Funding support through the
Agency for International Development

Leader with Associates
Cooperative Agreement

EEP-A-00-06-00016-00

INTSORMIL 2008

2008 Annual Report

# INTSORMIL

## Sorghum, Millet and other Grains Collaborative Research Support Program (CRSP)

**FRONT COVER**

**Food processor Mme Soumare Modie Sangare from Mali discussing the importance of clean millet for millet-based foods with a farmer of the Cooperative Yereta-Ton, Tingoni, Mali during the field trip for the INTSORMIL sponsored Production-Marketing Workshop, August 14, 2008. The cooperative supplies sorghum and millet grain to food processors in Mali.**

**BACK COVER**

**Food processors enjoying a sorghum-based yaourt drink during a break at the INTSORMIL sponsored Production-Marketing Workshop, Bamako, Mali, August 12-14, 2008. Commercial food processors and the name of their company left to right are: Mme Diori Maimouna Male, Laitiere du Sahel in Niger; Mme Coulibaly Aida Diop, La Corbeille in Mali; Mme Tene, Cooperative de LASSA in Mali and Mme Diallo Fatim Cisse, LTA/IER, Sotuba, Mali.**

# INTSORMIL
## Sorghum, Millet and Other Grains CRSP

# 2008 ANNUAL REPORT

This publication was made possible through support provided by the U.S. Agency for International Development, under the terms of the Leader with Associates Cooperative Agreement EEP-A-00-06-00016-00. The opinions expressed herein are those of the author(s) and do not necessarily reflect the views of the U.S. Agency for International Development.

INTSORMIL Publication 08-01

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

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INTSORMIL Board of Directors

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# Introduction and Program Review

The 2008 INTSORMIL Annual Report presents the progress and notable achievements by the Sorghum/Millet and Other Grains CRSP during the period of September 30, 2007 through September 29, 2008. These results are an outcome of partnerships between scientists at six U.S. Land Grant Universities (Kansas State University, University of Nebraska, Ohio State University, 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 and Other Grains Collaborative Research Support Program (INTSORMIL CRSP) conducts collaborative research through partnerships between 17 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 and funds projects in four regions, western, eastern, and southern Africa, and in Central America. INTSORMIL support to these regions promotes 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 a sustainable, global impact by 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 by yielding 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, e.g., 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 there have been significant advances in the improvement and production of sorghum and millet in the regions in which INTSORMIL serves, population growth continues to exceed rates of increase in cereal production capacity. Thus, 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 research posts in their countries after training. 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 the conservation of millet and sorghum germplasm, resource-efficient cropping systems, integrated pest management strategies that conserve natural control agents and cultivars with improved nutrient and water use efficiencies and evaluates the 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 employing multi-disciplinary research teams composed of U.S. 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 the battle against hunger and poverty because they provide means for economic growth, generation of wealth, and improved health. New technologies developed by INTSORMIL collaborative research are extended to farmer's fields and to processors and marketers of sorghum and millet products in developing countries and the United States through partnerships with NGOs, research networks, national extension services and the private sector. In addition, economic analyses by INTSORMIL researchers play 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. The ultimate goal is to provide economic and physical well-being to those involved in the 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. Thus, 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 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 as they strengthen 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 and Other Grains CRSP and is the primary recipient of the Leader with Associates Cooperative Agreement from USAID. UNL makes sub-awards 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) serves as the top management/policy body for the CRSP. 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 2007-2008, there were 41 students from 24 different countries enrolled in an INTSORMIL advanced degree program and advised by an INTSORMIL principal investigator. Approximately 80% of these students came from countries other than the U.S. The number of students receiving 100% funding by INTSORMIL in 2007-2008 totaled 4. An additional 37 students received partial funding from INTSORMIL. INTSORMIL places high priority on training of women. During the period 2007-2008, 44% 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 PIs in the United States. During this period, 13 host country scientists improved their education as either postdoctoral scientists (3) or visiting scientists (10). Their research activities were in the disciplines of agronomy, breeding, food science and pathology. These scientists came to the United States as postdoctoral scientists or visiting scientists from Argentina, China, Egypt, Ethiopia, Guatemala, India, Korea, Malawi, Senegal, Tanzania and Zambia. In addition to non-degree research activities there were 364 participants (177 male and 187 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, Kenya, Ethiopia, Uganda and Tanzania; Central America and with CORAF and ASARECA/ECARSAM in Africa 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 expenditure of research funds. 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. During the period of 2004-2007 INTSORMIL executed a Marketing-Processing Project funded by the USAID West Africa Regional Program (WARP) which focused 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). Since October 1, 2007 the Marketing-Processing project has been supported by INTSORMIL in Senegal and Niger and by the USAID/Mali Mission in Mali. INTSORMIL continues to promote free exchange of germplasm, technical information, improved technology, and research techniques.

## Regional Activities and Benefits

### *West Africa*

The West Africa Regional Program now encompasses five countries of the Sahelian region – Burkina Faso, Mali, Niger, Nigeria, and Senegal and one U.S. PI collaborates in Ghana.

Scientists from the 5 countries in the INTSORMIL West Africa Regional Program met to discuss collaborative research and participate in a planning workshop for the West Africa regional program in April of 2008. In Niger, as compared to work plan expectations, farmers exceeded planned goals. They significantly increased the amount produced and marketed and trained groups in grain processing and business planning procedures. Facilities and control measures for stored grain pests were surveyed in Niger. In Mali, a grass, Andropogon was used as a trap crop to provide pesticide-free control of stalk borers in millet. Sorghum and millet varieties were evaluated for resistance to sorghum midge, stalk borers, and millet head miner in Mali and Niger. Most sorghum lines evaluated were resistant to anthracnose in Mali. INERA evaluated and demonstrated improved varieties and chemicals for control of diseases of sorghum and millet for hundreds of farmers in Burkina Faso. Millet resistant to downy mildew and Striga was identified and demonstrated to 200 farm families in Nigeria. Students from 3 countries were trained in insect and disease management. Farmer Field Schools and demonstrations taught integrated Striga management to 127 farmers in Senegal. Sorghums were evaluated for resistance to ALS herbicides in Mali and Niger. Hundreds of farmers were trained by INERA and an NGO in micro-dose fertilizer technology and the use of improved sorghum and millet varieties on hundreds of hectares. The warrant credit system was introduced in Burkina Faso. Hundreds of sorghum varieties were evaluated across the region for yield and resistance. Seed produced with assistance from farmer organizations was given to farmers in Mali, Niger, and Senegal. Funding was received too late to begin several activities on grain storage problems but these activities will be conducted in 2008-09.

### *Horn of Africa*

The Horn of Africa Regional Program now encompasses four countries of the Horn of Africa Region - Tanzania, Uganda, Kenya and Ethiopia.

Scientists from the four countries within the Horn of Africa and U.S. Collaborators working with the INTSORMIL Horn of Africa Regional Program participated in a planning workshop in September, 2008 to discuss collaborative research. The Sorghum/Millet CRSP Grant program was closed after 27 years and the USAID created a new program, the Sorghum and Millet and Other Grains CRSP. This regional meeting was organized to develop workplans for the new program by building on the strengths of the previous program. There was discussion on whether the new framework should support country-specific goals and requirements or whether the program in each country should only support projects having regional significance (problems occurring in all four countries of the Horn of Africa Region). It was stated that only USAID Missions should be dealing with specific country programs and that the INTSORMIL Regional Program should emphasize activities having regional significance. The CRSP should assist the national programs in identifying other potential resources and to coordinate these resources in order to meet the country-specific needs of each national program in the region.

Discussion also centered on how to disseminate information and technologies to the farmers in order to have an impact. There is a vital need for national programs to increase their investment in technology transfer activities. This investment includes support of training activities as declining human capacity is currently a severe constraint to progress in the development and transfer of agricultural technology in the Horn of Africa.

### *Southern Africa*

The Southern Africa Regional Program now encompasses four countries of the Southern Africa region – Zambia, Mozambique, South Africa and Botswana.

Activities in the region were carried out as planned. Progress in achieving research objectives was made although field sorghum breeding activities in Zambia were hindered by too much rain early in the season followed by early cessation of rain later in the season. Research conducted will have an impact on sorghum production throughout the region. Technology development, testing and transfer can be used to partially quantify progress. In Mozambique, the national sorghum program has identified nine experimental breeding lines from the Texas A&M University sorghum improvement program as potentially useful varieties. The experimental lines were identified in the All Disease and Insect Nursery, the Grain Weathering Test, the Drought Line Test and the Midge Line Test. In the 2008-09 growing season the experimental lines will be grown at several locations in Mozambique and Texas to gather data on suitability for release and for potential release proposals. Collaboration in South Africa (and Botswana) has identified 16 experimental lines for the small farmer program. The lines, developed in a collaborative program, were used to produce new varieties with resistance to the sugarcane aphid. Agronomic and performance data will be collected in addition to end-use processing data. The releases will have improved grain yield potential and, depending on the germplasm, insect resistance, disease resistance, drought resistance, weathering resistance, and potentially enhanced end-use characteristics. It is anticipated there will be several releases of the experimental lines as varieties in years 4 and 5.

Food science research is directed at developing an understanding of the processing characteristics of sorghum and millet and identifying new products and uses. There is continued interest in new product development of sorghum especially for use in clear lager beer brewing. These activities will continue with private industry collaboration when possible.

There are no significant management issues which impede our research progress in the Southern Africa region at this time. However, budgetary constraints within the region limit participation in many of the opportunities for research and technology transfer. Additional scientists and institutions have expressed interest in participating in the INTSORMIL program should additional funds become available.

### *Central America*

The Central America Regional Program now encompasses three countries of the Central America region - El Salvador, Nicaragua, and Honduras.

The INTSORMIL program in Central America continues to produce results based on the long term activities in the region. Research in plant breeding, agronomy, pest management and utilization have created varieties and hybrids with improved yield potential and management programs to capitalize on that potential followed by the development of end uses for the products that are produced. Support of extension programs provides the conduit to educate producers and end users on the effective use of these materials.

The program faces several significant hurdles to future success. First and foremost, the current budget is marginal and it has required significant cuts in research, both in scope and the depth of the programs. Current funding levels simply cover basic research activities; leaving few resources for capacity building or technology transfer activities. It is imperative that program coordinators identify new and creative ways to access funds for the support of programs in the regions. Second, the development of human capacity through education is becoming a critical need. Due to budget constraints there is insufficient funding for formal training and this limitation will eventually reduce the effectiveness of the program. We must find an effective approach to minimize this problem in the near future.

### Associate Award

In 2007 INTSORMIL received a three year (September 29, 2007 – September 30, 2010) $250,000/year award "Transfer of Sorghum, Millet Production, Processing and Marketing Technologies in Mali" from the USAID/EGAT/AG/ATGO/Mali. The project was based on successful activities through the INTSORMIL West Africa Regional Project and was designed to rapidly move sorghum and millet production technologies onto farmers' fields, link farmers' organizations to food and feed processors and commercialize processing technologies so as to enhance markets and to significantly expand the existing project, especially into the northern areas of Mali. The award allowed INTSORMIL to significantly increase its impact in Mali by (1) expanding to new sites with more concentration in the poorer northern Tombouctou region where food insecurity is a severe problem for the small scale farmers who depend on sorghum and millet for their daily diet, (2) upscaling the research and (3) upscaling the technology transfer component.

The Cooperative Agreement consists of three components: 1) Production - Marketing activities led by John Sanders, Purdue University Marketing Economist; 2) Food Processing Technology and Training activities, led by Bruce Hamaker, Purdue University Cereal Chemist and 3) Décrue Sorghum (post water recession sorghum planted at the edges of the Niger River and Lakes after the rainy season has ended) production activities led by Vara Prasad and Scott Staggenborg, Kansas State University Agronomists. The team implemented a system including technology introduction, development of farmer groups, marketing strategy innovation, and linking of farmer groups to food and feed processors. Activities are conducted in collaboration with IER.

Progress toward meeting targets and benchmarks/indicators established is based on the following objectives set forth in the workplan:

1. Network establishment to enhance partnership development with relevant stakeholders
2. Increase farmer incomes by introducing better marketing strategies combined with new technologies.
3. Improve the efficiency of input markets for millet and sorghum in Mali
4. Developing alternative markets for sorghum and millet grain
5. Develop sorghum and millet production technology for the "culture de décrue" system
6. Upscaling the sorghum and millet seed production industry in collaboration with other agencies
7. Communications/ publications

### *Network Establishment*

Décrue sorghum - Partnerships have been developed through visits to Mali and include, INTSORMIL PIs, IER scientists, USAID /EGAT Team, local administrators of the Lake Faguibine revitalization program in Goundam, farmers from two villages surrounding the lakes Bintagoungou and Mgoudou. Participation in the Production-Marketing Workshop held in Bamako in August 2008 provided an opportunity to develop additional partnerships with food processors.

Production-Marketing- A strong network had already been established prior to the initiation of this project. That network involves, IER, USAID, ICRISAT, Sasagawa2000, ULPC Dioila, ECONOMETRE, INTSORMIL PIs and the food processors; Mam Cocktail, Beau Céreale, Sahélienne de l'Alimentation, Musola Jama Sewa, DANAYA Céreales, La Maraîchere, Corbeille and UCODAL. The network was strengthened by the Production –Marketing Workshop.

Food Processing- A consultant, M. Diouf has been selected to manage the project on site. Partnerships have been established with the USAID Mission, Mali AEG team, food processors associations, FENATRA, and stakeholders in Mopti and GAO. Participation in the Production-Marketing Workshop served to develop partnerships with several Malian food processors.

### *Increase Farmer Incomes*

The most successful marketing strategies were (1) getting the farmers' associations to sell later and (2) using the "bache" (tarps) to produce a cleaner product plus encouraging the processors to pay a quality premium. The Production-Marketing workshop lead to new markets (food processors) and expansion of current markets.

Yields of farmers in this program doubled in Year 1. Farmers made income gains from both yield and price increase. Price increase due to the marketing strategy alone was 31%. Total income gain increase due to higher sorghum yields (due to technology) and the higher prices received (due to marketing strategies) was 43% with the best farmers gaining 121%.

Production in the project area increased. In 2007-2008 the project area in Mali was 500 ha (350ha sorghum and 150 millet). Thus we have already reached our target area of 500 ha and will increase it to 900 ha by 2009. By 2009 we will double our Mali program and initiate activities in the north (Mopti Region) for both sorghum and millet.

### *Improve the Efficiency of Input Markets*

Training of farmer associations (cooperatives etc.) in the Production-Marketing Project began in Tingoni the summer of 2008. The farmers' organization (Cooperative Yereta-Ton) has have been storing the grain which provides them with input credits. The farmers' organizations have been acquiring identities as successful economic units. They buy inputs, store and sell the grain. Repayment rates for the inputs have been very high, generally over 95%. This approach is being expanded to several new villages in 2009.

### *Alternative markets*

1. Quantity of both millet and sorghum used for food processing by DANAYA Céréales in Bamako increased 300%.
2. Beau Céréales increased millet used for food processing by 33%.
3. La Maraîchére increased millet used for food processing by 25%.
4. Production-Marketing Workshop expected to result in an increase the number of entrepreneurs and the use of sorghum and millet
5. New processing technologies are currently under development

### *Décrue" System Production Technology*

Management practices evaluated in farmers' fields and compared to farmer's cultural practices include (1) varietal evaluation, plant density, row spacing, fertilizer levels and seed treatment

### *Sorghum and Millet Seed Production Industry*

Activities conducted by IER décrue scientists include cultivar collections and testing to identify most suitable cultivars for the region. Twenty varieties from the IER sorghum breeding program and thirteen from the farmers were planted at Bintagoungoun and Toukabangou.

Production-Marketing scientists extended local seed production activities to include some regional testing of new cultivars. To produce local seed of high quality means increased uniformity which requires sufficient roguing and an understanding of crop isolation by farmers. Tingoni Cooperative Association farmers' received training in seed production, including hybrid seeds and marketing concepts. Training to additional sites will be expanded in Year 2.

### *Communications/ Publications*

The Production-Marketing Workshop held in Bamako August 12-14, 2008 provided an opportunity to increase the awareness by entrepreneurs of opportunities for use of sorghum and millet in the food processing and poultry feed industries. The workshop brought the farmer producers of millet and sorghum in direct communication with the entrepreneurs (food processors).

Publications included (1) Transformation Commercial du Mil et du Sorgho au Mali, Projet Production-Marketing, INTSORMIL Bulletin No. 7, (2) Evaluation of Sorghum and Millet Technology and Marketing Strategy Introduction: 2006-07 Crop Year, Production-Marketing Project, INTSORMIL Bulletin No. 8, (3) INTSORMIL Impact, July 15, 2008. Sorghum Yields Doubled in Farmers' Fields in Three West African Countries, http://intsormil.org/, (4) INTSORMIL Impact, July 22, 2008. Sorghum Technology and Marketing Strategies Increase Farm Income in West Africa, http://intsormil.org/ and (5) Kansas State University Agronomists Help West African Farmers Increase Sorghum and Pearl Millet Production. KSU Ag Exp. Sta. & Coop. Ext. Service, Manhattan, Kansas, http://intsormil.org/. A bulletin on the intensive chicken industry in Mali and how to facilitate its growth with the availability of low cost sorghum is being produced for release in 2009.

## Future Directions

Prices of many basic foods skyrocketed in 2008 resulting in a major food crisis that affected millions of poor people throughout the world. The causes of the crisis are many and complex. An increasing demand for food and energy at a time of low food stocks, poor harvests and weak credit have led to record prices for oil and food.

Without appropriate interventions, the food crisis is not likely to resolve itself. In determining the proper response we must take into consideration that "Food crop prices are expected to remain high in 2008 and 2009 and then start to decline as supply and demand respond to high prices; however, they are likely to remain well above the 2004 levels through 2015 for most food crops. Forecasts of other major organizations (FAO, OECD and USDA) that regularly monitor and project commodity prices are broadly consistent with the projections". It is unlikely that demand will decline markedly in the future so in order to lower prices supply must be increased. Increasing agricultural production will require input from developing countries, international organizations, and donors.

The new Sorghum, Millet and Other Grains CRSP was authorized and funded by USAID effective October 1, 2006. Strategies under this new CRSP have maintained the previous INTSORMIL's highly productive momentum, built on its record of success, and continues to work toward accomplishing a whole new set of goals. INTSORMIL's new vision 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 is proving to be successful as indicated in this report. The CRSP is demonstrating international leadership in leading efforts to promote profitable markets for sorghum, pearl millet and other grains by working with agencies that identify and develop markets, assess economics, and facilitate the evolution of a production-supply chain and by expanding markets that deliver quality grain to end users. Future strategies will maintain the new CRSP's highly productive momentum, continue building on the old CRSP's record of success, and accomplish a new set of goals.

During the past 29 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. So what 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 needs of the livestock feed industry in the United States. Recent INTSORMIL research on the nutritional benefits of sorghum and millet forms 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 the 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 29 years and the training of sorghum and millet scientists in the United States, Africa and Central America by INTSORMIL now enables these 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.

# Sustainable Plant Protection Systems

INTSORMIL

# Grain Molds, Mycotoxins and Stalk Rots of Sorghum and Millet

## Project KSU 101
## John F. Leslie
## Kansas State University


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### Introduction and Justification

Sorghum and millet are plagued by numerous diseases, most of which have a fungal etiological agent. Stalk rot and grain mold, the most important diseases on a worldwide basis for which there is no effective management regime can be caused by several species of *Fusarium*, although at least 25 additional fungal genera may be present as secondary invaders or members of a dis-ease complex. Separating and identifying the roles and risks associated with the various members of this complex fungal community is necessary to estimate the risks posed by different members of the community and to provide breeders with the correct targets for resistance breeding. Fungi that cause grain mold also are linked with stand establishment problems as the seeds that are produced may germinate poorly or the germinated seedlings may be killed by fungi that accompanied the seed.

*Fusarium* spp. and the secondarily invading *Aspergillus* spp. may produce mycotoxins such as aflatoxins, fumonisins, ochratoxin, deoxynivalenol and zearalenone. These toxins may reduce the quality of the grain as a food/feed source as well as the value of the grain in a cash market scenario. These toxins are associated with a variety of human and animal health problems in-cluding acute toxicity and death, increased incidence of cancer, inhibition of normal growth and development, immune suppression and increased disease susceptibility, increased risks of birth defects, and reduced nutritional and economic value of the resulting grain. In most host-country settings these risks are inadequately quantified due to limited medical data reporting systems.

*Fusarium* and related species and the diseases they cause offer the most attractive targets for improved management that could be of importance in a global context. Isolates of *Fusarium* re-covered from sorghum and millet have long been a taxonomist's nightmare. Many species lack morphological characters that can be used to clearly and cleanly differentiate them from other re-lated species, and many cultures have been misidentified. Many of these cultures also have been identified as *Fusarium moniliforme*, a name that has now been abandoned due to the numerous species that it has been associated with. As all strains with the *F. moniliforme* name often were assumed (incorrectly) to be equivalent, breeding materials often were challenged with an im-proper strain with correspondingly inconsistent results. For example, *F. verticillioides* is a common pathogen of maize that once was termed *F. moniliforme*, as was *F. thapsinum*, a major cause of sorghum stalk rot. Challenging sorghum plants with *F. verticillioides* when screening for stalk rot resistance results in unpredictable results, as the only plants that become diseased are those infected by *F. thapsinum* due to natural causes. A similar challenge with F. thapsinum, however, can effectively flatten an experiment planted with a sensitive variety. Results from previous studies sponsored by INTSORMIL have indicated that the dominant *Fusarium* species varies by location, e.g., *Fusarium andyazi*, in southern Africa, *F. thapsinum* in West Africa, *F. proliferatum* in Egypt, and an as yet unnamed new species that is common from West Africa through Egypt and east Africa (Kenya and Uganda). Within region variation suggests that as many as 20 additional species remain to be described. Until they have been effectively separated it is difficult to determine which species are common in one area and less common in others. Such studies also are needed to enable breeders to effectively challenge the materials in their programs. The *Fusarium* species associated with pearl millet and finger millet also have been examined in a somewhat cursory manner. *Fusarium pseudonygamai* is the dominant species on pearl millet, while finger millet is host to an amazingly diverse group of *Fusarium* spp. (between 40 and 60 from samples taken in Uganda in 2000). The *Fusarium* species on these crops are not known to be associated with production problems, but many can produce mycotoxins that could contaminate grain. Such contamination is particularly important for finger millet as this grain often is used to produce a weaning food for children. These children would be particularly suscep-tible to the reductions in mental and physical development that can result from sub-lethal exposure to these toxins.

## Objectives and Implementation Sites

- Identification of *Fusarium* species associated with pearl and finger millet and with grain mold and stalk rot of sorghum. Kansas, South Africa, Mali and Uganda.
- Fungal localization and caryopsis health. Kansas and South Africa.
- Mycotoxins in sorghum and millets. Kansas, South Africa and Nigeria.
- Strengthen host-country research capacity. Kansas, South Africa (Malaysia & South Korea)

## Contribution to INTSORMIL Objectives

Collectively, the planned work impacts INTSORMIL objectives 2, 4, 5 and 7. Fewer mycotoxins in the grain improve food and nutritional quality of sorghum and pearl millet. Reduced disease pressure increases the yield and yield stability. Information on biotic stresses is being disseminated through the existing workshops and co-authored scientific publications and the training of graduate students and visiting scientists. Assisting INTSORMIL breeders with the development of germplasm resistant to various pathogens increases yield and yield stability.

## Research Methodology and Strategy

### *Species Identification*

After field collection, strains are subcultured to a selective medium to purify cultures from bacte-rial and most other fungal contaminants. These cleaned cultures are then purified further by sub-culturing individual microconidia that have been separated from the remainder of the colony by micromanipulation. Three different species concepts are used in Fusarium-morphological, biological and phylogenetic. Most species from sorghum and millet are very similar to one another morphologically, which means that the morphological characters are insufficient to differentiate the species, thus either biological or phylogentic concepts and strategies are usually employed after an initial morphological observation confirms that the strains have the morphological characters common to most sorghum Fusarium species. At this point cultures are grown for three days and DNA is isolated from all strains. DNA from strains is run through an Amplified Fragment Length Polymorphism (AFLP) protocol. At the end of the first run, strains with visibly similar patterns are grouped together and rerun to confirm their similarity. Genes with species specific sequences, usually one encoding β-tubulin (tub-2) and/or another encoding translocation elongation factor 1-α (tef-1) are amplified by PCR and sequenced. If there is less than 1% dif-ference between the sequences obtained and those available for standard strains, then the group is considered to have been successfully identified. If there are tester strains available for sexual crosses for a known species, then the identity of the remaining strains in the group are confirmed by crosses.

In many cases for strains from sorghum and millets in Africa, the species is one that has not been described. In such cases, additional strains are sequenced to confirm that the first set of sequence data typifies the group. At this time, a search for the sexual stage begins. Crosses are made in all possible pairwise combinations of all strains, with each strain serving as both the male and as a female parent in a cross (this results in the number of crosses made being the square of the number of strains in the group, e.g., 50 strains = 2500 crosses that must all be re-peated at least twice = 5000 crosses total), with the goal of finding strains that are fertile as the female parent. The number of crosses can be reduced by up to ½ if the mating type of the strains can be determined molecularly before the crossing process begins. Once fertile strains are iden-tified, female fertility usually must be improved through crosses with other female fertile strains, which may be a very time-consuming process. Once the sexual stage has been successfully identified then photographs of critical morphological features are made, strains are deposited in appropriate international culture collections and herbaria and the new species can be written up for publication. No more than 2-3 new species can be processed at any single time.

Most of this work is done at KSU with samples collected from numerous African countries including Egypt, Ethiopia, Mali, Nigeria and South Africa with the help of colleagues based there.

### *Fungal Localization and Caryopsis Health*

Disease severity parameters such as caryopsis formation, germination, emergence, vigor, seed weight, and peduncle colonization are being measured. Tissues within the caryopsis, including germ, endosperm, pericarp, and black layer, are dissected for isolation of fungi after natural and artificial inoculations. Fusarium spp. are then isolated from caryopsis tissues and identified with morphological characters and DNA sequences. Control and inoculated caryopses are evaluated for viability by staining of the scutellum, radicle, coleoptile, plumule, and embryo axis tissues with tetrazolium violet. Kernels from artificial inoculations are measured for grain hardness, diameter, and crush strength via the single kernel classification system. In vitro competition assays are being used to determine the interactions between grain molding species, grain weathering species and storage fungi.

To assess caryopsis quality, sorghum flours (from white-tan genotypes) are being screened for grain mold, grain weathering and storage fungi. Caryopses are decorticated to remove pericarp and black layer prior to flour preparation by using a tangential abrasive dehulling device. Samples also are decorticated by drilling to remove only the pericarp and the black layer tissues. α-, β-, and γ-kafirin proteins and protein complexes in caryopsis endosperm are being measured in sorghum endosperm from seed derived following fungal inoculation at anthesis.

Most of this work has been done at KSU in Dr. Little's laboratory and at the University of the Free State in Dr. McLaren's laboratory.

### *Mycotoxin Contamination*

The primary work reported this year is of a joint experiment conducted with IITA and MRC and evaluated for aflatoxin contamination. Similar work also has been conducted on fumonisin con-tamination but the necessary analyses for publication are not yet finished.

IITA routinely runs multi-location "on-farm" trials of traditional and improved maize, sorghum and pearl millet lines to determine yields and the effects of agronomic and other parame-ters not always observable in fields at research stations. The cooperating farmers are provided with seed and other inputs, e.g., fertilizers and pesticides, and allow the collection of data on yield, maturity and pest and disease incidence. For this study we used samples grown by farmers at 14 locations in the Northern Guinea savanna and the Southern Guinea savanna of Nigeria. Maize, sorghum and pearl millet are the primary cereal components in this cropping system. All three crops were grown at two locations, maize and sorghum only at 11 locations and maize and pearl millet only at one location. Crops were planted and tilled according to standard practices that varied somewhat by region.

Grain was harvested at plant maturity and stored in paper bags at 4°C until analyzed. One hundred kernels of each sample were placed on moist filter paper in a petri dish and incubated for 6 days on a laboratory bench at 25-28°C. The proportion of kernels infested with one or more *Aspergillus* spp., one or more *Fusarium* spp., and free of any fungal contamination was determined. This method underestimates the frequency of *Fusarium* in millet and sorghum as it often is outcompeted by other faster growing fungi that are already present.

Five hundred grams of grain from each sample was ground to a fine powder and passed through a 20-mesh sieve. One g of the powder was suspended in sterile H2O to make 10 ml total volume. Ten µl of the suspension was spread on plates of a medium selective for *Aspergillus*. The number of colony forming units (cfu) of A. flavus "S" (more toxigenic) and "L" (less toxi-genic) types, *A. parasiticus* and *A. tamarii* determined based on their morphology and toxin production potential. Twenty g of powdered grain was extracted by blending at high speed with 100 ml of 70% methanol for 3 min. The slurry was allowed to settle, the supernatant was filtered through filter paper, and 15 ml of the filtrate used for further evaluation. Aflatoxin was measured by using a commercial ELISA kit and following the manufacturer's instructions. Results are based on a standard curve with OD450 as the measure of aflatoxin present. Samples with more aflatoxin than that in the most concentrated standard were diluted and reassayed. The minimum detection limit was 1 ng/g. The amount of variation between subsamples was < 15%. Based on spiked recovery controls, ≥ 80% of the aflatoxin present was recovered by this method.

The field work was done in Nigeria and organized by IITA. Toxin analyses were conducted at IITA (for aflatoxin) and at MRC in South Africa (fumonisins). Book editing has been done primarily at KSU with assistance from colleagues at IITA in Nigeria and at ISPA in Italy. Authors were from 23 countries in North America, Europe and Asia, and included economists, plant pathologists, plant breeders, chemists, policy makers and politicians.

### *Strengthening Research Capacity*

Present workshops on Scientific Writing and Scientific Research Ethics as requested. Organize annual Fusarium Laboratory workshop.

## Research results

### *Species Identification*

A large pre-existing fungal population isolated from sorghum stored on farm in rural Mali is being analyzed for DNA polymorphisms and species identification. All cultures have been cleaned and purified by the micromanipulation of single spores to yield pure cultures. DNA has been extracted from most of the nearly 1200 strains, some AFLP comparisons have been run, enabling preliminary working groups of strains to be identified. These AFLP comparisons are being rerun with different primer pairs to confirm the preliminary results. Most of the observed patterns are significantly different from those of known species. A group of 400 strains from finger millet collected in Uganda are at a similar state of evaluation. We have done enough molecular work to have identified two putative new species, one from each set of strains. The finger millet strain appears to be limited to Uganda, but the sorghum strain has a broader distribution and includes isolates from Egypt and East Africa in addition to those from West Africa. Mating type tester isolates are being developed for both species. Both species are a part of the Liseola section of the genus, i.e., the section to which most of the other *Fusarium* strains isolated from sorghum belong.

### *Fungal Localization and Caryopsis Health*

This work has just begun this year at KSU. Work at the University of the Free State has been planned and will parallel the work to be done in Kansas, but is waiting for a student to do the work to be identified. To date, data from caryopsis tissue studies at KSU, indicates that most of fungi derived from undamaged sorghum seeds are found in black layer tissues.

### *Mycotoxin Contamination*

Edited book on mycotoxins is complete and will be published by CABI in 2008.

Sorghum, maize and pearl millet grain all could be contaminated with *Aspergillus*, *Fusarium* and other species of filamentous fungi, but these species were not equally present on all of the grains. Kernels of maize were four- and nine-fold more likely to be contaminated with *Aspergillus* than were comparable samples of sorghum and pearl millet, respectively, and 1.8-fold more likely to be contaminated with *Fusarium* than sorghum and pearl millet. Sorghum, however, was more likely to be contaminated with other filamentous fungi than were either maize or millet. Within the *Aspergillus* species recovered, the *A. flavus* "L" type was always dominant (> 80%) with one or two of the other types occasionally isolated, but never at a frequency > 17% of the total.

Average aflatoxin contamination was much higher in maize (36 ng/g) than in either sorghum (8.8 ng/g) or pearl millet (4.6 ng/g). The median amount of aflatoxin in a sample was similar for all three grains (4.2 ng/g, 5.0 ng/g and 4.4 ng/g, respectively), suggesting that the major problem was with samples that were heavily contaminated. Of the 23 maize samples, four (17%) exceeded the 20 ng/g FAO guideline as did two (5%) of the 40 sorghum samples and none of the pearl millet samples. In addition to having a higher proportion of samples that did not meet the guidelines, maize samples also contained higher levels of aflatoxin than did non-conforming sorghum samples. Maize samples could have up to 24-fold the recommended max-imum aflatoxin level, while those for sorghum (4.5-fold) were considerably less heavily contaminated with aflatoxin even at their worst. The likelihood of aflatoxin exposure to humans from maize is particularly high in zones where the frequency of maize consumption, the presence of aflatoxin in maize or the presence of *A. flavus* on maize is relatively high. The levels of aflatoxin we measured would be the lowest possible, as toxin levels may increase, but may not decrease, during storage. The toxin levels we measured will be higher than those observed in most commercial markets because the grain will be sorted at the farm level before being sold, with the better quality grain being sold for commercial purposes and the poorer quality grain being retained for on-farm consumption.

### *Strengthening Research Capacity*

Workshops held and number of attendees included in non-degree training report.

## Networking Activities

### *Editorial and Committee Service (2007)*

- Editor, Food Additives and Contaminants (2006-2009)
- International Society for Plant Pathology, Fusarium Committee (2000-2007)
- MycoGlobe Steering Committee (2003-2007)
- MycoRed Steering Committee (2007-2013)

### *Research Investigator Exchanges (2007)*

- Australia – August 25 - September 6
- Italy – September 30 - October 6
- Malaysia – September 6-13
- Netherlands – September 26-30
- Norway – March 10-18
- People's Republic of China – April 22-30
- South Africa – November 2-19
- South Korea – April 30 - May 5

### *Other Collaborating Scientists (Host Country)*

- Dr. Sofia Chulze, Department of Microbiology, National University of Rio Cuarto, Rio Cuarto, Argentina.
- Dr. Sandra Lamprecht, Plant Protection Institute, Agricultural Research Council, Stellen-bosch, South Africa.
- Drs. Yin-Won Lee & Jungkwan Lee, Dept. of Plant Pathology, Seoul National University, Seoul, South Korea.
- Drs. Antonio Logrieco, Antonio Moretti & Giuseppe Mulé, Inst. Sci. of Food Production, CNR, Bari, Italy.
- 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 Tony Glenn, USDA Russell Research Center, Athens, Georgia
- Dr. Gary N. Odvody, Texas Agricultural Experiment Station, Corpus Christi, Texas

### *Recipients of Fusarium Cultures in 2007 (Other than Collaborators)*

- Ridao Azucena, University of Buenos Aires, Buenos Aires, Argentina.
- Alison Bentley, Faculty of Agriculture, University of Sydney, Sydney, Australia.
- David Geiser, Pennsylvania State University, University Park, Pennsylvania.
- Fungal Genetics Stock Center, University of Missouri-Kansas City, Kansas City, Missouri.
- Bian Jiang, Chinese Academy of Sciences, Beijing, People's Republic of China.
- Ralf Kristensen, Institute of Veterinary Medicine, Oslo, Norway.
- Randy C. Ploetz, Tropical Research & Education Center, Univ. of Florida, Homestead, FL.
- David Schmale, Dept. Plant Pathol. & Weed Science, Virginia Tech. Univ., Blacksburg, VA.
- Keith Seifert, Agriculture and Agri-Foods Canada, Ottawa, Ontario, Canada.
- Amir Sharon, Department of Plant Sciences, University of Tel Aviv, Tel Aviv, Israel.
- Frances Trail, Department of Plant Pathology, Michigan State University, East Lansing, MI.
- Bettina Tudzynski, Westfaelische Wilhelms University, Muenster, Germany.
- Cees Waalwijk, DLO Institute for Plant Protection, Wageningen, The Netherlands.

## Publications and Presentations (2007)

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

- Bioforsk, Ås, Norway – 03/07
- College of Life Sciences, Dalian Nationalities University, Dalian, China – 04/07
- Shenyang Agricultural University, Shenyang, China – 04/07. Faculty of Agricultural & Life Sciences, Seoul National University, Seoul, Korea – 05/07
- FABI, University of Pretoria, Pretoria, South Africa – 11/07.

## Journal Articles (2007)


Bandyopadhyay, R., M. Kumar & J. F. Leslie. 2007. Relative severity of aflatoxin contami-nation of cereal crops in West Africa. Food Additives and Contaminants 24: 1109-1114.

Hornok, L., C. Waalwijk & J. F. Leslie. 2007. Genetic factors affecting sexual reproduction in toxigenic Fusarium species. International Journal of Food Microbiology 119: 54-58.

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*. Journal of Basic Microbiology 47: 16-24.

Leslie, J. F., L. L. Anderson, R. L. Bowden & Y.-W. Lee. 2007. Inter- and intra-specific genetic variation in Fusarium. International Journal of Food Microbiology 119: 25-32.

Ramirez, M. L., M. M. Reynoso, M. C. Farnochi, J. F. Leslie & S. N. Chulze. 2007. Population genetic structure of Gibberella zeae from wheat in Argentina. Food Additives and Con-taminants 24: 1115-1120.


## Abstracts (2007)


Anderson, L. L., Y.-W. Lee, R. L. Bowden & J. F. Leslie. 2007. Relationships between al-leles at lineage diagnostic loci in *Fusarium graminearum*. Fungal Genetics Newsletter 54(Suppl.): 67.

Lee, J., R. L. Bowden & J. F. Leslie. 2007. Pheromone functions in Gibberella zeae. Fungal Genetics Newsletter 54(Suppl.): 134.

Lee, J., J. F. Leslie & R. L. Bowden. 2007. Functions of the sex pheromones of Gibberella zeae. Proceedings of the 2007 National Fusarium Head Blight Forum (Kansas City, Mis-souri): 30.

Reynoso, M. M., M. L. Ramirez, J. F. Leslie & S. N. Chulze. 2007. Trichothecene chemo-types of isolates of Gibberella zeae recovered from wheat in Argentina. Proceedings of the 2007 National Fusarium Head Blight Forum (Kansas City, Missouri): 34.

Swett, C., L. L. Anderson, J. F. Leslie & J. Y. Uchida. 2007. Evaluating genetic diversity of *Fusarium proliferatum* from orchids in Hawaii. Fungal Genetics Newsletter 54(Suppl.): 69.

# Ecologically-Based Management of Sorghum and Pearl Millet Insect Pests in Africa and the United States

## Project WTAMU 101

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Dr. Gerald J. Michels, Jr. – Entomologist, Texas AgriLife Research, Amarillo, TX 79106
Dr. Roxanne A. Bowling – Extension-Agent Pest Management/Entomologist, Texas AgriLife Extension, 310 E. 1st Street, Room 100, Dumas, TX 79029
Dr. Michael W. Pendleton – Electron Microscopist, Microscopy and Imaging Center, Texas A&M University, College Station, TX 77843-2257


### Introduction and Justification

Entomologists, breeders, pathologists, economists, and extension agents in Mali, Niger, Mozambique, Botswana, and the U.S. are educating students and farmers in IPM and developing, evaluating, and transferring pest management technologies for insects of sorghum and millet. Development and adoption of ecologically-based technologies will decrease loss by insects in the field and storage, reduce pesticide use, conserve soil and water without contamination by pesticides, and increase yield of food and feed for domestic use and income from marketing. Sorghum and millet are damaged by such biotic stresses as larvae of shoot fly, *Atherigona soccata*, that kill the growing point of seedlings. Greenbug, *Schizaphis graminum*, in the U.S. and sugarcane aphid, *Melanaphis sacchari*, in Africa suck juice from leaves and vector viruses. Banks grass mite, *Oligonychus pratensis*, kills leaves and causes lodging. Bollworms such as *Heliothis armigera* eat leaves and kernels. Larvae of sorghum midge, *Stenodiplosis sorghicola*, feed on the ovary and can cause 100% loss of grain. Armoured bush cricket, *Acanthoplus discoidalis*, eats developing kernels. Larvae of millet head miner, *Heliocheilus albipunctella*, tunnel in spikes. Southwestern corn borer, *Diatraea grandiosella*, in the U.S. and maize stalk borer, *Busseola fusca*; and spotted stem borer, *Chilo partellus* in Africa tunnel in stalks, causing susceptibility to disease and lodging. Grain storage can take advantage of greater market price but result in more damage by insects that annually destroy 35% of grain worldwide. Pests of stored grain include the maize weevil, *Sitophilus zeamais*.

### Objectives and Implementation Sites

This project is contributing to INTSORMIL objectives to facilitate markets by managing insects that damage yield and quality of sorghum and millet; improve food and nutritional quality to enhance marketability and consumer health by grain not contaminated by pests or pesticides; increase stability and yield through crop and natural resources management by IPM strategies not dependent on pesticides; develop and disseminate information on biotic stresses to increase yield and quality by integrated management strategies against insects; enhance stability and yield through genetic technologies by determining differences among strains of insects and speeding development of resistant cultivars with yield and quality; and develop partnerships with agencies improving sorghum and millet and betterment of people through collaboration among scientists at West Texas A&M University, Texas AgriLife Research and Extension, and Texas A&M University in the US and Institut D'Economie Rurale in Mali, Institut National de la Recherche Agronomique du Niger, Instituto de Investigacao Agraria de Mocambique, Botswana College of Agriculture, private industries, volunteer organizations, and other agencies.

Specific objectives of this project were to: 1) support entomology and IPM research and education of scientists in African countries; 2) collaborate with scientists in Africa and the U.S. to develop and deliver IPM strategies against insects that damage sorghum and millet in the field and storage by improved understanding of biology, ecology, and population dynamics of insect pests and damage they cause; evaluation of potential arthropod pests; agronomic practices to prevent damage by insects and reduce pesticides; cultivars with greater yield and resistance to biotic and abiotic stresses; 3) provide education for students; and 4) develop partnerships with ICRISAT and PVOs engaged in improvement of sorghum and millet production and betterment of people. By presentations and publications, extension and other agencies will be assisted with transferring pest management information to farmers, scientists, and others in Africa and the U.S.

## Research Methodology and Strategy

### *Evaluating Potential Pests and Understanding the Life Histories of Insect Pests and Natural Enemies*

Populations of Banks grass mites were monitored for resistance to miticides on the Texas High Plains. Natural enemies of sorghum aphids were assessed by Dr. Munthali in Botswana. Using agronomic practices to manage pests. Intercropping grasses to draw stalk borers from sorghum or millet was evaluated by Dr. Yaro Diarisso in Mali and planned with Mr. Chitio in Mozambique. Developing germplasm resistant to biotic constraints. The PI and African entomologists collaborated with breeding projects in Mali, Mozambique, Niger, and Texas, and Milo Genetics for evaluating sorghum and millet for resistance to millet head miner, sorghum midge, greenbug, sugarcane aphid, shoot fly, stalk borers, and storage beetles. Studying pests of stored grain. Effectiveness of facilities against insect damage to stored sorghum and millet grain were evaluated in Africa. M.S. student Madani Telly studied when storage insects infest sorghum in the field and evaluated resistance to maize weevils. Microscopy was used by Dr. Michael Pendleton to relate starch and seed morphology to resistance to maize weevil.

### *Identifying and Evaluating Current and Novel Pest Management Tactics*

Ph.D. student Tebkew Damte Belete assessed whether spectrophotometry of phytochrome could be used to predict daily flowering times of sorghum and resistance to sorghum midge. M.S. student Camilo Garzon used pheromones to monitor seasonal abundance of southwestern corn borer moths in Texas. Pheromones were evaluated by Dr. Munthali to monitor lepidopteran pests of sorghum in Botswana.

### *Transferring Insect Pest Management Technologies*

Field demonstrations, workshops, and training manuals were used or being prepared to teach farmers to recognize and analyze pest problems and evaluate, adapt, and implement IPM options. Undergraduate and graduate university students in the U.S., Botswana, and Niger assisted with the research and were educated in entomology and IPM.

## Research Results

In Botswana, Dr. Munthali found shoot fly and stalk borers attacked sorghum 26-38 days after planting, while sugarcane aphid attacked at the milk stage. Blue panicle bug, armoured bush cricket, and birds attacked during grain filling to harvest. Panicle pests caused total loss. (Table 1)

Dr. Yaro assisted farmers with using Andropogon gayanus in 3 border rows 50 cm apart with 30 cm between plants planted on 7 and 8 July at Finkolo and Zanradougou in the Sikasso region of Mali, to attract stalk borers away from millet. Andropogon was attractive to stalk borers and/or parasitoids and selected by farmers for use and economic return. A randomized complete block with 5 farms was used. Millet was planted on 17 and 18 July in 15 x 10-m plots 2 m apart at Zanradougou and Finkolo. Millet was surrounded by Andropogon or millet (check). Pests and natural enemies were sampled on 10 plants 30, 70-80, and 100-110 days after emergence. Percentage of deadhearts and numbers of larvae and pupae were determined on 6 and 7 September, 30 days after emergence at Zanradougou and Finkolo. Damage was greater at Finkolo. Millet was less damaged surrounded by Andropogon (1.7%) than millet (5.3%). Damage scores were 5.8, 4.4, and 1.7 for millet surrounded by millet, Andropogon, and millet surrounded by Andropogon at Finkolo. Damage at Zanradougou was 4.7, 2.2, and 1.7 for millet surrounded by millet, Andropogon, and millet surrounded by Andropogon. (Table 2)

Rows of Desmodium grass as a border to trap stalk borers were planted before sorghum by Mr. Chitio in Mozambique. Rains stopped and sorghum died; the experiment will be repeated.

