support has contributed to increased collaboration among CENTA, INTA and UNA during the past six 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 University of José Matías Delgado. In Nicaragua, increased collaboration with the CIRAD-CIAT participatory sorghum breeding project. 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 initiatives with Cristiani Burkard. Close working ties with the Asociacíon Salvadoreña de Panifacadores (ASPAN) in El Salvador continues, and collaboration with both El Salavador and Nicaragua extension services.

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

Gebisa Ejeta
Purdue University

Coordinators

Gebisa Ejeta, Regional Coordinator, Purdue University, Dept of Agronomy, West Lafayette, IN 47907
Katy Ibrahim, Administrative Assistant, IPIA, Purdue University, West Lafayette, IN 47907
Tesfaye Tesso, Ethiopia Country Coordinator, EARO, P.O. Box 2003, Addis Ababa, Ethiopia
C. K. Kamau, Kenya Country Coordinator, Katumani National Dryland Farming Research Ctr, Box 340, Machakos, Kenya
Semere Amlesom, Eritrea Country Coordinator, DARES, P.O. Box 10438, Asmara, Eritrea
Elias Letayo, Tanzania country Coordinator, Hombollo Research Station, P.O. Box 299, Dodoma, Tanzania

Tanzania

Introduction

In Tanzania more than 40 percent of the population lives in chronic food-deficit regions including semi-arid zones where irregular rainfall causes recurring food shortages and consequent malnutrition. According to the 2004/05 Tanzania Demographic and Health Survey, 38 percent of children under five in the country are chronically malnourished (i.e. stunted height for their age) while over 30 % of all regions in the country have stunting rates of over 50 % [WFP 2006]. Between 1986 and 2005 the area planted to sorghum in the country has ranged from 380,000 to 890,000 ha depending on rainfall with the crop being of particular importance for food security in the semi-arid Dodoma, Mara, Mwanza, Shinyanga and Singida regions. Climate models predict that rainfall by 2100 will decrease by up to 20% in these central areas of Tanzania with national grain production falling by 10% by 2080, with particularly severe yield reductions in maize [Downing, 2002; Paavola, 2004]. Farmers are already responding to this climate variability by planting more sorghum with the area planted to the crop in Morogoro region increasing in three of the seasons from 1994/5 to 2000/01, when maize production remained static or declined (Paavola, 2004). Increasing sorghum productivity in the semi-arid zone of Tanzania will therefore be a continuing priority for both food security and household income. In sorghum consuming districts sorghum that enters the market competes strongly with maize on price, particularly when purchases are made for the national Strategic Grain Reserve [FEWS, 2004].

However, the semi-arid areas of Tanzania lie in a zone where the three most significant *Striga* species which infest cereals i.e. S. asiatica, *S. forbesii* and *S. hermonthica* occur. Most of the districts in these areas have been surveyed and the distribution of *Striga* here is broadly known [Mbwaga and Obilana, 1993]. Reichmann et al. (1995) reported that 75% of farmers interviewed in Shinyanga region of Tanzania considered *Striga* an increasing problem on sorghum, on which they were unable to obtain satisfactory advice from extension on effective control strategies. Mbwaga et al., 1998 reported that sorghum, the preferred staple, has been replaced by pearl millet which is not attacked by *Striga* in parts of Missungwi district in Mwanza Region. Farmers in Dodoma Rural district are well aware that poor sorghum yields are the norm in *Striga* infested fields and that poor crop vigor and *Striga* are associated with declining soil fertility.

While most farmers still use low yielding, drought susceptible traditional landraces, adoption of improved cultivars, which occupied barely 5% of Tanzania's sorghum area in the early 1990s, had risen to 36% of the area planted by 2002 [ICRISAT, 2002]. Cultivar Pato, has been promoted widely but while this produces high yields on favorable soils it typically becomes stunted resulting in poor harvests when planted on *Striga* infested soils without addition of either manure or fertilizer [Pierce et al, 2003].

To address this problem farmer participatory on-farm research was initiated in 2000 to identify, early maturing drought tolerant and *Striga* tolerant/resistant sorghum lines that fulfill farmer and consumer preferences. Here we summarize this process that by 2002 resulted in new cultivars being registered and subsequently promoted to farmers. Sorghum sales in Tanzania have largely been for consumption in producing areas with less than 1000 t per year used nationally by commercial processors due largely to inconsistent quality, high assembly, transport and cleaning costs [Rohrbach, 2002]. With new cultivars providing an opportunity for higher production, producers and processors were brought together to identify new markets to in turn stimulate higher production.

Development and Promotion of an Integrated Approach to *Striga* Management

The availability of Hakika (P9405) and Wahi (P9406) [new released varieties originated from Purdue University in the USA] provided an opportunity to improve sorghum productivity and also a challenge to promote appropriate, affordable sorghum management practices for *Striga* infested fields. Soils in sorghum producing areas of Tanzania are generally low in fertility and the low levels of nitrogen observed on farmers' field's favors the growth of *Striga*. Pierce et al, (2003) demonstrated in both laboratory and a field study that with sufficient nitrogen, Pato attained the greatest stem biomass of the cultivars tested, and typically had the highest yields, but was heavily stunted when infected with *Stri-*

ga. Wahi and Hakika were not stunted to the same extent, with Hakika retaining the same degree of tolerance despite severe nitrogen limitation. When animal manures or inorganic fertilizers are available yields of released sorghum lines can be enhanced, as has been demonstrated in on-farm trials in Dodoma region (Table 1). Planting legumes provides an alternative approach to soil fertility enhancement.

After the official release of Hakika and Wahi a program for promotion was initiated in three districts. The program focused on the use of integrated *Striga* management technologies (ISM) to increase sorghum yield in drought and *Striga* prone areas. The ISM technologies included *Striga* resistant sorghum variety, tied ridges for moisture conservation and inorganic fertilizers/animal manure for nutrients supply as compared to the traditional method of growing local sorghum varieties without ridges or manure. The performance of the demonstration plots gave relatively high sorghum yield (Table 2). Highest yields were produced from short duration sorghum cultivars Hakaka/Wahi combined with tied ridges and animal manure (2-2.7 and 2.9t/ha respectively).

The process of scaling up the ISM technology has been very successful in Singida and Dodoma regions. In Singida (Singida rural and Iramba districts), 10 Farmer Research Groups (FRG) have been formed and for the sustainability of the groups each has full management and a constitution to guide them. Some of the groups have even opened an account in the bank. The number of farmers per group is not less than 20, with the highest 70 members. But the ISM technology has gone even to more farmers beyond the groups so that of today we are talking about not less than 4000 farmers in the period of 2004-2007. The regional Commissioner of Singida has declared Singida to be a sorghum region by urging all farmers to grow sorghum. Any farmer growing maize will be at his/her risk and the government will not assist if there is hunger.

In Dodoma region (Kongwa and Mpwapwa Districts) the project started in the 2003-2004 cropping season in three Villages each having one group of 10 members in Sejeli, Manungu and Vilundilo respectively. Each farmer planted either Wahi or Hakika in a 10m x 10m demonstration plot. From the observations of the first season there was an advantage of increasing yield with the use of an integrated approach of *Striga* management from 50% to 70%.

In the following season 2004-2005 the project was extended to new six villages in the same District making up a total of nine villages in Kongwa District each having a group of 30 members.

Table 1. Effect of farmyard manure (FYM) on *S. asiatica* at harvest and grain yield of different sorghum cultivars, Mvumi village, Central Tanzania (After Pierce et al 2003)

Cultivar	FYM application (kg/plant)	*Striga* number (m^{-2})	Yield Kg ha^{-1}
Hakika	0	38	1360
	0.5	13	1800
Macia	0	476	1000
	0.5	59	1400
Pato	0	22	320
	0.5	36	440
Wahi	0	48	1240
	0.5	21	1400

Table 2. Performance of sorghum cultivars with ridging and soil fertility treatments, mean yield (t ha) at 12 farm sites Sepuka-Singida, 2004

Treatments	Villages	
	Msungua	Musimi
Farmer variety plus flat planting	1.7	1.4
Hakika plus flat planting	1.8	1.4
Hakika+tied ridge + animal manure	2.7	2.0
Hakika + tied ridge + Urea	2.6	1.9
Mean	2.2	1.7

Table 3. Potential buyers of Sorghum:

Company	Estimated amount (t/year)
Darbrew Ltd- Dar es Salaam	1000
Power Foods Ltd - Dar es Salaam	300
Nyerefamily Ltd – Arusha	300
Strategic Grain Reserve (SGR)	4000
Mwamba brewing industry – Mbeya	300
TBL (Eagle larger) – Moshi	2000
Fida Hussen Exporter – Dar es Salaam	>1000

With an intention of widening the project area and popularizing the two *Striga* resistant varieties (Wahi and Hakika) the project was extended to the neighboring Districts (Mpwapwa) in Dodoma Region in the 2005-2006 cropping season. In Mpwapwa a total of nine villages each with one group of 15 farmers as members joined the project.

So in Dodoma region we are now talking of 18 groups of farmers with an average of 40 members making up a total of 720 farmers growing Wahi and Hakika and more farmers are still joining the existing groups. According to farmers in these groups there are so many other farmers in their villages who took seeds of the two varieties and have planted them.

Constraints

The major constraint in adoption of the newly released sorghum varieties is the availability of seed for farmers, there is no any seed company that has interest to grow and distribute seed to farmers especially with sorghum. In Singida, the council is trying to grow a bit of seed at their Seed farm, but it does not satisfy the demand. Hence need to teach farmers how to grow quality declared seed. Secondly, because farmers are recycling seed and without dressing a problem of sorghum smut disease has emerged in a big way. This also needs to be addressed by teaching farmers how to select seed from the field not from sorghum heaped at homestead. Thirdly, the linkage between farmers and potential buyers of the grain have not been established yet to make sure that farmers are able to sell their surplus produce sustainably.

Linking Farmers to Sorghum Market

Previous attempts by commercial brewers to substitute imported grain with local supplies have been compromised by grain that is poorly dried and cleaned. To encourage increased production farmers need to be sure that buyers will visit local markets after harvest offering a stable and adequate grain price to ensure sorghum production is profitable. A number of support activities were agreed to develop the market. These include formation of farmer production and marketing groups, establishment of village-based seed supply mechanisms, training of farmers in post-harvest practices to supply quality grain, information dissemination on market demand and prices, increased purchase of sorghum by the national Strategic Grain Reserve, re-habilitation of village grain stores and establishment of sorghum marketing points. To facilitate this process a task-force has been established for Kongwa and Singida Districts involving district extension staff, farmers and representatives of processors based in Dar es Salaam. (Table 3)

Comments and Recommendations

- This project has all been a successful one in all aspects, the two varieties are very popular in the project areas and also an integrated approach in the control of the witch weed *Striga* spp.
- The implication of the two factors is revealed in the observed increase in yield and so production of sorghum such that farmers are now producing to surplus especially in the project areas.
- To the appreciable extent the project also embarked on the marketing aspects of the grain after production by organizing the first workshop where different stakeholders in sorghum met and discuss different aspects mainly connecting farmers with the existing potential buyers of the grain in Tanzania. It is our hope that what have started will be successful in the future making sure that sorghum apart from being a staple food crop in the Central zone will also be one among other crops as a cash earner for the farming community. Sustainable marketing system is of paramount importance to make sure that the farming communities deposit their surplus produce of the grain to earn cash for development.

Ethiopia

Introduction

Sorghum is one of the most widely cultivated crops in Ethiopia occupying over 1.6 million ha of land each year. It ranks second in total production contributing about 2 million metric tones to the national grain volume annually. In terms of acreage, sorghum ranks third after tef (2.2 million ha) and maize (1.8 million ha). It is a major source of food and cash income for millions of subsistence farmers in eastern highland and lowlands, the vast lowlands of northern and northwestern Ethiopia and other regions of the country where sorghum is grown as dominant crop. Nevertheless, sorghum in Ethiopia suffers from several factors reducing its yield. These include low genetic potential of the existing varieties, infestation by *Striga*, drought stress and certain pests and diseases.

Cultivars grown in Ethiopia are mainly farmers varieties that are fairly well suited to low input conditions but with low yielding potential. The national average yield is a little above one ton per hectare which is very low when compared with global average. Similarly, parasitic weed *Striga* and recurrent drought are another important factors affecting sorghum production in Ethiopia. Over one-half sorghum of produced in the country grows under heavy *Striga* pressure which is often confounded with drought stress. The weed causes up to 100% yield loss in heavily infested areas forcing farmers to either totally abandon their prime lands or switch to growing other crops that are of little preference in the areas. In order to address these problems, INTSOPRMIL and the Ethiopian Agricultural Research Organization signed a long term collaborative research agreement in 1996 and since then extensive efforts have been made through INTSORMIL support to develop, release and disseminate *Striga* resistant varieties along with compatible crop management technologies. Efforts were also made to identify sorghum hybrid cultivars adapted to moisture stress areas of Ethiopia. In this report we present summarized results of INTSORMIL supported sorghum research activities carried out in Ethiopia over the last three years. We also discuss the successes of the capacity building and Human resource development efforts as one of the outstanding contributions of INTSORMIL.

Integrated Striga Management (ISM) Pilot Project

Striga has been the key biological constraint in sorghum production in sub-Saharan Africa. In Ethiopia, the invasion by the

weed has dramatically expanded over years that today more than fifty percent of sorghum in the country grows under heavy *Striga* pressure. The economic damage as a result of the pest is dramatic. Farmers with infested fields loose 50 to 100% of their sorghum crop to the parasite. Traditional weed control methods are not effective. It is in fact incurring further economic loss to farmers as they allocate significant amount of labor force to manual weeding of the weed, the practice that has little effect to reduce the problem. Local landraces are generally susceptible to the weed while few of them posses some level of tolerance. Chemical weed killers are either less effective as most of them are applied after the weed has caused economic damage or simply not affordable by subsistence farmers. This dramatic expansion of the problem and lack of effective control means have frustrated farmers that many have been forced to switch to producing other lower priority crops while many others totally left their lands idle. Efforts have been going on at several national and international research centers to develop effective and practical control measures. The most successful effort in this regard was the development of *Striga* resistant variety. Resistant varieties bred at Purdue University were introduced to Ethiopia in the 1990s and with all round support by INTSORMIL, the varieties were tested in several *Striga* infested regions of Ethiopia. The multi-location and multi-season tests proved that all of the varieties were clearly resistant to both *Striga* species in Ethiopia. Based on other attributes two of the varieties, P-9401(Gobiye) and P-9403 (Abshir) were selected and officially released for large scale production in 2002. Following the releases of the varieties Integrated *Striga* management (ISM pilot project was launched with support from INTSORMIL in order to promote adoption of the new varieties. Other compatible control options namely soil fertility management using chemical fertilizers and soil moisture conservation using tied ridges were included as the ISM package components. The rational for the integration was based from the fact that both moisture stress and soil fertility apart from being associated with *Striga* infestation were among the critical factors that are limiting in much of *Striga* infested areas and thus was to exploit synergy that may arise from combinations of the different control options.

Project Implementation Approach

The integrated *Striga* management (ISM) project in Ethiopia was launched in 2002 following the release of the first two *Striga* resistant varieties (P-9401 and P-9403) developed at Purdue University. It was a multi-institution project that involved participation from Federal Research Centers, Regional Agricultural Research Institutes, Regional Bureau of Agriculture, and Institutions of Higher Learning and farmers in four major sorghum producing regions of Ethiopia. The project was organized around three sets of activities, testing of the ISM package on selected farmers fields "demonstration", evaluation of the *Striga* resistant varieties per se "popularization" and "seed production". Each of the activities served clear and well defined purpose with an overall goal of promoting and facilitating adoption of new *Striga* management technology. Participating farmers were selected with the assistance of extension staff of the district Bureau of Agriculture. Table 4 shows the number of farmers participated and land area allocated for the implementation of the project during the project lifespan.

The ISM package consists of *Striga* resistant sorghum varieties as a core component and complemented by soil fertility management using locally recommended rate of chemical fertilizers and soil moisture conservation using tie-ridges. The *Striga* resistant varieties P-9401 and P-9403 locally named Gubiye and Abshir, respectively were developed and released by Purdue University and recommended for large-scale production in *Striga* infested regions of Ethiopia 2000. Purdue University and the Ethiopian national sorghum research program of Ethiopia maintain breeder seeds of these varieties and the farm management unit of Melkassa Research Center produces and distributes foundation seeds of the varieties. Seeds and chemical fertilizers used in the implementation of the project were purchased using the project fund and distributed among the participating farmers. Tie-ridgers, manufactured at the local metal workshops from the prototype provided by the Farm Implement Research unit of Melkassa Research Center, were purchased with project funds and transported to all areas where the project was implemented. The ISM package was demonstrated on 0.25 ha plots planted next to local farmers practice for comparison. Data were recorded on grain yield and *Striga* count from both ISM and local practices.

The seed production component was an important unit in this project as there are little or no governmental and/or non-governmental entrepreneurs engaged in production and distribution of certified seeds of sorghum varieties in the country. It was thus to catalyze community based seed production and marketing system to fill the pitfalls in this area. It was to promote informal seed sector and ensure that seeds of *Striga* resistant varieties enter the traditional seed exchange system so that the varieties will remain in production after the project has terminated pending the development of formal seed system is put in place for sorghum and many other crops. Selected farmers in each of the project implementation area were identified and given training on basic skills of seed production. The project also reached an agreement with potential seed growers to buy farmer produced seeds (where the seeds meet the minimum required quality standards) with a premium price for redistribution to other farmers next season.

The third set of activity, popularization, was conducted in order to promote the varietal component of the ISM technology through distributing 2-5 kilograms each of either of the *Striga* resistant varieties to as many farmers as possible. This was done to farmers who were otherwise interested to participate in the ISM package demonstration but whose fields were distant from access roads for routine supervision. The farmers planted the resistant varieties using their own traditional practice. Yield data from some of the participating farmers have been recovered.

For all sets of activities, agricultural experts and rural development agents of district Bureaus Agriculture participated in the execution of the project. Prior to the implementation, the experts, National Agricultural Extension Service personnel, Zonal and District Heads of Bureau of Agriculture, and participating farmers were given appropriate training on the field implementation of the project. Field days were routinely organized towards the end of the season to demonstrate the results to local administration, representatives of non governmental organizations and other farmers who did not take part in the project.

Project Implementation Areas

The project was implemented in selected districts of the four major sorghum growing regions in the country, Amhara, Oromiya, South and Tigray regions. Amhara region is the second largest sorghum producing state in the country. It is also the region where the greatest diversity of sorghum and probably of *Striga* exists in the country. Most of the areas where sorghum is produced in the region are infested by *Striga hermonthica*. Infestation is rapidly expanding in the region perhaps from the use of unclean seeds harvested from already infested areas and transported for use in *Striga* free zones. Lack of effective local quarantine policy is aggravating this problem. Oromia is the largest state in the country. Over fifty percent of grain sorghum produced in Ethiopia comes from this region. Significant portion of the major sorghum growing areas in the region, eastern and western Hararghe zones, west Shoa and a number of districts in several other administrative zones are highly infested by *Striga hermonthica* and to a lesser extent by *Striga asiatica*. Like the Amhara region, infestation is expanding from time to time with large previously *Striga* free lands becoming infested every season. Tigray region located at the northern tip of the country is one of the major sorghum producing regions. Almost all of sorghum fields in the region are infested by *Striga*. The southern region, particularly the Konso and Derashe special districts grow sorghum as staple food source with the crop occupying some 80% of the cultivated land in both districts. Much of this land is infested by *Striga asiatica*.

Results

The *Striga* pilot project was implemented in the highly infested areas of several districts in the selected four regions. In Amhara region, a number of districts in north Shoa, South Wollo and North Wollo zones were covered by the project. Like wise several districts in East and West Hararghe zones of Oromia region were included under the project. Several districts representing Southern, central and western Tigray zones and Konso and Derashe special districts from the southern region were also included.

Demonstration of ISM technology

Farmers in all regions participated in the demonstration of ISM package over the four years of project implementation period (Table 4). At each demonstration site local variety with traditional management practice was planted next to the ISM demonstration plot for comparison. Mean grain yield and *Striga* count from both ISM package and control plots is presented in Table 5.