Serere and Tswana millets were planted in 3, 10 x 10-m plots by Dr. Munthali in Botswana. Seeds were sown 50 cm between plants in rows 80 cm apart. Pests were counted on 10 plants per plot. Ranges of 0-5 and means of 1.1 ± 0.4 and 1.0 ± 0.56 armoured bush crickets were found per plant of Tswana and Serere, respectively, that were equally susceptible.

Mr. Abdou Kadi Kadi, with Dr. Kadri Aboubacar and an intern from the University Abdou Moumouni at Niamey, evaluated at INRAN Kollo resistance to millet head miner of millet developed with Issaka Ahmadou, millet breeder. Millets evaluated were HKB, H80-10GR, TARAM, SOSAT–C, MANGARANA, HKP-GMS, ICMV IS89305, ZATIB, MANGARANA x ICMV IS89305, SOSAT-C x HKB, SOSAT-C x ZATB, and TCHOUMO. A completely randomized block with 3 replications was used.

**Table 1.**

| | Period of attack | | | |
|---|---|---|---|---|
| **Pest species** | **First day on sorghum** | **Damaging time (day after planting)** | **Stage of growth of sorghum attacked** | **Plant part damaged** |
| Shoot fly | 5 February | 26 | Seedling to vegetative | Shoot |
| Sorghum stalk borer | 5 February | 26 | Seedling to vegetative | Leaf, stem |
| Sugarcane aphid | 29 February | 50-69 | Milk (panicle formation) | Leaf |
| Blue bug, Calidea sp. | 4 April | 85-120 | Milk-dough (grain fill) | Kernels |
| Armoured bush cricket | 4 April | 85-120 | Milk-dough (grain fill) | Kernels |
| Quelea quelea birds | 4 April | 85-120 | Milk-dough (grain fill) | Kernels |

**Table 2.**

| Village | Farmer | % vegetative plants with deadhearts by stalk borers | | |
|---|---|---|---|---|
| | | Millet surrounded by Andropogon gayanus | Millet surrounded by millet | Andropogon gayanus |
| Finkolo | Diakalia Ballo | 1.5 | 10.3 | 2.0 |
| | Issouf Ballo | 1.5 | 4.3 | 3.0 |
| | Abdoulaye Kone | 2.8 | 5.2 | 5.5 |
| | Seybou Kone | 2.3 | 6.6 | 7.1 |
| | Oumar Traore | 0.5 | 2.5 | 4.6 |
| Zanradougou | Nouhoum Djourthe | 3.7 | 0.0 | 1.2 |
| | Siaka Djourthe | 0.0 | 12.5 | 3.0 |
| | Tidiani Sanogo | 1.5 | 1.5 | 2.4 |
| Mean damage | | 1.7 | 5.3 | 3.6 |

Each sub-plot 12 m2 had 4 rows 3 m long, with 1 m between rows and 1 m between hills. Yield will be recorded when the millet is harvested.

The PI evaluated 402 sorghum lines developed by Milo Genetics for resistance to greenbug biotype I and found 52.5% as, or more, resistant than the resistant check. Results were reported to Milo Genetics for release of sorghums produced from the lines to farmers in the U.S.

Mr. Abdou Kadi Kadi involved 4 extension agents, 12 men and 4 women farmers from 4 villages, and TAYMAKO farmer's association of 74 men and 6 women to introduce sorghum midge-resistant 99-SSD35 and its early parent Mota Maradi at farms in 5 villages in 2 regions of Niger. The group did 4 tests with 2 planting dates at a site. Farmers at one site are producing SSD35 in many fields. The farmer's association and FAO grew 60 and 30 hectares of 99-SSD35 to provide seed for farmers. The sorghum is not mature and yield data not available yet.

Sorghum genotypes in the Midge Line Test differed in resistance to sorghum midge (F = 2.1, P = 0.0048) and stalk borers (F = 5.57, P = 0.0001) in Mozambique. Four resistant sorghums scored 1.0/5 for damage by sorghum midge and one scored 1.0 for stalk borers. Lines 03LI6220.21 (1.0 score) and 03LI6206.07, 03LI6201, and 03LI6150.51 (1.5 score) were least damaged by stalk borers (F = 1.64, P = 0.21) in the All Disease and Insect Nursery.

Twenty-five ICRISAT Kenya sorghum varieties differed in damage by shoot flies (F = 2.3, P = 0.007) and stalk borers (F = 1.78, P = 0.045) at Namialo, Mozambique. ICSV700, ICSB654, ICSB324, and SPV1411 were resistant to shoot flies. S35,

**Table 3.**

| Sorghum | Damage (1-5) by shoot fly | Damage (1-5) by stalk borers |
|---|---|---|
| ICSV700 | 1.0 e | |
| S35 | | 1.0 d |
| ICSB654 | 1.3 de | 1.0 d |
| IESB92008DL | 2.7 bcd | 1.3 cd |
| SPV1411 | 1.7 cde | 3.0 a |
| IESB91104DL | 4.3 a | 2.7 a |
| Local check | | 2.7 a |
| CV% | 38.6 | 37.2 |

**Table 4.**

| Sorghum | Sugarcane aphid damage (1-5) | Sorghum midge damage | Stalk borer damage |
|---|---|---|---|
| 03CS487 | 1.0 c | 1.0 d | 1.0 c |
| 03BRON245 | 1.0 bc | 1.0 cd | |
| 02CS30736 | 1.0 bc | | |
| 02CS5247 | 1.0 bc | | |
| 01CS22295 | | | 1.0 bc |
| 98LB1886-B | | | 1.0 bc |
| 03CS174 | 1.25 abc | 1.0 cd | |
| 00CS21492 | 1.25 abc | 1.0 cd | 2.5 ab |
| BOTT75-B | | 2.5 a | |
| 02CS4495-1 | 2.0 a | | 3.0 a |
| 98LB2838B | 2.0 a | | 3.0 a |
| CV% | 39.4 | 32.5 | 48.4 |

ICSB654, and ICSB324 were resistant to stalk borers. ICSB654 and ICSB324 were resistant to both pests. (Table 3)

Varieties 03CS487, 02CS30736, 03BRON245, 02CS5247, and 00CS21492 were resistant to sugarcane aphid; 03CS487, 00CS21492, 03BRON245, and 03CS174 to sorghum midge; and 03CS487, 01CS22295, 98LB1886-B, and 01CS20804 to stalk borers in the Drought Line Test in Mozambique. Variety 03CS487 was resistant to the three pests. (Table 4)

Varieties 03CS-GWT115, 03CS-GWT102, 02CS-30455, and 01CS-20528 were resistant to sugarcane aphid (F = 6.36, P = 0.0024); 02CS-30455, 01CS-20528, 02CS20550, and 03CS3 to sorghum midge (F = 7.13, P = 0.0015); and 03CS234, 03CS-GWT115, and 02CS20550 to stalk borers (F = 11.02, P = 0.0002) in the Grain Weathering Test in Mozambique. Variety 02CS20550 was resistant to sorghum midge and stalk borers. (Table 5)

Seventy sorghum genotypes from the U.S. breeding program differed in damage by stalk borers in Mozambique (F = 4.24, P = 0.0001). Genotypes 04CS826-1-1, 04CS58-6-1, 04CS608-7-1, and 04CS804-2-1 were scarcely damaged (1-1.5 scores), while 04CS452-4-1 scored 3.75.

Three SADC varieties and 50 Texas-bred sorghum lines were evaluated by Dr. Munthali for resistance to aphids, shoot fly, and stalk borers in Botswana. Each genotype was planted in 3, 7-m rows in a completely randomized block. Damage was assessed on 5 plants per plot. Texas 06L12661, 07CA20174-BK, 07CA20053-BK, and 07CA20187-BK were most infested with sugarcane aphids (72.1, 61.1, 57.2, and 55.5% of plants) and most damaged (2.5, 2.2, 1.9, and 1.8 scores). *Coccinellids Chilopomenes lunata*, *Dysis quadrilineata*, *Exochomus flavipes*, and *Exochochomus nigromaculatus* were abundant. Most predators were on 07CA20021-BK (58.3% of plants). Predators were on >30% of plants of 06PR420, 07CA20019-BK, 07CA20053-BK, 07CA20114-BK, 07CA20126-BK, 07CA20168BK, 07CA20175-BK, and 07L13471-BK. Damage by sugarcane aphids was not severe enough (1.2 score) to cause significant yield loss. (Table 6)

M.S. student Madani Telly from Mali found fewest live (1.6 and 2.0) or total maize weevils (1.9 and 2.0) in grain of Tx7078 and BTx2959. Most dead weevils (1.9) were in PM12713* Tx2882. BTx2959 and Tx7078 were least damaged (1.2 and 1.3 scores) and lost least weight (0.8-1.6%). Dr. Michael Pendleton is relating starch in the sorghums to resistance to weevils. (Table 7)

A survey of 290 men and 30 women farmers from 16 villages in 2 regions by Mr. Abdou Kadi Kadi, 14 extension agents, and 4 interns from University Abdou Moumouni, Niamey identified storage insects, evaluated facilities, and assessed botanicals and cultural methods to prevent damage to sorghum and millet. Andropogon and stalks were used for cylindrical granaries at Maradi and bricks with a grass cover were used at Tahoua. Dry spikes and/or panicles were stored. Grain was stored in barrels, burlap bags, plastic bags, and storage houses. (Table 8)

Dr. Munthali used pheromones to trap lepidopteran pests in sorghum in Botswana. Moths were first trapped 50 days after planting. Spotted stem borer, *C. partellus* was most abundant, especially in mid-May and increased 10-fold between February and June. Early detection will enable timing of management for eggs and early instars. Bollworm, *H. armigera* was minor. (Table 9)

A M.S. student from Colombia monitored southwestern corn borer moths in pheromone traps from June to September in Texas. Numbers of moths varied among locations and differed with weather. Moths of the 1st generation were trapped from late-June until mid-July. Second-generation moths were trapped from the 1st week of August through 1st week of September, with most in mid-August. Plants were checked for eggs and larvae. The 1st larva was found 28 July.

Ph.D. student Tebkew Damte Belete from Ethiopia found that at 0600, 0900, 1200, 1800, and 2400 hours, phytochrome of susceptible RTx430 that flowers at daylight when sorghum midges are ovipositing was 1.7 times more than resistant TAM2566 that flowers at night. Resistant A8PR1013 x Tx2882 had 2.3 times more phytochrome than susceptible ATx399 x RTx430. All spikelets of TAM2566 and RTx430 closed before 0600 and 1000 hours, respectively.

Tebkew Belete surveyed sorghum farmers in Texas and found 54.1, 2.8, and 29.2% believed sorghum midge was a pest of dryland sorghum, irrigated, and both. Estimates of yield loss ranged from 0-40%. Most farmers (97%) scouted their sorghum. Two-thirds applied insecticide 1-3 times. Dr. Lal Almas, Agricultural Economist at West Texas A&M University, assisted with compar-

**Table 5.**

| Sorghum | Sugarcane aphid damage (1-5) | Sorghum midge damage | Stalk borer damage |
|---|---|---|---|
| 02CS-30455 | 1.0 b | 1.0 c | 1.25 de |
| 03CS234 | 1.25 b | 1.25 bc | 1.0 e |
| 02CS20550 | 1.25 b | 1.0 c | 1.25 de |
| 01CS-20528 | 1.0 b | 1.0 c | 1.5 cde |
| 03CS-GWT115 | 1.0 b | 1.75 b | 1.0 e |
| 02CS30425 | 1.25 b | 1.25 bc | 1.25 de |
| 02CS-30445 | 1.5 b | 1.25 bc | 1.5 cde |
| 03CS-GWT102 | 1.0 b | 1.75 b | 1.75 bcd |
| 01CS20529 | 1.25 b | 1.25 bc | 2.25 b |
| 03CS3 | 1.75 b | 1.25 bc | 3.25 a |
| 03CS6 | 3.5 a | 3.0 a | 2.0 bc |
| CV% | 29.7 | 20.8 | 16.8 |

**Table 6.**

| Sorghum genotype | % plants with shoot fly 50 DAP | % plants with stalk borer 50 DAP | % plants with sugarcane aphid 50 DAP | Overall damage score by aphids | Overall % plants with coccinellids |
|---|---|---|---|---|---|
| 05L1384 | 8.3 | 9.3 | 13.1 | 1.1 | 6.6 |
| 06PR397 | 13.9 | 13.3 | 8.3 | 1.0 | 12.2 |
| 06PR399 | 12.3 | 18.9 | 40.3 | 1.2 | 29.6 |
| 06PR405 | 0.0 | 23.4 | 18.6 | 1.1 | 27.3 |
| 06PR398 | 4.9 | 0.0 | 6.7 | 1.0 | 7.9 |
| 06PR414 | 3.7 | 17.8 | 20.0 | 1.0 | 14.0 |
| 06PR404 | 0.0 | 59.2 | 13.1 | 1.0 | 16.7 |
| 06PR415 | 0.0 | 0.0 | 0.0 | 1.0 | 7.8 |
| 06PR419 | 8.3 | 17.9 | 22.2 | 1.0 | 8.3 |
| 06PR420 | 4.8 | 25.0 | 14.3 | 1.0 | 32.7 |
| 05L1390 | 12.2 | 16.7 | 50.0 | 1.0 | 27.8 |
| 06L12661 | 25.0 | 12.4 | 78.0 | 2.5 | 12.5 |
| 07CA20013-BK | 0.0 | 0.0 | 33.3 | 1.0 | 25.0 |
| 07CA20016-BK | 33.3 | 13.3 | 13.3 | 1.0 | 6.7 |
| 07CA20019-BK | 0.0 | 0.0 | 33.3 | 1.0 | 33.3 |
| 07CA20021-BK | 0.0 | 25.0 | 8.3 | 1.0 | 58.3 |
| 07CA20042 | 5.5 | 12.2 | 16.7 | 1.0 | 22.9 |
| 07CA20043 | 0.0 | 16.7 | 16.7 | 1.0 | 16.7 |
| 07CA20053-BK | 16.7 | 4.8 | 42.9 | 1.9 | 30.5 |
| 07CA20057-BK | 6.7 | 12.0 | 28.9 | 1.1 | 29.7 |
| 07CA20061-BK | 0.0 | 0.0 | 11.1 | 1.0 | 13.9 |
| 07CA20062-BK | 22.2 | 16.7 | 16.7 | 1.0 | 29.4 |
| 07CA20065-BK | 8.3 | 6.7 | 15.0 | 1.0 | 3.3 |
| 07CA20067-BK | 0.0 | 11.1 | 0.0 | 0.0 | 17.0 |
| 07CA20072- BK | 21.4 | 4.8 | 4.8 | 1.0 | 2.4 |
| 07CA20088-BK | 21.4 | 4.8 | 0.0 | 1.1 | 22.2 |
| 07CA20089-BK | 0.0 | 20.0 | 17.8 | 1.0 | 15.6 |
| 07CA20096-BK | 0.0 | 44.4 | 6.1 | 1.0 | 4.6 |
| 07CA20099-BK | 0.0 | 11.1 | 0.0 | 1.0 | 16.7 |
| 07CA20101-BK | 11.1 | 11.1 | 5.6 | 1.2 | 16.7 |
| 07CA20114-BK | 11.1 | 11.1 | 0.0 | 1.3 | 33.3 |
| 07CA20122- BK | 13.3 | 0.0 | 20.0 | 1.3 | 10.0 |
| 07CA20123-BK | 0.0 | 0.0 | 16.7 | 1.0 | 8.3 |
| 07CA20126-BK | 15.0 | 0.0 | 35.0 | 1.3 | 32.5 |
| 07CA20153-BK | 0.0 | 0.0 | 22.2 | 1.0 | 11.1 |
| 07CA20161-BK | 0.0 | 22.2 | 33.3 | 1.0 | 16.7 |
| 07CA20165-BK | 33.3 | 0.0 | 0.0 | 0.0 | 0.0 |
| 07CA20168-BK | 11.1 | 22.2 | 33.3 | 2.2 | 39.3 |
| 07CA20174-BK | 22.2 | 0.0 | 16.7 | 1.1 | 25.6 |
| 07CA20175-BK | 8.3 | 26.8 | 5.6 | 1.0 | 32.9 |
| 07CA20177-BK | 0.0 | 21.7 | 23.3 | 1.0 | 12.5 |
| 07CA20181-BK | 0.0 | 0.0 | 33.3 | 1.0 | 0.0 |
| 07CA20187-BK | 15.9 | 11.4 | 54.0 | 1.8 | 15.9 |
| 07CA20223- BK | 0.0 | 0.0 | 0.0 | 1.0 | 0.0 |
| 07L13467-BK | 11.1 | 9.7 | 21.4 | 1.0 | 19.6 |
| 07L13468-BK | 3.3 | 8.3 | 12.4 | 1.0 | 18.6 |
| 07L13469-BK | 6.2 | 8.3 | 4.2 | 1.5 | 15.0 |
| 07L13470-BK | 0.0 | 32.2 | 18.9 | 1.1 | 29.4 |
| 07L13471-BK | 5.6 | 44.4 | 5.6 | 1.0 | 52.8 |
| 07L13472-BK | 0.0 | 15.1 | 13.9 | 1.0 | 12.5 |
| BSH1 | 22.5 | 29.2 | 39.1 | 2.0 | 20.9 |
| Mmabaitse | 57.1 | 0.0 | 42.9 | 1.4 | 23.8 |
| Macia | 16.7 | 26.8 | 31.7 | 1.8 | 29.0 |
| Overall mean | 9.3 ± 1.55 | 13.6 ± 1.77 | 19.6 ± 2.22 | 1.2 ± 0.05 | 19.4 ± 1.59 |

**Table 7.**

| Sorghum genotype | Maize weevils per gram | Damage score (1-5) | Weight loss (g)/5 g |
|---|---|---|---|
| Tx7078 | 1.9 ± 0.65 f | 1.3 ± 0.20 ef | 0.04 ± 0.07 c |
| BTx2959 | 2.0 ± 0.76 ef | 1.2 ± 0.19 f | 0.08 ± 0.09 c |
| BTx645 | 6.3 ± 1.50 d-f | 1.7 ± 0.27 d | 0.6 ± 0.16 b |
| SDSL89426 * 60B124 | 7.3 ± 1.73 d-f | 1.8 ± 0.45 cd | 0.7 ± 0.17 b |
| SV1 * Sima | 8.5 ± 2.47 de | 1.5 ± 0.28 de | 0.7 ± 0.21 b |
| Sureno | 8.3 ± 1.44 d-f | 1.5 ± 0.22 de | 0.8 ± 0.12 b |
| CE151 * TAM428 (06PR410) | 10.0 ± 1.57 cd | 1.7 ± 0.26 cd | 0.9 ± 0.16 b |
| Segaolane * WM#322 | 8.3 ± 1.52 d-f | 1.8 ± 0.27 cd | 0.9 ± 0.15 b |
| Macia * TAM428 | 9.1 ± 2.54 d | 1.9 ± 0.39 b-d | 0.9 ± 0.24 b |
| ICSR-939 | 16.4 ± 2.32 bc | 2.1 ± 0.21 bc | 1.4 ± 0.15 a |
| CE151 * TAM428 (06PR407) | 16.7 ± 2.22 b | 2.2 ± 0.30 ab | 1.4 ± 0.19 a |
| PM12713 * Tx2882 | 23.7 ± 5.08 a | 2.5 ± 0.36 a | 1.7 ± 0.33 a |
| 87EON366 * 90EON328 | 24.9 ± 3.19 a | 2.4 ± 0.23 a | 1.9 ± 0.16 a |

**Table 8.**

| Pests | Botanical plants/methods of use | Inert |
|---|---|---|
| Grain moth, *Sitotroga cereallella*; | Cowpea, *Vigna inguiculata,* leaves repulse storage pests; Zouray, *Boscia Salicifolia,* leaves under spikes or panicles during drying, leaves | Ash, |
| Confused flour beetle, *Tribolium confusum*; | superposed between tied spikes or panicles within granary; Yakuwa, *Hibiscus sabdariffa,*leaves and branches pounded and put on granary poles; | Salt, |
| Red flour beetle, *Tribolium castaneum*; | Karanguia, *Cenchrus biflorus,* spiny fruit used on path of mice and rats; Komeya, *Erasgrostis tremula*, threading of the superior part of *Erasgrotis* and | Ash and salt mix to |
| Lesser grain borer, *Rhyzopertha dominica*; | superposed between tied spikes or panicles in granary; Dorowa, *Parkia biglobos*, fruit pounded and powder used around granary poles; | control termites |
| Grain trogoderma, *Trogoderma granarium*; | Rumfu, *Cassia singueana,* and neem, *Azadirachta indica*, flowers of *Cassia* and leaves of neem mixed with seeds of cereals; | and ants, |
| Flour pyralid, *Ephestia kuehniella*; | Houda Sartche, *Caralluma dalzielli*, leaves and branches pounded and put in granary poles; | Fine sand, |
| Birds; | Onion, *Allium cepa,* and garlic, *Allium sativum,* powder to prevent damage | Sun drying |
| Mice; | | |
| Rats; | | |
| Mold; | | |
| Humidity | | |

**Table 9.**

| Assessment date | Day after planting | Sorghum growth stage | Number of moths of each species | | |
|---|---|---|---|---|---|
| | | | *C. partellus* | *B. fusca* | *H. armigera* |
| 10 January | Planting date | Seed | 0 | 0 | 0 |
| 5 February | 26 | Seedling | 0 | 0 | 0 |
| 17 February | 38 | Vegetative | 0 | 0 | 0 |
| 29 February | 50 | Panicle forming | 2 | 1 | 2 |
| 19 March | 69 | Milk stage | 2 | 1 | 0 |
| 4 April | 85 | All plants with panicles | 3 | 2 | 0 |
| 9 May | 120 | Kernel maturation | 19 | 2 | 3 |
| 3 June | 145 | Harvest | 20 | 1 | 3 |

ing cost of development to benefit of a resistant hybrid. Estimated yield losses ranged from 94.2 to 890.8 and 12.9 to 188.8 kg/ha for susceptible and resistant hybrids, respectively. Estimated farm-level benefits would be $93.3, -371.2 and -153.6 per hectare, if a susceptible hybrid was grown in the absence, presence, and protected by insecticide from sorghum midge, respectively. Benefits for a resistant hybrid would be $47.5, 1.0, and 26.7. Total state-level benefits from a susceptible hybrid were $-5.1, -39.4, and -25.2 million in the absence, presence, and protected by insecticide from sorghum midge. For a resistant hybrid, the values were $-8.6, -12.0, and -12.1 million.

The IIAM sorghum and millet program in Mozambique produced 2.8 and 3 tons of Sima and Macia seed to distribute to farmer associations or sell to NGOs to give to farmers. Seeds of 5 new varieties from pure lines are being multiplied for on-farm testing in January 2009.

## Networking Activities

### *Workshops and Meetings*

The PI and collaborators presented research at the INTSORMIL West Africa regional meeting, Bamako, Mali, 14-16 April 2008; INTSORMIL PI meeting, Lincoln, NE, 18-19 September 2007; 56th Meeting of Southwestern Branch of Entomological Society of America, Fort Worth, TX, 23-26 February 2008; Microscopy and Microanalysis, Albuquerque, NM, 3-8 August 2008 and Texas Society for Microscopy, Austin, TX, 17-19 April 2008; and attended the 55th Meeting of Entomological Society of America, San Diego, CA, 9-12 December 2007. Mr. Abdou Kadi Kadi taught farmers in the field in Niger identification, biology, and ecology of millet head miner and sorghum midge. He provided information on sorghum among researchers, extension, NGOs and development project personnel, private sector, and farmers at an ICRISAT/ INRAN open house. Dr. Munthali on 14-16 March 2008 visited Kasane, Botswana by invitation of the Chairmen of the "Pandamatenga Farms Association" to assess feasibility of a collaborative project on "Environmentally friendly methods of controlling major pests of sorghum and sunflower in commercial farms" and submitted a preliminary assessment report.

### *Research Investigator Exchanges*

From 25 October–9 November 2007, the PI discussed and reviewed research with scientists from INRAN in Niger and IER in Mali. The PI and collaborators met for a INTSORMIL West Africa regional meeting in Bamako, Mali, 14-16 April.

### *Research Information Exchange*

The PI advised extension, National Sorghum Producers, and seed companies on management of sorghum insects. Four hundred two sorghums developed for resistance to biotype I greenbug were evaluated for Milo Genetics. Supplies and funding were provided to Mr. Chitio in Mozambique, Dr. Yaro Diarisso in Mali, Mr. Abdou Kadi Kadi in Niger, and Dr. Munthali in Botswana. At Botswana College of Agriculture, insect pins, pinning boards, vials, boxes, rearing cages, and traps from INTSORMIL funds were used to teach insect pest management to 76 B.S. and 5 M.S. students in 7 Economic Entomology, Insect Taxonomy and Systematics, Introduction to Crop Pests, Pests of Field Crops, and Student Research courses. INTSORMIL experimental plots were used for teaching identification and monitoring pests and natural enemies, using scouting and pheromone traps for monitoring and identification of pests, and a student project "Evaluation of pest status of sorghum aphids and abundance of their natural enemies on five sorghum varieties." Published journal articles, research project reports, and other literature are being reviewed for use in solving pest management problems in Botswana. The PI, Dr. Yaro Diarisso in Mali, Mr. Abdou Kadi Kadi in Niger, and Dr. Alain Ratnadass, Entomologist, CIRAD/ICRISAT Niger, planned collaborative entomology research for the "Cereals for the Drylands" proposal to the Bill and Melinda Gates Foundation.

## Publications and Presentations

### *Journal Articles*

Ayyanath, M.M., B.B. Pendleton, G.J. Michels, Jr., and R.A. Bowling. 2008. Effect of greenbug (Hemiptera: Aphididae) from resistant sorghum on developmental rates of convergent lady beetle (Coleoptera: Coccinellidae). Southwestern Entomologist 33: 191-197.

Pendleton, B.B., M.W. Pendleton, and E.A. Ellis. 2008. Using energy dispersive spectrometry to compare the efficiency of metal coating techniques for scanning electron microscopy of insects. Texas Journal of Microscopy 39: 14.

### *Proceedings*

Pendleton, B.B., M.W. Pendleton, and E.A. Ellis. 2008. Using energy dispersive spectrometry to compare the efficiency of metal coating techniques for scanning electron microscopy of insects. In Proceedings of 56th Annual Meeting of Southwestern Branch of Entomological Society of America, 23-26 February 2008, Fort Worth, TX. Pp. 33-34.

### *Dissertations and Theses*

Damte Belete, Tebkew. 2007. Phytochrome content and economic assessment of sorghum resistant to sorghum midge (Diptera: Cecidomyiidae). Ph.D. dissertation. West Texas A&M University, Canyon, TX.

Telly, Madani. 2008. Resistance of stored sorghum to maize weevil (Coleoptera: Curculionidae). M.S. thesis. West Texas A&M University, Canyon, TX.

### *Presentations*

M. W. Pendleton, E. A. Ellis, B. B. Pendleton, and A. Holzenberg. Two methods of conductive coating for scanning electron microscopy of maize weevils (Sitophilus zeamais) compared by energy dispersive spectroscopy. Microscopy and Microanalysis, 3-8 August 2008, Albuquerque, NM. B B. Pendleton, M. W. Pendleton, and E. A. Ellis. Using energy dispersive spectrometry to compare the efficiency of metal coating techniques for scanning electron microscopy of insects. Texas Society for Microscopy, 17-19 April 2008, Austin, TX. B. Pendleton.

Ecologically-based management of sorghum and millet insect pests in Africa and the U.S. INTSORMIL West Africa regional meeting, 14-16 April 2008, Bamako, Mali. R. Bowling, B. B. Pendleton, G. Michels, Jr., and R. Bowling. Spider mite management since resistance to Capture – effective alternatives. 56th Annual Meeting of Southwestern Branch of Entomological Society of America, 23-26 February 2008, Fort Worth, TX. B. B. Pendleton, M. W. Pendleton, and E. A. Ellis. Using energy dispersive spectrometry to compare the efficiency of metal coating techniques for scanning electron microscopy of insects. 56th Annual Meeting of Southwestern Branch of Entomological Society of America, 23-26 February 2008, Fort Worth, TX. B. Pendleton. Ecologically-based management of sorghum and millet insect pests in Africa and the U.S. SMOG CRSP PI meeting, 18-19 September 2007, Lincoln, NE.

# Sustainable Production Systems

INTSORMIL

# Integrated Soil, Water, Nutrient and Crop Management Strategies for Improving Productivity in Sorghum and Millet Based Cropping Systems


## Project KSU 104
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### Introduction and Justification

Increasing population and limited availability of resources (land, water, nutrients and credit) along with lack of human resource and research capacity is constraining agricultural productivity in West Africa. Sorghum and millet based cropping systems are key components of farming practices in West Africa. Due to low productivity of sorghum and millet based cropping systems, the current management practices and cropping systems are not adequate and sustainable. Improved and intensive cropping systems will help transform sorghum and millet from subsistence to cash crop status, generate more income and provide food security. Low and erratic rainfall (water), high temperatures, poor soil fertility (nutrient), soil quality, limited use of fertilizers (both organic and inorganic) and limited availability of high yielding stress tolerant cultivars are key causes for lower productivity. We will focus on testing and integrating available soil, water, plant and nutrient management practices in different crop mixtures and crop rotations to understand interaction(s) and asses their long-term impact on yields and economic stability. Involving farmers in the decision making of technologies to be tested will have higher chances for adoption and diffusion. Therefore, during the first year farmers' participatory appraisals to understand farmers' perceptions about current management practices, cropping systems and their needs and preferences will be conducted. Based on survey results we will establish integrated multi-factor experiment which will have important components of the farmers' priorities and needs. In addition, options for technology transfer of prior knowledge will be assessed and implemented in farmers' fields. As a part of training and capacity building one or two graduate students (M.S. or Ph.D.) from Mali and/or Ghana will be recruited and trained on aspects of research, teaching and extension activities.

### Objectives and Implementation Sites

The main objectives during this year were:

- To conduct survey on farmers' perceptions and constraints to sorghum and millet production systems (participatory technology development);
- To identify components of Integrated Cropping Systems Management (ICSM) treatments for evaluation in on-station and on-farm conditions;
- To test and transfer improved crop, soil and water management practices to farmers field; and
- To initiate short-term and long-term training opportunities to host country students and scientists.

This research was implemented in several sites in each country which include:

- Ghana: Silbelle, Sorbelle, Piisi and Nakor
- Niger: Kallapate and Kollo region
- Burkina Faso: Gourcy, Saira, and Zondoma
- Mali: Sotuba, Cinzana, Fansirakoro and Konobougou

## Research Methodology and Strategy

### *Host Country: Ghana*

Participatory Technology Development Surveys: To quantify farmers' perceptions and constraints to sorghum and millet cropping systems, farmers' participatory technology development surveys were conducted in four communities in Upper West Region of Ghana. These were the Silbelle/Sorbelle and Piisi/Nakor communities in Sissalla East and Wa Central districts, respectively. Surveys were focused on producers (including men and women). The team of facilitators included researchers from SARI and extension personnel from the Ministry of Food and Agriculture. The questions and discussions were targeted to document the current farming systems in the area, major crops cultivated, cropping systems and management, constraints to production and farmers coping strategies. The results of these surveys were used to define research and extension needs of the target communities.

*Research Experiments*

Experiment 1: Tillage, Nitrogen and Cropping Systems Effect on Sorghum Growth and Yield

Objectives: The main objectives of this experiment were to (i) compare effects of conventional and no-till on growth and yield of sorghum; (ii) quantify dinitrogen fixation of cowpea under different cropping systems; and (iii) quantify contribution of cowpea to yield improvement in sorghum.

Treatments and Experimental Design: The experiment was arranged in a split-split plot design with three replications. Main plot treatments were tillage systems (conventional vs. no-till), sub-plot treatments were cropping systems (continuous sorghum, cowpea/sorghum rotation, cowpea/sorghum relay rotation and sorghum/cowpea intercrop rotation) and sub-sub-plot treatments were fertilizer rates (0, 40 kg N ha$^{-1}$, 60 kg P2O5 ha$^{-1}$, 40 kg N + 60 kg P2O5 ha$^{-1}$).

Experiment 2: Effect of Tillage and Nitrogen on Water and Nutrient Use Efficiency of Sorghum Cultivars

Objectives: The main objectives of this experiment were to (i) evaluate the response of commonly cultivated sorghum cultivars to conventional and no-till systems; and (ii) quantify water and nutrient use efficiencies of sorghum cultivars.

Treatments and Experimental Design: The experiment was arranged in split-split plot design with three replications. Main plot treatments were tillage systems (conventional vs. no-till), sub-plot treatments were nitrogen rates (0, 30, 60, 90 and 120 kg N ha$^{-1}$) and sub-sub-plots treatments were sorghum cultivars (kapaala, dorado and chere).

Experiment 3: On-farm Evaluation of Tillage and Cropping Systems Effects on Sorghum

Objectives: The main objectives of this experiment were to (i) evaluate effect of tillage systems on sorghum yield in Savanna zone; (ii) quantify N fixation by cowpea with and without P fertilizer; and (iii) quantify contribution of cowpea to succeeding sorghum crops.

Treatments and Experimental Design: The experiment was conducted in two communities Piisi/Nakor and Silbelle/Sorbelle in Upper West Region. These communities were selected based on earlier PTD surveys. The experiment was arranged in a factorial combination of 6 cropping systems and tillage system and two P fertilizer rates. Cropping and tillage systems (Factor 1) were cowpea/sorghum rotation in conventional till (T1), cowpea/sorghum rotation in no-till (T2), cowpea/sorghum relay rotation in conventional till (T3), cowpea/sorghum relay rotation in no-till (T4), sorghum/cowpea intercrop rotation in conventional till (T5), and sorghum/cowpea intercrop rotation in no-till (T6). Phosphorus rates (Factor 2) were 0 and 26 kg P ha$^{-1}$. These treatments were replicated in 15 farmers' fields at each location.

### *Host Country: Niger*

*Research Experiments*

Experiment 1: Influence of Fertilizer Application on Pearl Millet Yield in Sandy Soils of Niger

Objectives: The main objective of this experiment was to demonstrate and quantify yield benefit of micro-dose application in combination with additional N and P on yield of pearl millet under on-farm conditions.

Treatments and Experimental Design: This research was conducted in five farmers' fields in Kalapate and Kollo regions of Niger. Pearl millet cultivar Zatib was grown under traditional fertilizer practice (no fertilizer or micro-dose application) and improved fertilizer practice (micro-dose of NPK + 20 P + 30 N) application. Experimental design was a randomized complete block design with farmers' fields as replications.

Experiment 2: Influence of Tied Ridging on Sorghum Yield in Low Rainfall Zone of Niger

Objectives: The main objective of this experiment was to demonstrate and quantify yield benefit of tied ridging on sorghum yield under on-farm conditions.

Treatments and Experimental Design: This research was conducted in three farmers' fields in Tillabery regions of Niger. Improved sorghum cultivar IRAT-204 was grown under traditional practice (no ridges) and improved moisture conservation practice (tied ridges). Experimental design was a randomized complete block design with farmers' fields as replications.

Experiment 3: Integrated Sorghum – Cotton Cropping System to Control Striga on Grain Sorghum

Objectives: The main objective of this experiment was to demonstrate the impact of cotton – sorghum rotation and nitrogen application on striga infestation and yield of grain sorghum.

Treatments and Experimental Design: This research was conducted at Konni. The treatments comprised of four cropping systems (sorghum – sorghum, sorghum – cotton, cotton – sorghum, and cotton – cotton) and four nitrogen fertilizer treatments (0, 50, 100 and 200 kg $ha^{-1}$) applied to sorghum. Experimental design was a latin square design with cropping systems as rows and fertilizer treatments as columns, with four replications.

Experiment 4: Integrated Millet – Cowpea Cropping System to Improve Productivity

Objectives: The main objective of this experiment was to demonstrate the impact of different cropping system of cowpea and sorghum in combination with fertilizer application on productivity.

Treatments and Experimental Design: This research was conducted at Kollo. The treatments comprised of four cropping systems of cowpea – sorghum (rotation, intercropping, strip cropping and continuous cropping) and four technologies (combination of densities and fertilization). Experimental design was a latin square with cropping systems as rows and technologies as columns, with four replications.

## Host Country: Burkina Faso

Participatory Technology Development Surveys: To quantify farmers' perceptions and constraints to sorghum and millet cropping systems, farmers' participatory rural appraisal were conducted in Gourcy region of Burkina Faso. The team of INERA and PDCL/SAZ met with 22 farmers which consisted of both men and women. The questions and discussions were targeted to document the current farming systems in the area, major crops cultivated, cropping systems and management, constraints to production and farmers coping strategies. The results of these surveys were used to define research and extension needs of the target communities.

*Research Experiments*

Experiment 1: Integrated Soil – Water – Nutrient – Crop Management for Sorghum and Pearl Millet

Objectives: The main objective of this experiment was to develop package of practices which consisting of genotype, fertilizer practice and cropping system to improve productivity of sorghum and pearl millet cropping system.

Treatments and Experimental Design: This research was conducted at Saria research station in Central Burkina Faso. The treatments comprised of two cropping systems (continuous sorghum and sorghum – cowpea rotation), three water conservation practices (no conservation, stone rows and grass strips of Adropogan gayanus), and two genotypes (local landrace, Nongomsoba and improved variety, Sariaso) with four replications.

Experiment 2: On-farm Evaluation of Striga Tolerant Cultivars to Improve Sorghum Productivity

Objectives: The main objective of this experiment was to evaluate and promote diffusion of Striga tolerant cultivars to farmers' fields in Zondoma provide of Burkina Faso.

Treatments and Experimental Design: This research was conducted on five farmers' fields with improved striga tolerant sorghum cultivar (Sariaso 14). Experimental design was a complete randomized block with five replications (farmers' fields).

Experiment 3: Extension of Mechanized Zai, Micro-dose + Compost Application on Sorghum

Objectives: The main objective of this experiment was to evaluate and promote diffusion of mechanized zai and fertilizer application to improve sorghum productivity in Zondoma provide of Burkina Faso.

Treatments and Experimental Design: This research was conducted on five farmers' fields with improved sorghum cultivar tolerant to Striga (Sariaso 14). Experimental design was a complete randomized block with five replications (farmers' fields).

## Host Country: Mali

*Research Experiments*

Experiment 1: Impact of Reduced Tillage on Millet Yield

Objectives: The main objective of this experiment was to investigate the impact of different tillage practices on soil properties, growth and yield of millet.

**Table 1. Ranking and importance of various crops in Upper West regions of Northern Ghana.**

| Village | Crop | Rank | Reasons for relative ranking |
|---|---|---|---|
| Silbelle / Sorbelle | Maize | 1st | Staple food, highly productive and easy to cultivate |
| | Groundnut | 2nd | Easy to eat, no processing, low inputs, good animal feed and enriches soil |
| | Sorghum | 3rd | Raw material for local beer, porridge making, fencing and soap industry |
| | Cotton | 4th | Cash crop, high income and good price |
| | Millet | 5th | Staple food and used in social activities |
| | Cowpea | 6th | Source of protein, low input, and increases soil fertility |
| Piisi / Nakor | Sorghum | 1st | Staple food, brew beer, used in funerals, and to pacify ancestors and God |
| | Cowpea | 2nd | Cash crop, source of protein, cooked by men and improves soil fertility |
| | Maize | 3rd | Bridges hunger gap, source of income and mans crops |
| | Groundnut | 4th | Can be eaten without cooking, used in soups, and enriches soil |
| | Millet | 5th | Staple food, can be easily stolen and low yields |

Treatments and Experimental Design: This research was conducted at Cinzana research station. The treatments comprised of eight different tillage treatment (comprised of combination of no-till, reduced, tillage, conventional tillage and weeding practices), and two genotypes of millet (local landrace, Toroniou and improved variety, SO x SAT). Experimental design was a factorial randomized block with four replications.

Experiment 2: Impact of Different Millet and Legume Cropping of Yield

Objectives: The main objective of this experiment was to investigate the impact of inter cropping of two genotypes of millet (Toroniou and SO x SAT) with two legume species (groundnut and cowpea) at normal and delayed planting on soil properties, growth and yield.

Treatments and Experimental Design: This research was conducted at Cinzana research station. The treatments comprised of two millet genotypes (local landrace, Toroniou and improved variety, SO x SAT), two legumes (groundnut and cowpea) and two planting times (planted at the same time and delayed planting of legume intercrop). Experimental design was a factorial randomized block with four replications.

Experiment 3: Impact of Integrated Soil Fertility Management on Sorghum Yield

Objectives: The main objective of this experiment was to evaluate impact of different soil water management, fertilizer application, tillage practices and residue management on soil properties, growth and yield of sorghum.

Treatments and Experimental Design: This research was conducted at Sotuba research station. The treatments comprised of combinations of two each of soil water management (ordinary ridges and contour ridging), fertilizer practices (no fertilizer and micro-dose), tillage practices (conventional full tillage and reduced tillage) and residue management (with and without residue). Experimental design was a factorial randomized block with three replications.

Experiment 4: On-Farm Evaluation of Integrated Soil Fertility Management on Sorghum Yield

Objectives: The main objective of this experiment was to evaluate impact of different soil water management, fertilizer application, tillage practices and reside management on soil properties, growth and yield of sorghum under on-farm conditions.

Treatments and Experimental Design: This research was conducted at on-farm conditions in at four fields (Fansirakoro, Konobougou, Cinzana and Oumarbougou). The treatments comprised of two each of soil water management (ordinary ridges and contour ridging), fertilizer practices (no fertilizer and micro-dose), tillage practices (conventional full tillage and reduced tillage) and residue management (with and without residue). Experimental design was a complete randomized block with farmers' fields (4) as replications.

## Research Results

### *Host Country: Ghana*

Participatory Technology Development (PTD) Surveys:

Results: The overall assessment of livelihood activities in the four communities shows that crop production is the main source of income. The main crops cultivated in the region were maize, groundnut, sorghum, cotton, millet, cowpea, yams, sweet potato, bambara groundnut and cassava. The relative importance of crops and reasons for ranking are shown in Table 1. Most of the farmers were cultivating local cultivars of sorghum and millet. However, recently improved varieties of sorghum (Kadaga and Naga red) were gaining importance. Most of the sorghum and millet was planted during May – June in flat bed system. Sole cropping of sorghum and millet in rotation with groundnut or cowpea was most prominent cropping system. The main constraints to sorghum and

**Table 2. Effects of tillage, cropping system and fertilizer on pod, grain and biomass yield of cowpea, Wa, Ghana.**

| Main Effects | Pod yield | Grain yield | Biomass |
|---|---|---|---|
| | | kg $ha^{-1}$ | |
| **Tillage system** | | | |
| Conventional till (CT) | 1586.9a | 948.7a | 4608.3a |
| No-till (NT) | 1390.8a | 923.6a | 4180.2a |
| **Cropping system** | | | |
| Sorghum – Sorghum (S-S) | - | - | - |
| Cowpea – Sorghum rotation (C-S) | 1107.1a | 738.7a | 4399.0ab |
| Cowpea – Sorghum relay cropping (C-SR) | 1129.8a | 758.9a | 3938.0a |
| Cowpea/Sorghum intercrop rotation (C/S) | 2229.6b | 1310.7b | 4845b |
| **Fertilizer rate** | | | |
| 0 | 1300.9a | 907.5a | 3961.1a |
| 40 kg N $ha^{-1}$ | 1527.2a | 996.1a | 4131.3a |
| 26 kg $P_2O_5$ $ha^{-1}$ | 1467.7a | 966.7a | 4977.8a |
| 40 + 60 (N + $P_2O_5$ $ha^{-1}$) | 1659.7a | 874.2a | 4506.9a |

millet production in the region include low soil fertility, drought/lack of rainfall, lack of improved varieties, weeds (striga) and disease incidence. Additionally farmers also indicated lack of credit to carry out crop production activities as major limitation. Some of the common coping strategies include cultivation in lowlands, residue retention and diversification of crop production for drought and low rain fall; crop rotations of cereals and legumes for low soil fertility; and hand pulling, earthing-up to cover striga and application of manure or fertilizer to reduce nutrient and water stress.

*Research Experiments*

Experiment 1: Tillage, Nitrogen and Cropping Systems Effect on Sorghum Growth and Yield

Results: The cowpea components of the experiment have been harvested and results reported (Table 2). There was no influence of tillage practice or fertilizer application on cowpea yield. There was significant effect of cropping system on pod and grain yield of cowpea. Cowpea – sorghum intercrop rotation produced highest biomass, pod and seed yield of cowpea.

Experiment 2: Effect of Tillage and Nitrogen on Water and Nutrient Use Efficiency of Sorghum Cultivars

Results: This experiment is yet to be harvested and results will be reported in the next report.

Experiment 3: On-farm Evaluation of Tillage and Cropping Systems Effects on Sorghum

Results: Preliminary data analyses show that there were significant effects of cropping systems, phosphorus application and interaction between cropping systems and phosphorus application on cowpea yields. Pod and seed yield of cowpea intercropped with sorghum under conventional tillage or no-tillage were significantly higher than cowpea-sorghum rotation or relay cropping (Table 3). Application of phosphorus fertilizer increased biomass, pod and seed yield of cowpea.

## Host Country: Niger

*Research Experiments*

Experiment 1: Influence of Fertilizer Application on Pearl Millet Yield in Sandy Soils of Niger

Results: There was significant influence of fertilizer practices on stover and grain yield of millet across all farmers' fields (Table 4). On average across all locations application of additional 20 kg P and 30 kg of N increased stover, and grain yield by 200 and 180% respectively, when compared with no fertilizer control.

Experiment 2: Influence of Tied Ridges on Sorghum Yield in Low Rainfall Zone of Niger

Results: There was significant influence of moisture conservation practice on stover and grain yield of sorghum across all fields (Table 5). On average across all locations use of tied ridges increased stover, and grain yield by 42 and 193% respectively, when compared with no ridges.

**Table 3. Main effects of cropping/tillage system and P fertilizer rate on pod, grain and biomass yield of cowpea in farmers' fields at Wa, Ghana.**

| Treatment | Pod yield | Seed yield | Biomass yield |
|---|---|---|---|
| | | kg $ha^{-1}$ | |
| **Cropping/tillage system** | | | |
| Cowpea –Sorghum rotation – CT | 767 a | 490 a | 2380 a |
| Cowpea –Sorghum relay – CT | 903 ab | 601 a | 2480 ab |
| Cowpea – Sorghum intercrop – CT | 1390 c | 863 b | 2924 bc |
| Cowpea – Sorghum rotation – NT | 840 ab | 556 a | 2418 ab |
| Cowpea –Sorghum relay – NT | 955 b | 602 a | 2505 ab |
| Cowpea – Sorghum intercrop – NT | 1323 c | 876 b | 3296 c |
| **Phosphorus rate (kg P $ha^{-1}$)** | | | |
| 0 | 922 a | 594 a | 2303 a |
| 26 | 1137 b | 735 b | 3031 b |

**Table 4. Effects of traditional (F1, micro-dose or no fertilizer) and improved (F2, micro-dose + 20 P + 30 N kg $ha^{-1}$) fertilizer practice on stover and grain yield of pearl millet in farmers' fields in Niger.**

| Village / Farmers Field | Stover yield (kg $ha^{-1}$) | | Grain yield (kg $ha^{-1}$) | |
|---|---|---|---|---|
| | F1 | F2 | F1 | F2 |
| Kalapate | 1500 | 1450 | 11 | 398 |
| Louloudie | 2500 | 3110 | 33 | 703 |
| Kissin-Kissin | 2600 | 7400 | 96 | 1156 |
| Darey | 1000 | 7200 | 27 | 693 |
| Dabaga | 440 | 2200 | 7 | 398 |
| Average | 1608a | 4822b | 35a | 669b |

**Table 5. Effects of traditional (P1, no ridges) and improved moisture conservation (P2, tied ridges) practice on stover and grain yield of sorghum in farmers' fields in Tillabery region of Niger.**

| Village / Site | Stover yield (kg $ha^{-1}$) | | Grain yield (kg $ha^{-1}$) | |
|---|---|---|---|---|
| | P1 | P2 | P1 | P2 |
| Site 1 | 4500 | 4600 | 1400 | 2300 |
| Site 2 | 3400 | 5100 | 1100 | 2350 |
| Site 3 | 1600 | 3800 | 405 | 1600 |
| Average | 3167a | 4500b | 968a | 2833b |

Experiment 3: Integrated Sorghum – Cotton Cropping System to Control Striga on Grain Sorghum

Results: This experiment is yet to be harvested and results will be reported in the next report.

Experiment 4: Integrated Millet – Cowpea Cropping System to Improve Productivity

Results: This experiment is yet to be harvested and results will be reported in the next report.

## *Host Country: Burkina Faso*

Participatory Technology Development Surveys:

Results: The results participatory rural appraisals suggest that the main crops grown in the region are sorghum, pearl millet followed by cowpea, groundnut and sesame. The main production constraints to agriculture (and sorghum in particular) were low and erratic rainfall, low soil fertility, wind erosion, Striga infestation and lack of organic manure. Survey results were used to determine treatments for on-station research and technology transfer.

*Research Experiments*

Experiment 1: Integrated Soil – Water – Nutrient – Crop Management for Sorghum and Pearl Millet

Results: This experiment is yet to be harvested and results will be reported in the next report.

Experiment 2: On-farm Evaluation of Striga Tolerant Cultivars to Improve Sorghum Productivity

Results: This experiment is yet to be harvested and results will be reported in the next report.

Experiment 3: Extension of Mechanized Zai, Micro-dose + Compost Application on Sorghum

Results: This experiment is yet to be harvested and results will be reported in the next report.

## *Host Country: Mali*

*Research Experiments*

Experiment 1: Impact of Reduced Tillage on Millet Yield

Results: Preliminary observations suggest that improved cultivar SOxSAT was doing better than local millet genotype. Reduced tillage and weeding operations may reduce yield due to negative impact on weed control. Increase in weed populations and poor weed control operations was pointed as key constraint to adoption of reduced tillage.

Experiment 2: Impact of Different Millet and Legume Cropping of Yield

Results: Preliminary observations suggest that improved cultivar SOxSAT expressed better growth than local millet genotype. Delaying planting of legume intercrop seems to favor better establishment and growth of millet main crop. There was no differences in the response to either groundnut or cowpea.

Experiment 3: Impact of Integrated Soil Fertility Management on Sorghum Yield

Results: Any combination involving contour ridging known as ACN (Amenagement en courbes de niveau) was showing substantial improvement in sorghum growth. Micro-dose application of fertilizer showed beneficial impacts (> 30% increase) on growth and yield of sorghum. Beneficial impact of ACN is due to reduced runoff (by 22%), increase infiltration and better fertilizer use efficiency. Contour riding also improved several soil properties, especially organic matter by about 22%.

Experiment 4: On-Farm Evaluation of Integrated Soil Fertility Management on Sorghum Yield

Results: The trends were similar to those observed in on-station conditions. The plots are yet to be harvested and detailed results will be reported later.

Achievement and Status of Activities Proposed in Work Plan (Table 6).

**Table 6. Status of activities proposed in the work plan on 2007.**

| Year/ Month | Activities | Status |
|---|---|---|
| 2007 | | |
| July – Sep 07 | Planning for collaborators, identification of sites, villages for surveys. | Complete |
| Oct – Dec 07 | Visiting host countries, pre-testing questionnaire, visiting local universities for collaboration, and interviewing and identification of graduate students. | Complete |
| Jan – Mar 08 | Conducting village surveys to determine treatments for long-term experiments. | Complete |
| Apr – June 08 | Defining and planning of treatments for experiments at each site. Also conducting research experiments in U.S. related to abiotic stress physiology. | Complete |
| Jul – Sep 08 | Initiation of multi-factor experiment, technology transfer experiments. Starting academic training of graduate students in U.S. | Complete |

## Contributions to INTSORMIL Strategic Plan Objectives

Our research was mainly aimed at Strategic Objective – 3 of INTSORMIL which is Integrated Cropping Systems Management (ICSM) targeted to increase grain yield through development and adoption of improved crop, soil and water management. We have identified some of ICSM components that are being tested in on-station and on-farm conditions. For example: use phosphorus application (26 kg ha-1) in cowpea – sorghum intercropping or crop rotations in Ghana; use of 20 kg P ha-1 and 30 kg N ha-1 to improve productivity of millet and use of tied ridges to improve productivity of sorghum in Niger; and use of improved cultivar in combination with contour riding and micro-application for improved sorghum and millet yields in Mali.

## Training (Degree and Non-Degree)

Degree Training: Two students (one from Mali and one from Burkina Faso) are undergoing degree training.

Mali: Mr. Alassane Maiga, started his Ph.D. program at Kansas State University (KSU) in Fall 2008.

Burkina Faso: Mr. Boukare Sawadago, started his M.S. program at Ouagadougou University in Spring 2008.

Ghana: A student has been identified to start M.S. program at KSU. He is awaiting his TOEFL score.

In addition, two students from Kenya (Mr. Raymond Mutava and Ms. Rachel Opole) started Ph.D. programs in Fall 2008 at KSU (leveraging money from other sources).

## Networking Activities

We have initiated ties with ICRISAT to train students working on sorghum and millet at KSU. Dr. Hari D. Upadhyaya (ICRISAT – India) and Dr. J.B. Naab (PI from Ghana) visited KSU. Drs Prasad and Staggenborg visited all four host countries to initiate the current project and extend network with other scientists in the region.

## Publications and Presentations

### *Journal Articles*

Prasad, P.V.V., S.R. Pisipati, R.N. Mutava, and M.R. Tuinstra. 2008. Sensitivity of grain sorghum to high temperature stress during reproductive development. Crop Science 48: 1911 – 1917.

# Crop, Soil and Water Management to Optimize Grain Yield and Quality for Value-Added Markets in Eastern and Southern Africa

## Project UNL 101


## Charles Wortmann
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### Introduction and Justification

Research and extension activities were implemented in four countries of eastern and southern Africa and in Nebraska supporting the INTSORMIL objective of improving crop and soil management for increased and more stable yields and improved crop, soil and water management. Promising management practices have been identified and integrated into management packages. These practices are being promoted through extension activities in Ethiopia, Uganda and Nebraska while research continues. In Ethiopia, research and extension activities on water conservation, water use efficiency, and nutrient management targeted to *striga* infested and non-infested areas continued with increased emphasis on extension. A manuscript is under review reporting results of tied ridging by fertilizer use research. Research on the main and interaction effects of tied ridging and skip-row planting is to be completed in 2008. A research paper was published reporting results of spin-off research on highland pulses. Research on reduced tillage for teff production was initiated in northern Ethiopia. Extension activities continue to promote soil management technology. Skip-row results were reported at an international conference. In *striga*-infested areas of eastern Uganda, diverse extension partnerships have been developed to promote tillage and soil fertility management practices developed, fine-tuned, or verified with INTSORMIL support while the longer term sustainability of these practices is being studied. In central Tanzania, results of on-station research on tillage options initiated in 2005 indicate promising tillage options which will go into on-farm evaluation. Collaboration in Mozambique was re-initiated in 2007 to address issues of fertilizer nutrient use efficiency in diverse cropping systems through research and extension. Institutional capacity building has included technical support to research and extension activities and visits of two collaborators to the University of Nebraska. Research in Nebraska continued on 1) one-time tillage of no-till fields for the final year of field research, 2) on skip-row planting as means of reducing stress due to soil water deficits, 3a) sweet sorghum as an efficient biofuel crop relative to maize and sorghum grain crops, 3b) agronomic practices for sweet sorghum production, 3c) nutrient uptake by sweet sorghum relative to grain crops, and 4) water use efficiency of sweet and grain sorghum as well as maize to better allocate scarce water among these crops. Nebraska research results were presented at three national or international conferences.

### Objectives

The goal of this project is to improve food security and market development of sorghum and pearl millet in ESA through research, institutional capacity building, and technology dissemination. The specific objectives addressed include: 1) Enhancement of institutional capacity for soil and water research and extension in ESA and the U.S. through graduate degree and short-term training, and technical support. 2) Increased productivity of sorghum and teff based cropping systems through better management including: verification and/or promotion in Ethiopia of tied-ridge and skip-row planting, combined with soil fertility management; soil fertility management, tillage and striga management research and extension in Uganda and Tanzania; development of decision guidelines to soil fertility management in Mozambique; and improved responsiveness to variable weather conditions. A third objective "Enhanced demand for sorghum with activities in Uganda and Ethiopia on feeding of livestock and activities in Uganda on grain supply to breweries" was not addressed because of high current and expected future demand globally and in Africa for basic commodities. These objectives support the Sorghum, Millet and Other Grains CRSP vision to improve food security, enhance farm income, and improve economic activity in the major sorghum and pearl millet producing countries in Africa.

We addressed the objectives of the Sorghum, Millet and Other Grains CRSP in ESA and the USA primarily by: 1) increasing yield level and stability through crop, soil and water management while sustaining the natural resource base through research and extension; and 2) improving research and extension capacity through effective partnerships with local, national, and international agencies.

The implementation sites are in Ethiopia, Uganda, Tanzania and Mozambique including: Central Rift Valley (Melkassa and Mieso), Tigray, and possibly Sirinka in Ethiopia; eastern and northern Uganda through Kawanda ARI; Central (Hombolo) and Lake Province (Ukiriguru) in Tanzania; and Nampula and Manica in Mozambique. Collaborative activities are underway at these sites with the exception of Sirinka in Ethiopia and Lake Province in Tanzania.

## Research Plan

Role of host country scientists. T. Mesfin and G. Brhane continued as the main collaborators in Ethiopia. Dr. Kaizzi Kayuki continued to lead collaborative activities in Uganda with a research and extension focus on nutrient supply and tillage for water conservation. E. Letayo collaborated in tillage research in Tanzania with the expectation of initiating technology dissemination in 2009 while continuing to promote *striga* management practices with a possible extension of activities to the southeastern Lake Province. Ricardo Maria collaborated in soil fertility research in Mozambique. The interdisciplinary team in Nebraska includes Drs. Mason, Ferguson, Klein, Lyon, Dwekait, and Martin representing agronomy, soil science, plant breeding, and irrigation engineering. Callibration of the APSIM model (www.apsim.info/) for skip-row planting of sorghum was postponed to begin in Nov 2008 due to weather conditions. Outreach partners are numerous including the Teso Diocese Development Organization (TEDDO) working in five districts of Uganda, the Soroti Catholic Diocese, and various government and non-government extension partners and community-based organizations.

## Research Results

Data was collected for Malawi, Rwanda, Zambia and Zimbabwe and the atlas of sorghum production as been extended to include nine countries. Previously, Ethiopia, Kenya, Uganda, Tanzania, and Mozambique were covered by the atlas. A draft of the revised atlas is under review. The estimated area of sorghum production in these countries is 3.4 million ha (Fig. 1) and 39 production areas have been delineated and characterized. Over these nine countries, 60% of the sorghum is produced in sole crop with maize, cowpea and bean being the main intercrops. Forty three yield constraints were evaluated; the top six constraints were water deficits, stem borers, N deficiency, *striga*, weeds, and quela quela. The major uses of grain are for boiled foods such as ugali and uji and for brewing. Stover use accounted for approximately 30% of the crop value overall but greater than 40% in some production areas of Ethiopia. Approximately 34% of the grain is marketed (Fig.2).

In northern Ethiopia, grain and stover yields and harvest index were increased and *striga* infestation was decreased with skip-row planting and tied-ridging with positive interactions (Fig. 3). Yield was increased by planting two rows and skipping one but not with the plant one : skip one arrangement compared with all rows planted. The yield increase with tied-ridging was greater than with skip-row planting. Yield was not increased with skip row planting at the Central Rift Valley locations. In a study of tied-ridging x fertilizer interaction, tied-ridging and fertilizer use increased yield but the interaction was not significant (Table 1). On-farm demonstrations are being conducted in the Central Rift Valley.

Research to evaluate the sustainability of low input approaches to soil fertility management under different tillage systems continued. Extension activities were expanded with field demonstrations in 7 districts of eastern Uganda and partnerships with Soroti Catholic Diocese Development Organisation (SOCADIDO), Teso Dioceses Development (TEDDO), government extension, NAADS service providers, CBO's, NGO's, etc.

Research activities were reinitiated in Tanzania and Mozambique following a lapse of two years because of funding constraints and personnel change. In central Tanzania, a tillage trial was conducted and promising options were identified, including strip tillage, for farmer participatory evaluation. Mozambique-INIA led the implementation of trials to verify and fine-tune promising practices on-station and on-farm in northern Mozambique in collaboration with Zonal Research Centers in Nampula and at Manica in central Mozambique. Trials to evaluate the effect of green manure in rotation with Sorghum was also carried out and the treatments included were: sorghum fertilized with standard fertilizer (Urea + NPK); sorghum fertilized with urea; sorghum rotation with cowpea; sorghum without soil amendment; and sorghum following crotalaria. Foliar application of fertilizer was evaluated.

A paper on P sorption of soils from Ethiopia, Uganda and Mozambique has been submitted for publication: clay content and clay content as well as Al oxides determined P sorption for the Ethiopia samples and for the Uganda and Mozambique samples, respectively; P sorption was 40 to 300% higher for samples taken from termite mounds.

Field research on skip-row planting of grain sorghum in semi-arid western Nebraska was completed in 2007. Where grain yield is constrained by soil water deficits, the skip row configuration of planting 1 and skipping 1 row (S1:1) resulted in higher yield compared to planting all rows when mean trial yields were less than 4.5 Mg $ha^{-1}$ (Fig. 4). The S2:2 configuration resulted in higher yield than S1:1 when mean trial yield was less than 3.5 Mg $ha^{-1}$. Yield was more stable with skip-row planting than with all rows planted.

Sweet sorghum is being evaluated as a biofuel crop in Nebraska. Three rainfed trials were conducted in a rainfall transect

**Figure 1. Distribution of sorghum production across nine countries in eastern and southern Africa.**

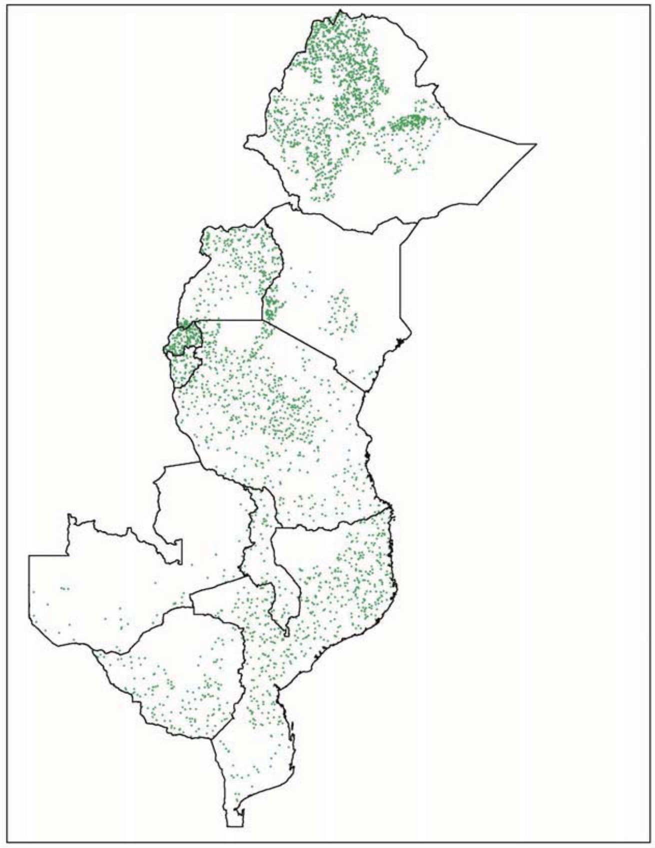


**Figure 2. The importance of marketing of sorghum grain in 39 sorghum production areas.**

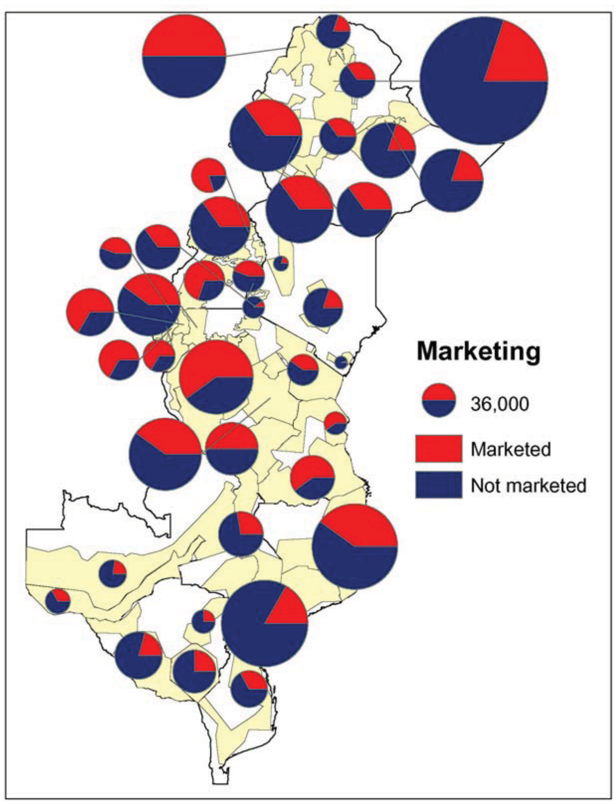
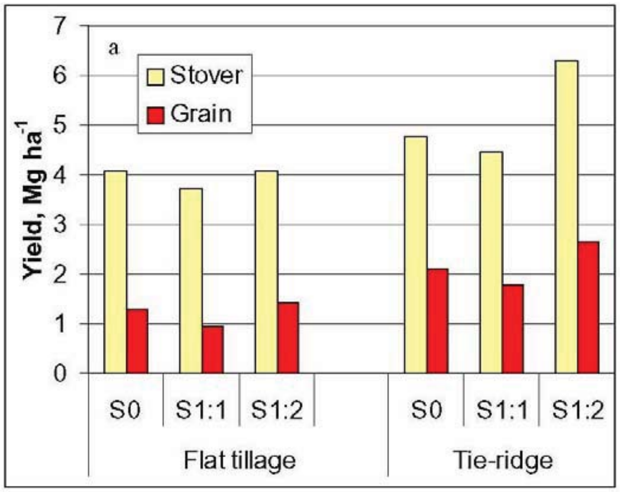


**Figure 3. The interaction effect of tied-ridging and skip-row planting on sorghum yield and *striga* density in northern Ethiopia. S0, S1:1, and S1:2 = all rows planted, one row planted and one row skipped, and two rows planted and one row skipped.**



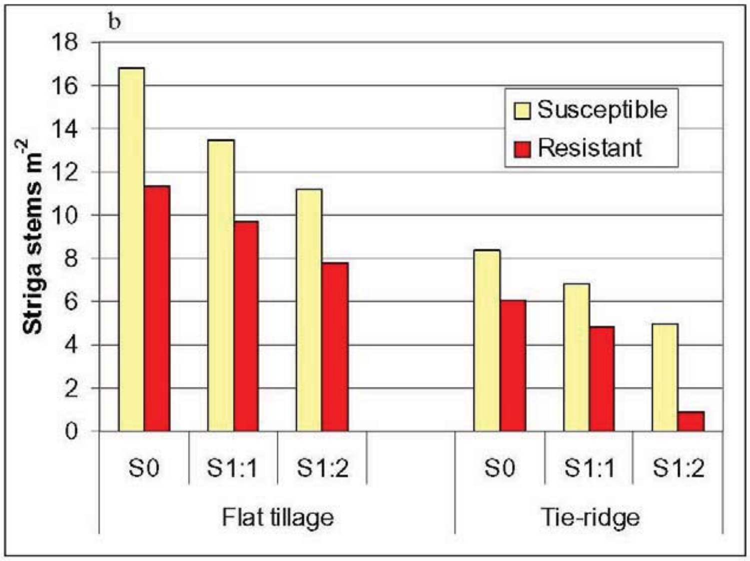



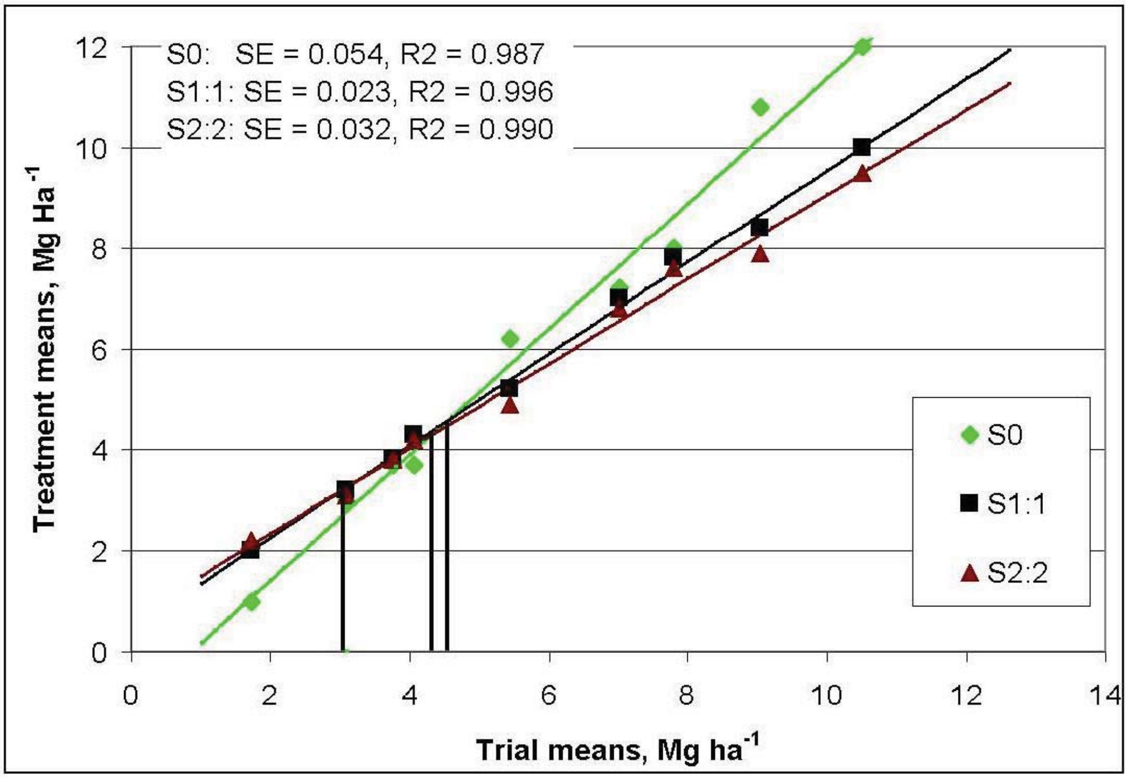

Table 1. Tied-ridging and fertilizer N and P effects on sorghum grain yield in semi-arid areas of Ethiopia.

| | Melkassa (n=3) | Northern (n=2) |
|---|---|---|
| **Tillage (T)** | Grain yield, Mg ha-1 | |
| Tied-ridge | 3.00a | 1.85a |
| Traditional | 2.53b | 1.41b |
| **Fertilizer (F)** | | |
| $0N\text{-}0P_2O_5$ | 2.43b | 1.59a |
| $10N\text{-}23P_2O_5$ | 3.01a | 1.62a |
| $22N\text{-}0P_2O_5$ | 2.83b | 1.83a |
| $32N\text{-}23P_2O_5$ | 3.10a | 1.72a |
| T x F | NS | NS |

Table 2. Energy yields of sweet sorghum, maize, and grain sorghum at three rainfed locations in Nebraska in 2007.

| Location | Sweet sorghum | Maize | Grain sorghum |
|---|---|---|---|
| | Gross energy yield, '000 Mj/acre | | |
| SCAL | 18.1 | 35.1 | 31.6 |
| WCREC | 25.6 | 39.0 | 28.7 |
| HPAL | 17.7 | 19.0 | 20.5 |
| | Net energy yield, '000 Mj/acre | | |
| SCAL | 12.5 | 11.1 | 9.8 |
| WCREC | 18.7 | 13.6 | 9.0 |
| HPAL | 13.2 | 7.1 | 7.7 |
| | Energy (gained:invested) | | |
| SCAL | 3.3 | 1.5 | 1.5 |
| WCREC | 3.7 | 1.5 | 1.5 |
| HPAL | 3.9 | 1.6 | 1.6 |

**Figure 4. Yield relative to trial mean and stability analysis of skip-row planting configurations in Nebraska. S0, S1:1, and S2:2 = all rows planted, one row planted and one row skipped, and two rows planted and two rows skipped.**




across southern Nebraska. Biomass and sugar yields were not affected by N rate or planting density. Severe lodging occurred with strong winds at two locations. Theoretical ethanol yield was less with sweet sorghum than with maize and grain sorghum but net energy yield was greater with sweet sorghum (Table 2). The ratio of energy invested to energy gained was much higher with sweet sorghum than with the grain crops. This research continued at four locations in 2008. Additional research was initiated in 2008 to determine nutrient uptake patterns for sweet sorghum compared to maize and grain sorghum and to determine water use under nine water regimes for sweet sorghum compared to maize and grain sorghum.

## Networking Activities

U.S. PIs met in Lincoln, NE for coordination of activities. Data was collected, analyzed and compiled for 4 countries of ESA to be added to the atlas which previously addressed 5 countries.

## Publications

### *Journal Articles*

Brhane, G. and C.S. Wortmann. 2008. Tie-ridge tillage for high altitude pulse production in northern Ethiopia. Agron. J. 100:447-453.

Wortmann, C.S., J.A. Quincke, R.A. Drijber, M. Mamo, T. Franti. 2008. Soil microbial change and recovery after one-time tillage of continuous no-till. Agron. J., in press.

Miller, D., M. Mamo, R. Drijber, and C. Wortmann. Sorghum growth, root responses, and soil-solution aluminum and manganese on pH-stratified sandy soil. J. Plant Nutr. Soil Sci. In press.

### *Abstracts*

Abunyewa, A., R. Ferguson, C. Wortmann, D. Lyon, S. Mason, and D. Tarkalson. 2007. Skip-row configuration and plant density effects on sorghum grain yield and yield component in southern Nebraska. North Central Extension and Industry Conference, Des Moines, IA.

Abunyewa, A., R. Ferguson, C. Wortmann, D. Lyon, S. Mason, and D.Tarkalson. 2007. Improving water use efficiency with skip-row planting of grain sorghum in semi-arid conditions. National Water Conference, Reno, NV.

Abunyewa, A., R. Ferguson, C. Wortmann, D. Lyon, S. Mason, and D. Tarkalson. 2007. Skip-row configuration and plant density effects on sorghum grain yield and yield component in southern Nebraska. Agron. Abstr., Amer. Soc. of Agron., New Orleans LA.

Mesfin, T., G.B. Tesfahunegn, C.S. Wortmann, O. Nikus, and M. Mamo. 2008. Skip row planting and tie-ridging to improve sorghum yield in semi-arid Ethiopia. International Sorghum Conference for Bio-energy. Houston, TX.

Mesfin, T., G.B. Tesfahunegn, C.S. Wortmann, O. Nikus, and M. Mamo. 2008. Skip row planting and tie-ridging to improve sorghum yield in semi-arid Ethiopia. Agron. Abstr., Amer. Soc. of Agron. Houston, TX.

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Wortmann, C., M. Mamo, G. Abebe, C. Mburu, K. Kaizzi, E. Letayo, and S. Xerinda. 2007. Atlas of sorghum production in five countries of eastern Africa. Agron. Abstr., Amer. Soc. of Agron. Houston, TX.

Wortmann,C., I. Dweikat, R. Ferguson, D. Lyon, 2008. Sweet sorghum as a biofuel crop in Nebraska. Agron. Abstr., Amer. Soc. of Agron. Houston, TX.

# Germplasm Enhancement and Conservation

# Breeding Pearl Millet with Improved Stability, Performance, and Resistance to Pests

## Project ARS 101
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### Introduction and Justification

Pearl millet is a staple food in the most difficult production environments of semi-arid Africa and Asia. It is used as a forage and cover crop in the U.S., Brazil, Canada, and Australia, but is also being developed for grain in these regions because of its superior water- and nutrient-use efficiency. Because of the dependability of harvests in harsh environments, and the potential for improvement, pearl millet will be a key component in the future prosperity of Africa, and will provide new economic opportunities for the U.S.

Advances can be made in production and use of pearl millet by targeting high-value and market-driven traits. In addition to increased yield, value for specific uses, such as fodder, grain for processed foods, poultry feed, or as ethanol feedstocks is needed for existing and developing markets is needed. The needs of growers must be met by facilitating crop production, and the needs of end-users must be met by providing a superior product. This project targets multiple traits including fertility restoration, staygreen, free-threshing grain, grain quality traits, and resistance to pests and diseases, including downy mildew, striga, nematodes, and grain molds.

The genetic diversity of open-pollinated varieties (OPVs) contributes to stable production in harsh environments. Early-maturing hybrids may have improved yield over the early OPVs, can increase grain availability during deficit periods, and will promote the development of a private-sector seed industry. Hybrid technology for Africa will require appropriate maintainer and restorer inbreds for the A1, A4, and A5 male sterile cytoplasms. Advancing hybrid technology for Africa will be facilitated through use of fertility restorer genetic stocks derived from African varieties.

### Improving Yield and Stability through Resistance to Diseases and Pests

Genetically uniform hybrids can be more susceptible to biotic and abiotic constraints that cause low or unstable yield. The downy mildew pathogen (*Sclerospora graminicola*) has a high potential for epidemics. Multilocation screening is necessary to identify resistance that is broadly effective to diverse pathotypes. Striga (*Striga hermonthica*) is a serious parasite in regions where food security is lowest. Resistance provides a low-cost means of control.

Other pests contribute to chronic production problems. Nematodes are widespread in association with pearl millet. African varieties differ in resistance to root knot nematodes (*Meloidogyne* spp.), and in each variety tested, most plants were susceptible. In the U.S., susceptible pearl millets have lower grain yield, and can result in greater root damage and yield losses in subsequently grown peanut. Peanut and cowpea are grown in intercrop and rotation with pearl millet, and both legumes are severely affected by root knot nematodes in Africa. Resistant pearl millets will promote long-term sustainability of the production systems.

Grain molds are another chronic problem that can occur when crops mature before the rainy season ends. When poor rural farmers need to raise cash, highest quality grain is frequently sold into the market, and poorer quality grain is kept for on-farm consumption. Molded grain has poorer nutritional qualities, and may be contaminated by mycotoxins that are associated with cancers, and that compromise the health of individuals with HIV/AIDS or hepatitis *C. Aflatoxins* and fumonisins are considerably lower in pearl millet compared to corn, but other mycotoxins associated with Fusarium infection (such as trichothecenes and zearalenone) are common.

### Improving Yield and Stability Through Tolerance to Drought and Low Soil Fertility

Drought and low soil fertility are significant abiotic constraints for pearl millet production in Africa. Drought stress during flowering through grain fill results in low and unstable yield. Staygreen is an expression of drought tolerance characterized by the retention of green leaf area at crop maturation and improved nitrogen utilization. The staygreen trait could further improve drought tolerance and nitrogen-use efficiency in pearl millet.

## Improving Marketability through Value-Added and Grain Quality Traits

Manual threshing and winnowing are labor-intensive tasks primarily performed by women using a wooden mortar and pestle. Traditional threshing and winnowing techniques require 5 to 11 hours of women's labor to produce a 50 kg bag. Winnowing requires about 37% of the total time of these operations. Plant breeding may help to improve the efficiency of this post-harvest operation. A "clean threshing" inbred has recently been identified in the USDA-ARS pearl millet program. The seed does not shatter, but it is released from the glumes more easily, with a lower rate of abscission of the pedicle from the rachis. This trait may be useful in freeing up women's labor in post-harvest operations in the African setting.

Market demand is the most effective stimulus to increase pearl millet production. Quality traits that provide value to the end-user are needed. These market-driven quality traits include those valued for pearl millet-based foods, or traits for the recreational wildlife, poultry, or ethanol industries. Traits such as grain color, proximate composition, feed value, and fermentability are important criteria. The value of pearl millet in poultry rations is relevant to Africa. Pearl millet-based pre-starter rations increase chick body weights compared to a corn-based ration, and the performance and yield of broilers fed diets with up to 50% pearl millet are equal to or better than those fed typical corn-based diets. Demand for ethanol feedstocks is historically high, and pearl millet may be a useful supplemental feedstock. It ferments faster than corn, and the value of the distillers dried grains with solubles from pearl millet is greater than that from corn. Limited information exists on the differences in fermentability among pearl millet genotypes.

## Objectives and Implementation Sites

### *Objectives*

1. Improve the stability and performance of pearl millet by identifying and preserving germplasm with superior agronomic traits and resistance or tolerance to diseases, pests, and environmental stresses.

2. Enhance the production and marketability of pearl millet by improving pearl millet for yield, stability, consumer nutrition, and other market-driven quality traits.

3. Enhance the improvement of pearl millet genetic resources through the application of molecular genetic technologies.

4. Develop effective partnerships with national and international agencies, and other partners engaged in pearl millet improvement and the betterment of people who depend upon pearl millet for their livelihood.

### *Implementation Sites*

The project will be coordinated through the USDA-ARS Crop Genetics and Breeding Research Unit at Tifton GA, and conducted with collaborators in the West and Southern Africa regions. Collaborative sites in West Africa include Maiduguri Nigeria and Kamboinse Burkina Faso. Collaborative sites in Southern Africa include Kaoma, Zambia, and Gaborone, Botswana.

*Objective 1. Improve the stability and performance of pearl millet by identifying and preserving germplasm with superior agronomic traits and resistance or tolerance to diseases, pests, and environmental stresses.*

## Research Methodology and Strategy

### *Development of a Reliable Inoculation Technique to Assess Resistance in Pearl Millet to Fusarium Grain Mold*

Grain and seed molds commonly occur when a pearl millet crop matures during times of high humidity or excessive rainfall. These molds can reduce seed viability and stand establishment, and can also contribute to mycotoxin contamination in food and feedstuffs. This study was conducted to develop a reliable method for grain mold inoculations, and to assess the grain mold resistance of pearl millet inbreds. Inbreds, Tift 454, Tift 99B, 106B, 206B, 406B, 506B and 606B were evaluated in a series of four inoculations in the greenhouse. Fifteen pots of each inbred were planted at 14-day intervals for four plantings. Plants were prepared for inoculation shortly after anthesis during early grain fill. Anthers were lightly brushed off using a test-tube brush to expose the developing grains. Fungal inoculation treatments used in this study were a mixture of *F. semitectum*, *F. chlamydosporum* and *F. verticillioides*, or a water-sprayed control. The number of replications in each inoculation was determined by the availability of an adequate number of plants at the correct growth stage on a given day when inoculations were performed. Ten panicles per inbred were used for the fungal inoculation treatment and two panicles for the water control treatment in the first three inoculations. In the fourth inoculation, five panicles per inbred were used for the fungal treatments and two panicles for the control treatment. Within each inoculation date, inoculated inbreds were arranged in a completely randomized design and each panicle was considered a replicate.

Cultures of *F. semitectum*, *F. chlamydosporum*, and *F. verticillioides* isolates were increased separately on PDA. Spores and mycelial fragments were harvested and used to produce 1.5 L of inoculum containing approximately 9 x 106 spores and mycelial fragments/ml. Suspensions of the three fungi were made separately. For the mixture, equal volumes (1:1:1 v/v/v) of each of the three fungal suspensions were combined in a flask. Thus, the mixed fungal suspension had approximately 3 x 106 spores and mycelial fragments of each fungus/ml. Inoculum was sprayed onto panicles with an agitated hand-held spray bottle. The panicles were sprayed to run off. The non-inoculated panicles were similarly sprayed with water. Immediately after inoculation, panicles were covered with pre-wetted plastic bags which remained in place for a 7 day incubation period.

Panicles were evaluated for mold severity at 2 and 4 weeks after inoculation. Ratings were assigned on a scale of 0-5 where 0 = no mold visible, 1 = scant superficial mold growth and up to 10% of grain and panicle surface covered by mold, 2 = moderate mold growth and 11-25% of grain and panicle surface molded, 3 =

considerable mold growth and 26-50% of grain surface molded, 4 = extensive mold growth and 51-75% of grain and panicle surface molded, and 5 = extensive mold growth and more than 76% of grain and panicle surface molded. In the analysis of variance of mold ratings, sums of squares were partitioned into inoculation date, replication, evaluation date, inbred, and two and three-way interactions among inoculation date, evaluation date, and inbred. Means were separated using Fisher's LSD at $P \leq 0.05$.

## Research Results

The inoculation and prolonged incubation treatment successfully resulted in grain mold development. Mold growth was visible at three days, and increased during the incubation period. A limited amount of mold developed in the water-treated control, probably due to infection from background inoculum levels in the greenhouse coupled with the increased relative humidity from the plastic bag incubation technique. Grain mold ratings averaged 0.7 for the control plants, which differed ($P<0.001$) from mold levels of the inoculated plants. Ratings were not affected by evaluation date, and averaged 3.0 when assessed at either 2 or 4 weeks after inoculation. Evaluation date x inbred and inoculation x evaluation date x inbred interactions were not significant ($P>0.05$).

Mean grain mold ratings differed for each inoculation date ($P<0.001$). Mean ratings across inoculation dates ranged from 2.6 for the third inoculation date to 3.5 for the second. This level of difference is likely to cause some difficulties in experiments requiring single plant inoculations over multiple dates. More precise control over environmental conditions during the incubation period should be explored to produce more consistent results across inoculation dates.

Inbreds differed in their susceptibility to grain molds. Tift 99B, Tift 454, and 606B were most susceptible inbreds, whereas 506B and 106B were the most resistant (Table 1). This information will be useful in decisions concerning germplasm releases, and for further breeding efforts for grain mold resistance. These experiments identified a combination of inoculation treatment and incubation technique that was sufficient for the reliable development of grain mold in pearl millet. This technique will be useful in germplasm screening and breeding applications, and in inheritance studies

### *Genetic Improvement of Nematode Resistant Pearl Millets*

Root knot nematodes are important yield constraints in pearl millet and in peanut and cowpea, which are frequently grown in intercropping and rotations with pearl millet in Africa. Advanced inbred progeny derived from African varieties P3Kollo, Sosat-C88, Zongo, and Gwagwa were selected based upon resistance to *Meloidogyne incognita* in greenhouse evaluations. F5 progeny consisting of 93 P3Kollo selections, 83 SoSat-C88 selections, 56 Zongo selections, and 104 Gwagwa selections were evaluated for yield at Tifton GA in 2007. The highest yielding progeny were selected and crossed onto inbreds 506B and 606B in the greenhouse, and F1 progeny were planted in the field in 2008 in two replications to increase seed for F2 progeny populations. Plots were assessed at grain fill for percent lodging.

*Results*

Analysis of variance indicated that both the male and female parents significantly affected lodging. Hybrids made with 606B tended to have greater lodging (19.8%) compared to hybrids made with 506B (5.4%) ($P<0.01$). Among the West African germplasms, lodging was greatest in hybrids made with P3Kollo progeny (16.6%), followed by progeny from Gwagwa (12.7%), SoSat-C88 (11.0%) and Zongo (0.6%) ($P=0.04$, lsd=12.3). Within each cross combination, specific cross combinations with improved stalk strength could be identified to advancing for breeding purposes (Table 2).

*Objective 2. Enhance the production and marketability of pearl millet by improving pearl millet for yield, stability, consumer nutrition, and other market-driven quality traits.*

### *Genotype and Environment Effects on Ethanol Yield from Pearl Millet*

In spite of rising feedstock costs and the grain-deficit status of the southeast, investors have committed to the construction of new ethanol plants in the region. The use of alternative feedstocks will help to alleviate market demand for corn both as a feedgrain and as an ethanol feedstock. As a drought tolerant grain requiring low nitrogen inputs, pearl millet may be a viable supplemental ethanol feedstock for the southeast. Because fermentation concentrates aflatoxins in DDGS, dryland pearl millet may supplement irrigated corn in the southeast. Limited information exists concerning genotype and environmental effects on grain yield, starch content and fermentation efficiency in pearl millet feedstocks. The objective of this study was to assess experimental pearl millet hybrids for genotype and environment effects on grain yield, starch, fermentation efficiency, and ethanol yield. Statewide yield trials were planted at Moultrie, Tifton, Watkinsville, and Newton, GA in 2006, and at Moultrie, Tifton (early and late planted trials), Plains, and Newton, GA and 2007. Planting dates ranged from May 23 to August 9, 2006 and from May 10 to August 13, 2007. Nine genotypes were evaluated in 2006, and 6 genotypes were evaluated in 2007. Entries were planted in three or four replications per location, with 35 cm row spacing. Fertilizer was applied at 88 kg N/ha. Grain was combine-harvested, and yields were corrected to 15.5% moisture. Grain was evaluated for starch content on a dry basis. Fermentation efficiency was determined from the difference between observed and theoretical ethanol production.

*Results*

Pearl millet yield and starch content are influenced by trial and hybrid. Yields and starch content typically decreased with later planting date. It is necessary to identify hybrids with stable yield and feedstock quality. Experimental hybrid (606 x 2304) was among the top yielding hybrids at all locations (Table 3). Across all locations, hybrid (606 x 2304) had 17% greater yield than the commercial standard Tifgrain 102 in 2006, and 30.3% greater yield in 2007. (606 x 2304) had 1.4 % and 2.2% greater starch compared to Tifgrain 102 in 2006 and 2007, respectively. Across all genotypes, mean grain yields were greatest in Watkinsville in 2006, and in

**Table 1. Grain mold development on pearl millet inbreds inoculated in the greenhouse with a mixture of *Fusarium semitectum*, *F. chlamydosporum*, and *F. verticillioides*.**

| Inbred | Grain mold rating1 | |
|---|---|---|
| Tift 99B | 3.8 | a |
| Tift 454 | 3.6 | a |
| 606B | 3.6 | a |
| 206B | 2.8 | b |
| 406B | 2.6 | bc |
| 106B | 2.4 | cd |
| 506B | 2.3 | d |
| LSD (P<0.05) | 0.3 | |

1Data were pooled for ratings taken at 2 and 4 weeks after inoculation. A score of 0 = no mold visible on grain surface, 1 = up to 10% of grain surface covered by mold, 2 = 11-25% of grain surface molded, 3 = 26-50% of grain surface molded, 4 = 51-75% of grain surface molded, and 5 = > 76% of grain surface molded.