In all project sites, the improved ISM package gave dramatically higher yields than the local farmers practice. Average grain yield from the ISM package plots across region and season was 1.84 t/ha in contrast to only 0.54 t/ha obtained from plots planted to the local farmers practice. The over three fold increase in yield comes primarily from the reduced *Striga* pressure in the ISM package as compared to the local practice. This was evident from Fig. 1 and *Striga* count data shown in Table 5. The mean number

Table 4. Farmer participation in the extension of integrated *Striga* management (ISM) technology in Ethiopia

Region	Number of farmers			
	Demonstration	Seed production	Popularization	Total
2002				
Amhara	36	13	71	120
Oromia	29	27	94	150
South	10	21	29	60
Tigray	70	22	50	142
Sub-Total	**145**	**83**	**244**	**472**
2003				
Amhara	32	30	321	383
Oromia	30	38	415	483
South	63	11	92	166
Tigray	10	33	265	308
Sub-Total	**135**	**112**	**1093**	**1340**
2004				
Amhara	76	30	820	936
Oromia	141	129	1250	1520
South	63	38	220	321
Tigray	107	108	1335	1550
Sub-Total	**387**	**305**	**3625**	**4327**
2005				
Amhara	66	30	320	416
Oromia	190	208	1660	2058
South	57	44	320	421
Tigray	107	108	1335	1550
Sub-total	**400**	**390**	**3635**	**4445**
Total	**1067**	**890**	**8597**	**10584**

Figure 1. A visual account of ISM package demonstration planted next to the farmers practice (local variety) in Hararghe in 2006 crop season

Table 5. *Striga* count and grain yield recorded on ISM and control plots in different *Striga* endemic regions of Ethiopia

Region	Grain yield (t ha-1)		*Striga* count at crop maturity (m-2)	
	ISM package	Local Practice	ISM Package	Local Practice
2002				
Amhara	3.40	0.80	6	2052
Oromia	1.12	0.12	32	1110
Mean	2.26	0.46	19	1585
2003				
Amhara	2.67	1.33	5	95
Oromia	2.02	0.29	7	104
South	0.53	0.00	4	128
Mean	1.74	0.38	6	108
2004				
Amhara	2.61	1.55	12	158
Oromia	1.02	0.25	12	122
South	0.13	0.00	0	0
Tigray	2.13	1.37	24	163
Mean	1.51	0.79	12	123
Grand mean	1.84	0.54	12	605

of *Striga* plant per square meter from the ISM package averages across years and regions was only 12 as opposed to 605 from the local variety. The difference in infestation was magnificent. The result for individual region or year was similar in trend with certain variation between region and between years depending on local and seasonal conditions. For instance *Striga* infestation was much higher in 2002 in Amhara region as compared to the rest of the years whereas both yield and *Striga* infestation were lower for the southern region in all years. But despite variations in local conditions, the ISM package consistently gave much higher yield and had dramatically low infestation compared to the local practice where severe infestation has cut yields by more than three fold.

It was evident from the data that the ISM package besides effectively reducing *Striga* pressure also offered better tolerance to drought stress. This may have resulted from combination of factors. The resistant varieties have short growth duration (only 110-120 days) vs. 180-200 days for the local cultivars, that it might have escaped drought during part of the growth period especially early season stress. Moreover, the resistant varieties have elements of drought tolerance in them, possess stay-green trait, a character associated with terminal drought tolerance in sorghum. In addition, the tied-ridges that go along with the ISM package may have helped to conserve moisture and thus reduce the effect of drought.

Production of Seeds of *Striga* Resistant Varieties

Seed production has been considered a core activity in this project. Since the ISM technology is delivered largely in form of seed, production and distribution of sufficient amount of seed was crucial for adoption and expansion of the technology. Farmers participated in seed production over the project period. But not all of them succeeded in producing quality seeds for redistribution. More than half of the seeds produced were rejected during field and laboratory inspection largely because of non optimal field management conditions (insufficient isolation, poor weed control

Table 6. Farmer participation in production and distribution of seeds of *Striga* resistant varieties in Ethiopia

Region	Number of Farmers	Area (ha)	Seed Produced (tons)
2002			
Amhara	13	2.1	4.1
Oromia	27	3.4	8.4
South	21	10.5	7.5
Tigray	22	14.5	6.5
Total	**83**	**75.5**	**26.5**
2003			
Oromia	26	7.32	8.2
South	11	7.5	2.4
Tigray	31	20.9	24.1
Total	**68**	**35.7**	**34.7**
2004			
Amhara	19	3.5	3.7
Oromia	60	19.1	17.4
Tigray	43	19.7	37.4
Total	**122**	**42.3**	**58.5**

and lack of proper follow up) and low germination capacity of the seeds especially in areas and seasons where moisture stress interfered with normal seed set and grain development. Only those seeds that met the minimum standard for national seed certification were recorded and used for redistribution in next season. In years 2003 and 2004, seeds produced by nearly half of the farmers set for seed production was not accepted. This was to avoid the negative effect that low quality seed may have in the effort to promote the technology. Nevertheless, in the first three years alone some 273 farmers successfully produced quality seed on more than 150 hectares of land producing a total seed volume of 200 tons. Part of this was purchased by the project for use in the next season project implementation activity while the rest was either purchased by non governmental organizations for distribution in farther areas where the pest was causing menace or entered the local seed distribution channel. Efforts were made to educate farmers and rural development service staff to help them understand seed as different from common grain so that seeds would not enter local grain market for consumption. This effort appear to have bore fruits that the number of farmers growing the resistant varieties in areas where the ISM technology was demonstrated previous year has increased from time to time. In many of these areas these varieties are routinely grown by local farmers. Table 6 shows the number of participating farmers and the seed produced in different seasons and regions. (Figure 2)

Popularization and Dissemination of the Resistant Varieties

Large number of farmers showed interest to grow the resistant variety as popularization. No formal data was recorded from popularization plots as many are located away from access roads making monitoring activities difficult. However, many farmers, especially in Hararghe, turned up to the district Bureau of Agriculture after harvesting for further request for seeds of the resistant varieties. Many of them admit that even without fertilizer input and soil moisture conservation practice, the resistant varieties yielded more than twice that of the local variety. In 2003 for example, about eighty farmers in western Hararghe zone of Oromia region participated on popularization activity on a total of 11 hectares of land and harvested 11.7 tones of grain. This was equivalent to 1.06 tons/ha and is more than four fold higher than the average of 0.3 tons/ha harvested from local varieties in the area in that season. This was primarily due to the difference in *Striga* resistance of the local and improved varieties. This supports our finding from a separate study where we compared the effects of individual control

Figure 2. Seed production of *Striga* resistant variety P-9403 on a farmers field in Hararghe (left) and P-9401 at Melkassa research station (right) during the 2006 season.

Table 7. The relative effectiveness of components in reducing *Striga* infestation and increasing sorghum yield

Treatments	Yield (t ha^{-1})	*Striga* count at crop maturity (m^{-2})
LV x F_0 x M_0	0.73e	216c
LV x F_0 x M_1	1.02d	680a
LV x F_1 x M_0	1.14cd	250c
LV x F_1 x M_1	1.46b	527b
SR x F_0 x M_0	0.80e	16d
SR x F_0 x M_1	1.22c	26d
SR x F_1 x M_0	1.15cd	11d
SR x F_1 x M_1	1.68a	15d
Mean	1.16	227
LSD	0.2	110

Means in a column followed by same letter are not significantly different; LV=Local variety (Jigurte), SR= *Striga* resistant variety (P-9401), F_1 and F_0= with and without chemical fertilizer, respectively, M_1 and M_0= with and without soil moisture conservation, respectively

options on *Striga* control. The result showed that the *Striga* count from resistant varieties with and with out other component options was the same indicating that resistant varieties alone may be as effective as when the whole package was applied. But yields were obviously higher when fertilizer and soil moisture conservation practice was applied together with the variety as these factors were limiting in the study area (Table 7). The local variety used in this study (Jigurte) was a high yielding tolerant variety that tends to give relatively better yield under *Striga* pressure. Unlike for the resistant variety, *Striga* count was different for different combination of the various control options.

Adoption and Diffusion of the ISM Technology

Excellent grain yields were recorded from the ISM package plots when local cultivars planted in contiguous plots were completely destroyed by the parasite. Some of the demonstration was conducted in plots that were previously abandoned due to severe infestation by *Striga*.

Each season, field days were routinely organized in all regions to inform and educate farmers through an organized and participatory approach. Local government representatives, delegates from agricultural extension service department of the ministry of Agriculture were often present during field days. Media personnel, NGOs involved in agricultural development activities also promoted adoption of the ISM technology. During field days and community programs, farmers' reaction to the technology has been consistently positive that the number of farmers interested to adopt the ISM package increased each year. Consequently the number of farmers participating in the project increased from 472 in 2002 and jumped to 4327 in 2004. In response to the increased demand by farmers, various NGOs stepped in to purchase and redistribute seeds of resistant varieties in heavily infested regions.

Besides the dramatic effect of the ISM package in reducing the damage by the parasite, farmers were impressed by the resistant varieties per se for their tolerance to drought, early maturity, and excellent grain quality. Farmers were also drawn to the *Striga* resistant sorghum varieties for their evident processing attributes in making the local fermented bread injera, porridges, and local beverages. It was repeatedly mentioned by local farmers that the texture of injera made from P-9401 was better than those of local landraces and stays fresh for longer period of time. In addition to being suitable for making an array of food products, the stalks of the resistant varieties were found to be preferred source of animal feed. This might be because of the stay green trait that allows the varieties to maintain higher level of sugar in the stalk. Feed value of stalks is an important consideration in breeding sorghum in Ethiopia.

Perhaps, the more sustainable impact of this study is the creation of high level of demand for the resistant varieties. Farmers in all *Striga* infested regions of the country including areas where the project was not implemented have been made very aware that these varieties offer effective control. In addition to the traditional information sharing channel, the national media and regional workshops conducted at various times have assisted in disseminating the information and creating demand. At present more than 100,000 farmers are estimated to be growing the resistant varieties in different regions of the country. Although no comprehensive formal adoption study has been carried out yet, information coming from the various districts where the project was implemented, the interest by farmers to participate in the project and the increasing demand for seeds of resistant varieties are among the many indicators of the acceptance of the technology by farmers. The price for seeds of the resistant varieties is exceptionally high at local markets. Seeds of P-9401 are sold at 15 to 20 percent higher price than local sorghum seeds. In Tigray, seeds of resistant varieties are exchanged (1:1) for tef grain, where tef normally fetches 60-100% higher price than that of sorghum grain. Farmers were willing to slash and plow under their already established local sorghum crops to replant with the resistant varieties. Another important indicator of success of this project is the official launching of the ISM technology by the Ethiopian government. This was officiated during the. The government of Ethiopia expressed its commitment at the launching workshop conducted on the 20th of February 2007 to multiply and distribute seeds of *Striga* resistant varieties and

other inputs that goes along with it to all areas where *Striga* is the major constraint to sorghum production. Regional Bureaus of Agriculture were given responsibility to implement the technology in their respective regions. A national team was also set up to oversee the implementation of the activities, organize production and distribution of foundation seeds and provide advisory services to government authorities.

INTSORMIL Sorghum Research Project

The ultimate goal of the INTSORMIL/Purdue and EIAR collaborative research project was to support local research for development efforts especially in addressing key problem areas where local capacity was limited so that new improved sorghum production technology suited to local conditions may be developed and distributed to farming community. The key areas of emphasis include development and deployment of *Striga* resistant varieties and hybrid sorghum cultivars in Ethiopia. Since the official signing of the collaborative agreement in 1996, the Ethiopian Sorghum Research program has been working closely with INTSORMIL and Purdue University in these areas. This collaborative activity expanded over years and at present constitutes almost half of 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. As discussed in previous sections these varieties are making significant impact in changing the course of sorghum production in *Striga* infested regions of the country. Progresses made in identification of suitable hybrid cultivars are very encouraging. In the subsequent sections, we provide highlights of the activities and major achievements registered.

Introduction and Evaluation of Advanced Germplasm Materials

Large number of advanced germplasm materials including *Striga* resistance germplasms, drought tolerant hybrids, food grade sorghum hybrids, high digestible sorghum hybrids were introduced from Purdue University and evaluated on replicated plots at Melkassa Research Center and its Miesso sub-station and Kobo station under Sirinka Research Center. (Table 8)

The introductions were primarily evaluated for their adaptation, yield, reaction to pests and diseases and their maturity under Melkassa condition along with standard checks for comparison. A number of materials excelled the check both in terms of yield

Table 8. List by testing group of sorghum germplasm materials introduced from Purdue University between 2003 and 2006

Test groups/years	Number of entries	Test location
2003		
Drought tolerant hybrids and varieties	66	Melkassa
Drought tolerant varieties	25	Melkassa
New experimental hybrids (sets 1 & 2)	646	Melkassa
Food grain tan hybrid	100	Melkassa
Striga resistant hybrids and varieties	30	Kobo
Striga resistant varieties	25	Kobo
High yield potential varieties	20	Melkassa
Sub total	912	
2004		
BMR and forage sorghum hybrids	64	Melkassa
Drought tolerant hybrids	128	Melkassa
Striga resistant hybrids	76	Kobo
Sub total	268	
2005		
Purdue new release hybrids	56	Melkassa , Miesso
Pre-release tan and non-tan pollinator hybrids	756	Melkassa
Tan hybrids yield trial	58	Melkassa
High yield potential hybrids trial	44	Miesso
Striga resistant hybrids trial	34	Kobo, FD
Sub total	948	
2006		
Tan Sorghum hybrids	60	Melkassa
Dual purpose forage sorghum hybrids	24	Melkassa
Sub total	**84**	
Total	**2212**	

and earliness. Seeds of selected materials (parental lines in case of hybrids) were imported the next season for further test in the next phase of evaluation.

Breeding *Striga* Resistant Varieties

Multi-location field testing of *Striga* resistant varieties in Ethiopia began following the initiation of the INTSORMIL collaborative program in 1996. The test started with a new set of *Striga* resistant varieties (P-94 series) developed at Purdue University. In the year 2000 the multi-location and multi season testing of the varieties was concluded with official release of two (P-9401 and P-9403) of the eight varieties for large scale production in the northern part of the country. Subsequent adaptation tests in other parts of the country confirmed that the varieties were best suited in *Striga* infested areas in east and southern Ethiopia. Additional set of varieties were subsequently received from Purdue University and tested at various locations. Among the latest introduction, two varieties were released in 2002 and 2006. A number of additional resistant varieties and hybrids are under evaluation at various *Striga* infested locations across the country.

Hybrid Sorghum Breeding

Almost all of the sorghum cultivars grown by subsistence farmers are low yielding local landraces. A number of open pollinated improved varieties have been released for different agro-ecologies over the last 30 years. However, the adoption is low primarily due to weak extension services and the inability of improved varieties to meet multiple needs of producers such as drought tolerance, *Striga* resistance, etc. The increasing demand for the newly released *Striga* resistance varieties supports this assumption. There is much hope that deployment of drought tolerant hybrid cultivars would complement some of the limitations of existing improved varieties and local landraces. Extensive evaluation of hybrid introductions from Purdue University and international centers has been carried out for several years. In addition, new sets of hybrids are developed and tested every year using introduced standard females and local pollinators. Results of multi-location tests indicate that hybrid cultivars hold great promise to enhance sorghum production in the country. Yields of the best hybrid entries were 30 to 70% higher than the best open pollinated checks at all locations and years. Majority of hybrids tested for five consecutive years out yielded the best check consistently (Tables 8 and 9). Two of these hybrids (P-9501A x ICSR 14 and ICSA21 x ICSR50) have been proposed for official release in 2007. The parents nicked quite well under Melkassa condition without a need for stagger planting. Preliminary observation of seed production potential of the hybrids in isolated fields showed that full seed set was obtained at 1:3 row ratio of pollinator to female parent. Moreover, several new sets of hybrids from latest introductions are showing superior performance under different environments (Table 9).

Capacity Building

The national sorghum program has highly benefited from INTSORMIL support in capacity building. The program over the last several years has received various office equipments and field supplies that were crucial not only for the implementation of the project but also for smooth conduct of the national research program in general. Table 10 shows the list of office and laboratory equipments received over the last three years. In addition, INTSORMIL donated one long range vehicle (Toyota Station Wagon) to facilitate effective monitoring of ISM project implementation sites across the country. Further, our program has been receiving at least 25,000 pollination bags every year and various supplies needed for field work. The equipment and supplies were shared among the different disciplines with in the national program and regional research centers working on sorghum.

Human Resource Development

The contribution by INTSORMIL to human resource development of the national sorghum research program was significant. In the last five years a total of five students (1 Ph.D. and 1 M.S.

Table 9. Mean grain yield (t ha^{-1}) of hybrid sorghum entries tested over locations and years under rain-fed conditions in Ethiopia

Entry	Test years					Mean
	2001	2002	2003	2004	2005	
P-9501 A x ICSR 14	5.5	5.3	5.2	5.0	-	5.26
ICSA-21 x ICSR 50	6.0	5.2	5.6	5.0	4.2	5.21
ICSA-22 x M - 4850	3.5	5.1	4.8	4.9	4.5	4.83
ICSA-90003 x M – 170	4.0	5.0	5.2	-	-	4.73
ICSA-90003 x M – 240	-	4.9	5.2	-	-	5.05
ICSA-15 x M – 5568	3.6	4.2	5.3	5.0	4.4	4.71
P-9534 A x KCTENT	5.2	4.2	5.1	5.2	4.3	4.78
ICSA 34 x P – 984108	-	-	5.0	5.1	3.8	4.65
ICSA 21 x 98 MW 6001	-	-	4.5	4.6	4.5	4.54
ICSA 21 x 98 MW 6100	-	-	4.9	4.5	4.0	4.45
Teshale (Std. check)	2.1	3.4	4.2	4.7	4.0	4.05

Table 10. Mean grain yield (t ha-1) of hybrid sorghum entries tested at low rainfall research stations under rain-fed conditions in Ethiopia

	2005		2006		
Identification	Melkassa	Miesso	Melkassa	Miesso	Mean
P-9526 A X ICSR - 16	7.4	4.0	5.7	4.2	5.4
P-9526 A X ICSR - 161	5.9	3.3	4.6	4.5	4.6
ABON 34 X PRL 983978	6.2	3.6	4.9	3.5	4.5
ABON 34 X P 89002	4.9	4.1	4.5	2.9	4.1
ABON 34 X P 89001	5.4	3.3	4.4	3.4	4.1
P-9526 A X ICSR -14	5.0	2.9	3.9	4.2	4.0
ABON 34 X A 3566	5.0	3.5	4.3	3.2	4.0
ABON 34 X P 89009	5.0	3.6	4.3	2.7	3.9
ABON 34 X P-9405	4.6	3.6	4.1	2.3	3.7
ABON 34 X PDL 984921	4.1	3.3	3.7	2.7	3.5
ABON 34 X PRL 983935	4.9	3.3	4.1	1.2	3.4
ABON 34 X PRL 984046	4.2	3.2	3.7	2.0	3.3
P-9526 A X 3443-2-OP	3.5	2.6	3.0	3.9	3.2
ABON 34 X PP 630	4.5	2.8	3.6	1.8	3.2
ABON 34 X PRL 983993	3.8	3.0	3.4	1.2	2.8
Teshale (standard check)	4.7	3.2	3.9	1.7	3.4

each in plant breeding and 2 M.S. in agronomy and 1 M.S. in research extension) have joined graduate program at local universities and in the United States. Three of the M.S. students have already finished their degree and joined the program while the others are in progress. In addition to the formal trainings, members of the national research team had benefited from opportunities opened up at different times to interact with project counterparts and international and regional scientists through participation on various international and regional workshops sponsored by INTSORMIL.

Uganda

Production and Utilization Constraints

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 African (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, however 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. Furthermore the parasitic weed *Striga* is widely distributed in eastern Uganda, causing significant reduction of cereal yields. Use of *Striga* resistant varieties has proved successful in Ethiopia in alleviating the effects of *Striga* on cereal production. Evaluating resistant varieties under Uganda conditions is important before multiplication and wide distribution to farmers can take place in the country. Maintaining and increasing sorghum production in these areas is important for food security and improved income for the smallholder farmers.

Research Findings and Project Output

The aim of this research was to evaluate, with farmer participation, alternative low-input practices for soil fertility improvement in sorghum-based cropping systems. The practices were: use of herbaceous legumes in improved fallow; a grain legume in rotation with sorghum; use of farmyard manure; application of low levels of N and P fertilizers; and reduced tillage. Four studies, comprised of 142 on-farm trials, were conducted at three locations over three years in drought-prone parts of eastern Uganda. Mucuna (Mucuna pruriens (L.) DC) on average produced 7 Mg ha-1 of above-ground dry matter containing 160 kg N ha-1 across the three locations. Application of 2.5 Mg ha-1 of manure and of 30 kg N plus 10 kg P ha-1 increased grain yield by 1.05 and 1.30 Mg ha-1, respectively. A combination of 2.5 Mg ha-1 manure with 30 kg N ha-1 increased grain yield by 1.50 Mg ha-1 above the yield with no nutrients applied (1.1 Mg ha-1). The increase in sorghum grain yield in response to 30 kg N ha-1 alone, to a mucuna fallow, and to a rotation with cowpea (Vigna unguiculata (L.) Walp) was 1.15, 1.55 and 0.82 Mg ha-1, respectively. These soil fertility management practices, as well as reduced tillage, were found to be cost effective in increasing sorghum yield in the predominantly smallholder agriculture where inorganic fertilizer was not used much. On-farm profitability and food security for sorghum production systems can be improved by use of inorganic fertilizers, manure, mucuna fallow, sorghum-cowpea rotation, and reduced tillage.

This confirms that low soil fertility is a constraint to sorghum production and the alternative strategies are effective in addressing it.

Description of Method of Work Used

The strategies include, (1) Herbaceous and grain legumes in improved fallows and in 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 and timely planting.

Methods used at the sites:

- Farmer managed (on-farm) adaptive research trials (for technology generation), demonstrations and exposure visits by farmers to research institutes (for technology dissemination). A total of 120 farmers participate in the field trials and attend village meetings where research findings and future plans are discussed. The trials were conducted at three sites.
- On-farm evaluation of Striga resistant variety received from Purdue University and the interaction of Striga resistant with soil fertility management
- Researcher managed trials to compare three tillage (conventional, reduced tillage and no till) systems for tillage effect on grain yield, soil water availability, and Striga; and also to determine the effects of soil fertility management practices and their interaction with tillage, on grain yield, and Striga. The trials are conducted at three sites.

Institution Building

Dr. Charles Wortmann from Nebraska University visited the research sites in Uganda during the period 4th – 12th February 2005, discussed with the project with participating farmers and future plans/activities with Dr. C. Kayuki Kaizzi and Dr. John Byalebeka.

Dr. Crammer Kayuki Kaizzi visited University of Nebraska for a short-term training and also attended the Annual meeting of the American Society of Agronomy meeting at Salt Lake City, Utah. (October 15 – November 19, 2005).

Networking Activities

Researchers, policy makers, community based organization's (CBO), government- and non-government (NGO) extension staff visit the on-farm demonstrations to observe sorghum response to alternative strategies for soil fertility improvement/enhancement, they also participate in seasonal evaluation and planning meetings (attended by over 150 farmers) where research results are discussed and problems identified. A total of 120 farmers are implementing the field trial and demonstration. Presentation of research results in Quarterly and Annual reports of Kawanda Agriculture Research Institute (KARI/NARLI) and the National Agricultural Research Organization (NARO).

Publications and Presentations

Kaizzi Kayuki C., Byalebeka John, Charles S. Wortmann and Martha Mamo. 2007. Low Input Approaches for Soil Fertility Management in Semiarid Eastern Uganda. Agron. J. 99:847-853.

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

Gary C. Peterson
Texas A&M University

Coordinators

Dr. Medson Chisi, INTSORMIL Coordinator for SADC Region and Sorghum Breeder, Ministry of Agriculture, Crops and Soils Research, Golden Valley Research Trust, Chilanga, Zambia
Dr. Gary C. Peterson, INTSORMIL Coordinator for SADC Region and Sorghum Breeder, Texas A&M University Agricultural Research and Extension Center, Rt. 3, Box 219, Lubbock, TX 79403-9803

Collaborators

Mr. F.P. Muuka, Pearl Millet Breeder, Ministry of Agriculture, Kaoma Research Station, P.O. Box 940084, Kaoma, Zambia
Dr. J. Wilson, Pearl Millet Breeder, USDA-ARS, P.O. Box 748, Tifton, GA 31793
Mr. G. M. Kaula, Plant Pathologist, Private Bag 7, Mt. Makulu Research Station, Chilanga, Zambia
Ms. P. Ditshipi, Plant Pathologist, Dept of Agricultural Research, Private Bag 0033, Gaborone, Botswana
Dr. N. McLaren, Plant Pathologist, Dept of Plant Sciences, University of the Free State, P.O. Box 339, Bloemfontein 9300 South Africa
Dr. W. Marasas, Pathologist, Program on Mycotoxins and Experimental Carcinogenesis, Medical Research Council, P.O. Box c 19070, Tygerberg 7505, South Africa (retired)
Dr. Hester Vismer, Pathologist, Program on Mycotoxins and Experimental Carcinogenesis, Medical Research Council, P.O. Box 19070, Tygerberg 7505, South Africa
Dr. Gordon Shepard, Pathologist, Program on Mycotoxins and Experimental Carcinogenesis, Medical Research Council, P.O. Box 19070, Tygerberg 7505, South Africa
Dr. J. Leslie, Plant Pathologist, Dept of Plant Pathology, Kansas State University, 4002 Throckmorton Plant Sciences Center, Man hattan, KS 66506-5502
Dr. J. Taylor, Cereal Quality, Dept of Food Science, University of Pretoria, Pretoria 0002, South Africa
Dr. Janice Dewars, Research Scientist, CSIR, Pretoria, South Africa
Dr. L. Rooney, Cereal Quality, Dept of Soil and Crop Sciences, Texas A&M University, College Station, TX 77843
Dr. H. du Plessis, Entomologist, ARC-Grain Crops Institute, Private Bag X1251, Potchefstroom 2520, South Africa
Dr. David Munthali, Entomology, Botswana College of Agriculture, Private Bag 0027, Gaborone, Botswana
Mr. Fernando Chitio, Entomologist, Instituto Nacional de Investigacão Agronómica, Nampula, Mozambique
Dr. Bonnie B. Pendleton, Entomologist, Division of Agriculture, West Texas A&M University, Canyon, TX 79016
Dr. Stephen Chite, Sorghum Breeder, Dept of Agricultural Research, Francistown, Botswana
Mr. Joaquim Mutaliano, Sorghum Breeder, Instituto Nacional de Investigacão Agronómica, Namialo, Mozambique
Dr. W.L. Rooney, Sorghum Breeder, Dept of Soil and Crop Sciences, Texas A&M University, College Station, TX 77843
Dr. Gelson Tembo, Ag Economics, University of Zambia, Lusaka, Zambia
Ms. Priscilla Hamukwala, Ag Economics, University of Zambia, Lusaka, Zambia
Dr. Donald Larson, Ag Economics, Ohio State University, CMPS/3064 Smith Lab, 174 Eighteenth Ave, Columbus, OH 43210
Dr. J. Mark Erbaugh, International Programs in Agriculture, Ohio State University, 113 Ag Admin Building, 2120 Fyffe Road, Columbus, OH 43210

Summary

Promote Economic Growth and Improve Nutrition

Research conducted by the scientist associated with this project contributes to different aspects of economic growth. Research on milling properties of sorghum and pearl millet will contribute to greater utilization of the grains in value added products by improving milling yield. Research on malting quality contributes to the successful lager brewing industry. Collaboration between food science and breeding programs will eventually result in development of novel genetic combinations in cultivars and hybrids with improved end-use properties. Development and implementation of research protocols to identify sorghums resistant to ergot reduces the grain yield loss, and thus economic loss, in farmers fields.

Increase Yield

Cultivars and hybrids released - such as ZSV-15, WP-13, MMSH-625 and MMSH-1365, produce a higher yield than local

varieties. The higher yield potential is the result of better adaptation and stress (abiotic and biotic) stress resistance.

Improve Institutional Capacity

Graduate students have received degrees in the disciplines of Food Science, Plant Breeding, Entomology, Plant Pathology, and Agronomy. The degrees were received at Texas A&M University, West Texas A&M University, the University of Nebraska, University of the Orange Free State (South Africa) and the University of Pretoria (South Africa). The degree research programs were a direct result of collaboration in the project and involved facility in the U.S. and Southern Africa. The students returned to their home institution to initiate or continue research, or are pursuing another graduate degree.

Objectives, Production and Utilization Constraints

Research Objectives

- Pearl Millet Breeding: Develop topcross grain and forage hybrids adapted to low rainfall regimes with the potential to transform pearl millet from subsistence to commercial status, test prototype cultivars in commercial and industrial ventures, and develop appropriate populations for sustaining research programs.
- Pathology: Identify sources of resistance and develop appropriate control measures for major disease pathogens. Determine disease reaction of new cultivars. Determine mycotoxin production capabilities of Fusarium species, and the presence of Fusarium mycotoxins in molded grain.
- Food Quality: Determine the physical, chemical and processing properties of sorghums and millets. Improve food product quality by modification of processes to reduce or eliminate anti-nutritional components. Summarize and transfer information on quality and utilization to potential end-users.
- Entomology: Identify, evaluate, and incorporate sugarcane aphid resistance into adapted sorghum varieties and hybrids. Assess the response of sorghums to insect pests including stored grain pests as appropriate. Develop control tactics and integrated pest management strategies to promote increased availability of high quality grain.
- Sorghum Breeding: Develop sorghum cultivars and hybrids with improved grain yield, stress resistance, environmental adaptation, and end-use quality traits for food, forage and feed. Maintain pre-basic and basic seeds of released and pre-released cultivars, hybrids and their parents, and assist with seed production and distribution systems at a community level. Develop appropriate farming systems agronomic management practices and assist in technology transfer.
- Marketing and Economics: Evaluate the effects of new technology and marketing strategies on sorghum and millet farmers' income in Tanzania and Zambia.
- Past research and development experience indicates that adoption of improved technologies in the absence of cash markets is rare. New markets for sorghum and millet will drive the adoption of new technologies and lead to enhanced output, farmer income, and improved rural livelihoods.

Production and Utilization Constraints

Constraints include low grain yield potential, infertile soils, variable moisture availability, insects and diseases, poor crop management practices, low uptake of new technology, poor grain and forage quality, lack of improved seed, quelea birds, and poor distribution and market structures. Lack of scientists resulting in less than adequate research in all disciplines hinders progress in technology development and transfer. Policy constraints frequently place sorghum and pearl millet at a disadvantage relative to other commodities. Novel crop genetics and better biotic stress management can economically address some constraints by increasing grain yield potential, and by improving grain or forage quality to meet end-use requirements. Beyond the farm gate market channels should be improved to increase end-use as sorghums or millets with the required quality to meet commercial requirements frequently has inconsistent production and supply. Inconsistent supply of quality grain is frequently cited as a major factor in deciding to not use sorghum or millet. Availability of a consistent supply of improved quality sorghum and pearl millet for processing into value added urban products is a major constraint limiting utilization. Food companies will use but cannot consistently acquire sufficient quantities of high quality sorghums for processing. A system of identity preservation for production, marketing, and processing is urgently needed.

New varieties and hybrids with increased grain yield potential, improved environmental adaptation, increased resistance to abiotic (drought tolerance) or biotic (disease and insect) stress, improved end-use traits (for food, feed and forage), and other desirable traits are needed. Exotic sorghums and pearl millets as sources of improved traits are needed. The identification of regionally adapted sorghum or pearl millet cultivars or hybrids with stable grain yield and multiple stress resistance will assist in developing lines, varieties, and hybrids for the diverse environments and production systems in each country and in similar SADC environments. Research is on-going to improve disease and insect pest management, to improve sorghum and pearl millet processing techniques to improve use in value added foods, and to identify marketing and policy constraints to increased commercialization of both crops.

Research Progress

The objective of the collaborative program is to develop and transfer science based technology solutions to increase production and use of pearl millet and sorghum. Component projects conduct research specific to the project goals but which has implications to research in other projects. Scientists are encouraged to collaborate across country boundaries. The Texas A&M University sorghum breeding program distributes tests and nurseries based on requests from individual collaborators. Multi-location testing establishes base-line data for performance response of introduced germplasm throughout the region. Germplasm suitable for direct use or use as parental lines in a breeding program is identified. Disease pathogen race and insect biotype distribution can be established as well as identification of resistance sources.

Food Quality

The University of Pretoria is the SADC regional center for post-graduate training in Food Science and Technology. Research into the food and nutritional quality of sorghum and millet is focused on cultivar food quality, milling technologies and sorghum and millet food nutritional value.

In the southern Africa region there is significant interest in using sorghum for production of lager beer and in the manufacture of value added food products from sorghum. For sorghum to be commercially successful in either use a consistent supply of high quality grain at a affordable price must be readily available. Sorghum quality research has been focused on both issues.

To support the brewing industry the primary research objective is to determine the role of sorghum grain quality in sorghum grain and malt lager beer brewing. Additionally, for sorghum lager brewing to be a viable alternative to brewing with barley there must be a consistent supply of sorghum of suitable quality for brewing. At present we are determining what are the suitable qualities and quantities required. It is clear currently available sorghum lines cannot produce malt of the required quality to be a total substitute for barley malt for lager brewing. Thus, the commercial enzymes must be used together with the malts. Sorghum lines with better malt brewing quality are required.

To manufacture value added food products from sorghum and pearl millet, the milling technologies must produce sufficient quantities of flour/meal of the required qualities utilizing the range of grain types that are currently available. Research to develop commercial sorghum and pearl millet technologies is focusing on two areas: a) Optimizing sorghum roller milling to produce meal at maximum grain extraction; b) Assessing the effects of traditional and roller milling technologies on pearl millet quality. Simple, small-scale roller mills have considerable advantages over the traditional dehuller-hammer combination for sorghum milling. Roller mills have much higher production throughput and produce meal at much higher extraction rate, i.e. much less of the grain is wasted. For pearl millet milling, roller milling also seems to have similar advantages.

Pathology

Panicle diseases, primarily ergot (*Claviceps africana*) and grain molds, have been major constraints to sorghum production in South Africa. Studies on pollen x *Claviceps africana* interactions led to the development of selection criteria and screening methodologies that culminated in the development of ergot resistant lines and hybrids that were released to producers. Ergot is no longer regarded as a constraint and annual screening of new releases ensures that susceptible material does not enter the production system.

Screening for grain mold resistance, particularly in white grain tan plant (food type) sorghums has been supplemented with studies on grain quality, particularly hardness, malt, phenol and AFP content and head bug resistance and control. Emphasis has shifted to potential health risks to consumers from mycotoxins associated with grain mold fungi. Principal toxins, notably aflotoxins and zearalenone, have been detected at critical levels in grains used for human consumption and commercial products. Epidemiological studies are in progress to relate environmental and genetic variables during critical points in grain development to the risk of grain molds/toxins and to develop a risk assessment model. Studies have also been initiated to determine the heritability of grain mold resistance and to develop grain mold resistant breeding populations.

Sorghum is produced under semi-arid and often low input conditions. Moisture constraints are exacerbated by root rots which limit water and nutrient uptake. A study of root rot etiology and resistance, and the effect of the edaphic, biological and chemical environment on the host x pathogen interaction was undertaken. *F. oxysporum, F. solani, F. verticilliodes* and *F. thapsinum* were the most frequently recovered species. Host x pathogen interactions proved significant indicating that resistance within a host genotype is pathogen specific and that breeding for root rot resistance requires a multiple disease approach. Biological (*Trichoderma* spp.) and organic amendments (chicken manure) were among those that effectively suppressed the colonization of roots by root rot pathogens. These studies will contribute to a protocol for breeding for root rot resistance and the development of integrated farming systems that reduce the risk of losses due to the disease complex.

Nurseries from the INTSORMIL/TAES program are screened annually at a number of strategic sites (primarily in South Africa and Zambia) to identify sources of disease resistance to principle diseases such as leaf blight, sooty stripe, anthracnose, ergot, grain molds and lodging in diverse germplasm and for adaptation. For example, in Zambia the strategic sites represent the major production sites and include: Golden Valley (sooty stripe, downy mildew, and leaf blight), Mansa (anthracnose, leaf blight, and sooty stripe), Mt. Makulu (viruses), and Lusitu (smuts). Thus major pathogens and their distribution in Zambia were identified: Region I - Long smut (*Tolyposporium ehrenbergii*) and Head smut (*Sporisorium relianum*); Region II - Sooty stripe (*Ramulispora sorghi*), Leaf blight (*Exserohilum turcicum*), Downy mildew (*Peronosclerospora sorghi*) and Maize dwarf mosaic virus; Region III - Anthracnose (*Colletotrichum graminicola*). Introduced germplasm with excellent disease resistance includes SC326-6, RTx430, SC414-12E and BTx631. Breeding and pathology programs collaborate to identify germplasm potentially useful as cultivars or hybrid parents and to develop new disease resistant germplasm. Selections from these nurseries will be included in a single nursery to be planted during 2007-2008 in demonstration plots for small-holder farmers and seed producers to evaluate with the goal of releasing disease resistant, high yielding lines and cultivars.

Many farmers use a mixed commodity cropping system to diversify risk, and to produce sufficient grain for home consumption or sale to cash markets. Thus there is the need to identify and characterize grain molds for potential human health problems. The Medical Research Council PROMEC Unit, in collaboration with with INTSORMIL and IITA (Dr. R. Bandyopadhyay, Ibadan, Nigeria), is conducting research on the natural occurrence of fumonisins and the Fusarium species associated with sorghum, maize and millet grain (collected in the same area of Nigeria) intended for human consumption in Africa.

All maize (n=23), and most of the sorghum (n=27) and pearl millet (n=7) samples although at lower levels, were naturally contaminated with fumonisins. In maize the levels ranged from not being detected (n=2) to 2856 mg/kg. In the sorghum samples levels ranged from not being detected (n=4) to a high of 1345 mg/kg. All the millet samples contained low levels of fumonisins (range: 8-29 mg/kg). None of the 14 localities where samples were collected showed consistently high or low levels of fumonisins for any of the grains, but levels were rather varied for each commodity in any one particular area.

Mycologically, the incidence of the main fumonisin producing *Fusarium* species, i.e., *Fusarium verticillioides* and *F. proliferatum*, varied between 1-31% of maize kernels infected (n=20), while three samples indicated no infection. Eight samples of sorghum showed levels of 1-32% kernel infection with mainly *F. proliferatum* and *F. verticillioides* (to be confirmed). The sorghum sample with the highest incidence of 32% correlated well with the high fumonisin levels found (1345 mg/kg). Only one of the millet samples showed 1% of kernels infected by these fungi.

It can be concluded that apart from maize, well known to contain fumonisins, these mycotoxins naturally occur in sorghum and millet in Nigeria. Furthermore, both maize and sorghum as can potentially harbour fumonisin-producing *Fusarium* species. The unidentified new *Fusarium* species isolated from sorghum and millet needs to be further investigated and toxin profiles determined. This will further elucidate the potential for mycotoxin contamination of these crops in Africa and the potential human health implications in rural communities consuming these staple foods.

Selected strains isolated from maize, sorghum and millet samples were used to determine the toxin profiles of potentially toxigenic *Fusarium* species. The work involved the determination of the production of fumonisins by 18 strains of selected isolates of *Fusarium proliferatum* and two unidentified strains of *Fusarium*. Ten of these strains were isolated from maize, nine from sorghum and one from millet samples.

Results indicated that overall the eight *F. proliferatum* strains isolated from sorghum produced higher levels of fumonisins (range: 4-7459 mg/kg; mean 2749 mg/kg) than the ten isolated from maize (range: from not detected to 4932 mg/g, mean 985 mg/kg) in maize patty cultures. The two unidentified strains isolated, one from sorghum and one from millet, did not produce meaningful levels of fumonisins, i.e., 9 and 18 mg/kg, respectively. It will now be optimal to test the ability of these strains to produce fumonisins in sorghum and millet patties, and to compare the results to the levels found in maize patties. Millet patty medium still needs to be developed.