**Table 2. Lodging in pearl millet hybrids derived from 506B or 606B x West African pearl millets resistant to Meloidogyne incognita**

| 08F entry | Female | | Male | 08GH entry | Lodging (%) | 08F entry | Female | | Male | 08GH entry | Lodging (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2325 | 506B | x | P3Kollo | 215-1 | 1.0 | 2360 | 606B | x | P3Kollo | 215-2 | 40.0 |
| 2326 | 506B | x | P3Kollo | 215-4 | 0.5 | 2362 | 606B | x | P3Kollo | 216-4 | 67.5 |
| 2327 | 506B | x | P3Kollo | 216-1 | 0.8 | 2363 | 606B | x | P3Kollo | 217-1 | 12.5 |
| 2328 | 506B | x | P3Kollo | 216-2 | 0.5 | 2364 | 606B | x | P3Kollo | 217-4 | 65.0 |
| 2329 | 506B | x | P3Kollo | 217-1 | 1.3 | 2365 | 606B | x | P3Kollo | 218-1 | 7.5 |
| 2331 | 506B | x | P3Kollo | 218-3 | 0.0 | 2366 | 606B | x | P3Kollo | 219-1 | 55.0 |
| 2332 | 506B | x | P3Kollo | 218-4 | 1.0 | 2368 | 606B | x | P3Kollo | 220-2 | 95.0 |
| 2333 | 506B | x | P3Kollo | 219-3 | 0.0 | 2370 | 606B | x | P3Kollo | 221-2 | 32.5 |
| 2334 | 506B | x | P3Kollo | 219-4 | 0.3 | 2371 | 606B | x | P3Kollo | 221-4 | 45.0 |
| 2335 | 506B | x | P3Kollo | 220-3 | 10.5 | 2372 | 606B | x | P3Kollo | 222-4 | 2.5 |
| 2337 | 506B | x | P3Kollo | 221-1 | 0.0 | 2373 | 606B | x | P3Kollo | 223-1 | 8.5 |
| 2338 | 506B | x | P3Kollo | 221-3 | 16.0 | 2374 | 606B | x | P3Kollo | 224-2 | 11.0 |
| 2339 | 506B | x | P3Kollo | 222-1 | 15.0 | 2375 | 606B | x | P3Kollo | 224-3 | 2.0 |
| 2340 | 506B | x | P3Kollo | 222-3 | 2.5 | 2376 | 606B | x | SoSat | 225-1 | 2.5 |
| 2341 | 506B | x | P3Kollo | 223-1 | 0.0 | 2377 | 606B | x | SoSat | 226-4 | 1.0 |
| 2342 | 506B | x | P3Kollo | 223-3 | 0.0 | 2378 | 606B | x | SoSat | 227-1 | 0.5 |
| 2343 | 506B | x | P3Kollo | 223-4 | 1.0 | 2379 | 606B | x | SoSat | 230-2 | 0.5 |
| 2344 | 506B | x | P3Kollo | 224-3 | 5.0 | 2380 | 606B | x | SoSat | 230-3 | 25.0 |
| 2345 | 506B | x | SoSat | 230-4 | 23.5 | 2381 | 606B | x | SoSat | 231-3 | 4.0 |
| 2347 | 506B | x | SoSat | 233-2 | 70.0 | 2382 | 606B | x | SoSat | 232-4 | 12.5 |
| 2348 | 506B | x | SoSat | 233-4 | 1.3 | 2383 | 606B | x | SoSat | 233-1 | 6.5 |
| 2349 | 506B | x | SoSat | 234-2 | 0.0 | 2384 | 606B | x | SoSat | 234-1 | 60.0 |
| 2350 | 506B | x | SoSat | 234-3 | 0.8 | 2385 | 606B | x | SoSat | 234-2 | 1.0 |
| 2351 | 506B | x | Zongo | 235-3 | 0.5 | 2386 | 606B | x | Zongo | 235-1 | 0.0 |
| 2352 | 506B | x | Zongo | 236-2 | 0.0 | 2387 | 606B | x | Zongo | 235-5 | 0.5 |
| 2353 | 506B | x | Zongo | 236-4 | 2.0 | 2390 | 606B | x | Gwagwa | 246-3 | 0.0 |
| 2354 | 506B | x | Gwagwa | 246-2 | 0.3 | 2391 | 606B | x | Gwagwa | 247-2 | 4.0 |
| 2355 | 506B | x | Gwagwa | 246-4 | 0.5 | 2392 | 606B | x | Gwagwa | 248-3 | 8.5 |
| 2356 | 506B | x | Gwagwa | 247-1 | 0.0 | 2393 | 606B | x | Gwagwa | 249-3 | 52.5 |
| 2358 | 506B | x | Gwagwa | 251-1 | 4.0 | 2394 | 606B | x | Gwagwa | 249-5 | 25.0 |
| 2359 | 506B | x | Gwagwa | 251-2 | 0.0 | 2395 | 606B | x | Gwagwa | 250-3 | 25.0 |
| | | | | | | 2396 | 606B | x | Gwagwa | 251-2 | 35.0 |
| | | | | | | 2397 | 606B | x | Gwagwa | 252-3 | 7.0 |
| | | | | | | 2398 | 606B | x | Gwagwa | 253-1 | 3.5 |
| | | | | | | LSD (P=0.05) | | | | | 16.9 |

**Table 3. Grain yield on experimental pearl millets grown in nine multi-location trials in Georgia during 2006-07.**

| Entry | Grain yield ($kg/ha^{-1}$) | | Starch (%) | |
|---|---|---|---|---|
| 606A x 2304 | 1980 | a | 64.7 | a |
| 506A x 2304 | 1847 | b | 64.7 | a |
| 106A x 2304 | 1830 | b | 64.7 | a |
| 406A x 2304 | 1696 | c | 64.4 | b |
| Tifgrain 102 | 1607 | c | 63.6 | c |
| 2304 | 1049 | d | 64.4 | b |
| LSD (P=0.05) | 110 | | 0.2 | |

the early Tifton trial in 2007. In both years, grain yields and starch content of the grain were lowest in the trials grown at Newton. Across all entries and locations, calculated ethanol yield per acre was highly correlated with grain yield per acre both in 2006 and 2007 (R2 > 0.99). It will be possible to select hybrids that produce higher levels of ethanol for the developing bioenergy industry in the southeast. Improving grain yield will be the most effective means of improving overall ethanol yield per unit of land.

## Networking Activities

### *Workshops and Meetings*

Presented "Global Applications of USDA-ARS Pearl Millet Research." Hunger Awareness Seminar Series, Emory University, Atlanta GA. 2-27-07

Presented "Growing and Marketing Pearl Millet." Randolph Co. UGA-CAES grower meeting, Cuthbert, GA. 3-6-07

Presented "Pearl Millet Processing – State of the Art and Opportunities." Hampshire College, Amherst, MA. 3-14-07

Conducted Pearl Millet Field Day at Sunbelt Agricultural Exposition. Discussed pearl millet cultivation and markets with 300 agribusiness professionals. 7-10-07

Presented "Improving Performance, Stability and Pest Resistance in Pearl Millet." INTSORMIL PI meeting, Lincoln NE. 9-18/19-07

Presented "Hybrid and Proximate Composition Effects on Ethanol Yield from Pearl Millet." Association for the Advancement of Industrial Crops, Portland, ME. 10-7/10-07

Presented "Ethanol from Pearl Millet" at the Future Farmstead On-Farm Energy Conservation and Production Workshop, Tifton GA. 10-27-07

Organized Pearl Millet Working Group meeting, an informal consortium of industry, research, extension, and instruction. Attended by 19 participants. Ft. Valley State University. 11-16-07

Presented "Sustainable Production and Niche Marketing of Pearl Millet". "Sustainable Agriculture Summit – Focus on the Future". Fort Valley State University, Ft. Valley, GA. 7-12-08

Presented "Transition Strategies for an Organic Peanut-Grain Cropping System". "Sustainable Agriculture Summit – Focus on the Future". Fort Valley State University, Ft. Valley, GA. 7-12-08

Presented "Improving Conservation Tillage Practices for Pearl Millet" at Conservation Tillage School/Southern Conservation Agricultural Systems Conference, Tifton GA 7-29-08

Presented "Genotype and Environment Effects on Ethanol Yield from Pearl Millet", Association for Advancement of Industrial Crops Annual Meeting, College Station TX 8-11 Sept 08

Presented "Pearl millet for the recreational wildlife industry" at the Georgia Wildlife Federation Great Outdoors Exposition. 30,000 people attended event. Perry, GA. 8-10 Feb 08

Conducted Pearl Millet Field Day at Sunbelt Agricultural Exposition. Discussed pearl millet cultivation and markets with 400 agribusiness professionals. Moultrie GA. 10 Jul 08

### *Research Information Exchange*

Consulted by Energy Information Administration-DOE for information concerning fermentation of pearl millet as part of a national assessment of alternative ethanol feedstocks 10-1-07

Consulted by Adriana Seed Co. (Brazil) on breeding strategies for disease resistance in pearl millet and marketing Brazilian pearl millet exports in the U.S. 1-4-07, 11-4-07

Consulted by Bioversity International (formerly International Plant Genetic Resources Institute IPGRI) (Italy) for information on pearl millet taxonomy and gene flow with wild and weedy relatives to assess risks and management of transgene escapes. 7-07

Requested by BioVision Foundation (Switzerland) for use of pathology images in Infonet-BioVision training material for small-scale farmers in Africa. 10-9-07

Consulted by USDA-APHIS about geographic and biological information to restrict entry of Pestalotia leaf spot on pearl millet into the U.S. 3-31-08

Invited by Compatible Technology International to review post-harvest processing technology for pearl millet. Evaluated prototype designs, functionality, appropriateness of the technology, affordability, ease of use, and maintenance. St. Paul, MN. 4-7/8-08

Invited by Adriana Sementes (the largest producer of soybean and pearl millet seed in Brazil) to review pearl millet breeding operations, hybrid seed production and quality control practices, and market development activities. 5-27 to 6-1-08

Served as advisory consultant to Donna Cohn, Hampshire College faculty member, in developing project proposal "Pearl Millet Thresher for Developing Countries". Project was selected (12% of submitted projects were selected) for the International Development Design Summit sponsored by MIT, Cambridge. Advances are documented at http://milllet.wetpaint.com/ Jul-Aug 08

Hosted visit by Alan Weber, staff economist for the Thomas Jefferson Agricultural Institute, Columbia, MO. Discussions included pearl millet market development, cropping systems, and variety development. 8-28-08.

### *Germplasm Conservation and Distribution (if applicable)*

4 pearl millet hybrids and 1 population sent to Pronaca (Ecuador)

3 pearl millet germplasms sent to University of Maryland Eastern Shore (MD)

1 pearl millet germplasm sent to Clemson Univ. (SC)

4 pearl millet hybrids and 1 grain population sent to Jefferson Institute (MO)

1 pearl millet germplasm sent to Kammermeyer Consulting (GA),

3 forage pearl millet populations sent to the University of Florida (FL),

125 germplasms sent to the University of Georgia (GA),

1 forage pearl millet inbred sent to Western Illinois Univ. (IL)

55 nematode resistant pearl millet inbreds sent to each collaborating location: Lake Chad Research Institute, Maiduguri, Nigeria; CRZ-ISRA, Kolda Senegal; CRZ-ISRA Bambey Senegal; SARI, Tamale Ghana; IER, Cinzana Mali; INERA, Ouagadougou, Burkina Faso, and Department of Agricultural Research, Gaborone Botswana

## Publications and Presentations

### *Journal Articles*

Buntin, G. D., Cunfer, B. M., Phillips, D. V. and Wilson, J. P. 2007. Sequence and rotation effects on pest incidence and grain yield of double-cropped soybean and pearl millet after wheat and canola. Online. Crop Management doi:10.1094/CM-2007-1023-01-RS.

Jurjevic, Z., Wilson, J.P., Wilson, D.M. and Casper, H.H. 2007. Changes in fungi and mycotoxins in pearl millet under controlled storage conditions. Mycopathologia 164:229–239.

Ni, X., Wilson, J.P., Rajewski, J.A, Buntin, G.D., Dweikat, I. 2007. Field evaluation of pearl millet for chinch bug (Heteroptera: Blissidae) resistance. Journal of Entomological Science. 42:467-480.

Nutsugah, S.K. and Wilson, J.P. 2007. Development of a reliable inoculation technique to assess resistance in pearl millet to Fusarium grain mold. Online. Journal of SAT Agricultural Research 5(1). http://www.icrisat.org/Journal/volume5/News/News5.pdf

Wilson, J.P., Sanogo, M.D., Nutsugah, S.K., Angarawai, I., Fofana, A., Traore, H., Ahmadou, I., and Muuka, F.P. 2008. Evaluation of pearl millet for yield and downy mildew resistance across seven countries in sub-Saharan Africa. African Journal of Agricultural Research. 3:371-378.

### *Books, Book Chapters and Proceedings*

Gulia, S.K., Wilson, J.P., Carter, J., and Singh, B.P. 2007. Progress in Grain Pearl Millet Research and Market Development. Pgs. 196-203 In: Janick, J., and Whipkey, A (Eds.) Issues in New Crops and New Uses. ASHS Press. Alexandria, VA. (Book Chapter)

Wilson, J.P., McAloon, A.J., Yee, W., McKinney, J., Wang, D., and Bean, S.R. 2007. Biological and Economic Feasibility of Pearl Millet as a Feedstock for Ethanol Production. Pgs. 56-59 In: Janick, J., and Whipkey, A (Eds.) Issues in New Crops and New Uses. ASHS Press. Alexandria, VA. (Book Chapter)

### *Miscellaneous Publications*

Buntin, G. D., Ni, X., and Wilson, J. P. 2007. Chinch bug control in pearl millet for grain production, 2006. Arthropod Management Tests 32: Report F41.

### *Abstracts*

Ni, X., Wilson, J.P., Buntin, D. 2008. Impact of chinch bug feeding on photosynthesis of forage pearl millet. International Plant Resistance to Insects Workshop, February 10-13, 2008, Ft. Collins, Colorado

Vencill, W.K., Wilson, J.P. 2008. Response of pearl millet to HPPD-inhibiting herbicides. Proc. Weed Sci. Soc. America, February 4-7, 2008, Chicago, IL. Pg. 27.

Wilson, J.P., Endale, D.M., Schomberg, H.H., Dale, N., Wang, D., Hanna, W.W., Vencill, W. 2007. Hybrid and proximate composition effects on ethanol yield from pearl millet. http://aaic.org/07program.htm

Wilson, J.P., Strickland, T.C., Truman, C.C., Schomberg, H.H., Maw, B.W. 2008. Improving conservation tillage practices for pearl millet. In: D.M. Endale (ed.) Proc. 30th Southern Conservation Agricultural Systems Conference and 8th Annual Georgia Conservation Production Systems Training Conference, July 29-31, 2008, Tifton, Georgia. http://www.ag.auburn.edu/auxiliary/nsdl/scasc/.

Wilson, J.P., Endale, D.M., Schomberg, H.H. 2008. Genotype and environmental effects on ethanol yield from pearl millet. Proceedings New Crops and Bioproducts Development. Assoc for Advancement of Industrial Crops. College Station, Texas. September 7-11, 2008. p. 21.

# Breeding Sorghum for Improved Resistance to *Striga* and Drought in Africa

## Project PRF 101
## Gebisa Ejeta
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### Introduction and Justification

Sorghum is an important crop worldwide both in area of production and in total tonnage produced. It is a particularly important crop in Africa where it the cereal of choice to cultivate because of its relative superiority in productivity under low input levels and where abiotic and biotic stresses prevail. In the United States, sorghum is the second most important feed crop for both poultry and livestock; it is also a major livestock feed in several countries around the world. The project has identified the two most important sorghum production constraints in Africa as its area of focus and concentration. Drought stress is the most important abiotic factor limiting crop productivity in Africa. It is most severe in marginal environments where sorghum is routinely grown, but a major constraint in most areas and every crop season. About one-third of the world's arable land experiences water deficits, and in these areas crop yields are significantly reduced by drought. The parasitic weed, *Striga*, is the most important biotic stress in semi-arid tropical Africa. *Striga* infestation is most severe in areas where moisture is the most limiting. Nearly 100 million hectares of field crops including sorghum, millets, maize are infested annually with *Striga* in sub-Saharan Africa. We focus on genetic improvement of sorghum for drought and *Striga* resistance through a collaborative interdisciplinary process involving colleagues in several national agricultural research services (NARS) in Africa. The project will have a research for development emphasis with a value chain approach. It will have as its major activities the breeding of drought and *Striga* resistant sorghum varieties and hybrids, deploying these superior cultivars with a package of well though out crop management or agronomic practices, seeking market opportunities for those adopting the recommended packages of technologies, and resulting with increased income and well being of poor farmers.

### Research Objectives

In this project period, the following research objectives were addressed:

1. Modify our laboratory methods developed for assessing *Striga* resistance in sorghum for use in maize.

2. Assess yield potential of experimental *Striga* resistant sorghum hybrids.
3. Validate use of molecular markers in breeding for abiotic stress tolerance

## Research Methods

### *Characterization of Striga Resistance in Maize*

We have in our program, an established laboratory procedure, "the Paper Roll Assay" that we use for characterizing sorghum cultivars for differences in mechanisms of *Striga* resistance in sorghum. We recently modified this procedure for use in maize. Idris Amusan, a graduate student from Nigeria developed a new assay, called Sand Packed Titer Plate Assay (SPTPA), and used it to characterize specific mechanisms for the trait expression in a set of *Striga* resistant maize inbred lines developed by the Institute of International Agriculture (IITA). The reaction and post-attachment events of pre-germinated *Striga* on maize was followed. The procedure as described in a recent publication (Amusan et al., 2008) is as follows: "The SPTPA involved an 11.5 × 26 × 5 cm rectangular titer plate with lower and upper lids, and an opening on top. The topmost 2.5 cm of the lower lid was covered with 26 × 2.5 cm perforated plastic poster board which has 5 cm low density foam glued to its other side. A 30 × 28 cm sheet of glass-fiber paper was placed in this lower case, which was added enough sterilized, sandy soil to cover the remaining space in the lower case (9.5 × 26 × 5 cm). A piece of the glass fiber paper was placed to cover the exposed sand in the lower lid. This ensured that the sterilized sand is entirely protected and contained within the glass fiber paper sheets. A sterilized black filter paper was placed on top of the glass fiber paper in the lower lid. Germinated maize seed was placed on the surface of the black filter paper; the upper lid case of the titer plate was replaced, and held together with the sand-packed lower lid by a rubber band. Perforations on the poster board and holes punched at the bottom of the titer plate ensured ease of watering, good aeration, and water drainage. The low density form on the plastic poster allowed shoot to emerge from the titer plate. The titer plate was covered with aluminum foil to exclude light, and placed in a growth chamber operating at 80% RH and 30ºC with 12 hours of light and darkness. Eleven days after transplanting, roots of the maize plants were inoculated with 2 mg of pre-germinated *Striga* seed by carefully aligning the seed along the host root. Inoculated plants were returned to the growth chamber. Each SPTPA was supplied with 60 ml of nutrient solution at transplanting followed by 30 ml of nutrient solution every 48 hours throughout the duration of the experiment. Measurements were taken on frequency of attached *Striga* seeds that had reached various stages of development at 3, 9, 15 and 22 days after infection (dai) using a flat bed scanner. Developmental stages of the parasite on host root were defined as: S1, attached *Striga* with seed coat intact; S2, emergence of the first pair of leaf primordia; S3, *Striga* shoots having two to four scale leaf pairs; S4, *Striga* shoots having five or more scale leaf pairs; D, attached *Striga* dead on host root. Verification of developmental differences was observed through further microscopy work. *S. hermonthica* development and penetration within the host root was monitored by dissecting representative haustoria of the parasite attached to the host roots at 3, 9, 15 and 22 dai. Samples were fixed, embedded in resin, and semi-thin section were stained with Toluidine Blue and attached to adhesive-treated microscopic slides for observation under the light microscope. Primary fixation of samples involved soaking in a solution of 2.5% paraformaldehyde and 2% glutaraldehyde in 0.1M cacodylate buffer at pH of 6.8 for 2 hours. The buffer was washed in 3 change of sterile water before the tissue was fixed in 2 % OsO4 in 0.1M cacodylate buffer at pH 6.8 for 90 minutes. After washing off the buffer, the fixative was dehydrated in an ethanol series (10, 30, 50, 70, 90 and 100%), and finally in propylene oxide. The resin was polymerized at 60ºC for 48 hours. Embedded samples were sectioned at a thickness of 2µm and attached to adhesive microscopic slides.

### *Yield Potential of Striga Resistant Sorghum Hybrids*

Sorghum germplasm with resistance to *Striga* have been released from our program and distributed into a number of countries. All of these releases have been open-pollinated cultivars to offer ease in seed handling in an area of the world where the seed industry has not been well developed. With the emergence of late, of new seed enterprises in Africa, the potential for successful exploitation of crop hybrids with adaptation to the varied ecologies and resistance to major biotic and abiotic stresses appears greater than in the past. *Striga* resistance is particularly important as the parasite population has expanded. In this project, experimental hybrids were synthesized from sorghum inbreds that have been selected for high level of resistance. An initial evaluation of these experimental hybrids was conducted at the Purdue University Agricultural Center for Research and Education in West Lafayette, Indian during the 2007 crop season.

### *Validation of Molecular Markers in Breeding for Cold Tolerance*

Genetic markers for quantitative traits are commonly identified in mapping populations to enhance selection for cultivar improvement. However, the plant breeding community recognizes the necessity to validate these putative quantitative trait loci (QTL) across various genetic backgrounds before embarking upon marker-assisted introgression or selection. Three important factors have been blamed for a QTL-marker association identified in one population will be useful for selection in a different population, including marker-QTL segregation (i.e., polymorphism of the QTL and of the marker on which to select), the linkage phase of the marker and QTL of interest, and epistatic interactions between the QTL and various other loci in the new population. Polymorphism of the genetic markers is easy to determine, but the association of a given marker with a quantitative trait in a new population may need to be determined experimentally. Also, other loci that may interact with the introgressed QTL are usually not known, but they can affect the magnitude of expression of the QTL, possibly even obscuring it completely. In this study, two sorghum lines contrasting for seedling cold tolerance were used in a set of experiments. An introduction from China, 'Shan Qui Red' (SQR), selected for its early-season cold tolerance, was used to generate several segregating populations in cross combinations with other sorghum lines assembled in our breeding program. Two of these breeding populations were chosen for this experiment to validate QTL for early-season cold tolerance identified in a previous RI population. The first test population was created by crossing SQR with a cold-sensitive line, Tx2794. In 2003, approximately 500 random heads of the F2 generation were selfed to produce a population of 394 F3 families. The second population was created by crossing SQR with 'Wheatland', a common commercial seed parent with moderate early-season vigor. The F1 was backcrossed to 'Wheatland' to produce the BC1F1 generation, which was then selfed to produce the BC1F2. Approximately 500 random heads of the BC1F2 generation were selfed in 2003 to produce a population of 390 BC1F3 families. Each panicle, representing one F3 or BC1F3 family from these populations, was kept for use in this study.

The above populations were used for both the laboratory genotyping and the phenotyping done in the field, greenhouse, and growth chambers. Data on SSR markers generated on the RI lines and their advanced backcross progenies were used to classify the F3 and BC1F3 families into 27 different genotypic classes based on the three possible genotypes at each of the three marker loci. Five random entries of each genotypic class were chosen for field evaluation. Where there were fewer than five entries for a particular genotypic class, two, three, or four entries were used. In the Wheatland backcross population, one genotypic class was not represented. A replicated field trial of progeny families representing each of the 27 classes was planted at the Purdue University Agronomy Center for Research and Education in West Lafayette, IN. A duplicate sample of seed was placed in cold storage, and was planted out for a second year trial on 11 Apr. 2005 in a different field at the same facility. These planting times are regarded as early for sorghum at this location, and provided exposure to cool temperatures. Each population was planted out in a separate experiment, and each experiment was laid out in a randomized complete block design with three replications. The parental lines were also included as checks for phenotypic assessment and comparison of seedling vigor. A border row of a common commercial hybrid was planted between each plot, and also along all edges of the experiment. Data on four early-season traits were recorded. Seedling emergence (total number of seedlings emerged in each plot) was counted twice during the early growing season. Early emergence was counted at approximately 15 days after planting in both years. A final count was taken at 23 d after planting. Seedling vigor scores were measured three times, at approximately 10-d intervals throughout the early season. Vigor scores were assessed visually on a scale of 1–5 in increments of 0.5, with 1 representing very high vigor and 5 representing very poor vigor.

## Research Results

### *Striga Resistance in Maize*

Sources of *Striga* resistance in maize are rare, perhaps because the early evolution of the maize species took place in the Americas in the absence of the parasite population. As a result, breeding for resistance to *Striga* in maize, with paucity of donor source and known mechanisms of resistance remains more challenging. We believe that a better understanding of the specific host responses associated with invasion by the parasite may encourage the development of improved selection schemes to improve *Striga* resistance in maize. Field testing of *Striga* resistance does not offer the means to study the basis of host plant resistsance to the parasite. Using the new biossay, we evaluated the development of *S. hermonthica* post-attachment, on two maize inbreds selected for field resistance and susceptibility reactions to *Striga* at the International Institute of Tropical Agriculture. Haustorial invasion of the parasite into roots of these inbreds was examined histologically. Observations of *Striga* haustoria development revealed critical differences in the invasion of host roots between the susceptible inbred line 5057 and the resistant inbred ZD19. On inbred 5057 (Fig. 1) by three days after infection (dai), the attached parasite had its seed coat intact with numerous primary root hairs and a viscid substance at the point of contact with the host root. Sectioning of this attached parasite (Fig. 2) showed that haustorium had successfully penetrated the entire host root cortex. The apical tissue of the endophyte was in contact with endodermis of the host plant. The haustorial tissue consisted mainly of parenchyma like cells. By 9 dai, the attached parasite had developed 3 scale leaf pairs and a distinct tubercle. A cross-section through the tubercle and the host root revealed complete invasion of the host stele, and highly differentiated haustorial tissues.

By 15 dai, *S. hermonthica* had 5 scale leaf pairs. The internal structures and tissue development of the haustorium were similar to that observed at 9 dai; however, the haustoria were much bigger with a well differentiated vascular core. At 22 dai, the parasite had 10 scale leaf pairs and had formed secondary haustoria which invaded the host root. The secondary haustorium is formed by lateral or terminal contact of secondary parasite roots with host roots. Longitudinal section of the primary haustoria exhibited the same structural components seen in the transverse section of haustoria growing on the susceptible maize at 9 dai. Several distinctive responses to the invasion of the resistant host root by *Striga* haustoria were observed at subsequent sampling days. At 9 dai, the attached parasite had developed one scale leaf pair. Although the parasite bridged the host xylem there was no evidence of tissue differentiation in the haustoria, in contrast to haustoria on susceptible maize at the same age. In rare cases, by 22 dai the parasite on the root of resistant maize produced 4 pairs of poorly emerged scale leaves on stunted and purpling shoot tissue.

In summary, morphological differences were observed between roots of the susceptible and the resistant inbreds. The resistant maize had fewer *Striga* attachments, delayed parasitic development, and higher mortality of attached parasites compared to the susceptible inbred. *Striga* on the susceptible inbred usually penetrated the xylem and showed substantial internal haustorial development. Haustorial ingress on the resistant inbred was often stopped at the endodermis. Parasites able to reach resistant host xylem vessels showed diminished haustorial development relative to those invading susceptible roots. These results suggest that the resistant inbred expresses developmental barrier and incompatible response against *Striga* parasitism. The assay was useful in identifying specific points in early parasitic establishment where resistance reactions were deployed. It could therefore be useful in pyramiding different traits that counter *Striga* parasitism into durably resistant maize germplasm.

### *Yield Potential of Striga Resistant Sorghum Hybrids*

The use of hybrids is helpful in encouraging the development of a functional seed industry in a country as well as in providing an effective way to deploy *Striga* resistance regularly without danger of contamination or loss of impact through out crossing with lo-

**Figure 1. Growth of *Striga hermonthica* on the roots of resistant (ZD19) and susceptible (5057) maize inbreds at 22 days after infection.**

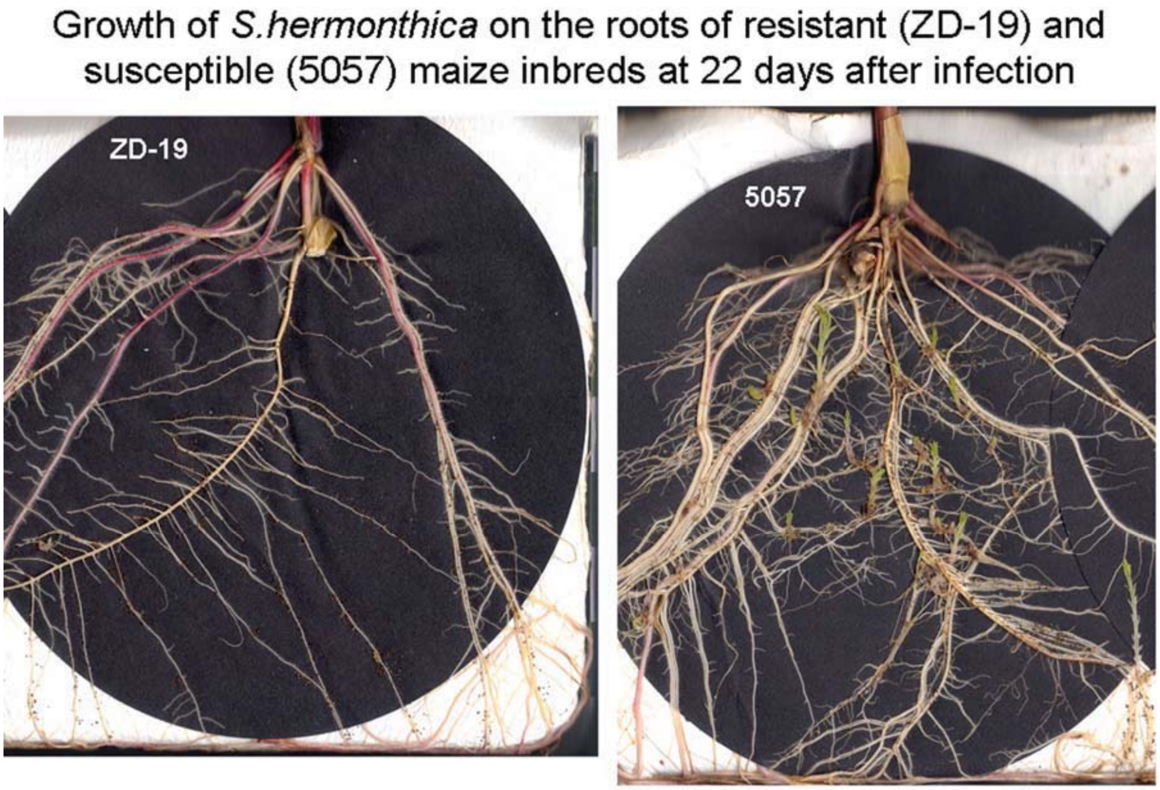


**Figure 2. *Striga hermonthica* penetration and growth in resistant (top) and susceptible (bottom) maize inbred lines.**

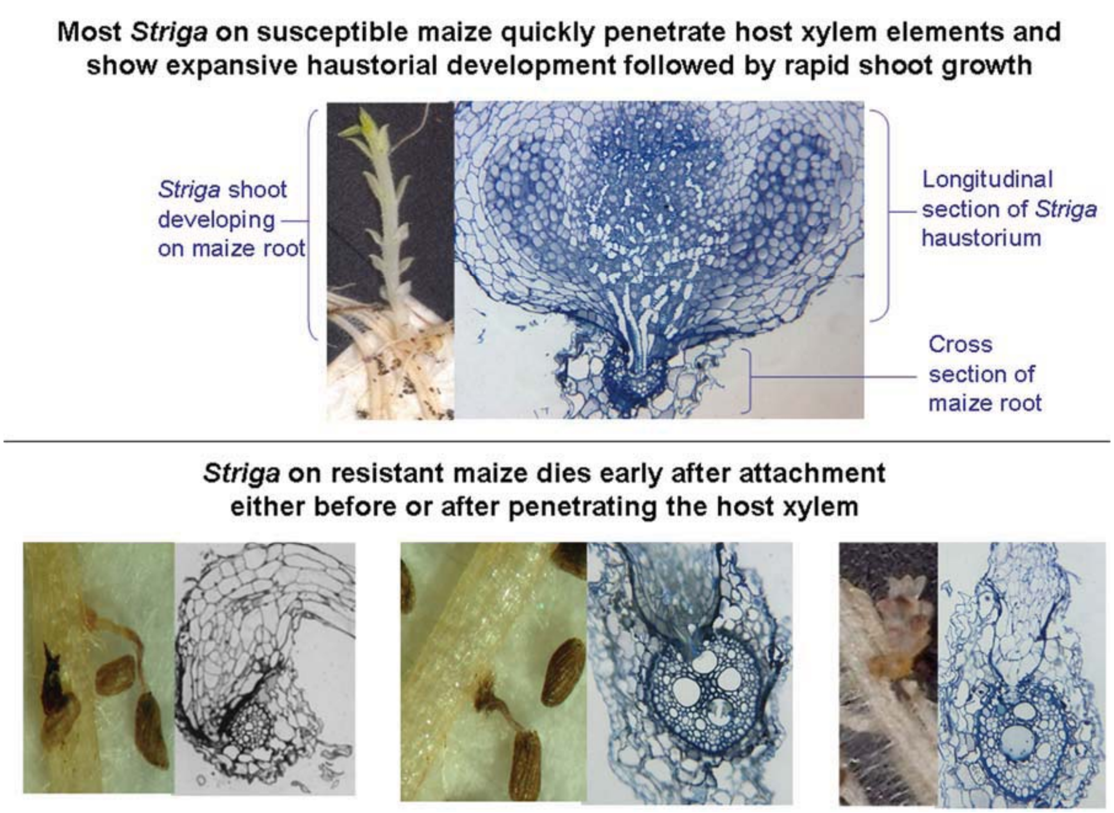

**Table 1. Yield potential (kg/ha$^{-1}$) of experimental *Striga* resistant sorghum hybrids grown in comparison with U.S.commercial feed sorghum hybrids in Lafayette, Indiana**

| Purdue Entry | Pedigree | Days to 50% Fl. | Height (CM) | Grain Yield (kg/ha$^{-1}$) |
|---|---|---|---|---|
| 8046 | A13 X PSL985003 | 83 | 183 | 9340 |
| 8807 | A9 X PSL985143 | 78 | 196 | 9280 |
| 8795 | A9 X PSL985003 | 83 | 175 | 9166 |
| 8045 | A13 X PSL984998 | 83 | 183 | 9052 |
| 8058 | A13 X PSL985143 | 80 | 218 | 9008 |
| 8066 | A1 X PSL985021 | 78 | 183 | 8942 |
| 8072 | A1 X PSL985087 | 74 | 183 | 8937 |
| 8062 | A1 X PSL985009 | 83 | 180 | 8918 |
| 8048 | A13 X PSL985011 | 81 | 170 | 8837 |
| 8068 | A1 X PSL985172 | 76 | 201 | 8633 |
| 8061 | A1X PSL985003 | 80 | 191 | 8593 |
| 8069 | A1X PSL985178 | 75 | 170 | 8509 |
| 8047 | A13 X PSL985009 | 82 | 178 | 8494 |
| 8797 | A9 X PSL985011 | 81 | 160 | 8432 |
| 8802 | A9 X PSL985172 | 80 | 178 | 8405 |
| 8073 | A1 X PSL985143. | 79 | 229 | 8364 |
| 8030 | A10 X PSL984998 | 84 | 180 | 8346 |
| 8054 | A13 X PSL985178 | 76 | 170 | 8293 |
| 8067 | A1 X PSL985027 | 75 | 178 | 8073 |
| 8796 | A9 X PSL985009 | 84 | 170 | 8009 |
| 8057 | A13 X PSL985087 | 73 | 163 | 7977 |
| 8070 | A1 X PSL985180 | 78 | 140 | 7735 |
| 8050 | A13 X PSL985006 | 81 | 178 | 7724 |
| 8063 | A1X PSL985178 | 79 | 180 | 7638 |
| 8801 | A9 X PSL985027 | 79 | 160 | 7576 |
| 8060 | A1 X PSL984998 | 77 | 216 | 7571 |
| 8059 | A13 X PSL985192 | 75 | 165 | 7531 |
| 8065 | A1 X PSL985006 | 78 | 185 | 7478 |
| 8052 | A13 X PSL985027 | 79 | 170 | 7458 |
| 8805 | A9 X PSL985069 | 82 | 165 | 7428 |
| 8053 | A13 X PSL985172 | 81 | 183 | 7274 |
| 8808 | A9 X PSL985192 | 75 | 145 | 7223 |
| | DK36-00(Monsanto) | 71 | 119 | 7210 |
| 8803 | A9 X PSL985178 | 76 | 155 | 7152 |
| 8031 | A10 X PSL984998 | 84 | 180 | 7149 |
| 8804 | A9 X PSL985180 | 77 | 132 | 7059 |
| 8056 | A13 X PSL985069 | 79 | 170 | 7038 |
| 8051 | A13 X PSL985021 | 81 | 170 | 7010 |
| 8794 | A9 X PSL984998 | 83 | 170 | 7006 |
| 8049 | A13 X PSL985061 | 83 | 170 | 6995 |
| 8032 | A10 X PSL985009 | 85 | 173 | 6989 |
| 8799 | A9 X PSL985006 | 78 | 160 | 6944 |
| 8055 | A13 X PSL985180 | 76 | 137 | 6861 |
| 8064 | A1 X PSL985061 | 80 | 180 | 6655 |
| 8798 | A9 X PSL985061 | 82 | 163 | 6274 |
| | W494-4(Warner Seeds) | 70 | 127 | 6230 |
| 8074 | A1 X PSL985192 | 75 | 168 | 5653 |
| 8041 | A10 X PSL985069 | 84 | 168 | 5402 |
| | ----- | | --- | --- |
| | Grand | 79 | 172 | 7747 |
| | LSD | 3 | 13 | 2733 |
| | C.V. | 2 | 4 | 18 |

cal cultivars. The results presented in Table 1 show that many of the experimental hybrids we tested have high yield potential, with many entries yielding significantly higher than U.S. commercial feed grain sorghum hybrids when grown in Lafayette, Indiana. Of the 45 experimental hybrids tested, 32 hybrids yielded higher than the best commercial hybrid in the test. All but two experimental hybrids yielded higher than the second commercial hybrid. A high yielding *Striga* resistant hybrid, Brhan also yielded higher than some of the hybrids including one of the commercial hybrid. Many of the experimental hybrids were in general taller and later in maturity than the commercial hybrids.

### *Validation of Molecular Markers in Breeding for Cold Tolerance*

Cool temperatures during the early growing season are a major limitation to growing sorghum (Sorghum bicolor (L.) Moench) in temperate areas. Several landraces from China have been found to exhibit higher emergence and greater seedling vigor under cool conditions than most breeding lines currently available, though they tend to lack desirable agronomic characteristics. If reliable markers for early-season cold tolerance can be identified, marker-assisted breeding could then be used to expedite the introgression of desirable genes from Chinese landraces into elite lines. Using a recombinant inbred (RI) population developed from a cross between Chinese landrace 'Shan Qui Red,' (SQR, cold-tolerant) and SRN39 (cold-sensitive), QTL associated with early-season performance under both cold and optimal conditions were identified by single marker analysis, simple interval mapping (SIM), and composite interval mapping (CIM). Two QTL for germination were identified: one on linkage group 3a, derived from SRN39, was significant under cold and optimal temperatures. The other, on group 7b, showed greater significance under cold temperatures and was contributed by SQR. A region of group 1a, derived from SQR, showed strong associations with seedling emergence and seedling vigor scores under early and late field plantings. A QTL for both early and late emergence was identified by CIM on group 2 which favored the SRN39 allele. SIM identified a QTL for early vigor on group 4 favoring the SQR genotype. Further studies are needed to validate the effects of these QTL, but they represent the first step in development of a marker-assisted breeding effort to improve early-season performance in sorghum.

In a preceding study we identified quantitative trait loci (QTL) for early-season performance in a recombinant inbred (RI) population, one parent of which was a cold-tolerant Chinese line, 'Shan Qui Red' (SQR). In this study, three SSR markers (txp43, txp51, and txp211), each representing a QTL, were tested in two new populations: (Tx2794 × SQR F3) and (Wheatland × SQR BC1F3). Individual families were genotyped, and early-season field performance was measured for two years. Statistical analyses showed that the SQR allele of txp43 had favorable effects on seedling vigor in both populations, and on emergence in the Tx2794 population. A large positive effect of the SQR allele of txp51 was observed in the Tx2794 population for vigor and emergence. Slight genotype by environment interaction was observed for txp51 in the Wheatland population. Marker txp211 had small but significant effects on seedling vigor and emergence in both populations. Various interactions between loci were also significant. This study validated QTL markers in various genetic backgrounds, and demonstrated the utility of MAS for a quantitative trait, early-season cold tolerance, evaluated in the field.

All three QTL markers were shown to retain influence in different genetic backgrounds than the one in which they were initially identified. In the original QTL analysis, the SQR allele of txp43 was shown to favor seedling emergence and seedling vigor. In this study, the effect of txp43 on seedling vigor and emergence was validated in the Tx2794 background under early-season planting. This effect was further confirmed by the positive effect of txp43 on stand biomass. This marker will be useful for introgressing early season cold tolerance from SQR into Tx2794. This marker also showed significant effects for vigor and emergence in the Wheatland background, though its effects were not as pronounced as in the Tx2794 population. There may be a slight negative effect of the SQR allele on emergence, but it has a favorable effect on seedling vigor. Also, it shows favorable interactions with the other two markers.

This study has shown that the effects of QTL can be validated in F2– or BC1F2–derived segregating populations. A straightforward analysis of variance model is used to test the main effects of selected QTL markers, while also identifying potentially important interactions between loci, or genotype by environment interactions when tests are conducted in multiple years or locations. This method could be extended to virtually any generation of segregating material, including advanced backcross generations, and could also be used to validate markers in selectively genotyped or bulked-segregant populations.

## Training (Degree and Non-Degree)

Zenbaba Gutema, a Ph.D. student from Ethiopia completed his education and returned to his home country.

## Networking Activities

Project PI Gebisa Ejeta visited CIRAD, France with potential collaboration in sorghum drought tolerance and *Striga* resistance partnerships.

A planning workshop was held in Nairobi, Kenya for the Horn of Africa region bringing together US and HOA PIs as well as other collaborators to kick start the new INTSORMIL and Other Grains

## Publications and Presentations

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# Developing Sorghum with Improved Grain Quality, Agronomic Performance, and Resistance to Biotic and Abiotic Stresses

**Projects PRF 104**
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### Introduction and Justification

Sorghum is poised to play a key role in agricultural development and food security in developed and developing countries around the world. The role of sorghum in agricultural development is expanding as genetic, genomic, and agricultural technologies that have been developed for the crop are transferred to targeted regions throughout the world. The primary goal of this proposal focuses on research and training activities to deploy genetic technologies that will enhance the value and performance of sorghum into farmer-accepted varieties in developed and developing sorghum production regions. These efforts will be accomplished through collaborative programs with sorghum breeders in national agriculture research systems throughout West Africa including Niger, Mali, Burkina Faso, and Senegal and regionally through interaction with ICRISAT. Other more basic research efforts will focus on the development and use of emerging genetic and genomic technologies to more efficiently use and study the natural genetic variation in sorghum.

### Problem Statement

The West Africa (WA) region produces over 30% of the total acreage of sorghum in the world and the U.S. produces another 5% (FAO, 2005). Most of the grain produced in WA is used to prepare foods and beverages for human consumption including traditional stiff or thin porridges (e.g., tô and fura), granulated foods (e.g., couscous), and local beers (e.g., dolo) (Drs. Awika and Rooney, 2004). In the U.S., sorghum primarily is used in animal feed, but the food and biofuel markets are expanding rapidly. Opportunities in new and expanding markets, especially emerging food and feed markets, will require that more attention be given to couple grain quality and end-use requirement traits with key defensive traits (e.g., *Striga* management) needed to maximize production potential in target environments. The goal of this research, development, and training program is to develop and implement genetic technologies to improve tolerance to biotic (weedy pests and grain molds) stresses in locally-adapted sorghum varieties, especially varieties with improved food- and feed-quality characteristics (e.g., tan-plant, high protein and fat, … etc.).