Entomology

In Mozambique, and many areas, stored grain pests cause significant damage to grain post-harvest. Technology to reduce the loss due to stored grain pests will improve the quality of food available for household and commercial processing. Research was initiated with the overall goal of identifying genetic resistance against maize weevil. Specific objectives are: 1)Evaluate when infestation begins in the field (soft or hard stage), 2)Evaluate if maize weevil appears at the same time every year, 3)Evaluate the use of harvest time to manipulate pest incidence. Five varieties were studied: Macia (from Mozambique), Sureño (Central America), BTx635 (Texas), Malisor 84-7 (Mali), and Sima (Mozambique). Growing season insect pests identified were sugarcane aphid and corn leaf aphids. Over two years the field occurrence of maize weevil appeared to depend on climatic conditions. During the first year the pest appeared after the grain was fully mature and low moisture while in the second year the pest appeared after the harvest was mostly completed. Additional research to determine if presence of the maize weevil relates to grain maturity or to the ecology of the insect and climate is needed. Ecology studies to determine when and where the insect oviposits, pupates and develops prior to infesting sorghum are also needed.

The sugarcane aphid can be sorghum pest throughout Southern Africa. Prior INTSORMIL research identified resistance sources and studied the inheritance of resistance. The objective of the present research was to utilize these results in a joint entomology/breeding program to develop improved cultivars with resistance to sugarcane aphid. Evaluations for sugarcane aphid resistance and adaptation to local environments was done at the mid-altitude research station of the ARC-GCI in Potchefstroom, the low-altitude, sub-tropical research station near Hazyview, South Africa, and at the Botswana College of Agriculture, Gaborone, Botswana, over a period of six years. Greenhouse evaluations were also conducted.

Of the entries screened over the six year period, 22% were resistant and 34% were highly resistant to sugarcane aphid in field trials at Potchefstroom. At Burgershall, 27% were resistant and 31% highly resistant to sugarcane aphid. An average of 42% of entries screened in a greenhouse over this period were resistant to sugarcane aphid. Results from the screening trials led to the conclusion that a number of entries express resistance in the seedling stage and the resistance is consistent over locations.

Selections were made based on sugarcane aphid resistance, agronomic traits and weathering data. A replicated trial to identify potential varieties for use by small-holder farmers was evaluated at the ARC-GCI in Potchefstroom, at Taung Research Station in the Northern Cape province and at Polokwane Research station in Limpopo Province. No natural infestation of aphids occurred at Taung and Polokwane research stations. At Potchefstroom, under high infestation pressure, all entries except one (moderate resistant) rated resistant to highly resistant. Yields were between 3 and 6 t/ha and some entries show promise and could be released for use by the small-holder farmers.

Genetic Improvement

The major focus of the Zambia breeding program is to ensure food security under the crop diversification policy by developing cultivars and hybrids with grain quality traits acceptable to end-users. Participatory approaches are used to achieve this goal. Through establishing markets and value chain management the program is working to move sorghum from a subsistence crop to a cash generating crop. Increased production and use of sorghum should provide household food security and increased income for the subsistence farming sector. Collaboration with INTSORMIL involving germplasm exchange and evaluation of trials with spe-

cific traits has resulted in the development of sorghum cultivars suitable for food, brewing, feed and forage. The cultivars ZSV-15 and WP-13, and hybrids MMSH-625 and MMSH-1365, have been released to farmers with a fair amount of success in terms of acceptance.

Issues of seed production and distribution continue as a major hindrance to increased production of sorghum in Zambia. They are largely due to government policy that restricts access to publicly released cultivars by private seed companies. The program has, with the support of INTSORMIL, increased seed of released cultivars WP-13, Kuyuma, Sima and ZSV-15. The seed was sold to farmers and various NGO's (more than 70 tons and enough to plant 8,750 ha). NGO's such as Harvest Help, Care International (Zambia), WVI, Oxfam and PAM are involved in the seed multiplication for distribution to farmers and the program provides technical support for this activity.

Collaborative activities in technology transfer though Care International (Zambia) and Harvest Help continued in Kazungula and Siavonga under a commercialization project. The activities are designed to promote sorghum production and consumption. With increased sorghum production it is expected that farm incomes and profitability will increase resulting in greater food security. In Kazungula the number of farmers participating has increased from 630 to 1,250 in 2007 with a combined 630 hectares. Some farmers have obtained high grain yields of 2 tons per hectare, 4 times higher than the average of 500 kg. Zambia Breweries has contracted a number of grain merchants that are purchasing the grain for their Eagle larger beer. It is expected that most households that grew sorghum will have enough grain for their subsistence or for sale to the cooperatives.

A sorghum and pearl millet extension handbook was published with the assistance of INTSORMIL. Copies of the handbook have been distributed to extension officers, NGOs and cooperatives. Some local communities have translated some parts of the handbook and developed charts in their local languages.

The general objective of Botswana sorghum program is to develop cultivars with wide adaptation, increased productivity and acceptable food quality traits. Adoption of new sorghum cultivars is often restricted as consumers prefer the taste of locally adapted cultivars. Thus there is the need to exploit the yield potential of exotic introductions to improve locally adapted cultivars. Concurrently, the lines are tested for fertility reaction and potential as a hybrid parent. Segaolane, a locally developed variety, has excellent pre-flowering drought tolerance but a purple plant. A tan plant version of Segaolane with improved food quality is being developed. Research is on-going to develop varieties with both pre- and post-flowering drought tolerance. Evaluation of trials from INTSORMIL has led to the identification of introductions potentially useful as either cultivars or hybrid parents. Although sorghums with red pericarps are generally classified as non-food sorghums most millers in Botswana will use red sorghums to make flour. This makes red pericarp sorghums candidates for both food processing and opaque beer brewing. Hybrid trials have identified combinations with excellent agronomic characteristics, early to medium flowering, and red pericarp. The livestock sector is constrained by inadequate feed and there is a need for development of good forage sorghums. Several forage hybrids have been identified in performance across locations as promising.

In Mozambique an INTSORMIL trained sorghum breeder has finished his first cropping season. Evaluations were conducted on populations developed while in graduate school (at Texas A&M Univ.) and on introductions from Texas A&M Univ. and the Zambian national program. Additionally, commonly used cultivars were increased to provide additional seed to farmers. Collaboration is being established with the Zambia national program to provide additional source germplasm and technical backstopping.

For pearl millet, abiotic constraints include poor soil fertility, low soil pH and erratic rainfall while the major biotic constraints are downy mildew, ergot, and smut. There is a lack of improved seed which affects productivity and production. The breeding strategy involves developing suitable topcross R4 (cytoplasm) restorer parents from adapted Zambian genetic stocks which can then be crossed with suitable exotic A4 CMS seed parents to produce hybrids. Top cross hybrids developed using diverse parents are in evaluation to determine the combinations with the best heterosis. Parental lines and hybrids that express a different response to stress and non-stress conditions have been identified. There are two cytoplasm systems that can be used to produce pearl millet hybrids - Aa and A4. Lines and related hybrids will express a genotype x environment interaction based on the plant genetics. Some perform well in non- stress environments and not as well in stress environments and vice versa. Comparison between the Aa and A4 systems based on hybrid performance was inconsistent between seasons. During the non-stress season, the line with the most grain yield in each pollinator class with dissimilar seed parents was also the most heterotic.

Marketing and Economics

Four market developments offer opportunities to increase farmers' income: (1) the agro-food industry, especially food processing, (2) feed concentrates, (3) clear beer brewing, and (4) energy markets. Some of these markets such as sorghum based clear beer brewing and feed concentrates can be expected to grow rapidly (10 to 15 percent or more per year) in the near future while others such as fortified foods may grow more slowly. The energy market, utilizing sorghum, is a longer term development that may grow rapidly but also carries higher risk.

Closer coordination between producers and commercial end-users on supply chain management has begun with clear beer brewing. Beer brewers have developed a sorghum based clear beer called Eagle Lager brand. Eagle Lager was introduced in Zambia in 2005. Early results indicate sales are exceeding expectations and clear beer brewing has developed as a new market opportunity for sorghum producers. Lack of a market is no longer the main supply chain constraint. Sorghum supply, adequate quantities of a reliable supply high quality product at reasonable prices, has become the main constraint.

A comparison of crop budgets between farmers using traditional and new technology for Zambia was conducted. The traditional technology is based on what most farmers are using at the present time and the new technology shows the potential of new

technologies recommended by INTSORMIL and host country research institutes. These new technologies include improved seed, manure/fertilizer, and ridge tilling/basins to conserve moisture. Crop yields and profits all increase with the new technology package. In most cases the increases are dramatic. A large gap exists between the traditional and new technology results. The new technology returns are higher; however, the risks (e.g., market, production, and financial) are also higher which may explain the gap between use of the traditional and adopting the new technology. Farmers will examine the risk to return ratio when choosing to adopt new technology. Finding ways to lower the risk relative to the return will increase technology adoption. Linking farmers to dependable markets is key to reducing the risk to return ratio.

Networking Activities

Food science research is carried out in close collaboration with Texas A&M University, the SA Sorghum Forum (the industry stakeholders association), the SA Agricultural Research Council, Novozymes SA, The Botswana National food Technology Research Centre, University of Namibia, and the Zambian National Institute for Scientific and Industrial Research.

The Zambia national program sent 15 sorghum lines to Mozambique in 2007 and will share with any other programs in the region.

In Zambia, the following NGOs are involved in sorghum seed production and technology transfer: Harvest Help, Care International (Zambia), WVI, Oxfam, and PAM.

Publications and Presentations

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

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

Institutions and History

The West Africa Regional Program is made up of six countries of the Sahelian region – Burkina Faso, Ghana, Mâli, Niger, Nigeria, and Senegal - following the merger in July 2004 of the previously existing West Africa Eastern and Western Regional programs. Participating African institutions are L'Institut de l'Environnement et de Recherches Agricoles (INERA) and Institut de Recherche en Sciences Appliqués et Technologiques (IRSAT) in Burkina Faso; Savanna Agricultural Research Institute (SARI) in Ghana; L'Institut d'Economie Rurale (IER) in Mali; Institut National de la Recherche Agronomique du Niger (INRAN) in Niger; University of Maiduguri, Lake Chad Research Institute, and Institute for Agricultural Research (IAR) in Nigeria; and Institut Sénégalais de Recherches Agricoles (ISRA) and Institut de Technologie Alimentaire (ITA) in Senegal. From the inception of the INTSORMIL program, core institution-building programs 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 a merger of the two regional programs into the one West Africa Regional Program. Another all-PI meeting was held in March 2006 and a strategic planning meeting with select PI's occurred in April 2007. Participating U.S. PI institutions in the period have been Kansas State University, Purdue University, Texas A&M University, University of Nebraska, USDA ARS, Tifton, Georgia, and West Texas A&M University.

Collaboration

The region organizationally has been divided into two subregions representing the geographic areas of Niger, Nigeria, and Burkina Faso (Eastern) and Mali, Senegal, and Ghana (Western) for purposes of oversight and reporting. Since 2001, country-oriented programs have undergone the change conceptually of moving to a large regional program. Accordingly, new activities were initiated to develop regional project ideas in the form of two committees focused on priority areas, crop utilization and technology transfer, that were voted on at the 2004 all-PI meeting in Ouagadougou. Both groups developed concept notes designed to transfer or commercial technologies in the region, many times in "technology packages". These have formed the basis for discussions of future regional project areas for a new West Africa regional program. The two committees and titles of the concept notes developed are listed as follows.

Crop Utilization

Expansion of Processed Cereal Product Markets in the West African Sahelian Countries through Development of Incubation Centers to Drive Value Chains.

Technology Transfer

- Expansion of processed cereal product markets in the West African Sahelian countries through development of incubation centers to drive value chains,
- Increasing millet grain production in West Africa through adoption of water and nutrient use efficiency technologies,
- Promoting sustainable production of quality grain millet for processed marketable products,
- Improving marketability of grain sorghum in West Africa through farmer adoption of technologies,
- Promoting sorghum hybrid seed and processed product enterprises in West Africa,
- Adoption of technologies to control Striga for increased sorghum production in West Africa.

The following report shows the wide breadth of research and extension activities in the West Africa Regional Program. A complement of projects spans genetic enhancement, sustainable plant protection systems, sustainable crop production systems, and utilization and marketing. 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. The West Africa INTSORMIL program 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. A separate project in the region on linking farmers to markets is funded through the USAID West

Africa Regional Program and is discussed elsewhere (PIs J. Sanders and O. Botorou).

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 2005, together they comprised overall production in Burkina Faso of 2.75 mMT vs. 0.89 mMT for the sum of maize, rice and wheat, in Mali 1.79 vs 1.59 mMT, in Niger 3.60 vs. 0.07 mMT, in Nigeria 16.35 vs. 9.59 mMT, and in Senegal 0.75 vs. 0.68 mMT (FAOSTAT, 2007). Ghana, which is dominated by savanna and rain forest regions, produced 0.54 mMT of sorghum and millet. 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 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. A new project for this period in poultry nutrition aimed to encourage poultry producers to use sorghum and millet for feed.

Research Progress

Genetic Enhancement: Sorghum Breeding

Ghana

Sorghum Breeding, Germplasm, and Characterization
I. Atokple, SARI; M. Tuinstra, KSU

Germplasm collection, characterization, and conservation

Collection trips covered the three regions of northern Ghana and parts of the Brong Ahafo region using modified FAO germ-

plasm collection forms to gather pertinent ethno-botanical data of the accessions. In all, 487 accessions have been collected so far. The accessions went through replicated agro-morphological evaluation across the regions. While, Upper East and Northern Regions have early and late maturing sorghum accessions respectively, the Upper West Region has all the maturity groups.

DNA analyses

In collaboration with the Biotech-Lab, Crop Science Department of the University of Ghana, representative samples (65) of the accessions went through DNA analyses. The aim was to provide a more accurate and detailed outline of true genetic diversity present within the accessions, to eliminate duplicates and to determine the national core collection for ease of management.

Biochemical, malting and brewing tests

Testing was carried out to determine the nutritional and functional properties of selected promising accessions and advanced breeding lines to define the specific end uses of the various accessions/lines. Seven out of seventeen accessions tested were found suitable for malting and brewing with the extract yield and limit of attenuation not less than 80%. The lines include Yakpai, Kazea Manga, Nakpaji, Global 2000, Kazea, Nwaagy or Red Belko, Belko Pielik. These will increase the number of commercial sorghum varieties for malting and brewing industries.

Breeder seed

Breeder seed of the commercial sorghum varieties, Kapaala and Dorado, have been produced since 2002. Other agencies and private farmers produce the foundation and the certified seeds. The two varieties are currently being used in brewing alcoholic and non-alcoholic beverages.

Mali

Sorghum Breeding and Seed Multiplication

A. Touré, S.B. Coulibaly, IER; M.Tuinstra, KSU

Breeding crosses

New breeding crosses were made annually from 2001 to 2006 to assure the gradual improvement of new breeding materials through recombination of the best materials. During this period, more than 500 new crosses were made at Sotuba and the F_1's grown during the off season nursery to produce F_2 seeds. From multi-location evaluation of 477 F_2 families in the rainy season, 3137 single-plant selection were made at Cinzana, Bema, Sotuba, Kolombada, Kita and Finkolo. These selections were advanced by the pedigree method. In the F_3 families grown in 6 locations (Sotuba, Cinzana, Kolombada, Bema, Finkolo and Kita), 1117 single heads were selected in 4215 families. The F_4 and F_5 generations were evaluated according to maturity group. The early and medium F_4 progenies were evaluated at Sotuba, Kolombada, Cinzana and Bema. The late F_4 progenies were evaluated at Finkolo and Kita. A total of 2285 F_4 and 3153 entries evaluated and 220 lines were retained for yield trial evaluation.

Advanced early maturity variety trials

During 2001-2006, more than 30 early maturity lines were evaluated for three years in two locations, Bema and Cinzana. The average grain yield was 1664 kg/ha^{-1}. One line 01-CZ-F5P-244 was retained for its high 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 an average of 1650 kg/ha^{-1}. 01-CZ-F5P-244 was in farm tests in 2005 and 2006.

Advanced medium maturity variety trials

A three year evaluation of 27 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-yielded the local check 41, 12, and 41%, respectively. A total of 18 lines were advanced on farm tests.

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 six localities of Sotuba, Kolombada, Kita, Finkolo, Bema and Cinzana to compare new breeding lines to their local. There were significant differences for grain yield and some breeding lines showed greater grain yield than the farmer local. They also showed superior grain quality compared to the local.

Several improved breeding lines were released during the period 2001-2006: Zarra blè (2500 kg/ha^{-1}) and Zarradjè (2500 kg/ha^{-1}), new tan varieties were released for the North Guinea zone; Wassa (2000 kg/ha^{-1}), Kénikédjè (2000 kg/ha^{-1}) and 98-BE-F5P-84 (2000 kg/ha^{-1}) Guinea types were released for the Sahel zone; and Darrellken (2000 kg/ha^{-1}), Niéta (2000 kg/ha^{-1}), Grinkan (2500 kg/ha^{-1}), Tiandougou (3000 kg/ha^{-1}), and Niéthithama (2000 kg/ha^{-1}) for the Sudan zone. All showed yield gains of 30-60% over the locals.

Seed multiplication

From 2001 to 2006, the Sorghum Breeding Program increased seed of fifteen improved cultivars and new breeding lines for distribution to NGO's. Seed increased are listed in Table 1.

Table 1. Quantities of increased seed obtained from different localities of Mali: cropping season 2001—2006

Varieties	Type	Localities	Weight (kg)
JACUMBE	Foundation/Certified	Béma	1900
SAGUIFA	Foundation Foundation	Béma	700
98-BE-F5P-84	Foundation Foundation	Cinzana	400
DARRELL KEN		Cinzana, Kolombada	800
WASSA		Kafara, Cinzana	1700
KENINKEDIE		Kolombada	100
CSM-417	Foundation Foundation Foundation/Certified	Kolombada	100
SEGUETANA		Tamala	400
JIGISEME	Foundation/Certified	Kolombada, Tamala	1200
N'TENIMISSA		Kolombada, Tamala	700
NIETA		Tamala and Sikasso	1387
TIANDOUGOU		Kolombada	1000
ZARRABLE	Foundation/Certified	Kita and Finkolo	2762
ZARRADJE	Foundation/Certified		322
KENKEBA	Foundation		610
	TOTAL		13,451

Niger

Breeding Sorghum Varieties and Hybrids with Good Processing Quality, High Grain Yield, and Resistance to *Striga* and Midge

I. Kapran, S. Souley, INRAN;
M. Tuinstra, KSU; G. Ejeta, PU

Objectives of this project were to evaluate various germplasm to identify highly productive and well-adapted, open-pollinated varieties and hybrids to be increased for food and feed uses. Specific objectives were to 1) evaluate a wide array of germplasm for evident adaptation traits, grain quality, yield potential per se or in hybrid combination, 2) screen exotic germplasm and local landrace derivatives for resistance to *Striga hermonthica* in infested nurseries and farmer fields, 3) conduct on farm trials with elite varieties and F1 hybrids, and 4) produce breeder seed for future nurseries or foundation/F1 seed of the most advanced material for commercial production in collaboration with the INRAN seed unit. More than 3,000 entries were evaluated in the period. Through multidisciplinary team collaboration, cultivars were selected and extended in collaboration with the INRAN seed unit, the Food Technology Laboratory, and the Animal Nutrition Department of INRAN, as well as end users (farmers, processors) and support groups (extension and NGOs).

Development of new germplasm for drought/sandy soil adaptation

An advanced population of ~900 recombinant inbred lines was developed through single seed descent (SSD) from crossing a well adapted landrace (MDK) to a breeding line (L153-5, itself derived from a cross involving *Striga*-resistant SRN39 with landrace ABH). A random set of 100 SSD F8 lines from the cross MDKxL153-5 was tested under natural drought at Maradi. There was a shift towards lower grain yield (55% loss), shorter plant height and earlier maturity, and premature plant death. Early maturity played a crucial role for escape. Eight new lines were retained showing good performance under drought like previously selected L28 in the same background.

Development of midge resistant cultivars

SSD35 was selected from a midge resistance study of a SSD population from cross (MMxICSV88032). Tested in successive plantings to increase midge infestation on-station, SSD35 yielded twice, 15, and 41 times more than MM from first to second and third plantings, respectively. On-farm trials in the midge endemic zone of Konni showed a very encouraging performance of SSD35. It was higher yielding than local checks, MM, and hybrid F1-223.

Introgression of genes for *Striga* resistance into landrace El Mota Galmi

A backcrossing procedure was used to introduce *Striga* resistance from SRN39 into El Mota Galmi, an otherwise adapted landrace preferred by Nigerien farmers. Field evaluation led to identification of new lines in BC2F3 population showing good level of *Striga* resistance and agronomic performance close to that of El Mota Galmi, especially entries B4-33, B4-8, B2-3, B5-5, and B1-13.

Experimental hybrid evaluation

Several thousand hybrids and lines were tested. In the advanced hybrid yield trials, the best was hybrid 223AxMR732 (F1-223), expressing a high level of heterosis for grain yield, and averaging 4 tons per hectare (Table 2). Out of 60 A lines and 74 potential R lines, the most promising for Niger and similar dry environments were 7 A lines (NE223, P9504, P9511, P9512, P9521, P9526, HF8) and 9 R lines (MR732, ST9007-5-3-1, MACIA, P9401, P9403, N7112R, 97M7642, 97M10522, 91BE7414).

Table 2. Sorghum hybrid advanced yield trial, Bengou (Niger)

	Emergence (%)	50% fl (days)	Height (cm)	Grain yield (kg/h^{-1})	High parent grain yield Heterosis (%)$^{\$}$
F test	**	**	**	**	
Entry designation					
223AxMR732	76ab	65de	140gh	4537a	109
AHF8xMACIA	32fg	70abc	173cde	2338cd	10
P9511AxMACIA	68bc	64e	222b	3819ab	79
P9513AxMACIA	47e	68cde	177cd	2639bc	24
NAD-1	62cd	70abc	217b	3843ab	63
223B	52de	70abc	103ij	1389cdef	--
BHF8	25g	73a	98j	369f	--
P9503B	49de	67cde	122hi	1342def	--
P9511B	51de	70abc	113ij	1319def	--
TX623B	43ef	69bcd	148fg	2361cd	--
MR732	67bc	74a	153efg	2176cde	--
MACIA	47e	74a	163def	2130cde	--
MM	83a	59f	270a	995ef	--
Trial Mean	56	69	164	2368	

$^{\$}$Heterosis calculated as (F1-Parent)/Parent

Figure 1. On farm demonstration of sorghum hybrid F1-223 (Konni, Niger)

Seed production

About 5 tons of foundation and hybrid seed was produced every year on-station and on-farm in support of the INRAN Seed Unit including seed increase of released cultivars MM, IRAT 204, SEPON82, 90SN7 and hybrid parental lines TX623A and 223A; and hybrid seed production for NAD-1 and F1-223 hybrids. On-farm trials and demonstrations focused especially on the midge resistant line SSD35 (MMxICSV88032). On-farm trials in the midge endemic zone of Konni (Figure 1) showed a very encouraging performance of SSD35. It was higher yielding than MM, and hybrid F1-223, and in comparison to local checks it yielded 62-223% more grain. Valuable germplasm was lost in some nurseries due to flooding or extremely late planting. Although seed production was envisioned to take off on a large scale with private farmers, it is still largely done by the breeding station. This situation may not change quickly as long as farmers lack start-up funds to invest in their fields for better seed production environment.

Senegal

Sorghum Breeding

N. Cissé, ISRA; M. Tuinstra, KSU; A. Touré, IER

Activities were conducted at Bambey and Kolda. Breeders, entomologists, weed scientist and plant pathologist intervened. Technologies were developed for the two zones.

Observational nurseries were conducted through INTSORMIL collaborative activities. Genotypes were from programs at Mali, Texas, Niger and Burkina Faso. High yielding lines with good grain qualities and resistance to grain mold were identified. These lines were introduced in crosses with CE 151-262; CE 145-66; CE 180-33 for the Central and Northern zones. Eighty-one new lines from these crosses were introduced in preliminary yield trials at Bambey. High yielding ones were identified and the best with good grain qualities were from the crosses between CE 151-262 x

Sorvato 1. The lines Sureño, Macia and 90EON-343 were found to have good resistance to grain mold, they were used in crosses to improve CE-151-262, CE-145-66, CE-180-33, F2-20 and B93-1057. Advanced segregation generations are obtained.

Screening for long smut resistance has shown that the lines B.9612 and R.9645 are promising. The line CSM63 has been confirmed to have resistance to drought and is used in crosses. On-farm tests of 93B-1057 and 93B-1062 were completed. These lines were released in the northern and central zones; and seeds were multiplied. At Kolda, the line 00-SB-F5DT-19 was used to improve F2-20 and CE145-66 for adaptation and grain qualities for the southern and eastern zones. Preliminary yield trials were conducted with 11 dwarf Guinea lines, selected from a total of 143 introduced from ICRISAT, in 2002. Six lines were selected for advanced yield trial next season in Kolda.

After 3 years of advanced yield trials with genotypes selected from the INTSORMIL collaborative nurseries, the line KL2 was the most productive. But because of poor grain quality and susceptibility to mold, it was not selected for inclusion in the on-farm test.

Genetic Enhancement: Millet Breeding

Mali

Millet Breeding
M. Sanago, A. Touré, IER; J. Wilson, USDA/ARS

Evaluation of varieties from Senegal, Niger, Nigeria, and USA

An experiment was designed to test 40 varieties from Senegal, Niger, Nigeria, and USA at Cinzana. The results showed significant differences among entries for sowing-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 infestations of 44.75 and 43.75% were 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 incidence. The less infested varieties to the 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 infested varieties by stem borer were TG 102 et 01 Miso NCD2-NE with the incidence of 2.25%.

Several millet hybrids were develop and tested for adaptation to Malian conditions. The valuation of hybrids F_1 showed promising results: Indiana 05 x ICMV 89 305 (2000 kg/ha^{-1}), Gwagawa x Indiana 05 (1883 kg/ha^{-1}), SoSank x KKP (1883 kg/ha^{-1}) and SoSank x Gwagawa (1783 kg/ha^{-1}). Heterosis effect observed varied between 69 and 115% over the mean of the two parents.

Niger

Regional Evaluation of Pearl Millet Germplasm
A. Issaka, INRAN; J. Wilson, USDA/ARS

Evaluation of varieties and combining ability

The project was regional in scope (Ghana, Mali, Niger, Nigeria, and Senegal) and aimed at selecting promising varieties among 40 entries from NARS and USA breeding programs.

The 9 best varieties for yield and pest resistance across multiple locations were selected and crossed in a half-diallel design to evaluate general and specific combining ability for yield, disease resistance, and agronomic traits. In Niger (Bengou research station), two hybrid combinations yielded over 4t/ha: HKP GMS x SoSat C-88 and Manga Nara x ICMV IS 89305. The next objective was to develop varieties with better yield stability that could be used as female parents for future hybrids. Eighty-two experimental lines were tested though, except for 7 lines, they were highly susceptible to downy mildew. New hybrid combinations are being explored with alternate restorers while pursuing the evaluation of "successful material" that provide visible resistance to downy mildew. Also hybrids with locally well adapted germplasm as female parents are being synthesized and African landraces used as pollinators.

Nigeria

Pearl Millet Breeding
I. Angarawai, B.Ndahi, Z.G.S.Turaki,
I Mohammed, LCRI; J. Wilson, USDA/ARS

Improved yield stability, performance, and disease/pest resistance

The objective of this work is to improve the productivity and yield stability of pearl millet in the semi-arid zones of Nigeria which will have a spill over effect to other neighboring West African countries. A new pearl millet hybrid, LCICMH-I, was registered and released on September 1, 2005 in Nigeria with yield potential of 4 t grain/ha, i.e. 33% more grain than farmers' local varieties, and early maturing characteristic.

Inheritance studies of downey mildew resistance

Millet variety SOSAT-C88 was identified with resistance to downey mildew. This line can be used as donor parent in hybrid parent improvement and is the subject of I. Angarawai's doctoral studies (funded in part through INTSORMIL).

Inheritance studies of *Striga* resistance

Millet variety PS563 monodii was identified as a source of *Striga* resistance, and is currently being used as donor parent in the *Striga* resistance breeding program.

Population density and N-fertilizer application on growth and yield

The objective of this study was to establish the requirement of newly developed millet hybrids. Micro-dose application of 60kgN/ha at 45cm intra row spacing was the optimum for maximum yield.

Senegal

Evaluation of varieties for combining ability

Forty genotypes of diverse origin (West and Central Africa, USA) were evaluated for productivity and grain quality. These genotypes were open pollinated varieties, hybrids and lines. Four out of the nine genotypes out-yielded the local check Souna 3. The best performing was SOSAT C88 x Ankoutess (C1). All four were at the first cycle of recombination and have SOSAT C88 as common parent. SOSAT C88 was concluded to have good combining ability.

Twenty-five out of the 40 showed a high level of resistance to mildew, while 37 had a resistance reaction to ergot. Genotypes resistant to both ergot and mildew were observed. And no resistance to *Striga* was observed.

On-farm tests were conducted for three years in the north-central zone, with the new breeds: ISMI 9301, ISMI 9404, ISMI 9506, ISMI 9507, along with introduced early genotypes (GB 8735, ICTP 8203) and the local checks Souna 3 and IBMV 8402. ISMI 9507 was the most productive and will be released.

High bread quality millet

A program to evaluate the local variety Thialack was initiated. This local variety is extensively cultivated in the South Central zone of Senegal. It has long panicles and its grains give flour adapted to bread making. However this variety is highly heterogeneous, containing Shibras and is susceptible to mildew. Improvement was made through S1 recurrent selection. The variety was planted on 2500 m^2. Self-pollination of main panicle of each plant was done. Five hundred self-pollinated heads from selected plants were harvested for evaluation. The S_1 families were subdivided after evaluation, in two groups according to their cycle length; intermediate and early (Table 3).

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. 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 and ICMV 98492, and lowest in GICKV 94135 and ICMP 96490. From the three years of trial, none of the materials can be described as being truly resistant to the key pests of millet. The local materials however appeared to be less susceptible to the prevailing pests and diseases than other improved ones.

IPM in millet

Two dates of planting and five cropping patterns were studied at Manga as possible components of an IPM system for millet. There were no significant effect of cropping patterns on incidence of all the key insect pests, notably stem borers (*Coniesta ignefusalis*), 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. Late planting also reduced grain yield significantly, in some cases by as much as 50%. The results 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
Diarisso, Y. Doumbia, M. N'Diaye, IER;
Pendleton, WTAMU

Sorghum pests

Trials of sorghum resistance to midge and other insects were conducted in Samanko, Cinzana and Kita. Sorghum midge damage scores ranged from 1 to 3 (low range). The three varieties which had the highest sorghum midge damage were least damaged

Table 3. Performance of S1 families of Thialack local variety

S_1	Flowering (Days)	Plant height (cm)	Panicle length (cm)	Yield (kg/ha^{-1})	1000 Grains weight (g)
Intermediate	53	253	64	1536 a	6.5
Early	49	261	65	1769 a	6.8
Check	57	263	68	1397 a	6

by head bugs. Except for Tx2882, all the entries had the head bug damage score of 1 (low).

A study on the use of local plant ash to control insects on stored grain was conducted on 5 varieties: Bibalawili, ICSH, DT-85, F6-4, and F6-6. The number of insects emerging on grains depended on sorghum variety, the time of storage, and the mode of the treatment. Ash positively affected most of the varieties. Bibalawili was resistant to *Rhyzopertha dominica*.

Results in 2003 on the use of local plants to control insects in the field showed highly significant differences among treatments for sorghum midge damage, head bug damage, grain mold, and grain weight. Protected panicles of the head bug susceptible variety S34 were not infested by midge, head bug, or grain mold. Cage protection and spraying with Dursban gave better insect and grain mold control than the use of the local plant material. Crop residue management to control stem borers was conducted in 2001-2003. Removal of crop residues from the sorghum field after the harvest and before planting date resulted in less stem borers than the sorghum field which had crop residues left, chopped and buried at the planting date. Millet was more susceptible to *Coniesta ignifusalis* than either maize or sorghum. Two local plant powders were used to control the stored grain insect *Rhyzopertha dominica*. Least percentage of seed lost due to *R. dominica* was found using treatments with 6 g of *Calotropis procera* or *Cassia nigricans* for 1 kg of sorghum seed. Over the time of storage, the effectiveness of the product decreases and the number of insects increases, and accordingly the two products tested at low doses were not as effective as the high doses. In practice, it would be necessary to reduce the interval of application of the products.

Millet pests

During 2001-2006, an integrated approach to reduce downy mildew and head miner on pearl millets was developed in Mali. At Cinzana, the millet mono-crop plots treated with the fungicide Apron Plus and neem extract were less damaged by downy mildew. In 2004, the lowest incidence was observed in the intercropped plot (millet:cowpea), except at Cinzana where the lowest incidence was observed in treated plots with the fungicide Apron Star. Millet mono-crop plots had higher infestation rate (seed treated (37.50 %) with Apron Star and untreated seed (22.50 %). At Cinzana, intercropping with the insecticide foliar spray resulted in less infestation by millet head miner (1.67%), followed by the plot treated with neem seed extract (4.00%).

Survey of pest control methods

A survey was conducted in 2006 among farmers in three different regions of Mali to obtain farmers perceptions of pest control in the field and during the storage. A total of 19 villages (4 in Koulikoro region, 10 in Ségou region, and 5 in Sikasso region) were considered. Results showed that of 190 farmers interviewed, 131 used the control method against pests in the field and 36 do not use any method of control. Sixty-eight farmers used a local plant or matter to control storage pest in their granaries. Among them, some think local plants are efficient and others think they cannot afford to buy chemicals. Koulikoro and Ségou regions use different types of granaries compare to the Sikasso region. Clay granaries are most common in all three regions.

Niger

Synthesis of Entomology Research Activities in Niger

H. Kadi Kadi, INRAN; Bonnie B. Pendleton, WTAMU

The goal of the project was to develop longer-lasting plant resistance to sorghum midge and millet head miner, and transfer of insect pest management strategies.

Sorghum

Damage scores and percent grain loss were obtained on single seed descent lines and parents. The lowest mean losses were estimated as 18.3, 15.4, 19.5, 10.6, 7.4 and 9.3% for the varieties, 99 F9-14, 99 F9-17, 99 F9-28, 99 F9-35, 99 F9-37 and ICSV 745, respectively.

The greatest damage score, 6.0, was for 99 SSD F9-10, with 51.6% grain loss. Mota Maradi (susceptible landrace parent) had a score of 4.5 and grain loss of 67.3% whereas ICSV 88032 (introduced resistant parent) had a score of 1.0 and grain loss of only 8.9%. The damage score was 4.0 and yield loss 45.5% for IRAT 204. In a separate test including locally developed and introduced ICRISAT lines, we identified DJ 6514, ICSV 197, ICSV 745, ICSV 93077, 99 SSD F9-35 and ICSV 90011-12 as resistant to sorghum midge. Two of these varieties (DJ 6514 and ICSV 90011) were highly infested with adult midges but lost little grain. During the project period, farmers were sensitized about sorghum midge as a constraint through field training on insect identification, biology, ecology, damage assessment and control options.

Millet

The highest mean yields were obtained for ICMV IS 99001, HKP-GMS, Faringuero, and ICMV 90311, and the lowest mean yields for ANKOUTESS, SOSAT-C 88, ICMV IS 95301, KBH, ICMV IS 92326, ¾ HK B-78, and ZATIB. Two hybrids (ICMH 2003 and ICMH 2104) performed well and had moderately low MHM stages as compared to those recorded on the other tested genotypes. Three improved varieties, TMK, ICMV IS 99001 and HKP-GMS, showed good reaction to MHM development and damages. The highest mean damage ratings were estimated on genotypes Faringuero, SOSAT-C 88, and ICMV IS 95301, respectively. For five other genotypes (ANKOUTESS, Gueriniari 2, ICMV IS903011, HKP-GMS and ¾ HK B-78), the mean damage ratings were between 2.3 to 2.9; slightly higher than the general mean of 1.6.

The results suggest that it is possible to achieve a level of tolerance to MHM damage by using the pearl millet hybrids as well as improved varieties (ICMV IS 99001, HKP-GMS, Faringuero and ICMV) showing good reactions to MHM development and damages. A case of pseudo resistance was observed for varieties ¾ HK B-78 and ZATIB that yielded below average but with damage ratings of 2.4 and 1.8 respectively, nearly equal to that of hybrid ICMH 2003.

Senegal

Control of Head Bugs
D. Badiane, ISRA; B. Pendleton, WTAMU

An insect population survey showed that different head bugs species are present in the north (*Eurystylus immaculatus, Creontiades pallidus, Dolycoris indicus, Spilosthelus*) than in the south and east where a pest complex [stem borers, midge (*Stenodiplosis sorghicola*), aphids (*Rhopalosiphum maïdis*), head bugs (*Spilosthetus* sp)] is present throughout the sorghum-growing period. This insect complex causes up to 35% grain lost on sorghum. Some resistance to head bugs was observed with the genotypes F2-20, Malisor 84-7, 97-C2F5-28; while CE145-66, CE151-262, CE180-33 were found susceptible. Trials were conducted to control insects with the botanicals neem powder, Nemix (azadirachtine) that reduced head bugs populations, as well as the chemicals Laser (spinosad) and Decis (deltamethrine). However, these were not accompanied with grain yield improvement.

Sustainable Plant Protection Systems: Pathology

Burkina Faso

Disease Nursery Evaluation and Screening (2003-2007)
A. Neya, J.B. Taounda, INERA; C. Magill, TAM

Disease nursery evaluation

The West Africa Sorghum Diseases Nursery (WASDON) comprised of 13 sorghum breeding lines replicated two times in randomised complete block design. The material were from Mali (3 entries), Nigeria (5 entries) and Burkina Faso (5 entries, including the local check). In order to increase the overall incidence and severity of leaf anthracnose, a mixture of three susceptible sorghum genotypes (i.e. IS 18442, IS 4585, IS 905) was planted prior to test genotypes, alternately every fifth row and as border rows on both sides. Analysis of variance for plant height showed significant difference (P<0.05) for days to 50 % flowering, plant height and grain yield, and significant difference ((P<0.05) for leaf anthracnose, grey leaf spot, and grain mold. Grain yield ranged up to 2506 kg ha^{-1} with a test mean of 1523 kg ha^{-1}. Leaf anthracnose severity ranged from 1.6 to 4.5, the entry EPII-2002-19 from Burkina Faso being the most susceptible with a rating of 4.5. Grey leaf spot severity was low, ranging from 1.0 to 1.2. The severity of stalk red rot also was low with a test mean of 1.2. Mean severity of stalk red rot ranged from 0.4 to 2.2 (scale 0-5). Under the condition of Farako-Ba, symptoms of sooty stripe and zonate leaf spot were recorded in a few cases on lower leaves but they were observed on the four upper leaves. Grain mold severity ranged from 1.2 to 3.2 with test mean of 2.3 (scale 1-9). Considering the reaction of the genotypes to all diseases the following entries exhibited field tolerance to multiple diseases: 02KIF-5T-22 and 99 SB-F-5DT-196 from Mali, SAMSORG 14 and SAMSORG 17 from Nigeria, and Sariaso 01 from Burkina Faso. These entries showed low leaf anthracnose severity (less than 2.0) and low grain mold severity (less than 2).