### Objectives and Listing of Implementation Sites

Recent West African Regional Workshops of INTSORMIL scientists in Ouagadougou, Burkina Faso in 2006 and Bamako, Mali in 2008 highlighted the need to actively transfer technologies developed in previously funded research to improve sorghum crop production, performance, and value (West Africa Technology Transfer Working Group, 2007). Similar workshops and planning sessions of scientists and producers in the U.S. identified the need to develop locally-adapted sorghum varieties and hybrids with improved grain quality characteristics, especially cultivars with improved food and feed quality traits (e.g., tan-plant, white-grain, grain mold and head bug resistance, high protein and fat content, etc.) and management of weeds including *Striga*. Specific objectives and implementation sites include:

Develop locally adapted sorghum varieties and hybrids having improved grain quality and feed value. Key collaborators and implementation sites:

- Soumana, INRAN, NIGER
- Dembele, IER, MALI

Develop and deploy technologies and strategies to manage biotic stresses, especially improved weed control, into locally adapted varieties and hybrids. Key collaborators and implementation sites include:

- Soumana, INRAN, NIGER
- Kayentao, IER, MALI
- Traore, INERA, BURKINA FASO
- Van Mourik, Weltzien, Rattunde, ICRISAT, MALI
- Al Khatib, Kansas State University, USA
- Bastiaans and van Ast, Wageningen University, The NETHERLANDS
- Ejeta, Purdue University, USA
- Aupperle, DuPont Crop Protection, USA

Identify and mine genes and alleles associated with improved sorghum performance in the natural gene pool. Key collaborators and implementation sites include:

- Yu, Kansas State University, USA
- Bean, USDA-ARS, Manhattan, Kansas, USA

This project and approach will directly contribute to the vision of the INTSORMIL CRSP for 2007-2011. The main focus of this project is to incorporate improved food and feed quality traits into locally-adapted sorghum varieties and hybrids thereby improving the accessibility of high-quality grains for new market development. The development of improved, locally-adapted, sorghum varieties and hybrids having enhanced food and feed quality traits will address INTSORMIL CRSP objectives 1 and 2 to increase availability of high-quality grains which will facilitate market development for these grains for use in new food products with enhanced nutritional value. Efforts to incorporate *Striga* resistance and herbicide tolerance traits into locally-adapted sorghum cultivars will provide new tools that are desperately needed for management of Striga and grassy weeds, the most important biotic constraints to sorghum production in Africa and the U.S. These efforts will enhance the productivity and stability of sorghum production in those environments and accomplish CRSP objectives to improve yield potential and stability and contribute to integrated management of the most important biotic pests through use of genetic technologies. Finally, the use and conservation of existing sorghum genetic resources will be improved through use of new linkage-association mapping strategies to study genes and identify alleles associated with important target traits. Each of these objectives will be accomplished through maintenance and expansion of established linkages with foreign collaborators which will afford opportunities to enhance national and international organizations in West Africa through short- and long-term training of students and research scientists.

## Specific Research Strategy and Approach

Collaborative research efforts are supported through short and long-term training programs, germplasm exchange and evaluation, and complementary basic research support activities. Crop improvement efforts to develop cultivars adapted to environments in West Africa utilize elite varieties and cultivars that are adapted to specific parts of the region. The lines used to create these populations are selected through evaluations of elite U.S. and host country germplasm in the target region. The populations are advanced and selected in summer and winter nurseries and then transferred to the target region for evaluation in conference with collaborating plant breeders.

The research to develop new herbicide tolerance traits in sorghum is focused on developing new tools for managing weed pests in the crop. A 2006 survey of sorghum producers in the United States indicated that new technologies for controlling weeds was thought to be one of the highest priorities for research investment. Herbicides are an important component of most weed management programs in sorghum. Many grain sorghum producers currently use preplant herbicides such as atrazine and metolachlor. Under dry conditions, preplant herbicides often fail or perform poorly and weeds can become a problem. New herbicides are needed to control broadleaf and grassy weeds. In 2005, a natural sorghum mutant with high levels of tolerance to ALS-inhibiting herbicides was identified. Genetic crossing and backcrossing are being used to transfer this trait into elite grain sorghum varieties. In 2006, a sorghum mutant with resistance to several ACCase inhibiting herbicides was identified. This trait also is being incorporated into elite sorghum parent lines through crossing and backcrossing. In the United States, inbred lines important in the hybrid seed industry are being converted to ALS and ACCase herbicide tolerance. In Africa, the ALS herbicide tolerance trait can be used in conjunction with seed treatments to control parasitic witchweed infestations. Inbred lines used for hybrid seed production and several open-pollinated varieties that are important in the region are being converted to ALS herbicide tolerance to facilitate the development and testing of this technology.

Association gene mapping strategies search for genes involved in complex traits at a population level using natural diversity rather than through individual bi-parental crosses (Yu and Buckler, 2006). It tests for relationships between molecular polymorphisms at the gene level with phenotypic variation among diverse genotypes. An association mapping (AM) panel of 300 sorghum genotypes collected from around the world has been assembled that captures the natural genetic variation of sorghum. The PI is collaborating with Drs. Yu and Bean to character the AM panel for grain quality and plant performance traits. In 2008, replicated field trials were planted at West Lafayette, IN and Manhattan, KS to evaluate the AM panel for phenological and grain quality traits. We hope to expand on these characterization trials to include locations in Africa in 2009.

## Research Results

*Develop locally adapted sorghum varieties and hybrids having improved grain quality and feed value.*

Sorghum has been grown as a food crop for many centuries in Africa and India. Food-grade sorghum is becoming an increasingly important crop in the developed world, especially as a cereal option for people with celiac disease. The highest quality sorghum flours and food products are produced using grain from food-grade sorghum varieties (Drs. Rooney and Waniska, 2000). Food grade sorghum varieties and hybrids with white pericarp, tan plant color, straw color glumes, and medium- to hard-endosperm kernels have been developed to maximize potential food quality, but these types of sorghum tend to be more susceptible to mold than sorghum varieties with a red pericarp. Grain molds and weathering in the field can have a major effect on sorghum grain quality and value. Grain molds result from fungal infections that occur at anthesis and/or during and after grain development. Fungal tissues that may contain mycotoxins can completely replace the seed in extreme cases (Da Silva et al., 2000). Mycotoxins can produce adverse health effects or mycotoxicoses. Seed quality is diminished not only for nutritive value, but the flour produced from molded grain generally has poor color quality and reduced aesthetic value. Therefore, grain mold resistance is an important factor in selection of improved varieties. In much of WA, the guinea sorghums have been found to possess superior head bug and grain mold resistance and are uniquely adapted to this region (Ratnadass et al., 2003). Continued improvement of the guinea varieties is needed since these types of sorghum varieties are nearly always preferred by farmers in the region from western Niger to Senegal.

This research objective focuses on development of locally-adapted, guinea and non-guinea sorghum varieties and hybrids having improved food- and feed-quality characteristics. Development of improved guinea cultivars having natural resistance to headbug and grain mold resistance would be extremely valuable in the region from Senegal to Niger because of the threat posed by these biotic constraints in this region. Some progress has been made in use of these germplasms to produce locally adapted varieties with improved grain quality. The NARS programs in Mali and Niger have been particularly successful in cultivar development with release of varieties such as the guinea sorghum variety Wassa developed by IER and the caudatum sorghum variety 90SN7 developed by INRAN. The success and leadership of these programs provides an opportunity to expand on this success through extension of germplasm resources and technical support to other sorghum breeding efforts in the region as needed.

The elite food-sorghum varieties Wassa, 90SN7, and other genotypes provided excellent starting materials for development of food-grade guinea and non-guinea sorghum varieties. Breeding populations based on these genotypes are being developed to incorporate food-grade sorghum traits from these and other genotypes into locally adapted varieties and hybrids.

*Develop and deploy technologies and strategies to manage weedy pests including Striga*

Sorghum researchers and producers in the U.S. and WA have indicated that weed infestations including parasitic witchweeds are among the most important production constraints for sorghum. *Striga* is recognized as a growing problem and it is estimated that more agricultural land in WA (3.5 million ha) is infested with *Striga* than in any other region. Long-term research investments by national and international donors across Africa have identified a suite of host-plant resistance traits that show promise for managing *Striga* infestations in sorghum (Hess and Ejeta 1992; Haussmann et al. 2000; Mohamed et al. 2003; Rich et al. 2004; Rodenberg et al. 2005). These studies demonstrated that differences in host-plant resistance often could be explained by differences in the level of *Striga* germination stimulant or haustorial factor produced by resistant or susceptible sorghum varieties. In other cases, resistant sorghum genotypes responded to *Striga* infestation with a hypersensitive or incompatible response. Efforts to breed for improved *Striga* resistance have been successful and *Striga* resistant varieties have been extensively evaluated in East Africa. No single technology has been shown to be fully effective in controlling *Striga* or containing its spread; however, the integration of control options has been shown to be effective in reducing damage by the parasite.

One new and promising *Striga* management technology being developed in our program involves use of herbicide tolerance traits for managing this weed. A project was initiated to develop sorghum varieties with tolerance to acetolactate synthase (ALS) inhibiting herbicides. The ALS enzyme, also known as acetohydroxy acid synthase (AHAS), performs a key role in branch chain amino acid synthesis. ALS-inhibiting herbicides can be used to control many different types of broadleaf and grassy weeds. Several very popular examples of herbicides defined by this mode of action include Accent® (nicosulfuron), Option® (foramsulfuron) and Lightning® (imazethapyr + imazapyr). A sorghum mutant with high levels of tolerance to ALS-inhibiting herbicides was identified in 2003. Genetic crossing and backcrossing was used to transfer this trait into elite grain sorghum varieties. Studies indicated that herbicide tolerance was inherited as an incompletely dominate trait and provided cross-resistance to several different herbicides in the imidazolinone (IMI) and sulfonylurea (SU) chemical families. Studies evaluating the efficacy of herbicide seed dressings indicated that low-dose imazapyr or metsulfuron seed coatings applied to herbicide tolerant varieties were highly effective in controlling *Striga* infestation in field and greenhouse trials.

The PI is collaborating with DuPont researchers and scientists from several NARs and IARCs in West Africa (Soumana, INRAN, NIGER; Kayentao, IER, MALI; van Mourik, Weltzien, Rattunde, ICRISAT, MALI; Traore, INERA, BURKINA FASO) to initiate regional testing of the efficacy of this technology for managing *Striga* infestations. An ALS herbicide tolerant genotype derived from the variety Macia was treated with varying rates of metsulfuron-methyl in collaboration with scientists from DuPont Crop Protection. In 2008, these seeds were planted at two locations in Mali and one location each in Burkina Faso and Niger. Visits to these trials in September of 2008 indicated outstanding control of *Striga* with low doses of herbicide (Figure 1).

A major focus of the technology transfer plant breeding program is to develop ALS herbicide tolerant guinea and non-guinea sorghum hybrids that are adapted in the West Africa region.

**Figure 1. Efficacy of metsulfuron methyl seed treatments in trials conducted in Birni N'Konni, Niger showing plots with untreated sorghum seeds (left) and sorghum seeds treated with 0.025 mg metsulfuron methyl per seed (right).**

N223A is one of the important food-grade sorghum seed parents being used in West Africa. The breeding program is advancing a large number of ALS herbicide tolerant derivatives of N223A. These seed parents will be used to produce interracial guinea and caudatum-based hybrids. The best of these hybrids will evaluated with seed treatments beginning in 2009. These sorghums will provide the tool and vehicle to test and deploy herbicide seed treatment technology for controlling *Striga* infestations.

Weed control also is an important problem for sorghum producers in the United States. The ALS herbicide tolerance trait and a second acetyl coenzyme A carboxylase (ACCase) herbicide tolerance trait are being incorporated into U.S. sorghum germplasm to allow use of these herbicides for grassy weed control in sorghum. The ACCase enzyme plays a key role in lipid synthesis in plants. Herbicides that target the plastidic ACCase enzyme of grasses have been identified and are highly effective at controlling grassy weeds. A sorghum mutant with resistance to several ACCase inhibiting herbicides was identified in 2006. DuPont was awarded exclusive commercialization rights to ALS and ACCase herbicide tolerance in sorghum. Research is underway to incorporate the ALS and ACCase herbicide tolerance traits into elite grain and forage sorghum cultivars. The PI is collaborating with researchers from DuPont Crop Protection and Kansas State University to conduct field research needed to label and optimize use ALS and ACCase herbicides as part of an integrated weed management strategy that incorporates post-emergence herbicide applications to control broad-leaf and grassy weed problems in sorghum.

*Identify and mine genes and alleles associated with improved sorghum performance in the natural gene pool*

This project has been initiated in an effort to more systematically identify and exploit natural genetic variation in the sorghum genome using the DNA sequence as a tool to identify and relate variation in specific genes associated improved crop performance (e.g., grain quality and crop performance) with phenotypic variation represented in the sorghum germplasm collection. We are collaborating with Dr. Jianming Yu, Kansas State University, and Dr. Scott Bean, USDA-ARS, Manhattan, Kansas, to collect and combine phenotypic trait data and relate that to gene function through a process called 'association mapping'.

One of our first sorghum genome targets for selective modification is the dw3 locus. The dw3 allele most widely used in the commercial U.S. sorghum sector has proven to be unstable resulting in increased seed production costs and the height mutants resulting from instability at this locus are unsightly in commercial grain production fields. We are using the sorghum genome sequence to develop a strategy whereby stable dw3 alleles can be identified for commercial use.

## Networking Activities

### *Workshops and Meetings*

Health, Research, and Entrepreneurship: Sorghum Food for Celiac Patients. Naples, Italy, Sept 16-18, 2007

Corn & Sorghum Research Conference. American Seed Trade

Association, Chicago, Dec 5-7, 2007

INTSORMIL PI Conference, Bamako, Mali, April 14-18, 2008

National Plant Breeding Workshop, Des Moines, IA, June 16-18

### Research Information Exchange

Meeting with DuPont Crop Protection to discuss herbicide trait development in Wilmington, DE on Feb 25-27, 2007

Meeting with Dow Agricultural Science to discuss translational genomics in Indianapolis, IN on April 21, 2008

Meeting with DuPont Crop Protection to discuss herbicide trait development and *Striga* management in West Lafayette, IN on May 5, 2008

Hosted potential student Lucky Omoigui from Nigeria for a campus visit in West Lafayette, IN on August 21-23, 2008

Meeting with DuPont Crop Protection, African Agriculture Technology Foundation (AATF), Purdue University, and Kansas State University to discuss commercialization of herbicide traits in Africa for *Striga* management in Manhattan, KS on August 25-28, 2008

Meeting with DuPont Crop Protection and the African Agriculture Technology Foundation to discuss *Striga* management in Africa in Nairobi, Kenya on Sept 23-24, 2008

Traveled with representatives from DuPont Crop Protection and visited research plots and collaborators at IER and ICRISAT in Mali, INERA in Burkina Faso, INRAN in Niger, and the Alliance for a Green Revolution in Accra, Ghana from Sept 25 to Oct 4, 2008

### Germplasm Conservation and Distribution

Coordinated growouts and evaluations of the Sorghum Diversity Panel at Purdue in West Lafayette, Indiana

Distributed 37 R-lines, 58 A/B line pairs, 34 ALS herbicide resistant seed stocks, and a BC1F2 R-line and B-line population source of the ACC herbicide tolerance trait to all major representatives of the private U.S. seed industry from Kansas State University

Distributed 40 elite varieties, R-lines, and A/B lines to Albert Chamango to initiate a breeding program in Malawi

Distributed selected lines from the Sorghum Diversity Panel to Mike Mikelbart for physiological evaluation at Purdue University

Distributed 12 elite varieties, R-lines, and A/B lines to John Cosgrove to initiate a breeding program in Sierra Leone

Distributed a replicated experiment to evaluate efficacy of herbicide seed treatments in controlling *Striga* to NARs and IARC collaborators in Niger, Burkina Faso, and Mali

Distributed a replicated 60 entry breeding nursery to NARs collaborators in Niger, Burkina Faso, and Mali to evaluate stacking of ALS herbicide tolerance and *Striga* resistance

Distributed a subset of *Striga* resistant lines to NARs collaborators to be included in a regional *Striga* Observation Trial to be conducted at 6 locations in West Africa

## Publications and Presentations

### Journal Articles


Salas-Fernandez MG, Hamblin MT, Rooney WL, Tuinstra MR, Kresovich S. 2008. Quantitative trait loci analysis of endosperm color and carotenoid content in sorghum grain. Crop Science 48: 1732-1743.

Prasad PVV, Pisipati SR, Mutava RN, Tuinstra MR. 2008. Sensitivity of grain sorghum to high temperature stress during reproductive development. Crop Science 48: 1911-1917.

Wang D, Bean SR, McLaren JS, Seib PA, Madl RL, Tuinstra MR, Lenz MC, Wu X, Zhao R. 2008. Grain sorghum is a viable feedstock for ethanol production. Journal of Industrial Microbiology & Biotechnology 35: 313-320.

Tuinstra MR. 2008. Food-grade sorghum varieties and production considerations: A review. Journal of Plant Interactions 3: 69-72.

Casa AM, Pressoira G, Brown P, Mitchell SE, Rooney WL, Tuinstra MR, Franks CD, Kresovich S. 2008. Community Resources and Strategies for Association Mapping in Sorghum. Crop Science 48: 30-34.

Hamblin MT, Salas-Fernandez MG, Tuinstra MR, Rooney WL, Kresovich S. 2007. Sequence variation at candidate loci in the starch metabolism pathway in sorghum: prospects for linkage disequilibrium mapping. Plant-Genome 47(Suppl.2): S1-25-S134.

Ioerger B, Bean SR, Tuinstra MR, Pedersen JF, Erpelding J, Lee KM, Herrman TJ. 2007. Characterization of polymeric proteins from vitreous and floury sorghum endosperm. Journal of Agricultural and Food Chemistry 55: 10232-10239.

Wu X, Zhao R, Wang D, Bean SR, Seib PA, McLauren JS, Madl RL, Tuinstra MR, Lenz MC, Wang D. 2007. Factors impacting ethanol production from sorghum. Cereal-Chemistry 84: 130-136.


### Books, Book Chapters and Proceedings


Tuinstra, M.R., and K.A. Khatib. 2007. New herbicide tolerance traits in sorghum. In Proceedings of the 2007 Corn, Sorghum, and Soybean Seed Research Conference and Seed Expo, Chicago, IL, Dec 5-7, 2007. American Seed Trade Association. Alexandria, VA.

# Breeding Sorghum for Improved Grain, Forage Quality and Yield for Central America

## Projects TAM 101

## William Rooney
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### Introduction and Justification

#### *Background*

Throughout Central America, (defined as the countries of Guatamala, Belize, El Salvador, Honduras, Nicaragua, Costa Rica and Panama), sorghum (*Sorghum bicolor* L. Moench)was grown and harvested for grain on approximately 250,000 hectares in 2005 (FAO, 2006). The majority of this production is located in the countries of El Salvador, Nicaragua, Honduras and Guatamala. The crop is typically grown in the dry season due to its enhanced drought tolerance and ability to produce a crop under limited water availability. Average yields in the region vary dramatically and are dependent on the production systems, environment and types of sorghums that are being produced. Depending on the situation, the crop is grown as a feed grain, animal forage and in many situations as a food grain when supplies of corn are limited.

Within the region, there are two distinct sorghum production systems. The first is a traditional hillside sorghum production system that uses landrace and/or improved sorghum cultivars known as Maicillos Criollos. These sorghums are a very distinct and unique group because they are very photoperiod sensitive, meaning that they require short daylengths to induce reproductive growth. In fact, Maicillos require even shorter daylengths to initiate flowering than most photoperiod sensitive sorghum from other regions of the world (Rosenow, 1988). They are primarily grown in intercropping systems with maize on small, steeply sloping farms where the maize matures before the Maicillos begin to flower. Because they are drought tolerant, they are grown primarily as food security crop where the grain is used extensively primarily to produce tortillas. The forage and excess grain produced by these crops are valued as animal feed. Traditional landrace Maicillos Criollos varieties are typically low yielding with relatively low grain quality. Previous research has resulted in the release and distribution of several improved Maicillos Criollos cultivars with higher yield potential and better grain quality (Rosenow, 1988). In addition to Maicillos Criollos, hillside production systems also utilize earlier maturing sorghum (i.e., photoperiod insensitive) for food and forage. Significant research has also been devoted to their improvement, resulting in the release release of cultivars such as Sureño and Tortillero that are now commonly grown throughout the region (Meckenstock et al., 1993). These cultivars have been adopted and used in the region as a food grain on small farms as well as a dual purpose crop (grain, forage) in mid-size commercial farms.

In addition to small farm production, sorghum is also grown in significant quantities on commercial farms in the Central American region. While some of these producers utilize cultivars for this production, most have adopted hybrids and are growing the crop as a feed grain for use in poultry, livestock and dairy production. More recently, there is significant growth of the crop in the region for grazing, hay and silage. This interest in sorghum forage has been increasing due to the increased dairy and beef production in the region, combined with the inherent drought tolerance of the crop, especially in the second, drier cropping season. In both grain and forage, the hybrids that Central American producers use are usually sold by commercial seed companies. In most cases, research and development for sorghum improvement in the region is relatively minimal. Hybrids grown in this region usually rely on improved germplasm from national programs as well as U.S. based sorghum improvement programs.

## Problem Statement

While the two production regions differ for types of germplasm, the constraints to productivity and profitability are similar. First, there is a continual need to enhance yield of both grain and biomass. The Maicillos Criollos cultivars have low but stable yield potential. Small farmers place a high value on stable yields as they grown to provide food security. Thus, they will adopt higher yield varieties only if they provide stability of yield as well. As feed grain demand continues to increase, yield increases are also needed in commercial hybrid production as well to make their production more economically profitable. Sufficient genetic variation is present in both germplasm pools to enhance yield potential, provided that effective evaluation, screening and selection can be completed in the region (Santos and Clara, 1988).

Improvement in grain and forage quality are also continually in demand. Most of the grain sorghum grown in the region is acceptable as a feed grain, but would not be acceptable as a food grain. The changes needed to make an acceptable food grain (plant color and grain color) are relatively simple and highly heritable traits that are easily manipulated. If adopted, these changes will facilitate to opportunity to partially substitute domestically produced sorghum flour for more expensive imported wheat flour (INTSORMIL report #6, 2006, www.intsormil.org). However, food quality sorghum must possess resistance to grain mold and weathering to protect the quality of the grain prior to harvest. For forage, there has been relatively little improvement in the forage quality of sorghum grown in Central America. The development and adoption of brown midrib forage sorghums in the U.S. indicate that high quality forage sorghums can be produced (Oliver et al., 2005). The challenge is to introduce these characteristics into forage sorghum adapted to the Central American region.

As improvements in yield and quality are made, these must be protected from both abiotic and biotic stresses that are commonly present in the region. The predominant abiotic stresses involve drought and fertility and both genetic and agronomic management approaches must be used to mitigate these problems. Biotic stresses also pose a significant threat to yield and quality in sorghum production. In Central America, the predominant SDM pathotype is P5 and this pathotype is known to cause significant yield reductions in areas of the region where environmental conditions are conducive to disease development (Frederiksen, 1988). While chemical control is a possibility, the most logical and reliable control mechanism is the incorporation of genetic resistance. Another disease of importance is anthracnose (caused by *Colletotrichum graminicola*), a fungal pathogen that is capable of infecting all above ground tissues of the plant that is endemic throughout the region. Because it can infect all above ground parts of the plant, it can cause significant reductions in both forage and grain yield and quality. Again, genetic resistance provides the only effective mean of managing this disease. Finally, grain mold (caused by a complex of fungi) is a common problem throughout the region and it reduces the quality of the grain as both a feed and food grain. In all of these abiotic and biotic stresses, sorghum germplasm has sufficient diversity to enable breeding programs to identify and select for tolerance and/or resistance to the specific stress or pathogen.

## Objectives and Implementation Sites

Given the goals of the Sorghum, Millet and Other Grains CRSP and the needs of the Central American region, the overall goal of this proposal is to enhance the genetic yield and quality potential of sorghum genotypes adapted to Central America for use as a feed grain, food grain and forage crop. To meet this goal, we will use previously established linkages with collaborators in the Central American region (i) to coordinate in-country research studies and breeding evaluations, (ii) to identify quality students for training through involvement in ongoing projects at Texas A&M University, and (iii) to enhance technology transfer for sorghum in the Central American region.

The objectives, the location of the research, and the collaborators include:

1. DEVELOP HIGH-YIELDING, LOCALLY-ADAPTED SORGHUM VARIETIES AND HYBRIDS WITH IMPROVED GRAIN AND/OR FORAGE QUALITY, DROUGHT TOLERANCE, AND DISEASE RESISTANCE USING BOTH CONVENTIONAL BREEDING TECHNIQUES AND MARKER-ASSISTED SELECTION TECHNOLOGY. The goal of this objective is to extend the breeding and molecular technology provided by the principal investigator to collaborators to enable the development of new varieties specifically adapted to the Central American region. When successful, this objective will be result in the release of improved, locally-adapted cultivars to be used for grain and/or forage production.
2. IDENTIFY AND MAP GENES RELATED TO FORAGE YIELD AND QUALITY. The purpose of this objective is to understand the genetic control of important components to forage yield and quality and generate genetic markers that can be used by sorghum improvement programs in the near future.
3. IDENTIFY AND CHARACTERIZE GENES RELATED TO DISEASE RESISTANCE IN SORGHUM WITH SPECIFIC EMPHASIS IN DOWNY MILDEW, ANTHRACNOSE AND GRAIN MOLD. UTILIZE THESE SOURCES OF RESISTANCE IN BREEDING IMPROVED CULTIVARS AND HYBRIDS FOR CENTRAL AMERICA. Over the past ten years our program has screened numerous accessions to identify specific sources of resistance to anthracnose, downy mildew and grain mold. These lines and populations derived from them are being evaluated in domestic and Central American sites to determine which sources will provide the most stable resistance.
4. IDENTIFY AND MAP GENES RELATED TO GRAIN QUALITY SUCH PROTEIN DIGESTABILITY, NUTRACEUTICAL POTENTIAL AND GRAIN QUALITY PARAMETERS PER SE. Variants that possess unique grain traits such as increased protein digestibility and enhanced antioxidant characters have been identified and characterized in our program. The purpose of this project is to assess the

feasibility of producing cultivars that possess these characteristics. In collaboration with the TAMU grain quality program (L. Rooney, D. Hays), we are assessing the feasibility of combining both grain mold resistance and enhanced digestibility.

5. PROVIDE TECHNOLOGY TRANSFER AND TECHNICAL ASSISTANCE IN PROMOTING THE USE OF IMPROVED SORGHUMS AS A FEED GRAIN, FOOD GRAIN AND A FORAGE CROP IN CENTRAL AMERICA. The purpose of this objective is to transfer the technology and knowledge needed to effectively produce and utilize the forage and/or grain produced from the improved sorghum cultivars (Maicillos Criollos, lines and hybrids). As appropriate, our program will coordinate these workshops with collaborating scientists in the specific area of expertise, such as animal feeding (J. Hancock) grain quality and utilization for human food (L Rooney), and agronomy and forage quality (J. Blumenthal). The technical assistance efforts will focus on industry and academic leaders in El Salvador and Nicaragua.

These five objectives merge together to provide a project that will have both short-term and long-term results. Objective 1 is a long-term and continual goal that will utilize the technology developed in objectives 2 through 4 and proven conventional breeding approaches. Objectives 2 through 4 should provide results in the short-term that will be important to work proposed in objective 1. The expected results of objectives 2, 3, and 4 include the identification of DNA-based markers to serve as tags for more efficient breeding. Objective 4 is a medium-term goal that will make the breeding programs and nutritionists more efficient in producing new cultivars that have enhanced market value. Ultimately, the success of objective 1 will be measured by the productivity of cultivars and hybrids developed in this project and how effectively they are utilized throughout Central America. For objectives 1 through 4, training of students from cooperating countries will be an integral part of the projects and potential students will be identified based on recommendations from researchers in the region and the in-country interaction of the PI with potential candidates. Finally, objective 5 is crucial because if the first four objectives are successful, additional sorghum (both forage and grain) with improved quality will be produced. It is imperative that there be the infrastructure (both technological and scientific) to utilize this grain. It should also be realized that while the efforts of this project are primarily targeted to Central America, the technology, basic knowledge, and personnel developed in this project will also be useful to sorghum and millet improvement programs in the United States and around the world. Because of these factors and their interrelationships, this project will address directly or indirectly all seven major goals of the Sorghum, Millet and Other Grains CRSP.

## Research Strategy and Approach

1. DEVELOP HIGH-YIELDING, LOCALLY-ADAPTED SORGHUM VARIETIES AND HYBRIDS WITH IMPROVED GRAIN AND/OR FORAGE QUALITY, DROUGHT TOLERANCE, AND DISEASE RESISTANCE USING BOTH CONVENTIONAL BREEDING TECHNIQUES AND MARKER-ASSISTED SELECTION TECHNOLOGY.

### *Maicillos Criollos Breeding*

Because these genotypes are photoperiod sensitive and they are uniquely adapted to the Central America, the breeding must be completed in the region. Segregating populations of breeding material from INTSORMIL was grown and selected in El Salvador for desirability, yield and disease resistance (see Central America Regional Report). On a regular basis these selections are advanced and the most advanced material is evaluated in replicated yield trials. To facilitate future development, a set of advance breeding material was sent to College Station Texas; and breeding crosses were made in greenhouse and winter nursery sites. These F1's are being grown in winter nurseries and F2 populations will be sent to El Salvador for selection in the fall of 2009. Many of these crosses were made between photoperiod sensitive material and photoperiod insensitive types to introduce specific traits such as disease resistance or enhanced forage or grain quality. Emphasis in selection is placed on improved food-type and Macio tan-plant cultivars as well as hybrids (where feasible).

### *Photoperiod Insensitive Line and Cultivar Breeding*

Breeding lines for use as cultivars and/or parents in hybrids will use traditional pedigree breeding approaches, with populations generated from the Texas A&M University/Texas Agricultural Experiment Station sorghum breeding program. Over 3000 segregating rows, ranging from the F2 to the F5 were grown in South Texas for selection. Advanced lines were evaluated for grain yield and adaptation in hybrid combination. The best performing material from these trials is provided to the Central American programs for evaluation and testing in Central America. Traits of emphasis in grain types include but are not limited to grain yield, grain quality, disease resistance and drought tolerance. Traits of emphasis in forage types include but are not limited to biomass yield, forage quality, regrowth potential, foliar disease resistance and drought tolerance.

2. IDENTIFY AND MAP GENES RELATED TO FORAGE YIELD AND QUALITY.

In both the U.S. and Central America, interest in sorghum as a forage crop (and even as a potential bioenergy crop) has never been greater. In Central America, both CENTA and INTA have released both varieties and hybrids for use as silage and forage crops (see Central America Regional Report). In addition to breeding for standard forage sorghums, our program has provided sudangrass pollinator lines with bmr genotype to the CENTA program; the goal is to develop bmr genotypes for Central America with greater digestability and palatability (Oliver et al., 2005). Additional breeding and evaluation of both bmr lines and corresponding hybrids is ongoing in the Texas A&M program; we have identified numerous combination that have bmr and are agronomically desirable as well.

In addition to breeding efforts, additional information on the genetic basis of biomass yield and how it is partitioned in the plant in botanical terms (stalks, leaves, and panicle) and compositional terms (carbohydrate, protein oil, ash, etc.) is critical to optimize production for specific end uses (forage, grain, or bioenergy). Our program has, in collaboration with researchers at Cornell University, recently published on QTL analysis of biomass partitioning in botanical and compositional terms (Murray et al., 2008a and b). This project identified a total of 145 QTL for 28 biomass and composition related traits. The results indicated that altering genetic potential for non-structural carbohydrate (primarily starch and sugar) as grain and stem sugar yield had greater impact on harvestable energy than altering grain and stem sugar composition. In the leaf and stem structural carbohydrates (i.e., lignocelluloses), a total of 158 QTL were detected among the 41 different biomass and composition traits that were measured. Many of these traits co-localized with loci for height, flowering time and density/tillering, indicating a strong albeit not surprising, pleiotrophic effect between these traits.

3. IDENTIFY AND CHARACTERIZE GENES RELATED TO DISEASE RESISTANCE TO ANTHRACNOSE, GRAIN MOLD AND QUALITY, AND SORGHUM DOWNY MILDEW, UTILIZE THESE SOURCES OF RESISTANCE IN BREEDING IMPROVED CULTIVARS AND HYBRIDS FOR CENTRAL AMERICA.

### *Anthracnose Resistance Mapping*

In Central America as well as the southern U.S., anthracnose (caused by *Colletotrichum graminicola*) can be a significant disease of sorghum. The disease can infect all above-ground portions of the plant, although infection in the leaves and stalks is usually the most economically damaging. Due to this, the disease can be very destructive to forage production because even if it does not reduce yield it will reduce forage quality. Over the past ten years, our program has identified new and unique sources of anthracnose resistance and this was highlighted in by Mehta et al. (2005) who described four sources of resistance controlled by different genes and determined that each was highly heritable. Our program has collaborated with molecular geneticists to identify at least one anthracnose resistance locus from SC748-5 to the end of linkage group 5 (Perumal et al., 2008). While this association is not strong enough to use in a marker assisted breeding program it does provide the basis for working with additional resistance loci in SC748 as well as other distinctly different sources of resistance. Our program is currently expanding efforts in mapping anthracnose resistance; focusing on more detailed mapping of resistance in SC748-5 as well as two other sources. Two different populations were and are being advanced for QTL mapping of anthracnose resistance; phenotypic screening will be completed in 2009 with mapping ongoing soon thereafter. Phenotypic screening will be completed in several locations because of the variation associated with pathogen and the need for broad based ressitance.

### *Sorghum Downy Mildew Resistance*

Sorghum Downy Mildew (caused by *Peronosclera sorghii*) is a significant pathogen of sorghum in both Central America and South Texas (Frederiksen, 1988). In endemic areas, the disease can be so severe that genetic resistance is the only effective means of limiting the damage. Fortunately, there are numerous sources of resistance to the disease, but the exact pathotype present in a region determines the best sources of resistance for use in breeding. In Central America, pathotypes 1, 3, and 5 have been identified so sources of resistance to these are critical for the region (Frederiksen, 1988). Previous research (some INTSORMIL funded) has identified several sources of resistance have been identified and within our program. We are continually evaluating and selecting for resistance in this material.

In addition to breeding with existing sources of resistance, there is a need to identify and characterize new and different sources of resistance to the pathogen. Our program has actively conducted SDM screening in Texas for the past five years and has identified a set of material that shows good resistance to at least two different SDM pathotypes (Isakeit and Jaster, 2005). These lines were screened in multiple locations against pathotypes 1, 3 and 6 (Isakeit and Jaster, 2005) and a total of 12 different accessions were identified with resistance. To determine if these sources possess the same source of resistance, they were hybridized in a partial diallel and segregating populations were derived from each. Segregation analysis of these populations indicates that there are at least three different sources of resistance; another is possible but contingent on confirmation with addition crosses that are currently not available. At this time, the plan is to create segregating populations for each unique source to determine the inheritance of the resistance and to transfer it to more adapted and useful germplasm.

### *Grain Mold Resistance*

Screening for grain mold resistance is done on a continual basis and all nurseries are rated for grain mold when environmental conditions are conducive for mold development. Based on previous research to map and characterize the genetics of grain mold resistance, our approach to research in grain mold has focused on molecular characterization of the host plant to grain mold infection. Katilé et al. (in press), described the expression of pathogenesis-related protein PR-10 in sorghum floral tissues in response to inoculation with *Fusarium thapsinum* and *Curvularia lunata*; significant differences in response were seen between susceptible genotypes (Tx430) and resistant genotypes (Sureno and Tx2911).

In previous work, Klein et al. (2001) identified five QTL for grain mold from a recombinant inbred line population derived from the cross of Tx430 x Sureño. These QTL have been used with some success in marker-enhanced selection (Franks, 2003). In collaboration with D. Hays (TAMU), selected RILs from this population are being grown in the greenhouse and challenged independently with specific grain mold pathogens (*Fusarium thapsinum* and *Curvularia lunata*). Preliminary evidence indicates that certain genotypes are more susceptible to specific species and show high resistance to the other. Because grain mold is such a complex trait, if resistance to specific species is confirmed then it may be possible to selectively breed resistance to each pathogen and essentially "stack" independent resistance genes in a single genotype. Further characterization and confirmation of this work is needed and that work is ongoing.

4. IDENTIFY AND MAP GENES RELATED TO GRAIN QUALITY SUCH PROTEIN DIGESTABILITY, NUTRACEUTICAL POTENTIAL AND GRAIN QUALITY PARAMETERS PER SE.

Our two main projects in grain quality are (1) combining improved protein digestibility with enhanced grain mold resistance and (2) the development and characterization of high antioxidant “healthly” sorghums. Our program, utilizing highly digestible lines from the Purdue University program, has introgressed the highly digestible trait into traditional grain sorghum parental lines in our program. We are currently evaluating these lines for grain mold resistance (summarized by Portillo, 2007). Initial efforts to determine if these two combinations are feasible in the same genotype indicate that they are, to a limited extent. These lines represent an intermediate step in the development of high digestibility sorghums with enhanced grain mold resistance. Because of the increased protein digestibility, it has been hypothesized that they may be more efficient for both malting and ethanol production. In 2008, bulk production of these lines was completed and testing for their efficiency of malting and ethanol production are being investigated in collaboration with J Taylor (Univ. of Pretoria) and D. Wang (Kansas State Univ.).

Another group of specialty sorghum receiving interest is the health food sorghums. These are grain sorghums with high levels of tannin and/or unique colors (primarily black); they possess very high levels of unique phenolic compounds that show high levels of antioxidant activity. Our program has developed a set of parental lines for use developing a series of lines designed to combine these traits into a single sorghum hybrid that could be grown as a “health” grain. While this does not directly affect efforts within Central America, it does provide the potential opportunity to be used in food products in the area. This work is in cooperation with the TAMU cereal quality lab (L. Rooney) and labs in Central American in CENTA (El Salvador) and at the Escuela Agricola Panamerica (J. Bueso). In 2008 our program produced 30 experimental hybrids that were planted in replicated yield trials in four locations (Weslaco, Corpus Christi, College Station, and Halfway, Texas) to evaluate their relative agronomic potential, their antioxidant content and the effect of environment and genotype x environment interaction on those traits. These trials have been harvested and analysis is currently underway.

5. PROVIDE TECHNOLOGY TRANSFER AND TECHNICAL ASSISTANCE IN PROMOTING THE USE OF IMPROVED SORGHUMS AS A FEED GRAIN, FOOD GRAIN AND A FORAGE CROP IN CENTRAL AMERICA.

Technology transfer in the project is primarily in the form of germplasm supplied to the Central American Program. Our program has sent over 100 different parental lines and germplasm of grain and forage sorghum for evaluation in Central America. Technology generated in this project will be accessible through improved germplasm, both parental lines and cultivars that can be used by small farmers and the seed industry to enhance productivity and quality. Cultivars directed at subsistence production will be distributed in cooperation with National research programs (CENTA in El Salvador and INIA in Nicaragua for example). Lines that have potential as parents in hybrids will be distributed to commercial seed companies (both domestically and internationally); use of these lines in commercial products will require some form of licensing that will be determined on a case by case basis in which the involved parties will write the agreements.

## Impact

This program focuses on the genetic improvement of sorghum with strong collaborations established with expertise in cereal chemistry, molecular biology, plant pathology, and agronomy. This will provide the critical mass of expertise to address problems that may arise during the research in sorghum. Given the development of sorghum cultivars and hybrids with improved quality and yield potential, and protection from pathogens such as anthracnose and grain mold, these crops should be more competitive with other cereal grains for end-use application in products for human and animal consumption. This is particularly important in the dry season in Central America and the central U.S. where sorghum are an important cereal grain. Increases in quality will enhance marketing opportunities and the potential for more favorable pricing. This will result in more stable income for producers and processors requiring high-quality grains for product development.

The success of the proposed research will result in technology transfer that includes the development of nutritionally enhanced sorghum lines and hybrids that can be grown in Africa, Central America, and the U.S. as well as technical assistance to effectively utilize these grains in human food and animal feed products. In many developing countries, this research will provide new entrepreneurial opportunities for production of animal feeds and forage as well as other products including meat and eggs. In developed countries such as the U.S., tan-plant sorghum hybrids will have enhanced marketing opportunities to industries that do not currently utilize sorghum or millet grain, particularly the U.S. poultry and food industries.

The genetic analysis described in this proposal will result in a better understanding of the genetic basis and relationship of genes controlling disease resistance (anthracnose, grain mold and SDM), yield (biomass), and quality (forage and grain) and genetic marker associated with each set of genes. These maybe used as markers in MAB and/or useful in isolating the gene sequence provided additional funding and access to the soon to be complete sorghum genome sequence. While this may not have immediate impact on Central America sorghum production, it does impact long term sorghum breeding efforts and that will impact all sorghum production in the future. A key product of this research will be marked "genes" that can be easily transferred to well adapted local cultivars. The need to verify the efficacy of the transferred genes will encourage further collaboration among U.S. and developing country participants.

In addition to providing new cultivars and the technology to utilize them effectively, this training program promotes the development of human capital for enrichment of participating countries. Graduate students and visiting scientists with interest in crop improvement, crop utilization, and molecular biology will complete much of the proposed research. For each objective, as specific research projects are identified, students from target areas will be recruited to conduct this research at Texas A&M University. As appropriate, the students will be expected to collaborate with other investigators within this project and at the other university. This approach should expose the student to interactive and interdisciplinary research that will enhance his/her productivity upon return to their homes.

## Evaluation of Project Impact

Crop improvement is a long term, continual process and measuring short term impact is often a challenging, but necessary task. To that end, short-term measurements of impact for this program will include: (1) the number of Material Transfer Agreements written for germplasm produced from this program, (2) the number of publications generated from research in the project, and (3) participation in research workshops and production shortcourses. Over the long-term, progress is easier to quantify and assess the impact. Several of the methods that we will use include: (1) the number of germplasm releases (including parental lines and cultivars) which have been released and may be utilized by subsistence producers and/or commercial seed industry, (2) the number of hectares of a released cultivar and/or hybrid that are being grown in the region (either domestically or internationally), and (3) the production levels of the new varieties and the relative value of that production, and finally (4) to survey potential or actual end-users to determine if the new material has enhance valued for their particular use, and if so, attempt to determine a monetary value to the enhanced value.

## Training of U.S. and Host Country Personnel

The PI in this project supports the collaborators in both El Salvador and Nicaragua. The PI traveled to Central America to interact, evaluate and collaborate on active research projects in the region. Funds are budgeted for support of a graduate student and as potential students are identified, they will be invited to pursue graduate studies in plant breeding and genetics. Unfortunately, a suitable candidate for this assistantship has not yet been identified; those funds are currently being to partially support two U.S. graduate students conducting sorghum breeding research.

## Contribution of Proposed Research to the Sorghum, Millet and Other Grains CRSP

The objectives of this proposal are designed (1) to fit precisely within this CRSP's vision, mission and global strategy for research, and (2) to complement and extend the efforts and the expertise of the INTSORMIL research team. The team assembled for this proposal is interdisciplinary and international in nature with a focus on three regions of the world in which INTSORMIL activities are concentrated. The proposed research will result in new and more competitive grain markets for sorghum and pearl millet. Enhanced value of these crops will contribute to a shift of sorghum and pearl millet from subsistence to cash crops in developing countries. Improvements in nutritional as well as grain quality characteristics (i.e., food-grade sorghums) will make sorghum more competitive with other cereal grains for end-use applications in the U.S. and in host countries. In addition, the development of these value-enhanced grains and the transfer of animal feeding technologies will promote the development of new entrepreneurial opportunities for production of meat and other animal products in countries where these crops are grown. Finally, the development of more competitive sorghum and millet cultivars will allow producers to conserve water resources that would otherwise be used by less water-efficient crops.

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# Breeding Sorghum for Improved Resistance to Biotic and Abiotic Stresses and Enhanced End-Use Characteristics for Southern Africa

## Project TAM 102

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### Introduction and Justification

Sorghum should be the major food grain in the semi-arid tropics. Challenges to increase food production include global warming with altered climate and rainfall patterns, increasing demands on the environment, increasing food production on marginal lands, desire for reliable high quality food produced with minimal environmental disruption, and natural resource base degradation. In the United States sorghum is a key crop in the semi-arid Great Plains due to its efficient water use, tolerance to high temperatures, multitude of uses (grain, forage, biomass), ability to produce harvestable grain yield in diverse cropping systems, and performance in rotation systems. Primarily a feed-grain in the U.S. demand for sorghum as a food grain, a nutraceutical, and for ethanol production is rapidly increasing. With increasing interest in water conservation and increasing grain prices driven by ethanol production sorghum is the ideal crop to enhance the economic viability of Great Plains agriculture through enhanced yield, grain quality, and marketing opportunities. Sorghum production is constrained by less than desired yield, biotic (insect pests and disease pathogens) and abiotic (primarily pre- and post-flowering drought) stresses that reduce yield, lower value of grain and forage quality, and government policy.

The overall output objective for this project is to develop the new genetic technology (germplasm, parental lines and cultivars). Individual research objectives and activities are directed at developing for release improved genetic technology with resistance to multiple abiotic and/or biotic stress. Field nurseries are planted a specific locations to evaluate and select in segregating populations for resistance to insects or disease, tolerance to drought stress, improved weathering resistance, and improved adaptation. Field research is complemented as needed by greenhouse or laboratory research to obtain more detailed data on specific traits of importance. Grain yield for hybrid combining ability is evaluated in replicated trials to identify the germplasm with the best potential for use by private industry. Replicated yield trials are also conducted to identify improved cultivars for direct use for small-holder farmers.

Several experimental breeding lines have been identified and progress has been made in identifying several additional lines. Research conducted in Mozambique has identified nine lines the national program will enter into advanced testing to gather data for release. Concurrently the line will be grown in south Texas to collect data for the releases. The lines represent nine different pedigrees and were selected from nurseries developed for resistance to sorghum midge, grain weathering, and drought tolerance. In South Africa, several lines with excellent resistance to sugarcane aphid and excellent yield in replicated plots are nearly ready for on-farm evaluation. In the U.S., observation at diverse locations in addition to replicated yield trials have identified several lines (all pollinators/R-lines in A1 cytoplasm) as possible candidates for release. Additional observations and yield trials will be conducted to select only the best lines for release. The lines are mostly tan plant with red or white grain and express excellent grain yield potential as hybrid parents.