The All-Disease and Insect Nursery trial was conducted at Farako-Ba Research Station with two replications, including 60 entries. The following fungal diseases were rated: leaf anthracnose, grey leaf spot, sooty stripe, and grain mold. All entries showed intermediate to high level severities to the three leaf foliar diseases. For leaf anthracnose, 14 entries showed more than 25 % of leaf area dead, with five showing more than 50% leaf area dead. With regard to grey leaf spot, 26 entries showed more than 25 % of leaf area dead with four having more than 50% of leaf area dead. Twenty-one entries showed more than 25% of leaf area dead in the case of sooty stripe. According to grain mold all the entries showed seeds slightly discolored. Thirty-four were moderately susceptible to mold with considerable discoloration. No smut was found on the entries.

Screening of sorghum varieties under field conditions

Sorghum collections from West and East Africa, India, and Sri Lanka (202 lines) were evaluated for leaf diseases in 2004. Only one line was resistant to leaf anthracnose and most of the lines tested are moderate resistant to leaf anthracnose, although all were resistant to sooty stripe and gray leaf spot. 126 lines are resistant to leaf anthracnose and 75 lines exhibited moderate resistance to gray leaf spot. For the second set of 59 lines, all of them were resistant to sooty stripe and zonate leaf spot. None of these lines was resistant to leaf anthracnose.

In another experiment, 12 sorghum varieties were screened under field conditions and found resistant to sooty stripe and gray leaf spot. Considering the reaction to leaf anthracnose, only BF 89-18/133-2-1 expressed resistance reaction. The other varieties are moderate resistant to leaf anthracnose. (Table 4)

Ghana

Breeding Sorghum and Millet for Improved Disease Resistance
S. Nutsugah, SARI; J. Wilson, USDA/ARS

Sorghum diseases

WASDON [25 genotypes] (West African Sorghum Disease Observation Nursery) and ADIN [70 genotypes] (All Disease and Insect Nursery) were evaluated in 2001 to identify sources of stable broad-spectrum resistance to sorghum diseases for use in the breeding program. SC326-6 was found to be severely attacked by bacterial leaf stripe (*Burkholderia anadropogonis*), a quarantine pathogen of sorghum in Ghana with a disease rating score of 8.0. Six genotypes in WASDON recorded scores of 4.0–6.0 for GLS while seven genotypes had scores of 4.0–5.0 for LB. Four genotypes also had scores of 4.0–6.0 for GLS on panicle. The performances of six genotypes ranged between 1670–2200 kg/ha^{-1} and were selected for further agronomic evaluation. These were (VG 153, 98-KO-F5-DT-39-2, 98-SB-F5-DT-4, SARIASO-01 and FOULATIEBA.

The two trials were repeated in 2002. Four genotypes in WASDON trial [25 genotypes] (SAMSOR 14, SARIASO-01, OUEDZOURE and FOULATIEBA) were infected by GLS with a score

Table 4. Mean severities of leaf diseases and grain mold of 12 sorghum varieties (medium cycle) under field conditions at Farako-Ba, Burkina Faso rainy season, 2006

Varieties	Mean severity ratings (scale 1- 9)				
	Leaf Anthracnose	Gray leaf spot	Zonate leaf spot	Sooty stripe	Grain mold
Kapelga	2.5 bc	1.2 a	1 a	1 a	2.1 a
Gnossicorni	3.2 bc	2 a	1 a	1 a	1.6 a
BF89-18/133-2-1	2 bc	1 a	1 a	1 a	2.4 a
Flagnon	2.9 bc	1.3 a	1 a	1 a	1.4 a
Raogo	3 b c	1.9 a	1 a	1 a	1.7 a
Local Dassa 1	2.7 bc	1.4 a	1 a	1 a	2.2 a
Local Some 2	3.2 bc	2 a	1 a	1 a	2 a
Local sandie 3	2.8 bc	2 a	1 a	1 a	2 a
Woro Pouni	2.8 bc	1.8 a	1 a	1 a	2 a
Sariaso 01	2.4 bc	1 a	1 a	1 a	1.8 a
Susceptible check (IS 4585)	5.1 a	1 a	1 a	1 a	1.7 a
Tolerant check (Sariaso 10)	2 bc	1.5 a	1 a	1 a	1.9 a
Mean	3.5 b	1.6 a	1 a	1 a	1.9 a

of 4.0. The disease reaction of the genotypes was slightly higher in ADIN [60 genotypes]. R9188 had a score of 5.0 for zonate leaf spot (ZLS). GLS was prevalent on 11 genotypes with scores of 4.0–7.0. Eight genotypes showed resistance to shootfly infestation. Three top yielding genotypes were SC 326-6, 96CA5986 and 98CD187 with grain yield of 1627, 1653 and 2013 kg/ha^{-1}, respectively. Five genotypes were selected for further evaluation based on their overall agronomic traits and disease/pest tolerance or resistance. These genotypes were 88BE2668, 96GCPOB124, 94CW5045, B9307 and Tx2783.

Millet diseases

Forty (40) pearl millet germplasm were evaluated in 2003 for their stability of grain yield and quality traits. Data were recorded for days to flowering, height, panicle dimensions, downy mildew incidence and yield. Zatib, Zongo, CIVT, SoSank, ICMV IS 89305, ICMV IS 90311, ¾ ExBornu and Gwagwa had no downy mildew infection while PT732B, 68A x 086R, TG102, 99M59043Mw x 68A4R4, T454 and T99B were the most susceptible with downy mildew incidence ranging between 51.0–96.3%. Grain yield was lowest for 99-72 (110 kg/ha^{-1}) and greatest for GB 8735 (1240 kg/ha^{-1}). In WASDON, 13 genotypes were evaluated for their reactions to foliar diseases and shootfly as in the previous years. One genotype (99-SB-F5DT-154) had a score of 4.5 for GLS, two genotypes (BES-SAMSORG 4 and SAMSORG 17) had scores of 6.0 – 6.5 and one genotype (99-SB-F5DT-154) had score of 4.0. Shootfly infestation of 47–85% and midge damage were recorded for three genotypes (BES-SAMSORG 4, 99-SB-F5DT-154 and EP112002-1). Sixty (60) genotypes were evaluated in ADIN for similar biotic stresses. Tx2911 had a score of 4.0 for GLS while BT x 642_B35 had a score of 4.0 for ZLS. Midge damage with severe rating of 8.0-9.0 was recorded on all the genotypes tested.

Forty (40) pearl millet germplasm were evaluated in 2004 for the second year for disease and agronomic traits. ICMV IS 90311 had the lowest incidence of downy mildew (3.4%) and Tiftgrain 102 was the most susceptible (49.3%). Minor variation for ZLS was observed with GB 8735, 68A x 086R and 01MisoNCD2-NE having the greatest severity of 4.5. Smut incidence was high with incidence up to 65.5% on Tift 99B. Head miner was only found on a few genotypes, with up to 43.8 and 65.5% infestation on 99-72 and T99B, respectively. Grain yield was lowest for 99-72 and greatest for Gwagwa. Head bug/grain mold sorghum varietal interaction on-station trial was established at Damongo and Nyankpala in Northern 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 genotypes. 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 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 confirming the critical role played by head bugs as factors aggravating mold infection.

Eighty-two (82) pearl millet germplasm were evaluated in 2006. The germplasm varied for several characteristics. Downy mildew incidence at 40 days after planting ranged from 0-10% (38 genotypes), 11-20% (14 genotypes), 21-40% (7 genotypes), 41-70% (5 genotypes) and above 75% (18 genotypes). SoSat x Tift 454, Ugandi x 99-70, Zongo x Tift 454 and Taram x 99-70 hybrids showed very high downy mildew incidence of 80-100%, suggesting that they are highly susceptible to Ghanaian downy mildew isolates. The yield potentials of all the hybrids tested were very low with the highest hybrid (Ankoutess x 99-70) F4 recording 391 kg/ha^{-1}.

Mali

Anthracnose-Resistant Sorghum Lines, Plant-Based Pesticide Control, and Downy Mildew Control
M. Diourte, IER; C. Magill, TAM; J. Leslie, KSU

Sorghum anthracnose (*Colletotrichum graminicola*)

Breeding accessions were artificially screened for Anthracnose resistance to obtain sorghum varieties to be used by farmers. Three varieties Wassa, Darellken and 98-SB-F2-78 were released and are being adopted by a large number of farmers in the Kolokani area.

Development and diffusion of a plant based pesticides for the control of sorghum pests including *Striga* and covered smut (*Sporisorium sorghi*)

Grain yield increase of 56% with 0.4% of covered smut incidence was obtained by seed treatment with Diro *(Securidaca longepedunculata)* + Nguo *(Canavalis ensiformis)* + Néré *(Parkia biglobosa)*. At least 15 farmers in the zones where the tests were conducted relatively adopted this technique of seed treatment.

Sustainable Plant Protection Systems: Striga

Burkina Faso

Evaluation of Sorghum Cultivars for *Striga hermonthica* Resistance and Integrated Management in Eastern Burkina Faso
H. Traoré, J.B. Taonda, INERA; G. Ejeta, PU

Varietal improvement

Very low numbers of emerged *Striga hermonthica* were recorded with only 2 varieties from Purdue (Shanqui Red, PSL 985062) and 3 varieties from the national breeding program (CEF 322/35-1-2, F 2-20, S 29); the highest grain yields (> 1 t/ha) were recorded with 3 varieties from the national program: F 2-20, BF 85-2 / 12-1-1 and BF 94-5 / 30K-2K-1K-1F).

In 2006, an *in vitro* screening study using the Agar Gel Assay method for resistant or tolerant sorghum or millet varieties was conducted at the experimental research station of Kamboinsé. The work was done by a student from ENSA-Montpellier (France) for a 3 months internship. Three genotypes (Sariaso 01, Sariaso 03, Sariaso08) known to be susceptible exhibited the highest Maximum Germination Distances of *Striga* whereas three others (ICSV 1049, ICSV 1001, F2-20) known to be resistant exhibited the lowest Maximum Germination Distances of *Striga*. The improved sorghum resistant varieties can be used in future integrated *Striga* management field tests.

Integrated *Striga* management

During the 3 years or 2004, 2005 and 2006, very few *Striga* plants were recorded in the trial. In 2005, only variety significantly influenced *Striga* emergence and number of emerged *Striga*. In 2006, tillage, fertilization and variety did not significantly influenced *Striga* emergence and number of emerged *Striga*, whereas tillage and the interaction tillage*fertilization*variety significantly influenced *Striga* biomass.

Field tests were also conducted in 2005 and 2006 in collaboration with farmers' organizations combining soil preparation (water conservation methods), variety, and fertilizer to control *Striga hermonthica*. The study was conducted at the village of Sokoroni in western Burkina Faso the objective to implement a participatory development and technology transfer of *Striga* control methods. Two improved sorghum varieties (Sariaso 03 and Sariaso 14) were compared to the local sorghum landrace of the farmer. In both years, the yields of the two improved varieties were greater than that of the local ones, and, in 2005, in most of the cases, the two improved varieties doubled or were 3-fold the production of the local one. After cooking the two improved sorghum varieties, some farmers found out that they were only good for "couscous" and porridge, but not good for "tô". Discussions have taken place with sorghum breeders to change these varieties.

In Vitro* screening of trap crops of *Striga

This study was conducted in laboratory in 2006 at the experimental research station of Kamboinsé by a student from the "Centre Agricole Polyvalent of Matourkou, Bobo-Dioulasso, Burkina Faso" for a 3 months internship from November 2006 to January 2007. Nine varieties of cotton (*Gossypium barbadense* L.), 15 varieties of cowpea (*Vigna unguiculata* L. Wap.) and six varieties of groundnut (*Arachis hypogaea* L.) were screened in laboratory for their ability to stimulate suicidal germination of *S. hermonthica*, using the cut-root technique. The three crops exhibited significant differences for their ability to stimulate germination of *S. hermonthica*. Cotton was the best stimulating crop of *Striga* germination (*S. hermonthica* seeds germination percentages of at least 75% recorded with all nine varieties), followed by cowpea (germination percentages of *S. hermonthica* seeds higher than 10% were recorded with only three varieties), and groundnut (a germination percentage of *S. hermonthica* seeds higher than 1% was recorded with only one variety). The trap crops varieties on which *S. hermonthica* seed germination percentages of at least 10% were recorded may be recommended for use in rotation or intercropping with cereals and especially in an integrated management approach against *S. hermonthica*.

Mali

Striga Control
B. Dembébé, M. Kayentao, IER; G. Ejeta, PU

Several breeding lines were evaluated in Mali for *Striga* resistance and 9 showed good *Striga* resistance (04-FI-F5T-1, 04-FI-F5T-1-19, 04-FI-F5T-61, 04-CZ-F5P-15, 04-CZ-F5P-21, 04-CZ-F5P-42-2, .04-CZ-F5P-100, 04-CZ-F5P-150, .04-CZ-F5P-250). Two susceptible varieties: 97-SB-F5DT-150 and 97-SB-F5DT-154 were crossed with 3 resistant lines: FARAMIDA, SRN-39 and PR904. Eight F1 * F1 obtained were planted in December 2005. Forty five F1BC1 are been made to obtain the F1BC2. Eleven (11) lines of herbicide tolerance were crossed with fives (5) lines of *Striga* resistant sorghum varieties. Lines WA-1, WA-4, WA-8, WA-10, and WA-11 have the highest levels of tolerance and provide the

best parents for crosses. The materials are planted and the crossing is undergoing in the off- season. Thirteen sorghum inbreeds and corresponding testcross hybrids were evaluated in replicated trials at Konni Niger and Cinzana Mali for differences in grain yield and *Striga* resistance. Seven herbicide seed treatments were evaluated in replicated trials at Konni Niger and Cinzana Mali for differences in control of *Striga*. Treatment 0.075 mg ai imazapyr was the most toxic on sorghum compared to the control.

Senegal

Between 2001 and 2004 field and screen-house tests have shown that different biotypes of *Striga hermonthica* attack millet and sorghum. Also the following sorghum lines have shown resistance: CE145-66-V ; SEGUETANA; KSV 111 ; Malisor 84-1; CEF 322/35-1-2; CEF 322/53-1-1; WASSA; 01-CZ-F5P-46. While these others are tolerant with delayed *Striga* emergence: SL 246 ; Pourdi blanc, CE 196-7-2-1, CE 151-262, 93B 1057, 93B 1062, CE 145-66-V. In 2005 and 2006, field screenings were conducted at Ngoye (Bambey) and screen-house tests were also conducted, with *Striga* seeds collected at 2 different sites (Diourbel and Kaymor) with these resistant and tolerant lines. Only CEF 322/35-1-2 ; CEF 322/53-1-1 and M92-1 were emergence free during the 2 years in field and screen house. Differential reactions of the others with *Striga* seed sources were observed. These results are indications that different *Striga* strains attacking sorghum are present in Senegal. Millet rotation with cowpea to deplete *Striga* seed stock in the soil showed that: The series cowpea-cowpea-millet reduced significantly *Striga* seed compared to millet-millet-millet. A one-year cowpea crop, followed by millet has no effect on *Striga hermonthica* seed reserve in the soil. Laboratory tests have shown that there are differences between cowpea and peanut genotypes in their capacity to stimulate *Striga* seeds. The weed *Indigofera astragalina* also stimulates *hermonthica* seeds to germinate.

Sustainable Plant Protection Systems: Agronomy

Millet and Sorghum Microdose Fertilization and Mechanized Zaï Water Management
J.B. Taounda, INERA; S. Mason, UNL

Microdose fertilizer formula studies – on-station

Four-year 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^{-1} N. Results indicated 1) grain yield increases due to application of microdose (4 g of NPK 15-15-15) ranging from 0 to 194% depending upon years, 2) grain yield increases due to application of Microdose+20P ha^{-1} +30N ha^{-1} ranging from 43 to 234% depending upon years, and 3) grain optimal marginal productivity for phosphorus is assured by the application of microdose +.20P ha^{-1} + 30N ha^{-1}.

Sorghum experiments were carried out from 2003 to 2005. Treatments consisted of zero fertilizer, microdose, microdose + 40 kg ha^{-1} P, zaï with 300g of compost per hill, recommended rate (75kg NPK ha^{-1} + 50 kg Urea ha^{-1}) and microdose + 20 kg ha^{-1} P + 30 kg ha^{-1} N. Compared to the check (zero fertilizer) and depending upon years, application of microdose (4 g of NPK 15-15-15) increased grain sorghum grain yield by 400 to 900 kg ha^{-1} (Table 5). Two years over 3, application of either microdose or recommended rate (75kg NPK ha^{-1} + 50 kg Urea ha^{-1}) resulted in similar grain yields. One year over 3, application of microdose out-yielded the recommended rate by 371 kg ha^{-1}. Only application of zaï with compost over-yielded microdose by 364 to 1021 kg ha^{-1} depending upon years.

Microdose fertilizer formula studies – on-farm

Satellite studies were conducted on farms using either zero fertilizer, microdose and microdose + 20 kg ha^{-1} P + 30 kg ha^{-1} N in some locations (2001-2004) or zero fertilizer, microdose, microdose + 40 kg ha^{-1} P and microdose + 20 kg ha^{-1} P + 30 kg ha^{-1} N treatments in other locations (2003-2004). Increase in pearl millet grain yield due to application of microdose (4 g of NPK 15-15-15) was confirmed over the 4 years (+130%). Application of microdose + 20P ha^{-1} + 30N ha^{-1} resulted in a greater grain yield increase of 188%. Application of either microdose + 40P ha^{-1} or microdose + 20P ha^{-1} + 30N ha^{-1} resulted in similar grain yield increases, but these two treatments out-yielded microdose alone and the check that resulted in the lowest grain yield.

Mechanized zaï study on millet production in farmers' fields

The traditional zaï system composed of planting pearl millet seed in a small hole with a small amount of manure which increases water infiltration in some soils and results in increased yield, but requires much hand labor. Scientists have developed a mechanized zaï using animal traction. The objective of this study was to determine the effectiveness of the mechanized zaï (with 300 g compost per hill) to the traditional zaï (with 300 g compost per hill) and a flat-planted control (without compost) across six different soil types in Burkina Faso. In farmers' fields, zaï greatly increases millet grain yield. Efficiency of both manual and mechanized zaï depends on soil texture and soil depth. Effect of zaï may vary from one year to another with rainfall changes. Farmers agree that mechanized zaï is more profitable than manual zaï due to labor reduction.

Sorghum Malt and Dolo (2003-2007)
S. Pale, J.B. Taounda, INERA ; B. Bougouma, IRSAT; S. Mason, UNL

On-station experiments

The use of grain sorghum in dolo production requires a constant supply of high quality grain available at a reasonable price through better cropping systems to develop and maintain the supply chain. The objective of this study was to identify the best cropping system to optimize grain yield and grain quality of two red grain sorghum varieties IRAT9 and ICSV1001 (Framida) for dolo production. Experiments combining five water management techniques and four fertilizer treatments (FT) in a randomized com-

Table 5. Year x mineral fertilizer rate interaction effect on grain yield of grain sorghum Sariaso 14 (on-station microdose Study, Burkina, 2003-2005)

Mineral Fertilizer Rate	Grain yield (kg ha^{-1}) 2003	2004	2005
	---------------- kg ha^{-1}		---------
Zero fertilizer	1244	539	634
Microdose	1642	824	1523
Microdose + 40P ha^{-1}	1408	522	1201
Zaï with compost	2662	1188	2377
Recommended rate	1694	680	1152
Microdose + 20P ha^{-1} + 30N ha^{-1}	1438	519	906

plete block design with a split plot arrangement of treatments were conducted in 2003 through 2005. Water management techniques were allocated to main plots and FT to subplots. For Framida, averaged over three years, tied ridges outyielded the control by 241 kg ha^{-1}. All fertilizer treatments except microdose produced higher grain yields in 2003, but the largest grain yield increases of 420 to 756 kg ha^{-1} occurred when applying microdose + 20 kg P ha^{-1} + 30 kg N ha^{-1}. For IRAT, all water management techniques produced higher grain yields in 2005. Tied ridges increased grain yield by 359 kg ha^{-1} in 2004 and 395 kg ha^{-1} in 2005. All fertilizer treatments except the control produced higher grain yields in 2005. Microdose + P and N increased grain yield by 812 kg to 1346 kg ha^{-1}. No matter the water management techniques, all fertilized plots outyielded the control. Combination of microdose + P and N with tied ridges increased grain by 1462 kg ha^{-1}. Correlations indicated that the number of panicles harvested ha^{-1} ($R_{Framida} = 0.83$; $R_{IRAT9} = 0.84$) and kernel weight ($R_{Framida} = 0.48$ $R_{IRAT9} = 0.86$) were associated with grain yield for Framida and IRAT9. The best cropping system to optimize grain yield of Framida and IRAT9 was combining tied ridges and microdose + P and N.