## Objectives and Implementation Sites

1. Develop sorghum genetic technology (germplasm, inbred lines and cultivars) resistant to selected biotic stresses.
2. Develop sorghum genetic technology resistant to pre- and post-flowering drought stress
3. Develop sorghum genetic technology with improved grain quality and grain mold/weathering resistance
4. Develop sorghum genetic technology with improved grain yield and adaptation for diverse cropping systems and environments
5. Evaluate forage and sweet sorghums for biomass and potential use in cellulosic ethanol production
6. Contribute to host-country institutional human capital development through short-term (non-degree) and long-term (M.S. and Ph.D.) educational opportunities

This project is composed of two intertwined components. U.S. research develops the genetic technology (germplasm and parental lines) required to improve U.S. sorghum production, and populations required for host country research. Collaborative host country research evaluates and develops technology for indigenous cropping systems. The multi-disciplinary research team includes plants breeders, entomologists, plant pathologists, and food scientists with the expertise and programs to develop and deliver new technology. Texas nursery sites provide geographic diversity that mimics many sorghum production regions. The Texas Coastal Bend environment enables selection for tropical adaptation and resistance to grain weathering, sorghum midge and disease(s). The Texas Southern High Plains enables selection in a semi-arid temperate location for yield potential and drought tolerance. A Puerto Rico winter nursery provides the opportunity for an extra growing season to reduce development time for new varieties, parental lines, or hybrids. Southern Africa locations provide additional evaluation environments - yield potential and adaptation nurseries in Zambia (Golden Valley Agricultural Trust at Chisamba), Mozambique (Nampula), Botswana (Sebele), and South Africa (Potchefstroom), insect resistance screening in glasshouse and field facilities at the Botswana College of Agriculture (Sebele) and the ARC-Grain Crops Institute (Potchefstroom, South Africa), and disease resistance evaluation at Cedara, South Africa (anthracnose, grain mold, and ergot). Cereal quality laboratories at the Univ. of Pretoria or the ARC-Grain Crops Institute Quality Laboratory (Potchefstroom) provide the opportunity to analyze selected advanced lines for milling qualities in comparison with local checks.

## Research Methodology and Strategy

Primary breeding methodology is the pedigree system. Additional breeding methodologies are used as needed to achieve the project objectives. Segregating populations, advanced lines (for potential use as either varieties or hybrid parents), and hybrids are subjected to multi-location testing to identify genetic combinations with the best expression of the trait(s) of interest. Selection in diverse environments will identify widely adapted multiple stress resistant genetic technology.

For Southern Africa primary biotic stress resistance traits are for sugarcane aphid, anthracnose, and grain mold with sorghum midge resistance incorporated as necessary. Grain mold/weathering resistance is required for grain acceptable for end-use processing. As needed, populations to combine drought tolerance with biotic stress resistance are developed. Southern Africa evaluation is for adaptation to indigenous cropping systems, seedling and adult plant stage insect resistance, and disease resistance (primarily anthracnose but also sooty stripe), grain yield and end-use quality. Grain from experimental entries with the highest grain yield will at the appropriate stage of development undergo standard grain quality analysis including diastasis (the chlorox bleach test, malting, germination, and distase), presence of polyphenols, abrasive milling, roller milling and meal color.

For the U.S. selection is practiced for resistance to head smut and foliar diseases including anthracnose, downy mildew, bacterial streak, bacterial stripe, rust, zonate leaf spot, grain weathering resistance, and drought resistance. Advanced lines are evaluated in hybrids for combining ability and adaptation. Seed of advanced lines and hybrids will be provided at the appropriate time to the TAMU Cereal Quality Lab for standard grain quality analysis. The entries will be screened for: density (g/mL), protein and moisture and starch use NIR (near infra-red) non-destructive analysis, kernel hardness and weight, diameter (mm), and color.

Linkages with private industry and development organizations including other CRSPs, Future Harvest Centers, other international development organizations, and NGOs facilitates identification and evaluation of new genetic technology. Entries with the best potential for success are offered to NGOs for use in on-farm demonstrations. New genetic technology will be available to private industry through material transfer agreements.

## Research Results

Sugarcane aphid (*Melanaphis sacchar*i [Zehntner]) trials were provided to collaborators at the ARC-Grain Crops Institute (Potchefstroom) and the Botswana College of Agriculture (BCA-Sebele). The first trial, provided to both the ARC-GCI and the BCA, was composed of 50 entries which had not been previously evaluated for resistance to sugarcane aphid. At Potchefstroom the three replication trial was evaluated in a seedling stage greenhouse trial with artificial inoculation. Seedlings were inoculated 10 days after emergence and plants rated for aphid abundance and plant damage 21 days after infestation. Plants were rated on a scale of 1 (highly resistant) to 6 (highly susceptible). TAM428, the resistant check, was rated as a 1 for plant damage and aphid abundance while Segaolane, the susceptible check, was rated as a 5.7 for plant damage and 4.3 for aphid abundance. Analysis of the Potchefstroom data indicated that for plant damage on the experimental entries 18% (7) of the entries rated 1, 34% (13) rated 2, 2% (1) rated 3, 29% (11) rated 4, 16% (6) rated 5 (Table 1). None of the entries rated a 6 for plant damage. For aphid abundance 32% (12) of the entries rated 1 and highly resistant, 50% (19) rated 2 and highly resistant, 16% (6) rated 3 and resistant, and24% (1) rated 4 and slightly resistant. None of the entries rated as susceptible based on aphid abundance. In the field trial 26% (10) rated 1, 55% (21) rated 2, 18% (7) rated 3. In the field none of the entries were rated completely susceptible. In the field 20% (10) of the entries rated under 2.3 (resistant to highly resistant) and under 2.3 based on greenhouse ratings. At Sebele there were few aphid present at

**Table 1.** **Sugarcane aphid damage, shoot fly and stem borer infested plants, plant color and grain color in the 2008 Sugarcane Aphid Test, Potchefstroom, South Africa and Sebele, Botswana.**

| Source | Designation/Pedigree | Plant Color † | Grain Color‡ | Potchefstroom Seedling Damage§ | Potchefstroom Adult Damage¶ | Sebele Adult Damage¶ | Sebele Shootfly Infested Plants | Sebele Stemborer Infested Plans |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | % | % |
| 06PR398 | TAM428 | P | W | 1.0 | 1.0 | 1.0 | 4.9 | 0.0 |
| 06PR413 | WM#177 | P | W | 1.0 | 1.0 | 1.0 | 3.7 | 17.8 |
| 06PR415 | Ent62/SADC | T | W | 1.0 | 1.0 | 1.0 | 0.0 | 0.0 |
| 07CA20013-BK | (9MLT176/(MR112B-92M2*Tx2880)*Segaolane)-CG1-LG1-CA1 | T | W | 1.0 | 1.0 | 1.0 | 0.0 | 0.0 |
| 07CA20043-BK | (Sureno*Tegemeo)-BE3-CA1-CCBK-CABK | T | W | 1.0 | 3.0 | 1.0 | 0.0 | 16.7 |
| | | | | | | | | |
| 07CA20061-BK | (Dorado*Tegemeo)-HW13-CA1-CC2-LGBK | T | W | 1.0 | 1.3 | 1.0 | 0.0 | 0.0 |
| 07CA20062-BK | (Dorado*Tegemeo)-HW10-CA1-CC2-CABK | T | W | 1.0 | 2.3 | 1.0 | 22.2 | 16.7 |
| 07CA20072-BK | (M50009/VG15*TAM428)-HW1-CA1-LGBK-LGBK | T | W | 1.0 | 2.3 | 1.0 | 21.4 | 4.8 |
| 07CA20153-BK | (Tegemeo*WM#322)-CA2-CC2-CABK | T | W | 1.0 | 2.0 | 1.0 | 0.0 | 0.0 |
| 07CA20057-BK | (Dorado*Tegemeo)-HW10-CA1-LGBK-CABK | T | W | 1.0 | 3.3 | 1.1 | 6.7 | 12.0 |
| | | | | | | | | |
| 05LI384 | Kuyuma | T | W | 2.3 | 1.7 | 1.1 | 8.3 | 9.3 |
| 06PR399 | Macia | T | W | 2.3 | 2.0 | 1.2 | 12.3 | 18.9 |
| 06PR419 | SDSL89426 | T | W | 2.3 | 1.3 | 1.0 | 8.3 | 17.9 |
| 0TCA20021-BK | (9MLT176/(MR112B-92M2*Tx2880)*A964)-LG8-CABK-LGBK-LGBK | T | W | 2.3 | 2.3 | 1.0 | 0.0 | 25.0 |
| 07CA20042-BK | (LG35*WM#322)-BE40-LG1-CA1-LGBK-CABK | T | R | 2.3 | 2.0 | 1.0 | 5.5 | 12.2 |
| | | | | | | | | |
| 07CA20067-BK | (Dorado*Tegemeo)-HG15-CA1-LGBK-CABK | T | W | 2.3 | 2.0 | 1.0 | 0.0 | 11.1 |
| 07CA20177-BK | (5BRON151/(7EO366*GR107B-90M16)*Tegemeo)-HG1-LGBK-CABK | T | R | 2.3 | 2.0 | 1.0 | 0.0 | 21.7 |
| 07CA20187-BK | (6BRON168/6OB172/(88CC445*Tx2862)*Tegemeo)-HG5-CC2-LGBK | T | R | 2.3 | 3.3 | 1.8 | 15.9 | 11.4 |
| 07CA20223-BK | (Tx2883*Tegemeo)-HG17-CC2_LGBK | P | W | 2.3 | 2.0 | 1.0 | 0.0 | 0.0 |
| 07LI3469-BK | (Tegemeo*ICSR-939)-CA6-CC1 | T | W | 2.3 | 2.3 | 1.5 | 6.2 | 8.3 |
| | | | | | | | | |
| 05LI390 | A964 | T | W | 2.7 | 3.0 | 1.0 | 12.2 | 16.7 |
| 07CA20053-BK | (Dorado*Tegemeo)-HW4-CA1-CCBK-CABK | T | W | 2.7 | 2.0 | 1.9 | 16.7 | 4.8 |
| 07CA20088-BK | (A964*P850029)-BE9-CA1-LGBK | T | W | 2.7 | 3.3 | 1.1 | 21.4 | 4.8 |
| 07CA20089-BK | (A964*P850029)-HW6-CA1-CC1-LGBK | T | W | 2.7 | 1.3 | 1.0 | 0.0 | 20.0 |
| 07CA20114-BK | (Kuyuma*LG35)-CA6-CC2-CABK | T | W | 2.7 | 3.0 | 1.3 | 11.1 | 11.1 |
| 07CA20168-BK | (Tegemeo*ICSB12)-CA12-CC1-LGBK | T | W | 2.7 | 3.3 | 2.2 | 11.1 | 22.2 |
| | | | | | | | | |
| 07CA20181-BK | (5BRON151/(7EO366*GR107B-90M16)*Tegemeo)-HG7-CC2-CAB | T | W | 2.7 | 2.3 | 1.0 | 0.0 | 0.0 |
| 07CA20165-BK | (Tegemeo*ICSB12)-CA2-CC1-CABK | T | W | 3.3 | 1.3 | 1.0 | 33.3 | 0.0 |
| 06PR420 | EPSON2-40/E#15/SADC | T | W | 3.7 | 1.7 | 1.0 | 4.8 | 25.0 |
| 06PR404 | SRN39 | T | LY | 4.0 | 2.0 | 1.0 | 0.0 | 59.2 |
| 07CA20019-BK | (9MLT176/(MR112B-92M2*Tx2880)*A964)-LG8-CABK-LGBK-CA | T | W | 4.0 | 2.3 | 1.0 | 0.0 | 0.0 |
| | | | | | | | | |
| 07CA20099-BK | (Tegemeo*5BRON139)-HW15-CA1-LD2-CABK | T | R | 4.0 | 2.7 | 1.0 | 0.0 | 11.1 |
| 07CA20101-BK | (R.88B928*Tegemeo)-HW1-CA1-LGBK-CABK | T | W | 4.0 | 1.7 | 1.2 | 11.1 | 11.1 |
| 07CA20122-BK | (Kuyuma*LG35)-CA10-LGBK-CABK | T | R | 4.0 | 2.3 | 1.3 | 13.3 | 0.0 |
| 07CA20123-BK | (Kuyuma*LG35)-CA12-CC1-LGBK | T | W | 4.0 | 2.7 | 1.0 | 0.0 | 0.0 |
| 07CA20161-BK | (Tegemeo*ICSR-939)-CA7-CC1-CABK | T | W | 4.0 | 2.3 | 1.0 | 0.0 | 22.2 |
| | | | | | | | | |
| 07LI3468-BK | (Tegemeo*ICSR-939)-CA5-CC2 | T | W | 4.0 | 3.0 | 1.0 | 3.3 | 8.3 |
| 07LI3470-BK | (Tegemeo*ICSR-939)-CA7-CC1 | T | W | 4.0 | 1.7 | 1.1 | 0.0 | 32.2 |
| 07LI3472-BK | (Tegemeo*ICSR-939)-HG2-CC1 | T | W | 4.0 | 1.7 | 2.0 | 0.0 | 15.1 |
| 07CA20065-BK | (Dorado*Tegemeo)-HW15-CA1-CC2-LG1 | T | W | 4.3 | 2.0 | 1.0 | 8.3 | 6.7 |

**Table 1. (cont'd) Sugarcane aphid damage, shoot fly and stem borer infested plants, plant color and grain color in the 2008 Sugarcane Aphid Test, Potchefstroom, South Africa and Sebele, Botswana.**

| Source | Designation/Pedigree | Plant Color † | Grain Color‡ | Potchefstroom Seedling Damage§ | Potchefstroom Adult Damage¶ | Sebele Adult Damage¶ | Sebele Shootfly Infested Plants | Sebele Stemborer Infested Plans |
|---|---|---|---|---|---|---|---|---|
| 07CA20096-BK | (CE151*Sureno)-HW3-CA1-LG1-CABK | T | W | 4.3 | 1.0 | 1.0 | 0.0 | 44.4 |
| 06PR405 | Tegemeo | T | W | 5.0 | 3.0 | 1.1 | 0.0 | 23.4 |
| 07LI3467-BK | (Tegemeo*ICSR-939)-CA3-CC2 | T | W | 5.0 | 2.0 | 1.0 | 11.1 | 9.7 |
| 07LI3471-BK | (Tegemeo*ICSR-939)-CA10-CC1 | T | W | 5.0 | 1.7 | 1.0 | 5.6 | 44.4 |
| 07CA20016-BK | (9MLT176/(MR112B-92M2*Tx2880)*A964)-CA3-CABK-CCBK-CA | T | W | 5.3 | 2.7 | 1.0 | 33.3 | 13.3 |
| 07CA20175-BK | (5BRON139/(6EO361*GR107-)*Kuyuma)-HG7-LG2-CABK | T | R | 5.3 | 2.7 | 1.0 | 8.3 | 26.8 |
| 06LI2661 | Segaolane | P | W | 5.7 | 4.0 | 2.5 | 25.0 | 12.4 |
| 07CA20126-BK | (Kuyuma*5BRON155)-CA5-CC1-CABK | T | R | 5.7 | 1.7 | 1.3 | 15.0 | 0.0 |
| 07CA20174-BK | (5BRON139/(6EO361*GR107-)*Kuyuma)-HG3-LD2-CABK | T | W | 5.7 | 2.7 | 1.1 | 22.2 | 0.0 |
| 06PR397 | CE151 | T | W | | | 1.0 | 13.9 | 13.3 |
| | MEAN | | | 3.0 | 2.1 | 1.2 | 9.3 | 13.6 |
| | LSD.05 | | | 2.7 | 1.1 | | | |

†P = purple plant color, T = tan plant color.
‡R = red grain color, W = white grain color.
§ Scored on a scale of 1 = 0-10% leaf necrosis, 2 = 11-25%, 3 = 26-50%, 4 = 51-70%, 5 = 71-90%, 6 = 91-100% leaf necrosis.
¶ Scored on a scale of 1 = 0=10% leaf tissue covered by aphids, 2 = 11-25%, 3 = 26 - 50%, 4 = 51-70%, 5 = 71-90%, 6 = 91-100% leaf tissue covered by aphids.

most entries were scored as a 1. At the BCA plots were also scored for percent of plants infested with shoot fly (*Atherigona soccata* [Rondani]) and sorghum stem borer (*Chilo partellus* [Swinhoe]). For shoot fly the percent of infested plants ranged from 0 to 33 and for stem borer from 0 to 59. Several experimental entries with excellent sugarcane aphid resistance also had no shoot fly or sorghum stem borers identified.

The second trial was a twenty-five entry three replication trial composed of 22 entries previously identified with a high level of resistance to sugarcane aphid and 3 local checks. The purpose of the trial was to identify entries wilth excellent adaptation and grain yield to the local production system. All experimental entries were rated as 1 or 2 for greenhouse damage and only two entries rated higher than a one for sugarcane aphid abundance. The test average was 3.2 tons/ha with the local hybrid check producing 3.83 tons/ha, Tegemeo 2.78 tons/ha, and Macia 2.70 tons/ha. Five entries produced more grain than the hybrid check with yield ranging from 3.94 to 4.40 tons/ha. Only two entries produced significantly less grain than the local hybrid check, PAN 8420. Five entries produced more grain than PAN 8420 although the differences were not significant. Fifteen experimental entries produced more grain than the local check cultivars, Tegemeo and Macia although a significant difference was identified for only one experimental entry. Several entries were selected for on-farm trials during the next growing season at three locations to identify entries suitable for small-scale farmer market. (Table 2)

The purpose of the sugarcane aphid resistance breeding program is to develop improved cultivars suitable for use in smallholder production systems with resistance to sugarcane aphid. Ideally the new cultivars will be tan plant and white grain with excellent resistance to aphids and foliar disease, grain yield at least equal to local checks, and good grain mold resistance. Analysis of the data led to the conclusion that sugarcane aphid resistance has been incorporated into elite cultivars with grain yield potential equal to a standard local hybrid check and significantly better than common cultivar checks. Grain will be grown during the next growing season in on-farm trial to better identify performance in the local production system. Additionally, grain from the tests will be subjected to standard quality tests in comparison with the local checks to identify any deficiencies in end-use quality. The overall objective of the program is too release at least one improved variety. The research program is making excellent progress toward this objective.

To assist in developing the Mozambique national sorghum breeding program germplasm from the Texas A&M University sorghum improvement was provided to the National Agrarian Research Institute (IIAM). Included was the Midge Line Test (MLT), All Disease and Insect Nursery (ADIN), Grain Weathering Test (GWT) and Drought Line Test (DLT). The germplasm was grown at the Namialo research station. From the tests Mr. Joaquim Mutaliano, IIAM sorghum breeder, selected 9 advanced lines for potential use as varieties in Mozambique.

Designation/pedigree of the lines are:

- 03CM15067 (((((Tx2880*(Tx2880*(Tx2864*(Tx436*(Tx 2864*PI550607)))))-PR3-SM6- CM3-CM1-CM2-CABK-CABK-CGBK
- 03CM15012 (85OG4300-5*Tx2782)-SM5-CM2-SM2-SM1-CABK-CMBK-CMBK
- 02CM1104 (((((Tx2880*(Tx2880*(Tx2864*(Tx2864*P I550610)))))-PR3-SM6-CM3-CM2- CG3-BGBK-CABK
- Sureño
- 01CS20538 (90LI9178 - (M84-7*VG153)-LBK-PR7-L4-L2
- 02CS30445 (99CA3019 - (VG153*(TAM428*SBIII))-23-B32-BE2-BE1)
- B409 (B1*(B7904*(SC748*SC630)))-HF17B
- 02CS5067 (B1*BTx635)-HF8
- 01CS19225 (B35*B9501)-HD9

During the 2008-2009 growing season in Mozambique and Texas multiple location data will be gathered on each line and selected local checks (such as Macia and Kuyuma). A release proposal will be developed and submitted to the Texas AgriLife Research Plant Release Committee. Intellectual property rights to the lines for use as varieties in Mozambique will be transferred to IIAM.

Sorghum midge (*Stenodiplosis sorghicola* [Coquillett]) is the most ubiquitous insect pest of sorghum. Present in most sorghum production environments damage is dependent on the pest population density at anthesis. Generally, the more insects present the greater the damage. For most developing country production systems a low level of resistance will be sufficient to protect the plant from economic damage. Research is on-going to develop sorghum midge resistant varieties with tan plant and white grain. The 2007 Sorghum Midge Line Test was evaluated at Corpus Christi, Texas under high pest density. Standard susceptible checks BTx3042 (early maturity) and BTx378 (medium/medium late maturity) both sustained 100% grain loss.

Resistant checks Tx2767, BTx2755 and TAM2566 all sustained 70-80% grain loss. Thirteen entries, all white grain, sustained less than 20% grain loss and were significantly less damaged than either Tx2767, BTx2755 and TAM2566. Several of the resistant experimental entries also have tan plant and taller (1.5 m) and may have potential in developing country production systems.

To evaluate hybrid combining ability and grain yield potential of new germplasm releases and advanced experimental lines three replicated yield trials were conducted at the Texas AgriLife Research Center, Lubbock during 2007. All trials had three replications with a plant population of approximately 52,000 plants per acre. Timely rainfall reduced the need for supplemental irrigation in the limited/full irrigation trials.

Yield trial 1 was composed of four check hybrids and 45 experimental hybrids. Test mean was 4411 lbs/A with the standard checks ATx2752*RTx430, ATx399*Tx2737 and ATx645*Tx2862 producing 3612, 3985 and 4455 lbs/A, respectively. Twenty-three hybrids produced more than the test mean. The top yielding hybrid, ATx643*Tx2956, produced 5705 lbs/A which was significantly more than the test mean. Ten hybrids ranging in grain yield from 4882 lbs/A (ATx645*Tx2945) to 5705 (ATx643*Tx2956) produced significantly more grain than the standard check hy-

**Table 2. Grain yield (tons/ha), sugarcane aphid damage, and selected agronomic characteristics in the 2008 Sugarcane Aphid Yield tests at Potchefstroom, South Africa, and Corpus Christi, Texas.**

| PEDIGREE | Plant Color | Grain Color | Potchefstroom Seedling Damage† | Potchefstroom SCA Abundance‡ | Potchefstroom Adult Plant Damage† | Potchefstroom Grain Yield | Corpus Christi Height | Corpus Christi Exsertion | Corpus Christi Midge Damage Rating§ | Corpus Christi Grain Weathering¶ |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | tons/ha | cm | cm | | |
| (SV1*Sima/IS23250)-LG15-CG1-BG2-(03)BGBK-LBK | T | W | 1 | 1 | 1 | 4.40 | 165 | 3 | 9 | 3.5 |
| (Macia*GR128-92M12)-HM20-CA2-CG1 | T | W | 1 | 1 | 1 | 4.02 | 127 | 10 | 4 | 3.5 |
| (SDSL89426*6OB124/GR134B-LG56-)-LG5-CG1-(03)BG2-BG1 | T | W | 1 | 1 | 1 | 3.98 | 127 | 0 | 9 | 3.5 |
| (A964*FGYQ336)-LG4-LG2-(03)BG1-BG3-LBK | T | W | 1 | 1 | 1 | 3.95 | 96 | 0 | 6 | 3.5 |
| (SV1*Sima/IS23250)-LG15-CG1-BG2-(03)BGBK-LBK | T | W | 1 | 1 | 1 | 3.94 | 165 | 5 | 7 | 3.5 |
| PAN 8420 | P | R | 1 | 1 | 1 | 3.83 | | | | |
| (6OB128/(Tx2862*6EO361)*CE151)-LG4-CG1-(03)BGBK-CCBK-LBK | T | W | 1 | 1 | 1 | 3.80 | | | 9 | 3.5 |
| (CE151*TAM428)-LG15-LG1-BG1-(03)BGBK-LBK | T | W | 1 | 1 | 1 | 3.76 | 157 | 10 | 9 | 3.5 |
| (Macia*TAM428)-LL9 | T | W | 1 | 1 | 1 | 3.53 | 114 | 0 | 2 | 3.5 |
| (6BRON161/(7EO366*Tx2783)*CE151)-LG5-CG2-(03)BG1-BG2-LBK | T | LY | 1 | 1 | 1 | 3.50 | 114 | 5 | 7 | 3.5 |
| (Segaolane*WM#322)-CG1-(03)BGBK-CCBK-LBK | RP | W | 1 | 1 | 1 | 3.46 | 127 | 5 | 1 | 3.5 |
| (5BRON131/(80C2241*GR108-90M30)*SDSL9426)-LG6-LG1-BG1-BG2-LBK | T | R | 1 | 2 | 1 | 3.38 | 119 | 10 | 2 | 2.5 |
| (Segaolane*WM#322)-LG2-LG2-(03)BG1-LG1-LBK | RP | W | 1 | 1 | 1 | 3.36 | 140 | 8 | 3 | 3.5 |
| (Macia*TAM428)-LL2 | T | W | 1 | 1 | 1 | 3.35 | 109 | 3 | 7 | 2.5 |
| (6BRON161/((7EO366*Tx2783)-HG54)*CE151)-LG1-(03)BGBK-CCBK-LBK | P | W | 1 | 1 | 1 | 3.09 | 102 | 0 | 1 | 2.5 |
| (6BRON161/(7EO366*Tx2783)*CE151)-LG5-CG2-(03)BG1-BG2-LBK | T | LY | 1 | 1 | 1 | 2.79 | 102 | 5 | 7 | 3.0 |
| Tegemeo | T | W | 6 | 3 | 2 | 2.78 | 122 | 3 | 3 | 3.5 |
| Macia | T | W | 6 | 3 | 3 | 2.70 | 127 | 5 | 6 | 3.5 |
| (60B128/(Tx2862*6EO361)*CE151)-LG16-CG1-LGBK-LG2-LBK | T | R | 1 | 1 | 1 | 2.69 | 104 | 3 | 9 | 3.5 |
| (SDSL89426*6OB124/GR134B-)-LG5-(03)CCBK-CCBK-LBK | RP | WB | 1 | 1 | 1 | 2.63 | 114 | 10 | 2 | 3.5 |
| (6BRON161/(7EO366*Tx2783)-HG54-*CE151)-CG4-BG1-BG1-LBK | T | W | 1 | 1 | 1 | 2.61 | 119 | 5 | 9 | 3.5 |
| (6OB128/(Tx2862*6EO361)*CE151)-LG19-(03)CCBK-CCBK-LBK | T | W | 1 | 1 | 1 | 2.60 | 66 | 0 | 6 | 3.5 |
| (6BRON126/((87BH8606-14*GR107-90M46)-HG10)*CE151)-CG1-(03)BGBK-CCBK-LBK | T | W | 1 | 1 | 1 | 2.31 | 109 | 3 | 3 | 3.5 |
| (EPSON2-40/E#15-SADC*TAM428)-LG3-BG1-BG1-LBK | T | W | 1 | 1 | 1 | 2.07 | 96 | 3 | 5 | 3.5 |
| (CE151*TAM428)-LG1-(03)BGBK-CCBK-LBK | RP | W | 1 | 2 | 1 | 1.68 | 107 | 0 | 8 | 3.5 |
| Mean | | | 1.4 | 1.3 | 1.2 | 3.20 | | | | |
| LSD.05 | | | 0.2 | 0.5 | 0.5 | 1.30 | | | | |

† Scored on a scale of 1 = 0-10% leaf necrosis, 2 = 11-25%, 3 = 26-50%, 4 = 51-70%, 5 = 71-90%, 6 = 91-100% leaf necrosis.

‡ Scored on a scale of 1 = 0=10% leaf tissue covered by aphids, 2 = 11-25%, 3 = 26 - 50%, 4 = 51-70%, 5 = 71-90%, 6 = 91-100% leaf tissue covered by aphids.

§ Scored on a scale of 1 = 0-10% aborted kernels, 2 = 11-20% aborted kernels, up to 9 = 81-100% aborted kernels.

¶ Scored on a scale of 1 = Seed bright, free from mold damage, 2 = Moderately resistant to mold and seed slightly discolored, 3 = Moderately susceptible and considerable seed discoloration, 4 = susceptible with extensive seed discoloration and deterioration, 5 = Very susceptible with extensive seed deterioration.

brid ATx2752*RTx430. Test weight was slightly larger than ATx2752*RTx430 and the hybrids all flowered within two days of the check. All of the hybrids were purple plants although several of the experimental male parent are tan plant. The tan plant males will combine with standard seed parents (A-lines) to produced excellent hybrids.

Yield trial 2 was composed of 7 standard checks and 43 experimental hybrids. All of the experimental hybrids were tan plant color with either white or red grain. Twenty-six experimental hybrids had new male parents and 8 with new female and male parents. Fourteen hybrids had new unreleased male parents and 6 had new female parents and unreleased male parents. The purpose of the trial was to compare the grain yield of experimental tan plant hybrids versus standard checks including ATx2752*RTx430 ( purple plant with red grain) and ATx631*Tx436 (tan plant with white grain). Test mean was 3584 lbs/A with ATx2752*RTx430 and ATx631*Tx436 producing 3442 and 4084 lbs/A, respectively. The top two grain producers and three of the top four hybrids are experimental pollinators in advanced testing. The top two hybrids, ATx2961*03BRON172 and ATx2961*02BRON159, produced 5165 and 4786 lbs/A respectively. Twenty-four hybrids produce more grain than the standard check ATx2752*RTx430. Thirteen hybrids produced more grain than the tan plant white grain check ATx631*Tx436. Test weight and days to 50% anthesis were similar for the experimental hybrids and check hybrids. Analysis of the data led to the conclusion that tan plant hybrids in advanced testing will produce grain yields equal to or better than current production hybrids with similar test weight and maturity.

Yield trial 3 was composed of 6 standard checks and 16 experimental hybrids. All pollinators (males) for the experimental hybrids are in advanced stages of evaluation. The test mean was 4365 lbs/A and the standard check ATx2752*RTx430 produced the most grain at 5249 lbs/A. Nine experimental hybrids produced more than the test mean. Four experimental hybrids produced over 5,000 lbs/A - ATx643*02BRON166 (5210 lbs/A), ATx642*02BRON166 (5067 lbs/A), ATx642*03BRON172 (5067 lbs/A) and ATx643*03BRON167 (5021 lbs/A). Test weight and days to 50% anthesis of the experimental hybrids were similar to the standard checks.

Interest is increasing in the development of sweet sorghum for use in production of biofuels (ethanol). In 2007, a program was initiated to develop sweet sorghums for use in rainfed or limited irrigation semi-arid production systems. To establish the range of variability for standard varieties and observation planting of 32 varieties was made. At maturity the plants in each plot were harvested, weighed, panicles removed, and leaves and stems crushed to obtain data on brix percent. Brix % ranged from 6.5 (M81E) to 20.4 (N99_PI535784). Eighteen parents produced a brix percent greater than 15.0. The data will be used to select parents for crossing to generate additional populations for selection. Two hundred sixty seven plots of F2 or F3 breeding material were grown to select for adaptation. One hundred eighty one selections were made with brix percent ranging from 7.4 to 20.4. Selections will be grown in 2008 to develop advanced generations.

Cooperative research with the TAMU Cereal Quality Laboratory continued. The research objective is to analyze and potentially exploit lemon yellow grain with high levels of eriodictyol and naringenin for human health benefits. Seed samples of 154 lemon-yellow grain color germplasms (representing 14 different pedigrees) were provided to the TAMU Cereal Quality Laboratory to analyze for presence of eriodictyol and naringenin. Several (all pollinators except on potential B-line) were identified with high levels of the compounds of interest. In 2008 plots were planted to produce lemon yellow hybrids from the best lines. Additionally, selections were made in new additional segregating populations to for lemon yellow grain color and better agronomic traits. Approximately 2.5 acres each of a lemon yellow seed line and a black seed line were planted to provide quantities of seed for commercial utilization trials.

A winter sorghum nursery in Puerto Rico was planted to facilitate research progress. The nursery was used to increase seed of selected sweet sorghum parental lines, grow F1 cross seed, produce additional hybrids for evaluation, make additional backcrosses for sterilization of potential new A-lines, and increase seed of lemon-yellow lines. Notes on evaluation for tropical evaluation were also obtained.

## Achievement of Activities Proposed in Work Plan

All activities proposed in the Work Plan were accomplished. For the U.S. the proposed activities included: preliminary consultations with collaborators to determine the segregating populations needed to achieve the research objectives; assess the germplasm and populations already in the breeding program to determine suitability for use; increase lines and exotic cultivars potentially useful in developing new populations; evaluate and select segregating germplasm for resistance to selected biotic (insect: greenbug or sorghum midge; disease: headsmut, downy mildew, anthracnose, rust, zonate, grain weathering) and abiotic (pre- and post-flowering drought) stress; evaluate advanced lines as hybrid parents for grain yield, biotic and abiotic stress resistance, and adaptation; based on consultations with collaborators and data collected, make crosses to develop new segregating populations; package and distribute to collaborators seed of replicated trials of advanced germplasm potentially useful in southern Africa cropping systems; utilize a Puerto Rico winter nursery to develop new breeding segregating populations, identify F1 plants, increase exotic cultivars and adapted lines, continue sterilization of potential new A-lines, produce seed of new hybrid combinations; distribute seed of lines approved for release to private seed companies; evaluate inbred lines and segregating forage and sweet sorghum populations for biomass production for potential use in cellulosic ethanol production; provide grain of lines and hybrids to food science collaborators for analysis of grain properties including density, protein, moisture, starch and kernel hardness.

For Southern Africa the proposed activities included: travel to the region to consult with collaborators and develop specific work plans; collaborate with regional scientists to evaluate sorghum for the traits (adaptation, grain yield, disease resistance, insect resistance, drought tolerance, grain quality and grain weathering) necessary for developing improved sorghum cultivars for local production systems; distribute replicated trials of advanced germplasm potentially useful in Southern Africa cropping systems; based on consultations with collaborators and data collected, make crosses to develop new segregating populations; select germplasm with improved genetics for use in local production systems; participate in graduate training for regional breeders as appropriate. (Table 3)

Progress can be measured in the eventual release of new germplasm or cultivars. A new released germplasm or cultivar may be classed into more than one objective.

## Networking Activities

Participated in the INTSORMIL Principal Investigators Conference, September 18-19, 2007, Lincoln, NE.

Participated in the Texas Seed Trade Association Production and Research Conference, February 4-5, 2008, Dallas, TX

Participate in the International Workshop on Sorghum for BioFuel, August 19-22, 2008, Houston, TX

Travel to Kenya, Mozambique, South Africa, Botswana and Zambia April 18 - May 9, 2008. In Kenya met with representatives of ICRISAT to discuss INTSORMIL participation in a sorghum and millet proposal to the Bill and Melinda Gates Foundation. In Mozambique met with collaborators in breeding and entomology; In South Africa met with collaborators in entomology, food science and plant pathology; In Botswana met with collaborator in entomology and potential collaborators at the National Food Technology Research Center (NFTRC); In Zambia met with collaborator in breeding and with representatives of the University of Zambia.

Seed of the following nurseries/test was distributed: All Disease and Insect Nursery (ADIN), Uniform Head Smut Nursery (UHSN), Sugarcane Aphid Test (SCA), Sugarcane Aphid Yield Test (SCAY), Midge Line Test (MLT). Seed was also request to private companies as requested. All seed is distributed under terms of a Materials Transfer Agreement (MTA).

## Publications and Presentations


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.

Teme, N., D.T. Rosenow, G.C. Peterson and R.J. Wright. 2007. Analysis of QTLs improving heterosis of grain yield in sorghum (Sorghum bicolor (L.) Moench). In Proc. of the 25th Biennial Sorghum Industry Conference. Albuquerque, N.M. Jan. 15-17, 2007. (CD-ROM).

Dykes, L., W.L. Rooney, G.C. Peterson and L.W. Rooney. 2007. Phenol profile and antioxidant activity levels of black sorghums grown in different environmental conditions. In Proc. of the 2007 AACC International Annual Meeting. San Antonio, TX. Oct. 7-10, 2007.


**Table 3. Relationship and contribution to INTSORMIL Strategic Plan objectives, target, benchmarks and indicators**

| Objectives | Targets | Benchmarks and Indicators | Throughputs |
|---|---|---|---|
| Nutrition, health and grain quality | - Higher grain quality cultivars<br>- Increased nutrition of food and feed products | Development of cultivars with improved grain properties | Release of cultivars with improved grain quality |
| IPM | - Increased grain quality<br>- Reduced pesticide use | Tolerance to grain insects and/or pathogens | Release of insect and/or disease resistant cultivars |
| Genetic enhancement | - Stable yielding genotypes | - Genotypes with less variation in yield<br>- Decrease in drought damage | Stable yielding and/or drought tolerant cultivars released |
| Genetic resource and biodiversity | Higher yielding genotypes | Selection of high yielding genotypes | Increase in yield of new genotypes |

# Crop Utilization and Marketing

# Enhancing the Utilization and Marketability of Sorghum and Pearl Millet through Improvement in Grain Quality, Processing, Procedures, and Technology Transfer to the Poultry Industry

**Projects KSU 102**
**Joe Hancock**
**Kansas State University**

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Dr. Mamadou Sangare, Animal Nutrition and Production, CIRDES, Bobo-Dioulasso, Burkina Faso
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## Introduction and Justification

Throughout human history, as economies have grown and people have experienced greater wealth, consumption of animal products has increased. Poultry production is particularly well suited to a rapidly growing demand for animal products because of relatively low expenditures for facilities, equipment, and land area to enter into the industry. Additionally, the short production cycle (less than two months of age at slaughter for a broiler vs six months for a pig vs 18 months for a feedlot steer) and extreme efficiency of growth (feed to gain ratios of about two in a broiler vs three in a pigs to six in a feedlot steer) make poultry attractive to growers that need minimal input of capital and rapid return on their investment. There are several beneficial aspects to the phenomenon of explosive growth in global production of poultry, especially in developing regions such as West Africa. These benefits include (but are not limited to) diversification of farm enterprises to include animal production in addition to crops, development of alternative/stable markets for cereal grains, and transition of cereal production from a subsistence activity to a cash crop (when sold to livestock producers) that yields disposable household income. Even more important are the contributions of a healthy livestock feeding sector to the nutritional status of humans that consume the resulting animal products and to a general increase in quality of life. Sorghum and millet do indeed have the potential, via their hardiness and drought tolerance, to bring the prosperity associated with animal agriculture into regions of the world that crops such as maize cannot. Thus it is our objective to ensure that sorghum and millet enjoy a prominent position in the development of animal agriculture in West Africa.

Our overall strategy for this project has been to assemble a team of U.S. and host country collaborators to focus on educational and promotional programs to ensure expanded use of sorghum as animal feed and research activities to ensure improvements in sorghum grain quality. We have worked, are working, and will continue to work to integrate research projects involving pathology/grain weathering, breeding for improved nutritional value, feed processing, and poultry nutrition/production. Specifically for the 2007-2008 fiscal year, we were able to complete a truly regional project involving a common protocol replicated in Senegal, Mali, Burkina Faso, Niger, and Nigeria. The objective of this project was to compare maize to locally produced sorghum grain that had been properly milled and, of equal importance, to develop a network of collaborating poultry scientists in this part of the world. Salissou Issa (Ph.D. student at Kansas State) spent the summer in West Africa visiting each experiment station to deliver feed ingredients and initiate the growth assays. As of this last month, all data have been submitted to Kansas State University and we are in the process of statistical analyses of those data. Additionally, we were able to complete a similar experiment with our collaborators in Nicaragua and those prize-winning data were presented by Carolina Feoli (Ph.D. student at Kansas State) at the PCCMCA in Costa Rica. Additional accomplishments included completion of a M.S. thesis on sorghum tannins by Cynthia Monge, numerous presentations by these three students at various professional meetings, and Dr. Hancock being invited to serve on the Scientific Committee as Chair of the Nutrition Section of the International Conference for the Improved Competitiveness of Poultry Production in Africa held in conjunction with the 40th Anniversary of the School of Veterinary Medicine, E.I.S.M.V. de Dakar.

## Objectives and Implementation Sites

Our efforts to expand use of sorghum grain and millet as animal feed necessitated integration of knowledge gained from researchers in pathology, breeding, agronomy, pest management, and economics as follows:

1. We were able to work with plant breeders (e.g., Clara, Tuinstra, and Rooney) in El Salvador, Kansas/Indiana, and Texas to identify genetic materials with superior agronomic and nutritional merit that will be used in feeding experiments conducted in Kansas during the next fiscal year.
2. The input of cereal chemists (e.g., Ndoye, Nkama, Rooney, and Bean) in West Africa, Texas, and USDA/Kansas were used to identify seed characteristics (endosperm type/texture/chemistry, tannin type and concentration, and molds/mycotoxins) deemed of value for the sorghums fed to broiler chicks in our just-completed regional project.
3. The expertise of economists (e.g., Abdoulaye and Sanders) in West Africa and Indiana was solicited to facilitate discussion of economic constraints on the poultry industry in West Africa during the International Conference for the Improved Competitiveness of Poultry Production in Africa that was held in Senegal.
4. Collaboration with grain scientists (e.g., McKinney and Behnke) in the Feed Science Program at Kansas State University was used to establish best manufacturing practices for diets used in our experiments in West Africa and Nicaragua.
5. Interaction with animal nutritionists (e.g., Issa, Traore, Hien, Sangare, Missohou, Rios, and Campabadahl) in West Africa, Central America, and Kansas was essential to diet formulation strategies and conduct of our chick-feeding experiments.

Specific sites targeted for our 2007-2008 activities included regional research institutes in West Africa, the Agricultural University of Nicaragua and, of course, continuation of our research activities on campus here at Kansas State University.

## Research Methodology and Strategy

Active participation of host country scientists was a core component of our project during the 2007-2008 fiscal year. Beginning with participation by Issa in the INTSORMIL Regional Planning meeting held in Bamako, our goal was to meet as many collaborators as possible and especially those that were not part of previous INTSORMIL activities. Issa visited with potential collaborators form Burkina Faso, Mali, Niger, Senegal, and Nigeria to formulate a common protocol for an experiment to address a region-wide concern among poultry producers as it relates to the use of sorghum grain. Also, Hancock used his time at the Poultry Conference in Senegal to network with many of these same collaborators and to finalize a common protocol. As for the Americas, Feoli garnered inputs from Francisco Vargus (of AMPROSOR, the National Sorghum Producers Association of Nicaragua) and Miguel Rios (at UNA) in regard to our second demonstration project at UNA in Managua. Finally, at Kansas State University Monge finished an M.S. degree resulting from her thesis efforts with sorghum tannins in close collaboration with Tuinstra, Bean, and Rooney.

## Research Results

Specifically for the 2007-2008 fiscal year, we were able to complete a truly regional project involving a common protocol replicated in Senegal (on-site supervisor was Dr. Ayao Missohou, Veterinary Medicine and Animal Nutrition, Department of Biological Sciences, School of Veterinary Medicine, Université Cheikh Anta Diop, Dakar), Mali (on-site supervisor was Dr. Bantieni Traore, Animal Nutrition and Production, Centre Régional de la Recherche Agronomique de Sotuba, Bamako), Burkina Faso (on-site coordinator was Dr. Ollo Hien, Nutrition and Production, Institut de l'Environnement et de Recherches Agricoles, Bobo-Dioulasso), Niger (on-site supervisor was Dr. Salissou Issa, Animal Nutrition and Husbandry, INRAN Rainfed Crops Program, Niamey), and Nigeria (on-site supervisor was Dr. Iro Nkama, Food Science and Cereal Chemistry, University of Maiduguri). Issa spend the summer in West Africa visiting each experiment station to deliver feed ingredients and initiate the growth assays. The objective of this project was to compare maize to locally produced sorghum grain that had been properly milled. For the experiment, 400 1-day-old broiler chicks were randomly allocated to 16 pens (4 treatments and 4 pens/treatment with 25 birds/pen). This allocation was repeated at 5 sites for a total of 2,000 birds used in the experiment. The control diet was corn-based with fishmeal, peanut meal, cotton seed meal, and soy bean meal as the primary protein supplements. Sorghum was used to replace the corn on a wt/wt basis so that treatments were corn- vs sorghum-based diets with the cereals ground through a 6.4 mm vs 2 mm screen. The birds were allowed to consume feed and water on an ad-libitum basis for 42 days with weights taken on day 0, 21, and 42. At the end of the experiment, 12 birds/pen were killed for carcass evaluation. Carcass measurements included weights of the live bird, carcass, gizzard, liver, mesenteric fat, and full/empty intestines. Additionally, gizzards were scored for lesions on a scale of 0 to 5. All data have been submitted to Kansas State University and we are in the process of pooling the data for statistical analyses with hopes of generating a presentation for the Poultry Science Meetings this next summer. This project will serve as the core of Issa's Ph.D. dissertation.

As for the Central America activities, we were able to complete an experiment with our collaborators in Nicaragua (Miguel Rios and Francisco Vargas). Four hundred sixty eight 2-day-old broiler chicks were used in a 14-day growth assay to determine the nutritional value of imported corn (US no. 2 with 7.7% CP and 3.6% crude fat) vs locally produced bronze (CB-8996, a hybrid with 7.9% CP and 2.5% crude fat) and white (Pinolero-1, a variety with 6.7% CP and 2.5% crude fat) sorghum grain. The chicks were allotted to pens with 26 birds/pen and 6 pens/treatment. Feed and water were consumed on an ad libitum basis. The corn and sorghums were ground through a hammermill (4-mm screen openings) and blended into diets that were formulated to 1.29% Lys, 0.99% Met+Cys, 1.1% Ca, and 0.49% available P. All data were analyzed as a randomized complete block with location within the barn as the blocking term and initial weight as a covariate. Orthogonal contrasts were used to separate treatment means with comparisons of corn vs the sorghums and bronze sorghum vs white sorghum. There was no effect of grain source on average daily gain. However, average daily feed intake was greater and gain to feed ratio was lower for chicks fed the corn-based diet compared to those fed the sorghum-based diets. There were no differences in rate of gain or food intake among chicks fed the two sorghums, but those fed white sorghum tended to have greater gain to feed ratio. For the diets with corn, bronze sorghum, and white sorghum, average daily gain was 24.7, 25.2, and 25.9 g/d, average daily feed intake was 48.5, 45.2, and 43.7 g/d, and gain to feed ratio was 509, 558, and 593 g/kg, respectively. In conclusion, bronze and white sorghums produced in Nicaragua supported equal or greater growth performance compared to imported corn when fed to broiler chicks.

As for the thesis work of Monge, 3 experiments were conducted to determine the effects of tannins on the nutritional value of sorghum grain in broiler chicks. In Exp 1, there was an 8% decrease in rate of gain and a trend for decreased gain:feed ratio as tannin in the sorghum was increased from none to 5.44% CE. The trend in gain:feed was consistent with quadratic responses in percentage retention of DM, N, and GE with concentration of tannins greater than 1.36% CE resulting in decrease nutrient utilization. In Exp 2, birds fed pericarp from tannin sorghum (Sumac) had less ADG and retention of DM, N, and GE with decreases of 8, 11, 8, and 6%, respectively, compared to birds fed diets with pericarp from a non-tannin sorghum (Mycogen). In Exp 3, birds were fed bran from three different tannin sorghums at the same catechin concentration (0.6 mg CE/g DM) to test the potency of tannins from different sources. When compared to birds fed pericarp from non-tannin sorghum (Mycogen), birds fed tannin sorghums had less rate of gain and MEn, but there was little evidence to suggest major differences in potency of the tannins from different sorghums.

Our overall objective and expected outcome for this project is to ensure that sorghum is a preferred cereal grain for poultry feeding. In the semiarid to arid environments of West Africa and the Central Great Plains of the U.S., such acceptance and recognition will go far to improve the marketability of sorghum. Enhanced marketing opportunities should result in more favorable pricing with stable income for grain producers and processors. Results such as those we have generated thus far should go far to make an argument for sorghum as a preferred feedstuff in diets for livestock. Our next steps will be to continue such research activities and emphasize transfer of our findings to livestock producers and feed manufacturers that will use the sorghum grain produced by crop farmers.

## Networking Activities

Our networking activities have been extensive during the 2007-2008 fiscal year with the efforts of Issa to accomplish a regional feeding project in West Africa as prime example. Beginning with his efforts at the INTSORMIL Regional Planning Meeting in Bamako, to his physical oversight of that project, to his presentation at the Southeast Poultry and Egg Expo in Atlanta (the largest poultry expo on the planet), Issa has been instrumental in or networking activities. Feoli has been the principal component of our networking activities in Central America with physical oversight of our feeding experiments in Nicaragua. Additionally, she has been active at professional meetings with presentations at the Poultry Science Meetings in Niagara Falls, the PCCMCA Meetings in Central America, and the CLANA Meetings in Mexico. Hancock also has been active in promoting sorghum with presentations and seminars given around the globe (e.g., China, Russia, Ireland, England, Denmark, Holland, Germany, France, Italy, Spain, Portugal, Colombia, El Salvador, Honduras, Nicaragua, and Costa Rica) and serving on the Scientific Committee as Chair of the Nutrition Section of the International Conference for the Improved Competitiveness of Poultry Production in Africa (held in conjunction with the 40th Anniversary of the School of Veterinary Medicine, E.I.S.M.V. de Dakar, Senegal).

## Publications and Presentations


Feoli, C., J.D. Hancock, M.G. Viscarra, R. Rodríguez, M.J. Ríos, F.J. Baltodano, F. Vargas, and S.C. Mason. 2008. Nutritional value of imported corn versus locally produced bronze and white sorghum grain when fed to broiler chicks in Nicaragua. Presented at the 64th Annual Meeting of the PCCMCA, San Jose, Costa Rica (April 14-18) and the Annual Poultry Science Association Meetings, Niagara Falls (July 21-23).

Hancock, J.D. 2008. Sorghum Utilization – Animal Diets. Great Plains Sorghum Conference, Manhattan, KS, September 3-4.

Hancock, J.D. 2008. Nutritional consequences of feedstuff selection and feed manufacturing practices. RAPCO (Cursos Regionales en Produccion Animal) Short Course in Feed Manufacturing, Atenas, Costa Rica (July 28-August 1) and Antioquia, Colombia (August 3-8).

Hancock, J.D. 2008. Nutritional Strategies for Production of Poultry in the Sub-Saharan Environments of Africa. International Conference for the Improved Competitiveness of Poultry Production in Africa, 40th Anniversary of the School of Veterinary Medicine, Dakar, Senegal, May 5-9.

Hancock, J.D. 2008. Merits and constraints for the expanded use of sorghum grain in animal feeding. The U.S. Grains Council Seminar Series for Western Europe with presentations in Ireland, England, Holland, and France (February 16-24), and Denmark, Italy, Spain, and Portugal (September 13-23).

Hancock, J.D. 2007. Merits of forage and grain sorghums in diets for livestock feeding. A presentation to the technical staff of PROLECHE (the National Dairy Association), San Salvador, El Salvador, December 7.

Hancock, J.D. 2007. Current concepts for the use of sorghum grain to reduce cost of gain in poultry. A presentation to the technical staff and Board of Directors for AVES (the National Poultry Growers Association), San Salvador, El Salvador, December 6.

Hancock, J.D. 2007. Diet formulation and milling strategies to maximize the nutritional value of sorghum-based diets for livestock feeding. The Ag Expo (i.e., State Fair) of Choluteca, Choluteca, Honduras, December 5.

Hancock, J.D. 2007. Effects of particle size of imported corn and domestically produced sorghums on growth performance in broiler chicks: A collaborative efforts among KSU, INTSORMIL, UNA, and ANPROSOR. Presented to the Board of Directors for ANPROSOR, Managua, Nicaragua, December 2.

Issa, S., J.D. Hancock, M.R. Tuinstra, I. Kapran, and S. Kaka. 2008. Effects of sorghum variety on growth and carcass characteristics in broiler chicks reared in West Africa. Presented at the International Poultry Scientific Forum, Atlanta GA, January 21-22.

Monge, C.R. 2008. Effects of Tannins on the Nutritional Value of Sorghum Grain in Broiler Chicks. M.S. Thesis, Kansas State University, Manhattan.

# Market Development in Support of Sorghum and Millet Farmers in Tanzania and Zambia


## Project OSU 101
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### Introduction and Justification

Improving the income and food security of small-scale sorghum and millet farmers in Zambia and Tanzania through the identification of new market opportunities and related constraints in the supply chain is the focus of this INTSORMIL/CRSP project. Sorghum and millet are traditional food staples and are important producer and consumer goods in Tanzania and Zambia. In both countries, the productivity and profitability of these crops is low and so is the income of small farmers who produce them. A huge challenge facing these countries is to increase the productivity and incomes of small farmers to improve food security and to accelerate economic growth and prosperity in rural and urban areas. Improving technology and linking producers to markets are important parts of the solution to the problem (USAID Agriculture Strategy, 2004). Improving production and marketing technology will lead to greater productivity and higher incomes for sorghum and millet producers and lower food costs for consumers.

The major achievements in the past year were completion of the project activities as specified in the work plan for Tanzania and Zambia. These included (1) studies of technology adoption in both countries in the low potential areas surveyed in year one of the project, (2) conducting baseline farm household surveys in high potential areas, (3) studies of sorghum-based clear beer supply chain, (4) initiating the collection of information on seasonal price variability, and (5) selecting a student from Tanzania and Zambia for M.S. study at The OSU, beginning Autumn term 2008 and a PhD student from Zambia to begin study in the Regional Universities Forum for Capacity Building in Agriculture (RUFORUM) agricultural economics program at Bunda College in Malawi. The project also supported two M.S. students in agricultural economics at SUA and two senior research projects at UNZA.

The combined studies are designed to identify new and/or rapidly growing markets for sorghum and millet in value added processing for clear beer, food, and feed concentrate markets. These value added processors offer opportunities for smallholders to sell their crops to more secure and stable markets than those currently available. Improved linkages to these markets will enable smallholders to adopt improved technology to increase yields, production, and incomes. The baseline farm household surveys completed in 2008 in the high potential areas and those farm household surveys completed previously in the low potential areas are designed to establish the benchmarks and indicators for yields, production, incomes, and amounts processed in these new markets. The same households will be surveyed in the last year of the project to measure the amount by which the baseline indicators have increased during the life of the project.

### Objectives and Implementation Sites

The INTSORMIL overall approach is to increase food security and promote market development of sorghum and pearl millet products. This is to be achieved by implementing the project specific goal of developing marketing strategies through a complementary applied marketing research program in Tanzania and Zambia.

These activities are centered on INTSORMIL project objectives one and seven: Objective 1: To facilitate the growth of rapidly expanding markets for sorghum and millet; Objective 7: To develop effective partnerships with national and international agencies engaged in the improvement of sorghum and pearl millet production and the betterment of people dependent on these crops for their livelihoods.

The project implementation sites are with collaborating universities and faculty located at Sokoine University of Agriculture (SUA) Morogoro, Tanzania and the University of Zambia (UNZA), School of Agriculture, Lusaka, Zambia.

### Research Methodology and Strategy

The research activities described below focus on two sorghum and millet producing countries in East and Southern Africa: Tanzania and Zambia.

**Studies of technology adoption:** This study will be conducted in high and low potential production areas in Tanzania and Zambia. Baseline surveys already conducted will be augmented by follow-up baselines to measure adoption of technologies and to assess the impact of new market development on technological uptake. Household surveys conducted in low potential areas in both countries have been analyzed and manuscripts prepared on factors affecting adoption of recommended improved sorghum production technologies.

Household surveys have now been completed in high potential sorghum production areas in both countries and are currently being analyzed.

**Sorghum-based clear beer studies:** In both countries we are examining the entire supply chain for sorghum-based clear beer to identify ways to remove these constraints. Three important dimensions/features of the supply chain that are being analyzed are a sufficient, reliable, and quality supply of sorghum.

**Seasonal price variability studies:** Many times farmers are forced to sell their crops at harvest time when crop prices are frequently at the lowest level. Crop prices may increase substantially during the remainder of the marketing year. Studies of the monthly price changes, costs of storage and household seasonal cash flows have been initiated to identify ways for farmers to sell at higher prices in the post-harvest season.

## Description of Interdisciplinary Team

This project is part of an INTSORMIL team of scientists from various disciplines that develop research and outreach program for sorghum, millet, and other grains. We maintain contact with several INTSORMIL researchers to identify opportunities for collaboration. The scientists include John Sanders (economist) at Purdue University, Gary Peterson, (plant breeding and Regional Program Coordinator for Southern Africa ) at Texas A& M University, Charles Wortmann (soil scientist) and David Jackson (food scientist) at University of Nebraska, Gbisa Ejeta (plant breeding and Regional Program Coordinator for the Horn of Africa) at Purdue University, Medson Chisi (sorghum breeder) at the Golden Valley Research Station in Zambia; the sorghum research team at Ilonga Agricultural Research Institute, Kilosa, Tanzania; and the Entrepreneurship and Product Development Group at the University of Nebraska and Sokoine University of Agriculture, Tanzania.

## Research Results

### *Tanzania*

In Tanzania, the project activities for July 1, 2007 to September 29, 2008 were to: (1) examine technology adoption in the Dodoma region, (2) conduct baseline farm household interviews in a high potential area, (3) study the supply chain for sorghum-based clear beer, (4) initiate the collection of information on seasonal price variability, and (5) select a student from Tanzania for M.S. study at The OSU to beginning Autumn term 2008.

### *Adoption of Improved Production Technologies Among Smallholder Growers Of Maize and Sorghum*

A draft manuscript on this topic has recently been completed that focuses on the Dodoma region. Empirical evidence from the study areas indicate that with respect to varieties grown, 63 % of respondents grew local varieties of maize and 37 % grew improved varieties. In contrast, 42 % of farmers grew local varieties of sorghum, and 59 % grew improved varieties. The improved varieties of sorghum that farmers used were Pato, Tegemeo, and Macia. Newly released sorghum varieties “Wahi” and “Hakika” were not being grown in the villages and many farmers were not aware of their existence. Results also indicate that the improved sorghum seed that farmers plant may not be the same quality as the seed first released to farmers. Sorghum farmers typically save seed from the current harvest for planting in the next crop year. This practice may continue for several years causing a decline in the genetic quality and productivity of the improved seed.

The analysis of tillage methods used indicates that the percentage of farmers in Dodoma-rural and Kongwa Districts who practiced no-tillage and conventional hand-hoe tillage were 64 percent and 77 percent for maize and sorghum, respectively. Conventional hand-hoe tillage practices are not well-suited to semi-arid areas because they do not conserve soil moisture. Deep tillage practices which conserve soil moisture more effectively were used by 37 percent and 23 percent of maize and sorghum farmers, respectively. In general, farmers appear slightly more willing to use deep tillage practices with maize than sorghum.

No respondent reported using inorganic fertilizers and herbicides. However, 28 and 13 percent of the farmers did apply manure on maize and sorghum, respectively. Mean manure application rates were approximately 0.14 and 0.63 tons/hectare for maize and sorghum, respectively. The low use of soil fertility supplements raises several concerns regarding the long term sustainability of farming without any attempts to enhance soil fertility and the benefits of using improved seed. Without fertilizers or manure, crop yields for most improved varieties will be low.

The most important factors explaining overall household adoption of improved maize and sorghum technologies are marital status, off-farm income, asset value and family labor. Adopters of improved technologies appear to have more resources including labor, income and capital. Adopters also appear to have larger farms; however, this variable was not significant perhaps because of limited variability among the observations. These results are consistent with the adoption literature, which indicates that adopters of new technologies have different household and farm characteristics than non-adopters and that farmer with more resources, both social and economic, are more apt to adopt new technologies. (Table 1)

### *Conduct Baseline Farm Household Interviews in a High Potential Area*

A survey of high potential sorghum and millet production areas was completed to establish a baseline for households in high potential areas. Designation of high potential areas was completed in collaboration with host country scientists. The high potential

**Table 1. Adoption of improved technology among smallholder growers of maize and sorghum, Dodoma Region, Tanzania, 2006.**

| Technologies | Maize | Sorghum |
|---|---|---|
| Seed | | |
| - Local | 63% adopted | 42% |
| - Improved | 37% | 59% |
| Tillage | | |
| - Traditional | 64% | 77% |
| - Deep tillage | 36% | 23% |
| Synthetic Fertilizer | 0 | 0 |
| Manure | 28% | 13% |
| - manure application rates | 0.14 tons/ha | 0.63 tons/ha |

areas selected were Singida Rural and Simanjiro which are important sorghum areas linked to the clear beer processor, TBL brewery, in Arusha. The villages were selected based on the introduction of new sorghum varieties in Singida Rural (four villages) and the market linkages identified in Simanjiro (three villages). The survey sample size was 107 households: 59 from Singida Rural and 48 from Simanjiro.

### *Examine the Supply Chain for Sorghum-Based Clear Beer*

The sorghum-based clear beer supply chain analysis is being conducted by Jeremia Makindara, a faculty member and Ph.D. candidate at SUA. The objective of the study is to assess the potential of producing sorghum-based clear beer value chain in Tanzania by mapping all the players along the chain, their roles and challenges they face. The farm survey is the initial stage in evaluating the supply chain of sorghum for commercial utilization. The sorghum value chain starts with smallholder producers who then sell their produce to village buyers. Some village buyers are agents of grain traders from urban centres who may sell produce to large scale industrial users such as Tanzania Breweries Limited (TBL) or Dar Brew Limited. Village buyers also sell to urban wholesalers. Some larger scale commercial sorghum farmers enter into contracts and sell directly to industrial users such as TBL or Dar Brew. Long term sustainability of a value chain depends upon potential demand of the buyers; consistent and high quality supplies from producers; as well as adequate transportation and storage infrastructure, profitability for all chain members, trust and contract enforcement mechanisms. In addition to the farm household interviews, interviews with traders (60), transporters (60), distributors and warehouse owners have been completed and are being tabulated.

### *Initiate the Collection of Information on Seasonal Price Variability*

The project is collecting monthly price data to assess seasonal variability of sorghum and millet prices over the next four years (2008-2011). To initiate this process the Tanzanian collaborators at SUA developed a protocol for data collection to undertake the following:

1. Collect wholesale and retail prices for sorghum and millet in Dodoma and Singida (central Markets) on a weekly basis and;
2. Collect farm gate prices in the main sorghum and millet producing regions on a weekly basis.

### *Methodology*

The contracted persons with support of SUA researchers from the Department of Agricultural Economics and Agribusiness (DAEA) are in charge of:

- Data collection process in respective regions
- The data are collected twice every week and are filled in a standard form translated into Swahili, which is appended over leaf
- Instruction for data collection are in the user-friendly form and the Lead consultants under DAEA demonstrated on how to fill the form
- DAEA shall collect these forms by the end of the year

### *Select a Student from Tanzania for M.S. Study at the OSU*

The project is supporting M.S. degree study at OSU in agricultural economics for Joseph Mgaya from Tanzania who began his graduate study in autumn of 2008. OSU provides a cost share tuition award for this student.

## Research Results

### *Zambia*

In Zambia, the project activities for July 1, 2007 to September 29, 2008 were to: (1) examine technology adoption in the Siavonga area, (2) conduct baseline farm household interviews in a high potential area, (3) study the supply chain for clear beer, (4) initiate the collection of information on seasonal price variability, and (5) select a student from Zambia for M.S. study at The OSU to beginning Autumn term 2008 and select a student for the RUFORUM Ph.D. program located at Bunda College.

### *Adoption of Improved Technologies Among Smallholder Growers of Maize, Millet and Sorghum*

A draft manuscript on this topic has recently been completed. This study used a household survey of smallholder farmers in sorghum and millet growing district (Siavonga area) to identify factors that influence adoption of improved technologies (improved seed, deep tillage, and manure/fertilizer) in the production of maize, millet and sorghum. Survey results from the study areas indicate that 40 % of respondents grew local varieties of maize and 60 % grew improved varieties. In contrast, 70 % of farmers grew local varieties of sorghum, and 30 % grew improved varieties. The improved varieties of sorghum that farmers used were Kuyuma and Sima and a few farmers reported planting the improved millet variety Lubasi.

The Tobit adoption model found differences among the key explanatory variables between adopters and non-adopters of improved technology. In addition to confirming that adopters are generally better off compared to non-adopters of improved technologies, the results indicate that some demographics (education, sex, marital status), farm size, wealth (as measured by the dwelling index, off-farm income), accessibility, and perception about the existence of production and marketing problems are important in explaining adoption in at least some of the crops. Besides the need to recognize the inherent heterogeneity among crops, broad-based investment in education, and marketing infrastructure and institutions could improve technology uptake. (Table 2)

### *Survey of Sorghum and Millet Farmers in Luanshya - A High Potential Area*

A survey of sorghum and millet farmers in a high potential area was conducted in two blocks of Luanshya district north of Lusaka. Luanshya is a high potential sorghum producing area that also has market access advantages because of its close proximity (60 kilometers) to the Zambian Breweries Ndola facility that brews Eagle lager. Luanshya was selected after the researchers visited the Mumbwa area (the original high potential area selected) in June only to discover that very little sorghum is now grown there. Maize is the major crop now grown in the Mumbwa area. The change to maize is due in part to large government subsidies (60%) on maize seed and fertilizer prices. In the Luanshya survey, 170 households were visited, of which 164 were complete interviews. Data entry and cleaning has been completed. Progress toward indicators such as income growth, yield increases, and production increases will be measured against this baseline information in the high potential area. Sorghum breeders at the Golden Valley Research Station plan to introduce an improved sorghum variety (WP-13) to farmers in the area with assistance from CARE in 2008-09.

### *Sorghum-Based Clear Beer Supply Chain Study*

The sorghum-based clear beer supply chain analysis is being conducted by Research Assistant, Bernadette Chimai and supervised by Dr. Gelson Tembo. A recent progress report has identified the value chain players, from farmers to retailers of the clear beer. Interviews were conducted with various representatives of firms that form part of the chain on their activities and experiences in the chain. The producer of Eagle lager, Zambian Breweries, was the first organization to be visited and was the primary source of information on the other chain players. Interviews were also conducted with CHC commodities, the sole supplier of sorghum to Zambian Breweries, and two of the official distributors of Eagle lager, R.S. Distributors and Nenima Trading. Various retailers within Lusaka were also visited.

In the work plan for 2008, the main activity outlined in the examination of the clear beer supply chain was the completion of interviews with retailers, wholesalers, brewers, warehouses, transporters, local buyers, farmers, and others. Information was required on supply chain players' operations, information flows, promotion flows, ownership flows, product flows, payment flows, constraints and the means for smallholders to sell in commercial markets. Estimates of future demand for the clear beer are planned to assess the growth potential of this market.

An interview conducted at CHC commodities, a grain trading company, with one of the employees yielded useful information on the flow of information on the quantities, quality and prices of sorghum required for production of clear beer as well as the ownership of the sorghum as it moves from the farmers' fields to Northern breweries. Further interviews are being conducted to collect actual prices of sorghum this year (including how they are determined) and how payments are made. Further interviews were also conducted with R.S Distributors on its operations and flow of clear beer from the brewers to the retailers. The main activity that remains to be done is the estimation of future demand for Eagle lager. We intend to estimate the future demand using sales/ production forecasts and trends in sales and production of the beer

**Table 2. Adoption of improved technology among smallholder growers of maize and sorghum, Siavonga Region, Zambia, 2006.**

| Technologies | Maize | Sorghum |
|---|---|---|
| Seed | | |
| - Local | 40% adopted | 70% |
| - Improved | 60% | 30% |
| Tillage | | |
| - Traditional | 46% | 60% |
| - Deep tillage | 45% | 40% |
| Synthetic Fertilizer | 0 | 0 |

since its introduction in 2005. Data will be obtained from Zambian Breweries in Lusaka. Currently efforts are being made to get interviews with the people authorized to provide the information.

### *Price Variability Study*

Data collection has been completed. We collected monthly historical data from the Central Statistical Office (CSO) and the USAID FEWS NET project. The data have been re-organized and variables and values labeled in readiness for statistical analysis. A final-year student in the Department of Agricultural Economics and Extension Education, University of Zambia, has been spearheading this study and is using it as her thesis project.

### *Select a Student from Zambia for M.S. Study at the OSU and for Ph.D. at Ruforum*

The project proposed M.S. degree study at OSU in agricultural economics for one student from Zambia. Bernadette Chimai, a recent UNZA graduate in agricultural economics, who was selected to begin her M.S. studies at OSU in autumn 2008 through the INTSORMIL project with a cost share from OSU. However, she had to postpone her plans because she is expecting a child. She, or possibly another candidate, is expected to begin studies at OSU in autumn of 2009.

Rebecca Lubinda, a faculty member in the Department of Agricultural Economics and Extension Education at UNZA, has decided to begin Ph.D. studies in agricultural economics this spring or next fall through the RUFORUM program located at Bunda College in Malawi. Her studies will be supported on a cost share basis between the INTSORMIL/Zambia project and the Regional Universities Forum for Capacity Building in Agriculture (RUFORUM).

## Networking Activities

The project maintains important linkages to the INTSORMIL program in Tanzania, Zambia, the U.S. and with the USAID Missions in each country. Contacts have been made with several INTSORMIL researchers to discuss collaboration. They include John Sanders (economist) at Purdue University, Gary Peterson, (plant breeding and Regional Program Coordinator for Southern Africa ) at Texas A& M University, Charles Wortmann (soil scientist) and David Jackson (food scientist) at University of Nebraska, Gbisa Ejeta (plant breeding and Regional Program Coordinator for the Horn of Africa) at Purdue University, Medson Chisi (sorghum breeder) at the Golden Valley Research Station in Zambia, A.M. Mbwaga (sorghum breeder) at Ilonga Agricultural Research Institute, Kilosa, Tanzania; the Entrepreneurship and Product Development Group at the University of Nebraska and at SUA and at UNZA. An important linkage for training is the Regional Universities Forum for Capacity Building in Agriculture (RUFORUM).

We presented a paper on preliminary research results and also networked in the INTSORMIL organized Horn of Africa (HOA) regional workshop held in Nairobi, Kenya in September, 2008. The workshop afforded an excellent opportunity to learn about the work of all the HOA researchers and the opportunities to further collaboration and to seek added funding.

## Publications and Presentations

J. Mark Erbaugh, Donald W. Larson, Emmanuel R. Mbiha, Fredy T.M. Kilima, Gelson Tembo, and Priscilla Hamukwala. 2007. “An Evaluation of New Market Development and Marketing Strategies on Sorghum and Millet Farmers’ Income in Tanzania and Zambia.” INTSORMIL Annual Report. USAID/INTSORMIL Grant. University of Nebraska. Lincoln, Nebraska. Pp. 79-84.

J. Mark Erbaugh, Emmanuel R. Mbiha, Fredy T.M. Kilima, Jeremia Makindara, and Donald W. Larson. 2008. “Market Development in Support of Sorghum and Millet Farmers in Tanzania and Zambia.” Presented at International Sorghum and Millet & Other Grains Meeting for PIs in the Horn of Africa Region, Holiday Inn Nairobi, September 22-24, 2008.

Gelson Tembo, Priscilla Hamukwala, Donald W. Larson, J. Mark Erbaugh, and Thomson H. Kalinda 2008. “Adoption of Improved Technologies by Smallholder Cereal Producers in Siavonga District of Zambia.” Revised paper prepared for USAID/INTSORMIL, University of Nebraska and The Ohio State University project. Columbus, Ohio.

Fredy T. M. Kilima, Emanuel R. Mbiha, J. Mark Erbaugh and Donald W. Larson. 2008. “Adoption of Improved Agricultural Technologies by Smallholder Maize and Sorghum Farmers in Central Tanzania.” Revised paper prepared for USAID/INTSORMIL, University of Nebraska and The Ohio State University project. Columbus, Ohio.

# Product and Market Development for Sorghum and Pearl Millet in West Africa

## Project PRF 102
## Bruce R. Hamaker
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### Introduction and Justification

The overall objective of this project is to facilitate the development of markets for high quality processed sorghum and millet products mainly in urban areas of the West Africa Sahelian region (Senegal, Mali, Burkina Faso, Niger and northern Nigeria) through extension of processing technologies to NARS food technology laboratories and entrepreneurs for product commercialization. Related to this, activities also focus on improvement of grain and flour properties (nutritionally-enhanced sorghum and method to make seed proteins functional in leavened bread systems) for improved utilization and competitiveness. This addresses a need in Africa to find other avenues for farmers to sell their grain and to receive premiums associated with industrial uses.

In the past year, we have been involved in three activities: 1) incorporation of the high digestibility/high-lysine mutant sorghum in composition bread, 2) continued work on the pregelatinized 'instant' flour project, and 3) launching of the processing part of the larger USAID Mali mission-funded project "Transfer of Sorghum, Millet Production, Processing and Marketing Technologies in Mali" aimed to increase farmer's incomes through expanded markets. During this period, three Senegalese scientists visited Purdue food science laboratories for training and planning purposes. Additionally, the PI traveled three times to West Africa to meet with M. Diouf (consultant) and Y. Kouressi (IER scientist), to identify entrepreneur partners and later launch the Mali processing project (February and August), deliver presentations on newer technologies for sorghum and millet processing at ITA in Dakar (February), the Galweye Hotel in Niamey (February), to participate in a workshop in Bamako organized by J. Sanders and O. Botorou (August) on opportunities to expand sorghum/millet processing in the region, and help conduct an INTSORMIL regional all-PI meeting in Bamako (April).

Previous work partly supported by this project showed that maize zein storage proteins can be made viscoelastic similar to wheat gluten proteins to produce a leavened bread product. We have extended this work to test the hypothesis that the analogous sorghum protein, kafirin, can be made likewise functional to an extent that higher amounts of sorghum flour can be incorporated into composite flour leavened baked products. Such proteins in both sorghum and maize normally exist in the form of rigid protein bodies (~1 µm in diameter) that do not break apart in normal mixing to release the protein for viscoelastic fiber formation. Instead, we have used the high protein digestibility/high-lysine sorghum mutant (non-transgenic) developed at Purdue as it has protein bodies of irregular shape with potential for a melding and interaction of the kafirin protein. Studies this year show, at an incorporation level of 50% mutant sorghum/40% wheat flours, an improvement in dough properties and loaf volume over normal sorghum at the same mixture level. These are not optimum breads at this point, however these studies do show conceptual proof that sorghum kafirins can be made to functionally participate in bread making.

Work shows the potential of a pregelatinized 'instant' sorghum flour product in West Africa. This output from the Master's thesis project of M. Moussa at Purdue showed that instant flours produced using a high shear, low pressure continuous mixer make thin and thick porridges were preferred compared to those traditionally made using the same starting grain. The INTSORMIL Niger food technology project is actively seeking funding to set up a pilot-scale processing facility at INRAN with the design to work with local entrepreneurs and to test the product in the marketplace.

In Mali, a project was launched in the Mopti/Gao region in the north that included selection of six entrepreneur partners who will be working with our team (M. Diouf, consultant, Y. Kouressi, IER cereal scientist, B. Hamaker) to introduce new processing technologies to process more competitive sorghum and millet products for market expansion of these grains. This effort ties into the larger on-going work of J. Sanders and O. Botorou aimed to increase farmer's incomes through market expansion.

## Objectives and Implementation Sites

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. Implementation sites are ITA, Dakar, Senegal; IER, Bamako and Mopti, Mali; IRSAT, Ouagadougou, Burkina Faso; INRAN, Niamey, Niger; and University of Maiduguri, Maidurguri, Nigeria.

## Specific Objectives

- Through the buy-in project from the Mali USAID mission, work to create successful incubation center at IER to assist entrepreneurs in establishing six millet and/or sorghum processing enterprises in the Mopti and Gao regions of northern Mali,
- Facilitate the optimization of products and processes through a partnership approach between West African NARS food technologists and entrepreneurs,
- In collaboration with Institut de Technologie Alimentaire in Dakar and with G. Ejeta, continue work towards the goal of enhancing wheat-like properties of sorghum grains for high incorporation of sorghum (high digestibility/high lysine mutant lines) into baked products (mainly bread),
- Further develop, refine, and transfer technologies to appropriate West African NARS food technology laboratories to make high quality sorghum and millet processed foods (e.g., pregelatinized "instant" sorghum, agglomerated products, and millet flours for thin and thick porridges),
- Continue previous collaborative work on nutritionally-enhanced sorghum lines developed at Purdue to further improve grain quality and to test in sites in East and West Africa,
- Train two West African young scientists, one to the Ph.D. level (Malian, Mohamed Diarra at University of Maiduguri under advisement of Prof. Iro Nkama and B. Hamaker) and the other to the M.S. level (Senegalese, Aminata Diatta at Purdue).

## Research Methodology and Strategy

Senegal: Continue current collaborative work with A. N'Doye, interim Director General for ITA, on product optimization and testing work on the wheat-like properties of sorghum proteins and high incorporation of the high digestibility/high lysine sorghum mutant into composite flour baked products. We will extend our current baking optimization trials and work towards field trials in the private sector. Project beginning date – October 2007, ending date – September 2011.

Niger: (1) Our overall aim has been to achieve commercial processing of high quality sorghum- and millet-based products (agglomerated - two sizes of couscous products and degue) and flours. Moustapha Moussa obtained his M.S. from Purdue in May 2007 and has returned to Niger to become a scientist at INRAN. Our work now focuses on further development of pregelatinized flours and agglomerated products for urban markets and assisting in gaining funds for an entrepreneurial unit. This processed product marketing objective is linked to the hybrid development program of I. Kapran. Project beginning date – October 2007, ending date – September 2010.

Mali: Through Mali USAID mission support of the project "Transfer of Sorghum, Millet Production, Processing and Marketing Technologies in Mali", a entrepreneurial-based processing project was scheduled to be launched in 2008 in Mopti (consultant Mamadou Diouf of ITA/Dakar, Y. Koureissi of IER/Mali, and B. Hamaker). Future activities will involve assisting entrepreneur(s) with technology expertise (training workshops), basic equipment procurement, and linkage with the grain contracting project of J. Sanders and O. Botouru. Project beginning date – October 2007, ending date – September 2010.

Nigeria: Develop a project on millet processing with funding additionally through PRF-102 for graduate student training at University of Maiduguri. Project beginning date – October 2007, ending date – September 2011.

Burkina Faso: Collaboration with B. Bougouma on millet processing and millet varietal differences suitable for specific processes; expand focus from screening of varieties to commercial products. Work through the regional West Africa program. Project beginning date – October 2007, ending date – September 2011.

U.S.: 1) Continue research project on making sorghum (and perhaps millet) grain storage proteins behave as wheat gluten to make leavened products. This follows recent work of ours showing the same for maize storage proteins (zeins). Project beginning date October 2007 –, ending date – May 2010. 2) Obtain a new graduate student from the West Africa region to work on the bread making project. Project beginning date – January 2009, ending date – December 2010. 3) Continue to work with G. Ejeta toward further improving grain quality of high protein digestibility (and possibly wheat-like property) sorghum. Project beginning date – October 2007, ending date – September 2011.

## Research Results

### *Sorghum/Wheat Composite Bread*

The hypothesis pursued in this project rests in previous work in our laboratory, partly funded through INTSORMIL, showing that maize zein proteins can be made functional to behave similar to wheat gluten, thereby forming a viscoelastic dough that can make a leavened bread product. Sorghum grain, as well as millet, has analogous proteins called kafirins (for sorghum). In studies this year, both at Purdue and ITA/Dakar, we investigated whether it is possible to mobilize the sorghum kafirins so that they participate in viscoelastic properties of dough. Our objective of this ongoing research is to examine the potential of using our high digestibility/high-lysine mutant sorghum (non-transgenic), which has kafirin proteins existing outside the confines of typical protein bodies, at high incorporation rates with wheat flour to make acceptable bread products. Our goal is to substantially increase the amount of sorghum flour that can be incorporated into composite breads and associated products both to increase market opportunities for local sorghum farmers and to reduce need for imported and often high priced wheat.

In this first year of the project, proof of concept was shown that kafirin proteins can be made functional in a dough and bread making system. At 50% incorporation level of the sorghum mutant flour with wheat flour, the dough was noticeably more viscoelastic than the control with 50% normal sorghum flour (Figure 1a). Likewise, the bread had somewhat higher loaf volume and the crumb texture was more viscoelastic (Figure 1b). While these are not optimum breads, the finding that kafirin proteins, when released from the confines of protein bodies, can participate in dough formation and bread leavening, gives promise to the idea of a sorghum type that could have high incorporation in composite flour baked products.

### *Pregelatinized 'Instant" Flour for Thin and Thick Porridges*

Pregelatinized 'instant' sorghum flour was the M.S. thesis research topic at Purdue of M. Moussa who returned to INRAN, Niamey, Niger in 2007. The novel aspect of this project was the "continuous mixer" used to produce the product. This is a low moisture, high shear, and low pressure system that processes a gelatinized flour that does not require further drying, and is then ground to an flour. This was used in sensory tests in four locations in Niger as was previously reported. In all cases, the 'instant' flour made thin and thick porridges that sensory panelists rated significantly higher than traditionally made porridges made from flour of the same grain.

The process was further optimized to produce fully gelatinized flours with high viscosity. Our objective is to find funding for installation of an entrepreneurial level unit in Niamey for demonstration, training, market testing, and further process optimization purposes. In this year, a proposal was submitted to a funding group in Niamey and presentations were made to a number of NGO's regarding the process and market potential of these products. All processing projects at INRAN are done in integration with the breeding group and Marketing-Processing project to meet the overall objective of promoting new high quality hybrids and expanding markets for farmers.

### *Mali Marketing-Processing Project*

As noted above, USAID Mali mission has provided funds for the project "Transfer of Sorghum, Millet Production, Processing and Marketing Technologies in Mali". The goal of the project is to increase farmer's incomes through activities concentrated on expanding markets for sorghum and millet. In our processing part, our team is comprised of M. Diouf, consultant to the project and former ITA staff and director of the PROCELOS/CILS project in

**Figures 1a: (left) shows baking scientist Ibrahim M'Bhaye of ITA, Dakar making bread dough with 50% high digestibility/high-lysine mutant (non-transgenic) sorghum flour with improved viscoelastic properties compared to 50% normal sorghum flour.**

**Figure 1b: (right) shows 50% sorghum mutant bread on the left and 50% normal sorghum bread on the right; both loaf volume and crumb structure were improved with the mutant flour.**

West Africa for 9 years, Y. Kouressi, IER cereal scientist and doctoral candidate at Wageningen University, the Netherlands, and B. Hamaker. Djibril Drame, on leave from IER and heading a food processing project in the Mopti region, and Mamarou Diourte, an INTSORMIL regional coordinator from IER, also are assisting. In the first year, the team made two trips to the project site in the Mopti/Gao region in the north. In February 2008, meetings were made with potential partner entrepreneurs in the region as well as FENATRA, the Mali food processor association headquartered in Bamako. Six processor groups were identified, four in the Mopti area and two in Gao.

In August, the team traveled to Mopti to formally launch the project and to start initial training on processing high quality, competitive products for the marketplace. The first training workshop will be in early 2009 on basic mechanization of processing units, high product quality, and management of enterprises.

## Training

Three non-degree scientists trained at Purdue University during the year, all from ITA, Dakar, Senegal. Djibril Traore, a doctoral student in nutrition sciences at Oklahoma State University, spent 2 weeks in June 2008 working on fonio beta-glucan carbohydrate structure and function. Djibril worked with us before on glycemic index studies of sorghum, millet, and fonio. Aminata Diatta trained for 6 weeks beginning in September 2008 on sorghum/wheat composite breads, and to improve her English skills. It is expected that Aminata will begin her M.S. studies at Purdue in 2009. Ababacar N'Doye, acting Director General of ITA, visited Purdue for 2 weeks in September 2008 for purposes of strategic planning, proposal writing, and work on the sorghum/wheat composite bread project.

PRF-102 additionally is funding Mohamed Diarra from IER, Mali to attend the University of Maiduguri, Nigeria for his Ph.D. studies. Mohamed's start date was delayed to January 2009. He will be under advisement of Dr. Iro Nkama, INTSORMIL regional PI and B. Hamaker.

## Networking Activities

In April 2008, co-U.S. coordinator and B. Hamaker organized a West Africa Regional Program all-PI meeting held in Bamako. In addition to regional PI's, six INTSORMIL US-PI's, J. Yohe and J. Frederick from the ME, B. Duguma from USAID/Washington, O. Botorou from Marketing-Processing project, and representatives from USAID Mali, ICRISAT, CORAF, and Sasakawa Global 2000 attended. Activities included development of our regional strategic plan, networking, and finalizing workplans.

In August, B. Hamaker attended and presented at the Marketing-Processing project workshop held in Bamako. Afterwards, M. Diouf, Y. Kouressi, and B. Hamaker formally launched the processing sub-project in Mopti with partner entrepreneurs. A cereal processing training workshop is planned for early 2009.

## Publications and Presentations

### *Journal Articles*

Tesso, T., Hamaker, B.R., and Ejeta, G. 2008. Sorghum protein digestibility is affected by dosage of mutant alleles in endosperm cells. Plant Breeding 127:579-586.

Kean, E.G., Hamaker, B.R., Ferruzzi, M.G. 2008. Carotenoid bioaccessibility from whole grain and degermed maize meal products. Journal of Agricultural and Food Chemistry 56:9918-9926.

### *Presentations*

Hamaker, B.R., Mejia, C.D., Goodall, M.A., Petros, D.D. The potential of non-wheat cereal prolamins to function in bread making, American Association of Cereal Chemists annual meeting, September 2008, Cereal Foods World 53:A29.

# Development of the Input and Product Markets in West Africa for Sorghum and Millet

## Project PRF 103
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### Introduction and Justification

For any agricultural research program to be successful there needs to be results on farms. The farm level effect has been a weak point of both national and international agricultural research programs in sorghum and millet in Sub Saharan Africa. Contributing to this failure have been the popular promotion of low input agriculture and the perception that sorghum and millet are subsistence crops. Increasingly it is being realized that low inputs mean low outputs especially in the African context of low fertility soils and failure to use adequate inorganic fertilizers. In Sub-Saharan African whether the cereal is consumed or sold it still needs the basic crop nutrients of N, P, and K. New cultivars are also needed to take advantage of the increased soil fertility levels[1]. Water harvesting technologies reduce the riskiness of these higher fertilizer levels. Other agronomic improvements can also be required regionally. These innovations, when combined with the improved prices from the marketing strategies, not only increase yields but more significantly increase farmers' incomes.

To pay for inorganic fertilizers especially with their rapidly rising prices with the increases of world oil prices, farmers can unify to get bargaining power from farmers' associations and to introduce a series of marketing strategies. The farmers' associations enable the farmers to sell and buy in quantity with potential benefits on both the prices paid and the costs for inputs. The marketing strategies include producing a higher quality product and obtaining a price premium for the quality improvement. Moreover, the marketing strategies enable farmer responses to the annual and the between year, good weather price collapses. As the farmers' associations mature we will move to inventory credit programs either financed by bank loans or by the farmers' association. This is our primary strategy to obtain benefits for farmers from the seasonal price fluctuations. Farmers have pressing financial requirements at harvest time so prices traditionally collapse then. Inventory credit provides cash at harvest while still allowing the farmer to sell his grain later in the season[2]. The good season price collapse requires the development of new markets to reduce its effects. Our program collaborates with food and livestock nutrition scientists to help develop the food and feed markets for these crops. Another more difficult policy objective is convincing public policy makers not to depress the higher cereal prices of the bad rainfall years.

The combination of the introduction of both new agricultural technologies and a series of new marketing strategies to increase farm prices is a central innovation of this project. In the summer of 2008 there will be approximately 1,143 ha and approximately that many farmers involved in this combined technology-marketing strategy introduction in the three Sahelian countries of Niger, Mali, and Senegal.

### Objectives and Implementation Sites

The principal focus of our program continues to be getting new sorghum and millet technologies onto farmers' fields in the three Sahelian countries of Niger, Senegal and Mali. The new technologies include improved cultivars defined in collaboration with the national agricultural research institutes, inorganic fertilizers, seed treatments, water harvesting techniques, and the introduction of tarps to keep the grain off the ground during threshing. These technologies are combined with a series of marketing strategies to get higher prices for farmers enabling them with the higher yields and prices to pay for the increased input levels. Finally, the third objective of our program is to facilitate the growth of strong farm-

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1. Besides being higher yielding with shorter, squatter cultivars, new cultivars often have specific resistances to diseases and insects. But the ability to respond to the higher fertility levels is critical for this technology combination. Traditional cultivars tend to be selected over time for low yield variability under adverse conditions and do not respond well to higher soil fertility and water availability conditions. Their response to these higher input levels is stalk growth and lodging rather than increased grain production.

2. There are two ways to implement this program. First the farmer can retain ownership and repay the farmers' association for storage, interest, and principal for providing credit at harvest. Or the farmers' association can buy the crop at harvest, sell it for the farmers and then divide profits proportionately to the grain sold after deducting storage and interest costs.

**Table 1. Area in New Technology in the Production-Marketing Project of INTSORMIL in 2008**

| | | 2008 | Specific Site |
|---|---|---|---|
| **Senegal** | | | |
| | Millet | 250[1] | Thiare |
| | Sorghum | 35 | Nganda |
| Total | | 285 | |
| **Niger** | | | |
| | Sorghum | 140 | Gabi |
| | Sorghum | 100 | Maraka |
| | Sorghum | 30 | Safo |
| | Sorghum | 30 | Angoua Mata |
| | Sorghum | 20 | Dan Arao |
| | Millet | 60 | Doutchi |
| Total | | 380 | |
| **Mali[2]** | | | |
| | Sorghum | 100 | Kafara |
| | Sorghum | 78 | Diola |
| | Sorghum | 100 | Koutiala |
| | Sorghum | 50 | Kolokani |
| | Millet | 150 | Tingoni |
| **Total Area** | | 478 | |
| **Overall Total Area** | | 1143 | |

**Source: Put together by Botorou Ouendeba from the reports of the national research and extension agencies collaborating with the Production-Marketing Project of INTSORMIL.**

ers' organizations. These organizations, which already handle input credit and grain storage, will engage in inventory credit in the future.

In 2008 field activities were increased by 150 ha in Mali with the financial support of the Mali USAID program. We moderately increased activities in Niger and Senegal with support from this INTSORMIL program (PRF 103). This included an additional 40 ha in Niger and 60 ha in Senegal (25 ha financed by the farmers' association of Thiare). Our overall total is 1143 ha in new technologies in the three countries (Table 1). We plan to double the Mali area from 500 to 1,000 ha in the summer of 2009.