Survey of malt producers, dolo producers, dolo resellers, and consumers and malt dealers

Surveys have been completed, with data analysis yet to be finished, to 1) collect information on malt and dolo qualities for a good dolo, parameters that can affect malt quality, and propositions to improve the dolo chain in Burkina Faso, and 2) to collect information to assess the economical impact of malt production. Malt dealers were surveyed to 1) collect information on parameters that can affect malt quality during storage, propositions to improve the dolo chain in Burkina Faso, and 2) to collect information to assess the economical impact of the malt dealers' activity. Altogether, nearly 200 people within the different groups were surveyed.

Ghana

Analysis of the Comparative Response of Sorghum and Cowpea to P-fertilizer Application

S. Buah, L.N. Abatania, SARI; S. Mason, UNL

An experiment was initiated in the year 2000 to establish the method and frequency of P-fertilizer application. Results obtained so far demonstrate the importance of P-fertilizer application when cowpea is grown in rotation with sorghum. Direct application of P-fertilizer up to 60 kg/ha^{-1} of applied P increases net returns of sorghum. When P is applied on an annual basis, the results suggest an optimum level of 30 kg P/ha; however, P applied at any level is better than 0 kg P/ha. When P is applied to the preceding cowpea crop so that sorghum benefits from the residual effect during the subsequent season, max net returns are obtained with 90 kg P/ha.

Economic analysis of the effect of preceding crop on response of sorghum grain yield to N-fertilizer application

Maximum net benefits were obtained with 40 kg N /ha when cowpea precedes sorghum. With groundnut as a preceding crop, maximum net benefits were obtained with 80 kg N/ha. Results with soybean as preceding crop are similar to those obtained with cowpea. When sorghum follows sorghum, a higher rate of N input is required (120 kg N/ha). This has implication in terms of access to fertilizer by smallholder farmers given their financial constraints.

Effect of crop residue removal and fertilizer use on cereal yield

Crop residue is known to improve soil fertility. Farmers burn or remove residue for other uses. An experiment was established to find a balance between residue retention and removal rates. Results had indicated that residue removal affects sorghum yield negatively. Net returns decline with increasing rate of residue removal. Maximum net benefit was obtained with 0% residue removal and fertilizer application.

Mali

Crop Management, Acid Soils, and Fertilization

M. Bagayoko, M. Doumbia, A. Toure, S. Traore, IER; S. Mason, UNL

Sorghum previous crops effect

Compared to sorghum (with 957 kg/ha^{-1}), grain yield increased about 35, 40, 55, 62 and 63% for millet, peanut, dolichos, cowpea and maize, respectively, as previous crops.

Rock phosphate

Rock phosphate effect was about 32% with sorghum, 30% with peanuts, 17% with dolichos, 8% with cowpea, 2% with maize

and 0% with millet. Sorghum grain yield recorded on the check (no fertilizer) was 1267 kg/ha^{-1} with sorghum, 1738 kg/ha^{-1} with peanut, 1731 kg/ha^{-1} with dolichos, and 1671 kg/ha^{-1} with cowpeas.

N effect

For grain yield, there was no response to N application with peanut; the response was linear with cowpeas and millet, quadratic with dolichos and maize, and cubic with sorghum.

Sorghum and mucuna intercropping

In sorghum and mucuna intercropping, the decrease of mucuna biomass production was about 42% in a rows basis rotation, compared to that of the all plots rotation basis, when the planting date of mucuna was 15 days delayed to that of sorghum. When simultaneously planted, rows rotation 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, compared to sorghum planting date, leaded to a 28 % decrease of mucuna biomass production.

Adapting sorghum to soil stresses

Poor soils and limited rainfall properties coupled to socio-economic conditions disfavoring the use of chemical fertilizers have oriented sorghum breeding programs to adapting to soil stresses and low input agriculture. To achieve this objective, several experiments were conducted: (i) screening nurseries to identify sorghum genotypes tolerant to soil acidity, (ii) testing sorghum lines going through programs, and (iii) breeding activities using genotypes selected from screening nurseries.

Local cultivars, Babadia Fara, Bagoba, El Mota Galmi and Gadiaba showed a good tolerance to soil acidity. Recognized soil acidity tolerant sorghums, IS 7173C, IS 3532, IS 3553, MN 4508, IS 2765, ICSV 745 and Dorado, did not perform well under acid soil stresses of the Sudano-Sahelian regions of West Africa. Limited rainfall properties might have restricted their tolerance. Five local Malian sorghums, CSM 63, CSM 205, CSM 219, CSM 228, and CSM 388, showed some tolerance to acid soil stresses.

The best progenies were consistently those obtained from crosses made with the above tolerant genotypes. Few progenies have shown good tolerance to soil stresses and low input agriculture, and are now released to producers. The varieties include Darrell-ken, Djakumbe, N'Tenimissa, Seguifa, and Wassa.

Millet

Microdosing as an important solution of increasing crop productivity

The efficacy of chemical fertilizers on millet production is obvious and does not need any more demonstration. However, the inadequacies between the price of chemical fertilizers and that of rain fed crops like millet and sorghum does not favor the application of recommended rates of mineral fertilizers (41-46-0) N-P-K on these crops. Results obtained at ICRISAT Sahelian Center indicate that micro-dose fertilization is an important alternative to classical broadcast or row application of chemical fertilizers which require relatively large amount of nutrients for increased crop productivity. The following studies were undertaken to: (1) evaluate the performance of micro-dose with and without complementary fertilizer application on millet yield; (2) evaluate the interactions between micro-dose application and different weeding strategies.

After four years of positive results on station and one year of exploratory test on farm, large efforts have been deployed by Cinzana Agricultural Research Station and the Millenium Village of Dioro in Mali to promote millet production by using microdoses of chemical fertilizer. In 2006 alone, 2000 farmers applied microdoses of cereal complex (15-15-15) on 1 ha for each farmer. Pearl millet yields ranged from 600 kg ha^{-1} to 2000 kg ha^{-1}. More than half of the farmers produced more than a ton per hectare. The average yield on farm is 700 kg ha^{-1}.

Improved technology transfer strategies

Before using microdose technique in the area of intervention of the Millenium Village of Dioro Project, nocturnal presentations were done in eight villagers to inform farmers about microdosing and how to solve the major crop production constraints faced by producers. In addition to existing channels of communication, on farm experimentations and demonstrations, field days, diffusion through local and community radios, participative technology development, research antennas in farming communities, I have initiated a two years ago the Nocturnal Village Level Presentations of well performing production technologies. This new technology transfer strategy has the advantage of zero interference with people' occupational calendar. Also it reaches at the same time all the active groups involved in various activities of agriculture. It also allows direct interactions with all the farming communities. The Millet Program, in its collaborative efforts with INTSORMIL have produced several leaflets on different aspects of crop production including intercropping, crop rotations, microdose usage, weeding strategies and crop residues management.

Niger

Pearl millet grain yield improvement with combination of poultry manure and inorganic fertilizer

M. Nouri, INRAN; Steve Mason, UNL

The objective of this work was to determine the best way to use local organic fertilizer and its possible combination with inorganic fertilizer in improving crop yields. Activities included a survey in 2004 with 10 farmers to assess farmer's management practices of this type manure; an on-farm study in 2004, 2005 and 2006 with application of the manure alone and combined with inorganic fertilizer; and On-research station studies in 2005 and 2006 comparing the effect this type of manure alone and combined with P fertilizer.

The survey showed that poultry manure can be found to be used on all dryland crops, pearl millet, grain sorghum, peanut, and cowpea at levels of 1600 to 2300 kg ha-1. Although incapable to compare it to inorganic fertilizers, farmers understand the value of poultry manure for soil fertility improvement especially

when incorporated into soil. Finally they are willing to pay for it. Poultry manure was found to contain 13, 39, and 2.78 g kg-1 of total N, P_2O_5, and K_2O, respectively; higher values than found in cattle manure. A 3-year on-farm study indicated that poultry manure increased pearl millet grain yield by 57% and stover yield by 54%, and when combined with 40 kg ha-1 of NPK (15-15-15) grain yield was increased to 117 % and stover yield to 93%. The importance of combining organic fertilizer with inorganic fertilizer for better yield increase is obvious. A first on-station experiment showed, with rates of 0-6 t ha^{-1}, millet grain yields ranged from 977 to 1142 kg ha^{-1} with no significant difference indicating that the 2 t ha^{-1} used with the on-farm study was sufficient to reach the potential level of grain yield increase with this manure alone. A second on-station experiment examined the effect of adding P inorganic fertilizer to poultry manure to increase pearl millet grain yield. Maximum grain yield (750 kg ha^{-1}) was found with treatments combining manure with 10 kg P ha^{-1} and manure plus 200 kg PNT ha^{-1}, significantly different from the control.

Poultry manure is an important source of fertilizer that can be used to improve soil fertility and pearl millet grain and stover yield. This manure contains more nutrients, N, P, and K, than cattle manure. It is beneficial agronomically and economically to add inorganic N fertilizer.

Technologies in Millet and Sorghum Agronomy in Niger
S. Sirifi, M. Nouri, INRAN; S. Mason, UNL

NPK microdose fertilization of pearl millet

As part of a regional study in Niger, Burkina Faso, and Mali optimal grain increases were observed when applying microdose plus 20 P and 30 N. In Niger, a series of microdose trials were conducted on-station and on-farm in Kalapate region, on an extremely poor sandy soil. On farm trials were limited to three out of eight on station treatments: a check (T1), microdose (T2), microdose plus 20 P and 30 N (T3). This technology seems to be appropriate in growing conditions similar to Kalapate that is characterized by poor sandy soil and low rain fall. Large differences were observed between the microdose, the microdose + P and N and the check. The technology will certainly contribute to the promotion of pearl millet in Niger and the region.

A four year experiment on seed bed preparation across three rainfall zones (Tillakaina, Konni and Bengou) showed significant effect of ridging and tied ridging on sorghum yield (Table 6). The technology was then tested at farm level where the results were confirmed. The on-farm tests showed also that these two technologies were more appropriate in low rainfall zone like Tillakaina region. Usually in this area farmers practice a kind of no-till cultural practice on heavy soils with low infiltration, high runoff and bad aeration. This greatly limits sorghum production because of poor germination and stand. Ridge and tied ridge technique helped reduce most of the soil constraints, thus increasing sorghum production. Yield increase was up to 10 fold that obtained with traditional farmer practice. The technology is also labor saving in terms of number and time of weedings. The technologies were developed in collaboration with INRAN sorghum and millet breeders, specialists of plant protection, economists, and extended on-farm with help from projects including PNRA (World Bank), FIDA ARSAS, and PADER Dosso, the NGO's World Vision, and CRS, and the national extension service and producers.

Utilization and Marketing: Cereal Technology and Processing

Burkina Faso

Sorghum Food Processing in Burkina Faso
B. Bougouma, L. Ouattara, H. Sawadogo, B. Diawara, IRSAT; B. Hamaker, PU

Nutritional quality improvement of "ben-saalga" (fermented porridge)

A strong amylolytic potential strain, *Lactobacillus plantarum* A6 was used in the fermentation of millet porridge as a starter to improve the conditions of fermentation and the energy density of the fermented porridge. Results showed that acidification was faster with the crude starch suspensions than with the gelatinized starch suspensions. The population of lactic bacteria was 10 times higher in both cases of fermentation. The energy density of porridge fermented with *Lb* A6 was twice higher than that of natural fermentation.

Characterization of sorghum and millet varieties for specific end uses

A set of ten varieties possessing high agronomic potential were characterized for nutritional value. Most of them had an interesting nutrition profile. In particular Sariaso 11, tan Nazongala, ICSV 1049 and Fibmega are characterized by protein content higher than 12% db.

Storage and packaging tests of millet products

The impact of packaging on the quality of three millet products: rolled flour, millet flour, and millet weaning flour was evaluated. Two types of packaging, polyethylene and polypropylene films, were used. Physicochemical analyses were performed once per month. Quality was evaluated by the follow-up of fatty acid and water contents. Product conservation was increased up to four months and the best packages were polypropylene film (of 80, 100 µm thickness) and polyethylene film (150 µm thickness).

Inventory of dolo processes and conservation equipment in Burkina Faso

Sorghum traditional malting is characterized by two types of steeping, normal steeping and steeping with air rest, and two phases of germination, low temperature germination (30-40°C) and high temperature germination (60-70°C). Brewing processes are decoction processes, particularly single mash process. There are two types of sorghum beers: a clear one (dolo), and an opaque one (bourou-bourou). There are two dolo brewing processes: the on-mash process and two-mashes process. Malting takes places during 5 to 9 days and brewing 2 to 3 days.

Table 6. Average sorghum grain and stover yields obtained on farm at Tillakaina (Niger) when comparing ridges, tied ridges plus manure and inorganic nitrogen, to traditional growing practices

Genotypes	Treatments	Grain yield (kg/ha^{-1})	Stover yield (kg/ha^{-1})
NAD 1	tied ridges	1920	6584
NAD 1	ridges	1116	4079
NAD 1	Traditional (no ridges)	190	1073
	LSD	665	679

Figure 2. Dolo container, Burkina Faso

Study and improvement of the conservation of the dolo

A study was conducted on the conservation at room temperature of the dolo (traditional sorghum beer) in specially designed polyethylene barrels without any preservatives. This method increased dolo shelf life from 1 (usual) to 4 days. Acidity increased from day 4 leading to deterioration of the organoleptic quality of the dolo. Dolo containers (Figure 2) improved hygienic and organoleptic quality of the dolo and the incomes of the "dolotières" (women selling dolo), and safeguards consumer health. The use of these containers is being actively promoted with support from the Comité Interprofessionel sur les Céréales du Burkina.

Mali

Screening of Breeding Lines, High Quality Products, and Training

F. Cisse, IER; L. Rooney, TAM; B. Hamaker, PU

Grain from improved breeding lines from early, medium and late maturing groups were evaluated for physicochemical properties and food traits. Several entries showed similar decortication yield percentage compared to local Guinea checks (more than (80%). Almost of the lines evaluated showed good tô consistency and acceptable color.

In 2001, a new food product, SORBIS, a cookie made fully from the white-seeded, tan-plant cultivar, N'Ténimissa, was used in value added products and commercial utilization. The area cultivated this year was 38 ha. Four villages were involved in the cultivar production - Tamala, Tadjana, Kafara and Tadjanabougou. About 50 farmers took place in this new venture by contracting with a grain trader and entrepreneur. More than 220 t with an average grain yield of 2000 kg/ha^{-1} was produced. Part of this production was sold to the grain trader and in local markets with an increased price of 10-20 FCFA per kg compared to local market price. Niéta and Wassa derivatives of N'Ténimissa were also used in value-added products and in commercial utilization.

In 2001, 15 women from the Bamako District were trained in sorghum processing (cakes, biscuits, syrup, malta, etc.). In 2002, more than 50 women from Kolokani were trained in sorghum malt production. In 2004, 15 women from Dafara, Kafara and Manako were trained in sorghum processing (cakes, biscuits, syrup, malta etc.). More than 100 farmers were trained in production of food quality seed across Mali (Kolokani, Kafara, Tamala, Bema, Cinzana, Kaniko, Sikasso).

Niger

Cereal Quality and Utilization

S. Kaka, M. Moustapha, S. Ramatou, I. Kapran, A. Tahirou, INRAN; B. Hamaker, PU

The overall objective of this project was processing and commercialization of value-added sorghum and millet products with particular emphasis on utilization of improved sorghum and millet grain and locally or/and regionally fabricated food processing equipment.

In the first phase, improved sorghum and millet cultivars/lines were characterized and used in agglomerated products. The process of producing couscous, using the CIRAD-designed agglomerator or rouleur, was optimized through control of parameters

including grain cleaning, extraction level, milling, hydration, agglomeration, steaming, solar drying to low moisture.

Quality parameters for making NAD-1 couscous were analyzed to quantify couscous yield, nutrition information, and microbiological quality. A consumer study was then conducted to determine acceptability and commercial potential of NAD-1 couscous. It was concluded that NAD1 has a good technological potential for making couscous, and consumers found it a good quality product for commercialization. In the second phase, an attempt to produce a large quantity of couscous using blended grains from the market indicated the importance of pure source grain, since the decortication yield and couscous yield were very low.

In the third phase an extended production and market study of sorghum couscous was conducted in two different cities (Niamey, Maradi) using sale stores and restaurants. The objective was to confirm the flour and couscous making quality of improved cultivars F1-223 (hybrid) and SEPON82, and to better assess the pricing of the product in support of its private marketing. Previously consumers had suggested a price of CFA 250/kg for flour (~$1.00) and CFA 350/500 g for couscous (~$1.25). Six tons of grain of three cultivars (landrace MDK, F1-223, SEPON82) were obtained from farmers and processed to flour and couscous for organoleptic and commercial evaluation. Quality parameters varied according to cultivars, but were higher for F1-223 and SEPON82 than for MDK (62%, 70%, 56%, respectively). Consumers suggested prices between CFA 298 and CFA 352 for 500 g of couscous which were consistent with previous study in phase 1. Restaurant owners liked the package and intrinsic quality comparable to wheat couscous, but were divided on cooking time being shorter or similar to that of wheat couscous. Overall, the most important production parameter was the source of grain and its handling. It appears important to have an acceptable packaging and price for private marketing of the couscous.

In 2006, 4 tons of grain of F1-223 and SEPON82 were used to produce couscous for a marketing trial in 4 cities (Niamey, Konni, Maradi, Zinder). Preliminary data collected on questionnaires indicated that all buyers accepted the commercial quality of the product while suggesting better packaging and price between CFA 300-CFA 500/500 g of couscous in Niamey, and CFA 200-CA 250/500 g of couscous in Maradi. Product color was acceptable to all. It appears important to use the media for marketing.

Nigeria

Food and Nutritional Quality and Processing 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

Project accomplishments

Grain and food quality were determined of 31 pearl millet varieties, 10 millet hybrids, and 11 sorghum cultivars couscous developed by the Lake Chad Research Institute. Foods evaluated were extruded fura, ogi, kunu, tuwo, biscuits and weaning food. Malting properties of 10 pearl millet hybrids and production of amylase rich flour were also completed. Facilities were improved through purchase of a baking oven, grinding machine, and a handheld pH meter. One solar dryer and one dakuwa making machine were constructed. Performance of broiler chicks fed pearl millet, low and high tannin sorghum cultivars compared to maize as source of energy was established.

This project involves graduate training and over the time period of the grant 3 Ph.D. and 2 M.Sc were graduated, and over 40 undergraduate students were assisted.

Senegal

Cereal Technology Project

A. N'Doye, ITA; B. Hamaker, PU

Three millet varieties grown widely in Senegal were characterized for composite flour bread: Thialack (traditional variety); SOSAT C (improved variety), and SOUNA III (improved variety). Based on composite flour bread tests (15% millet flour and 85% wheat flour) the Thialack variety was revealed to be most appropriate for composite flour bread. Based on the different characterization parameters determined, the superior performance of Thialack could be explained mainly on a higher amount of fermentable free sugars. This result gives breeders excellent information for future selection of millet lines for composite flours. Entrepreneurs in Senegal are already advised to use Thialack variety for flour production to supply bakeries.

A study on characterization of three millet varieties grown in Senegal for couscous production was conducted. The objective was to compare the technological characteristics of the 3 millet varieties (Souna 3, THIALACK, IBMV 8402) often used for couscous production. Chemical and functional analyses were performed on each variety followed by sensory tests to evaluate customer preferences. The visual aspect (color) and the taste determined the choice made on a specific variety. Thialack showed better couscous quality. Compared to Souna 3 and IBMV 8402, two improved varieties, Thialack had a better imbibition coefficient and good swelling and deliquescence indices making this cultivar an excellent genetic material for the breeding program. The preference shown by the sensory test for Thialack could lay down a foundation for future contracts between farmers and processors to supply quality grain.

A glycemic study of sorghum comparing rice and fonio was conducted. About 0.5 to 1.5% of the population in Senegal is affected by the diabetes. The methodology of this study was based on recommendation of FAO/WHO. Fifteen healthy male adults were selected for this study done on two types of products (porridge and couscous) with glucose as the reference. Glycemic index obtained using couscous was higher than with porridges. Lower glycemic index was obtained with fonio followed by sorghum.

Utilization and Marketing: Poultry

Niger

Use of Sorghum in Poultry Nutrition
S. Issa, K. Saley, I. Kapran, INRAN; J. Hancock, and M. Tuinstra, KSU

Poultry and egg production are rapidly increasing throughout the developing world. These industries are providing increased market opportunities for sale of grain not consumed by humans. Indeed, many economists agree that new entrepreneurial opportunities for production of animal feed, meat, and eggs in developing countries are needed to move sorghum and millet from subsistence crops to value-added commodities. Thus, our research and outreach efforts in poultry production were focused to address sorghum traits and processing technologies that would make sorghum the cereal of choice in diets for broilers and layers in West Africa.

Numerous laboratory and animal feeding experiments were conducted in the United States and West Africa to demonstrate the value of sorghum grains for use in animal feed. Of particular importance was determination of the impacts of local sorghum varieties (Mota Galmi and IRAT 204) and various manufacturing processes (such as fine-grinding) on feed value of sorghum grain compared to imported corn. Our experiments conclusively demonstrated that when properly milled, sorghum grain was similar to corn as a feedstuff in diets for broilers and layers used for meat and egg production in West Africa. Transfer of these finding to poultry producers was coordinated through Dr. Salissou Issa, Head of the Animal Husbandry Unit at the INRAN Rainfed Crops Program in NIGER. Technology transfer included farm visits, completion of a Poultry Field Day, and formation of the Nigerien Poultry Growers Association.

Institution Building

Equipment and Other Support

The collaborative host country programs were supplied with various equipments over the period including computers, and various field and laboratory research equipment and breeding supplies. The Mali and Niger programs were supplied with four-wheel drive vehicles identified by the INTSORMIL logo.

Training and Education (INTSORMIL-Supported)

Graduate Degree Training (2001-2007)

Completed

Tahirou Abdoulaye (Niger), Ph.D., Agricultural Economics (Purdue University)
Maman Nouri (Niger), Ph.D., Agronomy (University of Nebraska)
Moustapha Moussa (Niger), M.S., Food Science (Purdue University)
Siébou Palé (Burkina Faso), M.S., Agronomy (University of Nebraska)
Soumana Souley (Niger), M.S., Plant Breeding (Kansas State University)
Niaba Temé (Mali), Ph.D., Plant Breeding (Texas Tech University)
Karim Traoré (Mali), Ph.D., Plant Breeding (Texas A&M University)
Tiécoura Traoré (Mali), M.S. (Texas A&M University)

In-Progress

Ignatius Angarawai, PhD, Millet Breeding (University of Maiduguri)
Salissou Issa (Niger), Ph.D., Animal Nutrition (Kansas State University)
Seriba Katilé (Mali), Ph.D., Plant Pathology (Texas A&M University)
Siébou Palé, Ph.D., Agronomy (UKZN, South Africa)
Madani Tely (Mali), M.S., Entomology (West Texas A&M University)

Short-Term Training (2001-2007)

From Mali, Bocar Sidibé, Abocar Oumar Touré, Kissima Traoré, Seriba Katilé, Sibène Déna, and Moussa Sanogo received short-term training in the U.S provided by INTSORMIL in breeding and plant pathology. Training funds were also provided for Adama Neya (Burkina Faso) to attend two pathology workshops/training in the US, and Iro Nkama and Ababacar N'Doye in food science to Purdue University.

Travel to International Meetings (2001-2007)

Various regional PI's were provided funding to attend the 2002 Principal Investigator's Conference held in Addis Ababa, Ethiopia. The regional program provided full or partial travel expenses for the two all-PI meetings held in Ouagadougou, Burkina Faso in 2004 and 2006 for West Africa regional and US PI's. Other support was provided for sub-regional coordinators to travel to the US, as well as four regional PI's to travel to *Striga* meetings in East Africa, and Senegalese ITA investigators to travel to Gambia, France, and Morocco for international scientific or coordination meetings.

U.S. scientists traveling in the region in 2001-2007: Bonnie Pendleton (Burkina Faso, Mali, Niger), Bruce Hamaker (Burkina Faso, Mali, Niger, Senegal), Joe Hancock (Burkina Faso, Mali, Niger, Senegal), Clint Magill (Burkina Faso, Mali), Steve Mason (Burkina Faso, Niger), Lloyd Rooney (Senegal), Darrell Rosenow (Burkina Faso, Mali), John Sanders (Burkina Faso, Mali, Niger, Nigeria, Senegal), Mitch Tuinstra (Burkina Faso, Mali, Niger), Jeff Wilson (Burkina Faso, Niger).

Publications

Refereed Publications (2006-2007)

Angarawai, I.I., Ndahi, W.B., Turaki, Z.G.S., Nkama, I., Gupta,

S.C., Aladele, S.E., Yakubu, Y. and Ezeaka, I.E. 2006. Registration of pearl millet hybrid: LCICMH-1, in Nigeria. *Journal of Arid Agriculture* In press.

Badau, M. H, Jideani, I. A and Nkama, I. 2006. Rheological behaviour of weaning food formulations as affected by addition of malt. *International Journal of Food Science and Technology*,41:1222 - 1228.

Kadi Kadi, H., Kapran, I.and Pendleton, B.B. 2005. Identification of sorghum genotypes resistant to sorghum midge in Niger. *International Sorghum and Millets Newsletter* 46:57-59.

Maman, N., Mason, S.C., and Lyon, D. J. 2006. Nitrogen rate influence on pearl millet yield, nitrogen uptake, and nitrogen use efficiency in Nebraska. *Communications in Soil Science and Plant Analysis* 37:1-15.

Mariac, C., Luong, V., Kapran, I., Mamadou , A., Sagnard, F., Deu, M., Chantereau, J., Gerard, B., Ndjeunga, J., Bezançon, G., Pham, J.L. and Vigouroux, Y. 2006. Diversity of wild and cultivated pearl millet accessions (Pennisetum glaucum [L.] R. Br.) in Niger assessed by microsatellite markers. *Theoretical and Applied Genetics* In press.

Proceedings (2006-2007)

Kapran, I., Grenier, C. and Ejeta, G. 2007. Introgression of Genes for *Striga* Resistance into African Landraces of Sorghum. Ch.10. Proceedings, The International Symposium on Integrating New Technologies for *Striga* Control. G. Ejeta and J. Gressel, eds. In press.

Educational Activities

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 years covered by this report, 116 students from 28 different countries were enrolled in an INTSORMIL advanced degree program. Approximately 70% of these students come from countries other than the U.S. which shows the emphasis placed on host country institutional development (Figure 1).

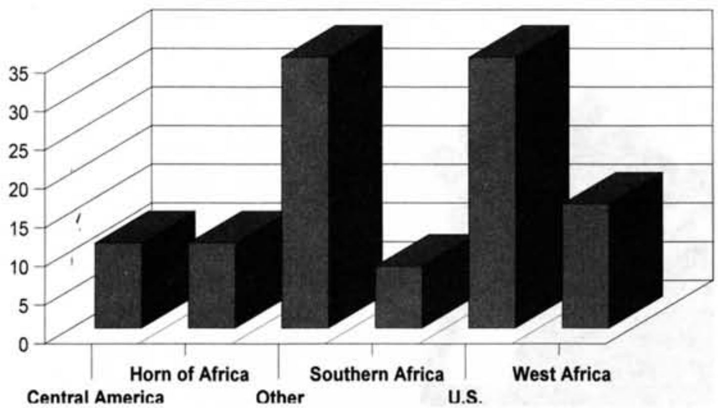


Figure 1. Degree Participants by Region

INTSORMIL also places a high priority on training women which is reflected in Figure 2. From 2001-2007, 31% of all INTSORMIL graduate participants were female. Twenty-four of the total 116 students received full INTSORMIL scholarships. An additional 88 students received partial INTSORMIL funding and the remaining four students were funded from other sources.

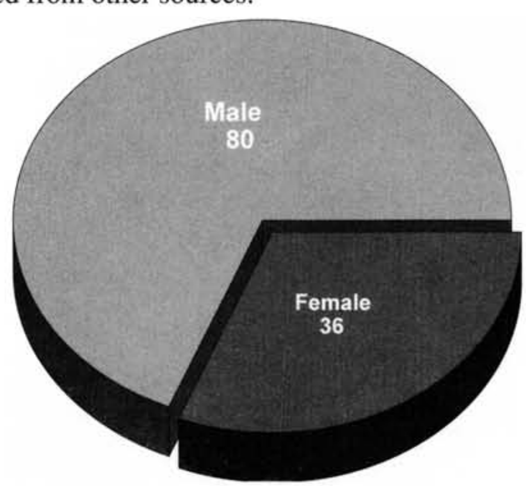


Figure 2. Degree Participants by Gender

All 116 students worked directly with INTSORMIL principal investigators on INTSORMIL projects. These students are enrolled in graduate programs in seven disciplinary areas, agronomy, 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 2005-2006 there were 20.

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. Nineteen postdoctoral scientists and 60 visiting host country scientists were provided the opportunity to upgrade their skills in this fashion from 2001-2007.

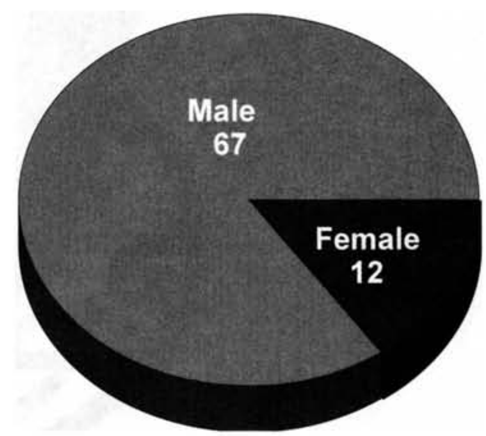


Figure 3. Non-Degree Participants by Gender

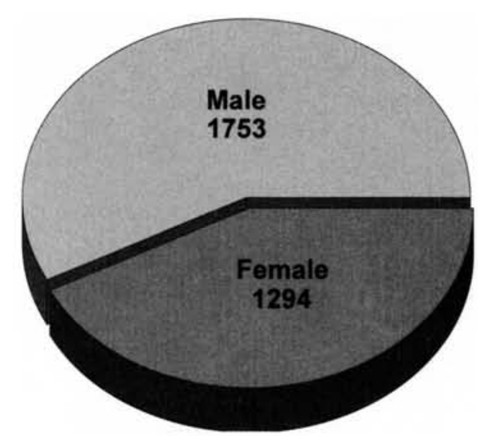


Figure 4. Conference/Workshop Participants by Gender

Appendices

INTSORMIL Sponsored and Co-Sponsored Workshops 1979 - 2007

Name	Where	When
International Short Course in Host Plant Resistance	College Station, Texas	1979
INTSORMIL PI Conference	Lincoln, Nebraska	1/80
West Africa Farming Systems	West Lafayette, Indiana	5/80
Sorghum Disease Short Course for Latin America	Mexico	3/81
International Symposium on Sorghum Grain Quality	ICRISAT	10/81
International Symposium on Food Quality	Hyderabad, India	10/81
Agrimetorology of Sorghum and Millet in the Semi-Arid Tropics	ICRISAT	1982
Latin America Sorghum Quality Short Course	El Batan, Mexico	4/82
Sorghum Food Quality Workshop	El Batan, Mexico	4/82
Sorghum Downy Mildew Workshop	Corpus Christi, Texas	6/82
Plant Pathology	CIMMYT	6/82
Striga Workshop	Raleigh, North Carolina	8/82
INTSORMIL PI Conference	Scottsdale, Arizona	1/83
INTSORMIL-ICRISAT Plant Breeding Workshop	CIMMYT	4/83
Hybrid Sorghum Seed Workshop	Wad Medani, Sudan	11/83
Stalk and Root Rots	Bellagio, Italy	11/83
Sorghum in the 80's	ICRISAT	1984
Dominican Republic/Sorghum	Santo Domingo	1984
Sorghum Production Systems in Latin America	CIMMYT	1984
INTSORMIL PI Conference	Scottsdale, Arizona	1/84
Primer Seminario National Sobre Produccion y Utilizacion del Sorgo	Santo Domingo	2/84
Evaluation Sorghum for A1 Toxicity in Tropical Soils of Latin America	Cali, Colombia	4/84
First Consultative and Review on Sorghum Research in the Philippines	Los Banos, Philippines	6/84
INTSORMIL Graduate Student Workshop and Tour	College Station, Texas	6/84
International Sorghum Entomology Workshop	College Station, Texas	7/84
INTSORMIL PI Conference	Lubbock, Texas	2/85
Niger Prime Site Workshop	Niamey, Niger	10/85
Sorghum Seed Production Workshop	CIMMYT	10/85
International Millet Conference	ICRISAT	4/86
INTSORMIL PI Conference	Kansas City, Missouri	1/87
Maicillos Criollos and Other Sorghum in Middle America Workshop	Tegucigalpa, Honduras	12/87
2nd Global Conference on Sorghum/Millet Diseases	Harare, Zimbabwe	3/88
6th Annual CLAIS Meeting	San Salvador, El Salvador	12/88
International INTSORMIL Research Conference	Scottsdale, Arizona	1/89
ARC/INTSORMIL Sorghum/Millet Workshop	Wad Medani, Sudan	11/89
Workshop on Sorghum Nutritional Grain Quality	West Lafayette, Indiana	2/90
Sorghum for the Future Workshop	Cali, Colombia	1/91
INTSORMIL PI Conference	Corpus Christi, Texas	7/91
Workshop on Social Science Research and the CRSPs	Lexington, Kentucky	2/92
Workshop on Adaptation of Plants to Soil Stresses	Lincoln, Nebraska	8/93
International Conference on Genetic Improvement of Sorghum and Millet	Lubbock, Texas	9/96
Conference on Ergot of Sorghum in the Americas	Sete Lagos, Brazil	6/97
Ethiopia Sorghum and Millet Traveling Workshop	Ethiopia	9/97
Mali Sorghum Characterization Workshop	Cinzana, Mali	11/97
INTSORMIL PI Conference	Corpus Christi, Texas	6/98
Impact Assessment Workshop	Corpus Christi, Texas	6/98
Conference on the Status of Sorghum Ergot in North America	Corpus Christi, Texas	6/98
Regional Hybrid Sorghum and Pearl Millet Seed Workshop	Niamey, Niger	9/98
CRSP Symposium/Annual Meeting of the American Society of Agronomy	Baltimore, Maryland	10/98
Global 2000 Sorghum and Pearl Millet Diseases III	Guanajuato, Mexico	9/00
INTSORMIL PI Conference	Addis Ababa, Ethiopia	11/02
West Africa Regional Meeting	Ouagadougou, Burkina Faso	04/04
South Africa White Sorghum Workshop	Univ. of Pretoria, South Africa	09/04
Marketing & Processing for Dryland Crops in West Africa	Bamako, Mali	11/04
Forage Sorghum Workshop	San Miguel, El Salvador	11/05
Marketing & Processing for Dryland Crops in West Africa	Saly, Senegal	12/05
West Africa Regional Meeting	Ouagadougou, Burkina Faso	03/06
Southern Africa Regional Sorghum Breeders Workshop	Lusaka, Zambia	04/06
Forage Sorghum Workshop	San Salvador, El Salvador	11/06
International Symposium on Integrating New Technologies for *Striga* Control	Addis Ababa, Ethiopia	11/06
Central America Regional Planning Meeting	San Salvador, El Salvador	03/07
West Africa Regional Planning Meeting	Ouagadougou, Burkina Faso	04/07
Southern Africa Regional Planning Meeting	Pretoria, South Africa	04/07
International Workshop on the Poultry Sector of the Sahel	Saly, Senegal	05/07

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
EAVN	Extended Anthracnose Virulence Nursery
EIAR	Ethiopian Institute for Agricultural Research
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
FENALCE	Federación Nacional de Cultivadores de Cereales
FHIA	Fundación Hondureña 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
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

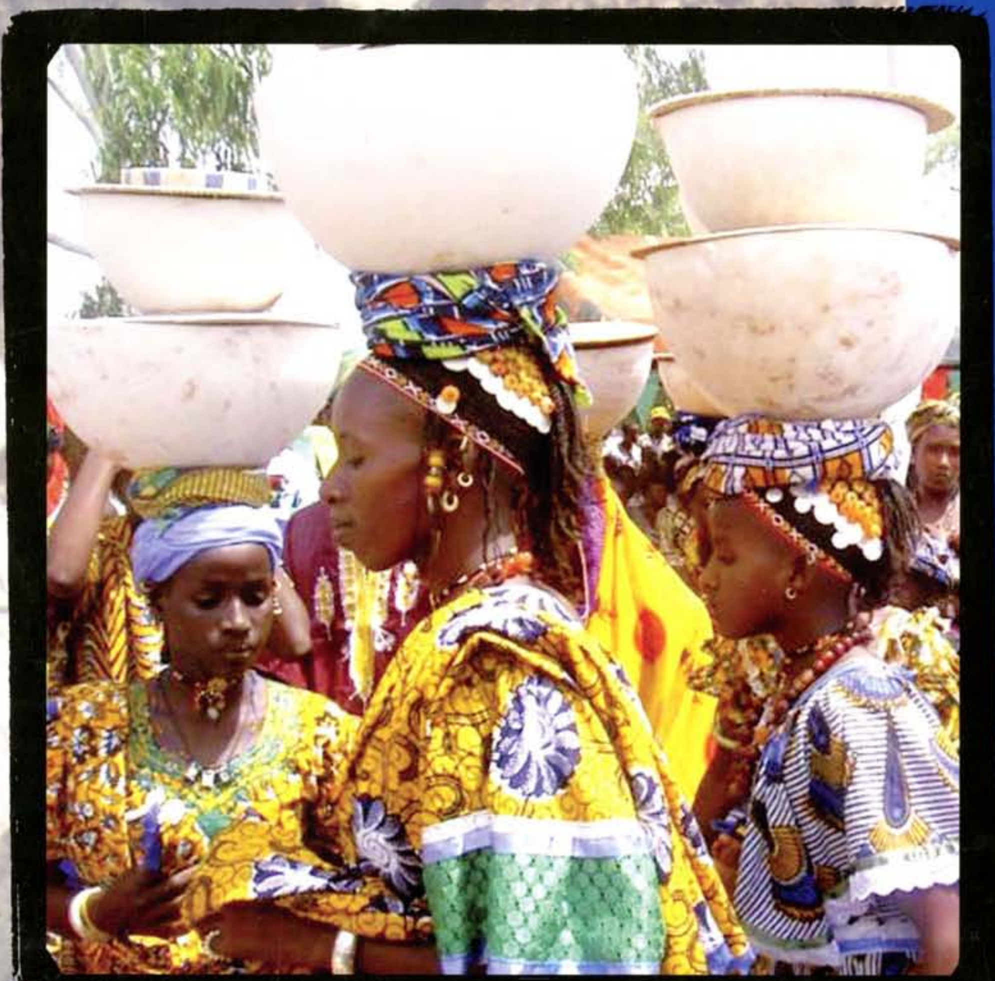
JCARD	Joint Committee on Agricultural Research and Development
KARI	Kenya Agriculture Research Institute
KIRDI	Kenya Industrial Research and Development Institute
KSU	Kansas State University
LASIP	Latin American Sorghum Improvement Project, Mexico
LC/MS	Liquid Chromatography/Mass Spectrometry
LCRI	Lake 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	Proyecto 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
RFA	Request for Assistance
RFLP	Restriction Fragment Length Polymorphism
RFP	Request for Proposals
RI	Recombinant Inbred
RIIC	Rural Industry Innovation Centre, Botswana
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

A Fulani Festival in Burkina Faso



INTSORMIL

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