## Research Methodology and Strategy

There are two principal objectives of the research activities of 2008 to support the extension program. First, we research the marketing activities. We documented the increased value of clean cereals and indicated to food processors the price premium they could afford to pay based upon the higher value of the clean uniform grain. Secondly, we make annual estimates of the income gains to farmers from our program. This starts with the yields and then income estimates are made separating the effects of the technology introduction and the new marketing strategies.There is a lag with this analysis since we need to wait until the grain is sold and the farmers associations wait for the price recovery until April[3]. So the reporting here is for the production season of 2006.

3. If they could wait longer, the product price tends to go even higher. However, they need the cash from this rotating fund to buy inputs for the members for the coming crop season.So they have to sell before the end of April to buy the inputs in May.

The introduction of plastic or tarp ground cover is a fundamental aspect of the Production-Marketing Project to avoid impurities in the grain (Picture 1). The estimated average impurities in millet purchases according to the processors interviewed was 13% (see Bulletin 7 of INTSORMIL). At a millet price of 100 CFA/kg and a cost of cleaning the grain of 10 CFA/kg that gives a price premium of 23 CFA/kg. One of the principal objectives of the summer workshop in Bamko (see networking) was to present these survey results and calculations for the price premium to the millet food processors as we continue to lobby for higher prices for farmers. These higher prices help raise incomes and enable farmers to continue investing in higher input levels.

The Production-Marketing Project has been most successful in the lowest income, most difficult agricultural region of the three countries, i.e., eastern Niger. The introduction of improved sorghum technologies requires the simultaneous introduction of a series of labor intensive agronomic practices including replanting, thinning, weeding and the construction of water harvest techniques. In the high population pressure, low income region of Maradi farmers are doing regularly these practices and substantially increasing yields. They have fewer alternatives in or out of agriculture than farmers in the other countries so they invest more labor in raising their returns from this technology introduction. Compared with traditional farm yields of 500 to 600 kg/ha of sorghum in the region average yields of the new technologies are almost tripling the traditional sorghum yields in Gabi and Maraka (Table 2). The new cultivar is a short stature Caudatum cultivar called Sepon 82. This cultivar has been in the region since the early '90s but never before systematically combined with moderate fertilization and improved agronomy (Picture 2). Project farmers have been selling the Sepon 82 seed to both Niger and Nigerian farmers. The introduction of the Sepon 82 alone has become very popular in the greater region.

**Picture 1. Farmers threshing sorghum on a tarp in Tingoni, Mali.**

**Source: T. Abdoulaye et al., 2008, p. 11. Photo Credit. Sandinan Camera, SG, 2000.**

The critical thing in the introduction of any new technology is whether it is profitable to farmers. The income effect from comparing these cultivars to traditional ones are summarized in Table 3. The technology effect compares traditional and improved yields. The price effect uses the prices received by the farmers' association from selling later in the season, in larger quantities, and a cleaner grain compared with the harvest price received by farmers in the region. The results for sorghum in 2006 show staggering gains from both the technology introduction and the marketing strategy.

As farmers acquire more experience with the agronomy and marketing aspects, they are expected to plant on their best land and to follow the agronomic practices. This will enable them to approximate the best farmer yields of 2.3 to 2.5 tons/ha. Our main program emphasis now is to obtain these same types of cultivars and yields in Mali and Senegal (see sections VIII and IX of this report for further information on the success of new cultivar introduction in Mali in 2008 and expected in Senegal in 2009).

## Training

Felix Baquedano is presently writing his Ph.D. thesis on the income alternatives in one cotton region, Dioila, of Mali. New sorghum activities are being tested there. So he is looking in detail at our sorghum technology extension program and comparing it with various new activities in cotton. He is also evaluating different marketing strategies.

On the 1,143 ha of new technology activity of the Production-Marketing Project in 2008 there were approximately that many farmers[4]. This introduction of new practices is combined with improved agronomy and marketing strategy. Farmers need to be trained in these practices. We can only train a small number of these farmers but field days are encouraged and the farmers talk to each other.

Finally our workshop described below involved three days of presentations, discussions and two field visits for 38 participants.

## Network Activities

On August 12-14 we held in Bamako, Mali a workshop entitled "Building Value Chains for Millet and Sorghum Processing." The workshop was designed to improve ties between food processors of millet/sorghum with farmers' association representatives and between food scientists and both of these groups. The workshop included visiting farmers' fields of the farmers' association of Tingoni and one of the millet food processors in Bamako (Mme Demb). The concentration was on Mali (23) but there was also representation from Niger (3), Senegal (5), Benin (1), and INTSORMIL (U.S.-6).

Specific objectives were to demonstrate to food processors the calculation of a price premium based on increases in value as well as to reinforce to the farmers' associations the continuing importance of improving the quality of their cereals for the processed food markets. Another objective was to convince millet food processors of the potential for the partial substitution of sorghum for millet as in done in other countries. South Africa and Japan make excellent processed food products from sorghum.

## Publications and Presentations

Mme Toure Aminata, T. Abdoulaye, J. Sanders, and B. Ouendeba. Transformation Commercial du Mil et du Sorgho au Mali, Proj-

4. We attempt to limit participation to one farmer per ha. In practice those influential in the village and farmers' association often end up with more than one ha. Then we put pressure on the farmers' association to reduce farmer holding to one ha per farmer. In the heavy population pressure Nigerien sorghum holdings farmers often have less than one ha with as many as four farmers per ha.

ect Production-Marketing, INTSORMIL Bulletin No 7, INTSORMIL, University of Nebraska, Lincoln, Ne., November 2007, 38 pages.

Tahirou Abdoulaye, John Sanders, and Botorou Ouendeba, Evaluation of Sorghum and Millet Technology and Marketing Strategy Introduction: 2006-07 Crop Year, Project Production-Marketing, INTSORMIL Bulletin No 8, INTSORMIL, University of Nebraska, Lincoln, Ne., November 2007, 23 pages

**Table 2. Sorghum yields (kg/ha$^{-1}$) in Niger from farmers' estimates and crop cuts, 2006**

| Village | Crop | All Farmers | | |
|---|---|---|---|---|
| | | Interviews | Crop cuts | Best Farmers' Interview |
| **Gabi, Maradi** | Sorghum | 1440 | 2140 | 2542 |
| **Maraka, Maradi** | Sorghum | 1397 | 1670 | 2337 |

**Source: T. Abdoulaye et al., 2008, p. 8 Note: Best farmers average yield of 6 farmers with sorghum yields higher that 2 tons per ha**

**Picture 2. Farmers' visit on a field day in Maraka, Niger with an improved cultivar and inorganic fertilizer.**

**Source: T. Abdoulaye et al., cover. Photo Credit: Botorou Ouendeba.**

**Table 3. Estimated income gains from sorghum technology and price effects based on average and best farmers' yields, Niger 2006.**

| | Gabi (Sorghum) | | Maraka (Sorghum) | |
|---|---|---|---|---|
| | **Average** | **Best Farmers** | **Average** | **Best Farmers** |
| **Technology effect, %** | 92 | 292 | 28 | 193 |
| **Price effect, %** | 87 | 153 | 108 | 212 |
| **Total gain, %** | 179 | 445 | 136 | 405 |

**Source: T. Abdoulaye et al., 2008, p. 15.**

# Product and Market Development for Sorghum and Pearl Millet in Southern Africa and Central America

## Project TAM 103
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### Introduction and Justification

This project's major activities relate to objectives 1 and 2 on supply chain management and development of super healthy foods from sorghum. It provides for education of students on new, more effective ways of processing sorghum / millet into profitable food products. Extensive breeding and analysis of sorghums for flavanoids is ongoing.

Major activities include work in Central America to utilize sorghum as a substitute for costly wheat flour in a wide array of foods. CENTA in El Salvador has been quite effective.

The project has worked effectively with Professor Taylor in South Africa (University of Pretoria) to educate students from Botswana, Zambia, Namibia and South Africa on sorghum and millet processing. This effectively maximizes use of our limited funds to assist in education of African students because of the reduced costs. We are developing a "sandwich" Ph.D. degree for M.Sc. Chiremba of the Agriculture Research Council (ARC) in South Africa.

We participated in workshops in Central America and West Africa to educate and provide information to scientists, PVO's and NGO's interested in supply chain development. We worked with other INTSORMIL CRSP projects in economics, grain marketing and food science to promote healthy foods from sorghum using supply chain management.

### Objectives and Implementation Sites

We have focused our efforts on improving the utilization of sorghum in Central America and Southern Africa. More specifically, key targets are El Salvador and South Africa. We are working with Ms. Calderon, who completed her M.S. thesis at Texas A&M and returned in September 2007 to El Salvador; she is leading efforts to utilize sorghum in food systems. We are using her expertise to assist Ms. Palacio in Nicaragua (INTA).

We are working with Professor Taylor, University of Pretoria and his associates to provide education and key research activities that apply to utilization of sorghum and millet in Southern Africa. University of Pretoria has a strong program in food science and technology with significant numbers of students from African countries.

In addition, the PI has provided support for value added supply chain activities in West Africa led by Dr. Sanders at Purdue. These projects are making a significant impact on production and use of millets and sorghum by small processors and entrepreneurs. The objectives are:

1. Facilitate the growth of rapidly expanding markets for sorghum and millet products by providing information (skills or know-how) on nutritional properties, processing quality, food manufacturing processes with improved efficiency, and prototype products using sorghum/millet as an ingredient.
2. Improve the food and nutritional quality of sorghum and pearl millet to enhance their marketability and image as

grains that promote healthy wholesome convenience foods.

3. Contribute to host-country institutional human capital development through short-term and long-term educational opportunities. Non-degree (short-term) training will include research methodology and conferences or hands-on training workshops; degree (long-term) training includes M.S. and Ph.D. programs.
4. Provide practical technical assistance and information on supply chain management and processing technologies, plant management and related matters.

Central America, especially El Salvador, made significant progress in using sorghum flour to replace expensive wheat flour and corn in baked products and ethnic foods. The other major research site was Southern Africa where collaboration with Professor Taylor, University of Pretoria, and other research groups has been excellent.

## Research Methodology, Strategy and Role of Host Country Scientists

The host country scientists in the project are well-educated, experienced and are truly working as colleagues to provide leadership for the activities. Information and technology generated flow both directions and is synergistic in nature. The teams have a significant number of experienced scientists who provide leadership and advice to younger scientists involved. For example, Dr. Kebakile completed his Ph.D. at University of Pretoria and returned to Botswana to conduct processing research on sorghum and millet. He is a good scientist and provides excellent leadership in the Botswana Food Processing Center.

The Agricultural Research Council (ARC) in South Africa has significant efforts in grain quality evaluations of new cultivars. Interaction with that program accentuates efforts to improve quality and productivity of sorghums. We are planning a training program for M.s. Chiremba at Texas A&M as part of her Ph.D. program at University of Pretoria with Professor Taylor and L. Rooney, TAMU.

## Results/Significance

**Sorghum for Healthy Foods:** Specialty sorghum varieties have potential health benefits with high antioxidant levels and reduced starch digestion. Different levels of phenolic compounds significantly ($p<0.005$) affect the rate of starch digestion and estimated glycemic index (EGI) of sorghum products. White, high-tannin, black, and black with tannin sorghum varieties were used to investigate starch digestibility and EGI of whole sorghum porridges.

Porridges made with sorghum varieties containing high levels of condensed tannins and anthocyanins had significantly ($p<0.001$) lower starch digestion rates (k=0.06-0.09) and EGI values (78-86) than porridges made with whole white sorghum (k=0.11, EGI= 91) and whole white corn (k=0.12, EGI= 95).

Research has confirmed that special sorghums containing condensed tannins and high levels of flavanones, flavones and 3-deoxyanthocyanins exist. They are quite high in anti- inflammatory compounds that are difficult to find in natural sources. In addition, whole grain high tannin sorghums and their brans significantly reduce the estimated glycemic index (EGI) of foods. Cooking tannin bran extracts with corn starches significantly reduced the EGI in model system porridges. Cooking starches with tannin sorghum extracts significantly decreased EGI and enhanced resistant starch because the tannins reacted with protein and other components in porridges.

The black sorghums contain high levels of unique 3-deoxyanthocyanins that have stability to pH, temperatures, and water activities. Their stability is equal to commercial Red Dye #40 and Red Dye #3. Natural colorants from sorghum with more stability than fruit and vegetable colorants are promising.

Our research on these special sorghums has stimulated several research groups to initiate research on sorghum as a health food. The use of sorghum in developing healthy foods and as a source of beneficial compounds improves the image of sorghum and should lead to significantly greater use in nutraceutical foods worldwide. The desirable components are concentrated mainly in the pericarp which can be easily removed to concentrate the materials. The new sorghum hybrids containing these compounds have reasonable yields.

**Sorghum Has Promise to Lower Cholesterol in Animals:** The phenolic composition of brans obtained from Sumac (high tannin) and Shawaya (black) sorghums were used to determine their hypocholesterolemic effects when brans were fed to hamsters. Both sorghum brans and 80% methanol extracts of bran decreased plasma and liver cholesterol and improved the LDL/HDL ratio in hamsters. Thus, the data suggests that high tannin and black sorghum brans may be used as natural therapy to lower total and LDL-cholesterol and prevent cardiovascular diseases.

Potential anti-cancer compounds extracted from tannin sorghum were obtained using fast centrifugal partition chromatography (FCPC). This separation technology allowed recovery of enough natural products for testing in colon (Caco-2), hepatic (HepgG2) and hormone-dependent mammary (MCF-7) cancer cells. Some tannin sorghum compounds besides flavonoids have potential for inhibiting colon and hepatic cancer. A compound with molecular formula $C_{17}H_{30}O_3$ or $C_{18}H_{34}O_2$ is a candidate for anticancer activity observed in the fractions obtained by FCPC from the methanolic extract of tannin sorghum.

**Phenolic Profile, Antioxidant Activity and Anticancer Properties of Different Types of Sorghums and Brans:** The phytochemical profile of 25 different types of sorghums/brans was evaluated for potential as anticancer agents using in vitro colon (Caco2), hepatic (HepG2) and hormone-dependent mammary cancer (MCF-7) cell lines. Genotypes included white, red, yellow and black, (type II), and high-tannin or brown (type III) sorghums. The hydrophilic and lipophilic antioxidant activities (ORAC) were evaluated and correlated to total phenolics, flavonoids, anthocyanins and tannins and to the inhibition of the three different cancer cell lines.

- Among the different sorghum samples analyzed, several showed high antioxidant activity and significant inhibition of

MCF-7 cells.

- A significant negative correlation between tannin content and hormone-dependent mammary cancer cell inhibition was observed. Sorghum genotypes containing condensed tannins had the best potential as natural anticancer agents.
- Almost all samples had antiproliferative activity at least in one of the cancer cell lines evaluated. Hormone dependent mammary cancer cell viability was the most affected by sorghum methanol extracts.

**Highly Digestible Sorghums:** Progress was made in developing improved mold resistance in sorghums that have genes for improved protein digestibility. The original highly digestible types developed by Purdue University are quite susceptible to molds. The new lines developed at TAMU appear to have increased resistance to molding and were tested for use in malting and brewing and ethanol production. Dr. Hays has demonstrated that they produce significantly higher levels of alcohol (up to 15%). Preliminary information from Prof. John Taylor at University of Pretoria indicates that they produce slightly higher levels of free amino nitrogen (FAN) during malting. Increased levels of FAN would be highly useful for malting. These types with extra lysine may be adapted for production in areas of the world where the grain matures during very hot, dry conditions. Ideally they could be used in Sudan, Ethiopia and similar places. In humid areas during grain maturation, there must be improvement in resistance to molds.

**Outreach Activities:** Several fact sheets and posters contributed from this project are on the INTSORMIL website. They summarize information for use in understanding factors affecting composition and sorghum quality; they provide information on tannins.

- Myths about Tannins (in English, French and Spanish)
- Sorghum Composition, Structure and Quality
- Antioxidant Activity in Sorghum Bran Diets and Their Effect on Colon Cancer
- Decortication Level and Particle Size Effect on Direct-Expanded White Sorghum Extrudates
- Antioxidant Properties of Sorghum Assessed by Three Methods
- Bongos® the Cool Snack™
- Corn Tortillas Enriched with Brown Sorghum Bran
- Effects of Bran Fortification on Physical Characteristics and Antioxidant Activity in High Tannin Sorghum Extrudates
- Effect on Whole Sorghum Extrusion Performance and Products
- False Positives for Tannin Sorghum in Non-Tannin Sorghum Using the Bleach Test
- Grain Quality Analysis of Sorghum Cultivars from El Salvador, C.A.
- Developing Quick Methods to Cook Whole Sorghum
- Market Development for White Sorghum
- Vita Bread®
- Properties of White Food Sorghums Grown in Different Environments

## Training (Degree and Non-Degree)

Three Ph.D. and three M.S. degrees were awarded to students working on sorghum. This includes Ms. V. Calderon who returned to CENTA, in El Salvador, to provide leadership in sorghum use in food systems.

L. Rooney collaborated with Professor Taylor, University of Pretoria, South Africa, on one M.S. thesis and a Ph.D. dissertation that were completed. Another Ph.D. and M.S. are in the pipeline at the University of Pretoria.

"Sandwich" degree programs reduce the costs of obtaining degrees to enable education of more students while providing them exposure to U.S. universities and related technologies. Ms. Constance Chiremba, M.S. student, University of Pretoria, was selected for short-term training at Texas A&M University. She is a technician in charge of sorghum quality evaluations at ARC in South Africa.

**International Foundation for Science (IFS) Workshop:** IFS sponsored a workshop for young African food scientists in Pretoria, South Africa in November 2007. L. Rooney presented information at the conference which was organized by Professor Taylor and the University of Pretoria. These young, newly-educated scientists were mentored and helped to develop potential research projects for submission to funding agencies.

Topics presented included the role of supply chain management in developing sustainable technology from African grains including millets and sorghum. Topics ranged from natural sorghum plant dyes to new foods from millets and sorghum.

**Supply Chain Activities:** L. Rooney participated in workshops held in Bamako, Mali (August 2008) and Dakar, Senegal (December 2007) on supply chain developments for food and feed by discussing the effective ways to make the chain work.

**Short Courses:** L. Rooney assisted Ms. V. Calderon CENTA, El Salvador in developing milling technology/short courses materials for interaction with a large number of food processors who wanted to use sorghum in baked and other products.

More than 40 participants enrolled in a one-week short course on practical snack foods processing held at Texas A&M. Information on sorghum utilization was included in the training for these domestic and international food processors.

**Short-Term:** Educational opportunities (one semester) were provided to a food science student from Guatemala who was a senior at Escuela Agricola Panamericana (EAP), Zamorano, Honduras.

Many scientists in Southern Africa have been educated at the University of Pretoria by Prof. Taylor and his colleagues. Through our INTSORMIL association with this program we have assisted in producing a cadre of dedicated scientists working with food processors and others to improve quality of sorghum and millet. In turn, they educate many students from Africa in food processing and related areas.

**Agricultural Research Council (ARC), South Africa:** Ms. Constance Chiremba, who runs the South African sorghum quality evaluation trials, is determining the phenolics and antioxidant activity of South African sorghum cultivars and developing antioxidant-rich sorghum foods as part of her M.S. research together with Drs. Taylor and Duodu at the University of Pretoria.

Ms. Doreen Hikeezi, former INTSORMIL M.S. graduate and lecturer in the Food Science and Technology Dept, University of Zambia, initiated her doctoral research work on sorghum grain end-use quality for food and beverage applications. She is working in collaboration with Prof. Taylor, Dr. Medson Chisi (sorghum breeder) and L. Rooney.

Mr. Luke Mugode, Zambian National Institute for Scientific and Industrial Research, is nearing completion of his M.S. degree related to protein hydrolysis during brewing of sorghum. He is evaluating highly digestible sorghum cultivars developed and increased by Dr. Hays at Texas A&M University.

Mr. Stephen Barrion, University of Namibia, completed a M.S. from University of Pretoria with Taylor and Rooney on pearl millet quality. He provided key inputs into pearl millet processing quality in the network.

Dr. Martin Kebakile, Botswana, completed a Ph.D. working with Prof. Taylor and L. Rooney. He has several publications showing that the modified roller mill developed in South Africa efficiently produces improved quality sorghum flour better than the abrasive milling equipment currently used. Dr. Kebakile is an important component of the network in Southern Africa.

**Central America/ Mexico:** Ms. Vilma Calderon, Food Scientist, CENTA, completed her M.S. in Food Science at TAMU with Lloyd Rooney and returned to CENTA in September 2007 to lead utilization research on sorghum for food in El Salvador.

Ms. Calderon's M.S. thesis on sorghum use in foods provided useful information to meet these opportunities in promoting sorghum foods. She also provided excellent leadership to develop procedures to use the low-cost Omega VI grinders designed by Compatible Technology International (CTI) to mill sorghum into flour for use in a wide variety of products.

The Omega VI grinder was integrated with a low-cost sifter designed and constructed by K. Duville of CENTA which produced an array of flours with different properties.

After the successful use of the first Omega VI grinder, INTSORMIL purchased 4 additional Omega VI grinders. They were distributed to small processors in El Salvador who use sorghums in food systems, but needed improved grinders. We appreciate their excellent support and providing 5 Omega VI grinders at modest cost. The 4 Omega VI grinders were sent to CENTA, and 1 was presented to INTA in Nicaragua.

New varieties developed by Rene Clara, CENTA, retired sorghum breeder, with excellent food quality have been effectively used to extend wheat flour, snack foods and related products where the bland flavor and light color have real advantages.

Mr. Kris Duville, who formerly worked for a rice processor in El Salvador, assisted Ms. Calderon to conduct a large number of workshops on sorghum properties, processing and use in food products. More than 65 industrial participants were trained with special workshops for some companies. The workshops conducted in the CENTA food laboratory covered most aspects of sorghum quality and processing.

Lloyd Rooney traveled to El Salvador twice to provide assistance with processing equipment and other activities in the CENTA Food Laboratory.

The equipment purchased earlier by INTSORMIL to partially equip the CENTA food lab has been effectively utilized.

Drs. Serna-Saldivar, Professor, Monterrey Institute of Technology (ITESM), Monterrey, Mexico and Francisco (Javier) Bueso, EAP, Zamorano, Honduras have provided expertise. Drs. Serna and Rooney obtained funding from TAMU-CONACYT for testing in vitro anti-cancer activities of sorghum extracts. This led to Dr. Sara Guajardo's Ph.D. dissertation demonstrating that certain sorghums had important anticancer activities.

Interaction with Escuela Agricola Panamericana (EAP) in Honduras continues with short- training programs conducted each spring for EAP students. These students are provided training in cereal technology and related activities. L. Rooney was part of a team that reviewed the EAP curriculum.

Development of end-use markets is contingent upon availability of a dependable supply of high quality grain at prices where all parts of the supply chain can make profits. Previous INTSORMIL activity demonstrated that supply chain management linking research with farmers and end-users was crucial in generating sustainable income for all parts of the system. Sanders has made significant progress in Sub-Saharan Africa by demonstrating that food processors' sales and profits are improved by accessing a reliable supply of grain with payment of a premium.

Supply chain management allows farmers to invest in new varieties, fertilizer and other inputs because of higher earnings and more reliable markets. Thus, there are increasing opportunities for small farmers to participate in new markets and generate income. Other examples exist across Southern and East Africa where South African Breweries (SAB) is using supply chain management to secure sorghum for brewing.

Research and development proposed in this project is directed at key components of a supply chain management scheme. The plan, in conjunction with economics and marketing, can successfully expand production of cost-competitive, convenience food products of sorghum and millet for urbanized areas.

## Publications and Presentations

### *Journal Articles*

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Njongmeta, N. 2008. Concentration effects and temperature stability of 3-deoxyanthocyanins from black sorghum bran. Student Research Week, TAMU. March 27, College Station, TX (3rd place prize on poster + 2 awards: Environmental Health & Safety Recognition Award + Outstanding Accomplishments in Interdisciplinary Research

Cardenas, A. 2008. Concentration effects and temperature stability of 3-deoxyanthocyanins from black sorghum bran. Student Research Week, TAMU. March 27, College Station, TX (3rd Place Prize-Poster and also Safety Recognition Award)

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Dykes, L. 2008. Flavonoid composition and antioxidant activity of pigmented sorghums of varying genotypes. Ph.D. Dissertation. Texas A&M University, College Station, TX. 175 pp.

Guajardo-Flores, S. 2008. Evaluation of anticancer potential of sorghums with different genetic characteristics and levels of phenolic compounds. Ph.D. Dissertation. Texas A&M University, College Station, TX. 85 pp.

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# Building a Sustainable Infrastructure for Product Development and Food Entrepreneur/Industry Technical Support: A Strategy to Promote Increased Use of Sorghum and Millet in East Africa

**Project UNL 102**
**David S. Jackson**
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### Introduction and Justification

Sorghum and millet are ideal crops for many parts of Africa. Maize, however, is favored by many as a food source; farmers thus grow Maize even though on a multi-year basis sorghum is a more reliable crop. The use of sorghum and millet in food products is limited throughout the world. In many parts of Africa, there is a lack of high-quality grain plus little knowledge regarding sorghum and millet's potential use in a wide variety of both traditional and non-traditional foods. There is also little infrastructure for conveying and demonstrating the food value of sorghum and millet to those most willing to invest in its potential, namely small businesses.

***Our approach involves three core initiatives in order to achieve rapid, yet sustainable, impact.***

During the past year we have made progress in all three areas: a) maintenance of a business development and technical support network, b) sharing the business development educational materials and program success with others in East Africa and, and finally c) Establishing a M.S. and Ph.D. program, emphasizing Sorghum/ Millet grain quality, food product development, and entrepreneurship, for East African University faculty members. Specifically, we have:

- Continued operation of the entrepreneurial assistance program in Tanzania with existing clients and established linkages with new clients.
- Shared educational materials and approaches with faculty, administrators and staff at the University of Zambia and explored sources of additional/start-up funding for their program.
- Strengthened workshop offerings for food processing entrepreneurs and educational programs for farmers.
- Begin planning of regional entrepreneurial assistance education workshop that would demonstrate program and distribute educational materials and explore additional funding opportunities in order to expand the number of workshop participants.
- Recruited and started a Ph.D. academic program of one M.S. degree-holding faculty member from the University of Zambia at the University of Nebraska's Department of Food Science & Technology.
- Recruited into a M.S. program (at the University of Nebraska) a non-research M.S. degree holder from Tanzania (his program will start in January 2009).
- Began the process of developing a systematic and objective program evaluation model.

### Objectives and Implementation Sites

Our specific objectives during year 2 of this project were to:

- Continue operation of entrepreneurial assistance program in Tanzania with existing clients; start new clients through initial workshop.
- Share educational materials and approaches with staff in Zambia (University of Zambia); explore sources of additional/start-up funding for their program.
- Strengthen workshop offerings and/or educational programs to farmers.
- Begin planning of regional entrepreneurial assistance education workshop that would demonstrate program and distribute educational materials; explore additional funding opportunities in order to expand number of workshop participants.
- Recruit M.S.-level faculty members (2) into a Ph.D. program at the University of Nebraska's Department of Food Science & Technology.
- Develop a systematic and objective program evaluation model.
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These program objectives specifically address the overall CRSP objectives to “Facilitate the growth of rapidly expanding markets for sorghum and pearl millet,” “Improve the food and nutritional quality of sorghum and pearl millet to enhance marketability and consumer health,” and “Develop effective partnerships with national and international agencies engaged in the improvement of sorghum and pearl millet production and the betterment of people dependent on these crops for their livelihoods." Primary implementation sites are: 1) Tanzania, 2) Zambia, and 3) training for scientists in Nebraska.

These objectives were to be implemented at the following sites:

As we have a strong partnership with Sokoine University of Agriculture, our regional efforts are coordinated from Tanzania. As funding is limited, the Food entrepreneur workshops and farmer education activities will continued to be offered in Tanzania. Our initial sharing of curricular material took place in Zambia, at the University of Zambia in Lusaka.

Our student education program emphasizing food science, product development and marketing/entrepreneurship is taking place at University of Nebraska in Lincoln, NE, USA. Marketing and entrepreneurship education will take place through internships with UNL's Food Processing Center, and the traditional educational program will be in the Department of Food Science and Technology.

## Research Methodology and Strategy

This program involves three main elements to support entrepreneurial food processing businesses in Africa by developing a support infrastructure within University systems. This support infrastructure involves personnel with both scientific and businesses development backgrounds. The three main elements include: a) Engaging potential entrepreneurs/small business groups in Tanzania with an introductory workshop on food processing and marketing, b) Providing ongoing technical and business support services that are customized to individual needs, and c) Building educational infrastructure by supporting Ph.D. and M.S. training of Food Science & Technology faculty and/or governmental officials directly involved in supporting food processing businesses.

Additional activities include providing workshops for small stake-holder farmers in Tanzania (grain harvesting techniques to maintain quality) and curriculum support to other African institutions interested in Food Science & Technology / Sorghum entrepreneurship outreach programs.

## Research Results

Ongoing activities are characterized in Table 1.

### *Details of 2008/Year 2 Program Progress*

Continue operation of entrepreneurial assistance program in Tanzania with existing clients and establish contacts with new clients.

- Provide support to existing groups of sorghum processors in Dar es Salaam and Dodoma (5 groups were supported on an intensive ongoing basis.) As examples, one group was facilitated by the Project to attend the Board of External Trade (BET) trade fair in Dar Es Salaam in July 2008. Also, 3 groups were facilitated to participate in the Farmers Day exhibitions "Nane Nane" in Morogoro in August 2008. One group in Dar es Salaam, the Nzasa Women Group, was provided with the support necessary to obtain registration/certification with the Tanzania Food and Drug Authority (TFDA). Their processing premises were inspected by the TFDA and approved with minor modifications. The registration process for this group is at an advanced stage (September 2008). Once registered, their products are allowed to enter into any market (local and external markets).
- As resources are limited, it is especially important to pre-identify businesses/entrepreneurs that have a realistic opportunity to succeed when entering the program. Therefore, potential clients were identified and visited (new groups/ entrepreneurs/companies) and after screening invited to be involved in the next Workshop to be held in Dar es Salaam. Baseline information about these groups has been collected and focus group discussions held. A total of 14 firms in Dar es Salaam, 2 in Dodoma and 6 in Singida have been identified as potential participants to the Workshop. Most of the identified processors are small-scale (processing up to 10 kg per day) and relatively new in the business. However three sorghum stakeholders were identified who operate on a commercial scale; (i) one miller based in Buguruni, Dar es Salaam (Mr. Faki Bakari) mills up to 20 tones of sorghum per day, (ii) one Supermarket (Imalaseko – based in Dar es Salaam) sell sells about 100-1kg packets of sorghum products per day, and (iii) one retail outlet based in Dodoma and owned by Mr. Peter Roberts sells about 30-1kg packets of sorghum products per day.

### *Share educational materials and approaches with staff in Zambia (University of Zambia); explore sources of additional/start-up funding for their program.*

Dr. David Jackson (Principal Investigator) and Dr. Joseph Mpagalile (Collaborating Scientist in Tanzania) made a trip to the Faculty of Agriculture at the University of Zambia (UNZA). The Department of Food Science and Technology at UNZA hosted the visit. While at UNZA the team met with

- The Dean of Faculty of Agriculture
- The Faculty of Agriculture Research Coordinator
- Staff members of the Faculty of Agriculture and in the Department of Food Science and Technology
- The Acting Director of Research and Postgraduate Studies (Campus-Wide)

In addition to broad-based discussions, the team made presentations to the faculty. The talks focused on the project's background and activities being carried out in Tanzania and USA. In addition to sharing project materials, an effort was made to develop wider interest in outreach services to those interested in the food processing / sorghum processing industry.

### *Strengthen workshop offerings and/or educational programs to farmers.*

Plans are underway to conduct farmers training to farmers in Morogoro, Dodoma and Singida regions. As of October 1st, the

**Table 1.**

| Objective (Planned Target/Activities) | Status of implementation | Problems encountered | Corrective measures |
|---|---|---|---|
| 1. Continue operation of entrepreneurial assistance program in Tanzania with existing clients and create linkages to new clients. | Five existing clients are receiving *intensive ongoing* support by Sokoine University of Agriculture (SUA) in Tanzania. SUA has further identified a total of 14 firms in Dar es Salaam, 2 in Dodoma and 6 in Singida to receive additional intensive business and technology support services. | None | None |
| 2. Share educational materials and approaches with faculty, administrators, and staff in Zambia (University of Zambia) and explore sources of additional/start-up funding for their program. | Drs. Jackson and Mpagali made one trip to the University of Zambia in Lusaka, Zambia. They made public presentations to the Faculty of Agriculture, visited with individual staff and administrators regarding the SUA outreach program. | None | None |
| 3. Strengthen workshop offerings and/or educational programs to farmers. | New workshops were planned; educational approaches were updated. | None | None |
| 4. Begin planning of regional entrepreneurial assistance education workshop that would demonstrate program and distribute educational materials; explore additional funding opportunities in order to expand number of workshop participants. | Initial planning activities initiated | None (so far) | None (so far) |
| 5. Recruit MS-level faculty members (2) into a Ph.D. program at the University of Nebraska's Department of Food Science and Technology. | Two M.S. holding students were identified, one from Tanzania and one from Zambia. The Zambian student enrolled in the fall of 2008 in a research-based Ph.D. program. No Tanzanian student was identified that had a sufficient research background to enter into UNL's Food Science and Technology program (best student had a non-research M.S. degree from the UK). This student, therefore was enrolled into our research-based M.S. program. | Delay in recruiting a suitable PhD student from Tanzania. | Recruited MSc student instead. Student will start in January 2009. |
| 6. Develop a systematic and objective program evaluation model. | Development of the model is one of the ongoing activities. | None (so far) | None (so far) |

exact dates for these programs had not been set (they will start, however, in January 2009. The training content will be similar to training offered to farmers in Melela village (Morogoro region) and Mpalanga village (Dodoma region) during the first year. The intent, however, is to reach reach more farmers by inviting more farmers per each session and having a greater number of sessions. We will, however, invite and interact with district leaders / influencers and Extension professional in order to make recommended grain-quality harvesting practices more sustainable.

### *Planning was initiated for the of regional entrepreneurial assistance education workshop that would demonstrate the program and distribute educational materials.*

Initial planning was initiated. Specific inquires were made in regard to venue, local participation, and other in-country logistics. Beginning in January 2009, a more resources will be expended to insure this activity is completed.

### *Recruit and Begin Degree Programs in Food Science and Technology*

One Ph.D. student was recruited from UNZA (she is a MS-holding Lecturer in the Department of Food Science & Technology) and started her program at the University of Nebraska (Fall 2008 Semester). A Tanzanian student will start his program in the Spring of 2009 (M.S. program).

## Develop a Systematic and Objective Program Evaluation Model

Initial work on this output is underway which include development of a Monitoring and Evaluation (M&E) calendar. We are also developing M&E assessment grids that will objectively capture relevant economic advancement.

## Networking Activities

Visit to University of Zambia (March 2008) noted earlier in the report.

# Host Country Program Enhancement

INTSORMIL

# Central America (El Salvador, Honduras, Nicaragua)


## William Rooney
## Texas A&M University


### Regional Coordinators


Ing. Rene Clara-Valencia (Central America Regional Host Coordinator), Plant Breeder CENTA (retired), Apdo. Postal 885, San Salvador, El Salvador

Dr. William L. Rooney (Central America Regional Coordinator), 2474 TAMU, Dept. of Soil & Crop Sciences, Texas A&M University, College Station, Texas 77843-2474


### Country Coordinators


Ing Rafael Obando Solis, Agronomist, CNIA/INTA, Apdo. 1247, Managua, Nicaragua (Nicaraguan Country Coordinator)

Ing. Hector Sierra, Agronomist, DICTA, Choluteca, Honduras (Honduras Country Coordinator)


### Collaborating Scientists


Ing. Humberto Salvador Zeledón, Plant Breeding/Agronomy, CENTA, San Andres, El Salvador
Dr. Máximo Antonio Hernández, Entomologist, CENTA, San Andres, El Salvador
Mario Ernesto Parada Jaco, Entomologist, CENTA, San Andres, El Salvador
Ing. Vilma Calderón, Food Scientist, CENTA, San Andres, El Salvador
Ing. Reina Flor de Serrano, Plant Pathologist, CENTA, San Andres, El Salvador
Alfredo Alarcón, Agronomy, CENTA, San Andres, El Salvador
Edgard Ascencio, Agronomy, CENTA, San Andres, El Salvador
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Ing. Nury Gutiérrez, Plant Breeding/Agronomy, INTA/CNIA, Managua, Nicaragua
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Dr. Joe D. Hancock, Dept. of Agronomy, Kansas State University, Manhattan, Kansas 66506


### Collaborative Program (Regional Program Description)

The regional programs of the INTSORMIL program are designed to support national research program efforts to develop dynamic, competent institutional research programs which contribute to productivity, economic growth, natural resource conservation and improved nutrition of people in the region. By accessing available expertise and infrastructure in the region, support from INTSORMIL is designed to facilitate and promote interaction between national programs, NGOs, international research centers, private sector and scientists from the U.S. land grant universities to achieve the goals of improving producitivity, profitability, economic growth and food security for producers and consumers as well. Historically, the Central American Regional Program has been a robust and active program. Given the new INTSORMIL program, the Central American program is in the process of reorganization including but not limited to development of new program priorities and project development.

### Institutions

Active INTSORMIL collaboration in Central America is occurring primarily among the following institutions: Centro Nacional de Technologla de Agropecuaria y Forestal (CENTA), El Salvador; Instituto Nicaraguense de Tecnologia Agropecuaria (INTA), Nicaragua; Universidad Nacional Agraria (UNA), Managua, Nicaragua; Kansas State University, and Texas A&M University. In addition, INTSORMIL has a current MOU with the Universidad Nacional Autónoma de Nicaragua (UNAN), Leon, Nicaragua, and maintains ties with the Escuela Agricola Panamericana (EAP), Honduras based upon past collaboration. INTSORMIL maintains a Memorandum of Understanding with the Dirección de Ciencia y TecnologIa Agropecuaria (DICTA) in Honduras, and program activities continue on a limited basis. Historically, INTSORMIL has developed linkages with the regional seed companies Cristiani Burkart and Productores de Semillas (PROSEMILLAS), allowing activities in Guatemala, primarily for testing of hybrids/varieties and coordinating support of the sorghum industry in Central America. Given consolidation in the seed industries, these collaborations are, as always, subject to change.

### Organization and Management

Since 1999, INTSORMIL program emphasis in Central America has been based in El Salvador and Nicaragua. Scientists from collaborating institutions in El Salvador and Nicaragua have met to discuss and develop country-based research plans for the next year with projects proposed in plant breeding, utilization, plant protection (entomology and plant pathology) and agronomy, and grain quality/utilization.

## Financial Inputs

Primary financial support for the program is from the INTSORMIL Central America Regional Program budget, which totaled $40,000 in 2007-2008 which is a significant reduction in budget compared earlier years (which averaged ~$120,000). This drop has obviously had an effect on the scope and depth of the Central American program. These funds were allocated to individual projects within both the Nicaraguan and El Salvadoran research programs. In addition, these funds are used for short-term training, equipment purchases and administrative travel.

Discuss how jointly developed collaborative research plans of work are planned and organized.

## Sorghum/Millet Constraints Researched

### *Collaboration*

INTSORMIL's Central America program has collaboration with many non-governmental organizations mainly in validation of new sorghum varieties on-farm (see form for complete list), and formal collaboration with national extension services, and it has served as a catalyst for Central American grain sorghum research and technology transfer. Collaborative relationships have been established with a number of universities in El Salvador and Nicaragua, and undergraduate students often complete thesis research on INTSORMIL supported experiments. In addition, René Clara Valencia continues to coordinate the regional grain sorghum yield trials conducted by the PCCMCA. In addition, a strong collaborative relationship has been developed between INTSORMIL's regional sorghum research program and ANPROSOR, the Nicaraguan grain sorghum producers association, which has assisted in identifying research priorities and has collaborated with a number of research studies since 2004. Until 2007, regional scientists have collaboration with the CIRAD-CIAT project on participatory plant breeding for sorghum (and upland rice) (this program was discontinued in 2007).

### *Sorghum Production/Utilization Constraints*

Grain sorghum is the third most important crop in Central America (El Salvador, Guatemala, Honduras, and Nicaragua) after maize and beans. The area devoted to grain sorghum in 2003 totalled 225,000 $ha^{-1}$, the average grain yield was 1.5 Mg $ha^{-1}$ (FAO, 2004). More recently, statistics in El Salvador document an average yield of > 2.0 Mg $ha^{-1}$ and given that production area has remained static, the overall sorghum production has increased due to the increased yield. While some of this increase may be due to favorable weather, other reasons include the adoption of improved technology (including improved cultivars and hybrids, herbicides, insecticides, planting date, minimum tillage, seed treatments and fertilizer) available to producers.

Small-scale Central American farmers are burdened with low productivity and limited land resources. Intercropping provides a means to increase total productivity per unit land area and reduce the risk of dependence on one crop. The dominant cropping system is maize intercropped with maicillos criollos (called millón in Nicaragua). These tropical grain sorghums are three to four meters tall, drought tolerant, and photopenod sensitive. The grain is used as human food and a feed grain for livestock, and the stover is used for livestock forage. Although maicillos criollos produce low yields, they are planted on approximately 67% of the grain sorghum area in Central America. The limited grain yield response of traditional maicillo criollo varieties to management practices is a primary constraint to increased production. Soil and water conservation, improved production practices and soil fertility management, and increased genetic potential of both maicillos criollos and other sorghum varieties is essential to obtain economical yield increases. To date, increased grain sorghum production, yield and area are due primarily to utilization of improved cultivars (hybrids and varieties), with recent studies documenting improved N use efficiency and N fertilizer response of cultivars spurring interest in increased use of fertilizer. (Figure 1)

The rapid increase in the cost and availability of wheat for bread recently emphasized the critical need to develop alternative uses for sorghum grain need to be developed to encourage sustainable economic growth in semi-arid areas in Central America. White-grain, tan-plant colored grain sorghum cultivars are well adapted to Central American human food and livestock feed systems. Innovative processing systems, like extrusion and flaking, are needed to increase starch digestibility and maximize net energy intake for livestock feed. Given current wheat prices, the lack of milling equipment (and the knowledge to use it) for production of grain sorghum flour limits adoption of the use of grain sorghum flour for baked products. Right now, there is a significant economic opportunity reason to utilize sorghum flour in bread products. A critical component of the INTSORMIL program involves the use of that technology to capitalize on this opportunity. Finally, the growth of the animal feeding industry provides a real opportunity for the development and use of sorghum as both a forage and dual purpose crop.

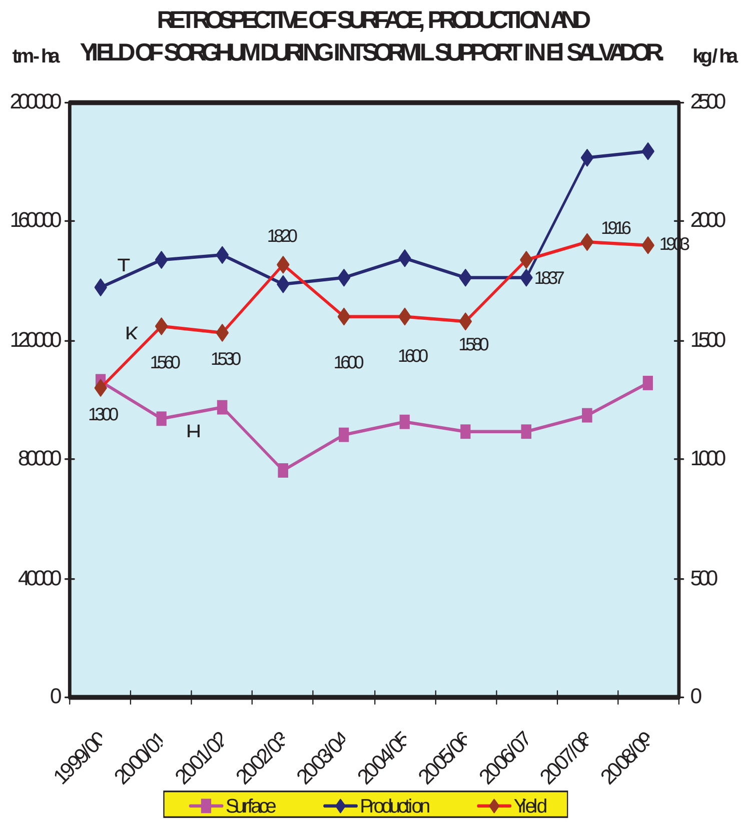
## Research Projects and Results

Given the limited funding available for research in the region, scientists in each country were asked to submit proposal that focused on important aspects of the INTSORMIL mission specific to Central America. The areas of emphasis were plant breeding, agronomy, plant pathology, entomology, economics, quality and extension. Within each country proposals were evaluated and funding provided on a merit basis. Projects were implemented in the fall of 2007 and completed by the summer of 2008.

### *Plant Breeding*

Most of the sorghum improvement program is localized in the CENTA program in El Salvador. At this location, selection, evaluation and the production of hybrid sorghum seed have been emphasized. Segregating populations of both Macio Criollos breeding material and photoperiod insensitive sorghum (both forage and grain types) have been grown in San Andres, El Salvador

**Figure 1.**




and selections were made at this site. Of special emphasis is the development of dual purpose sorghums with high forage yield and grain yield. In these populations, both the bmr and tannin trait are segregating; while all combinations are being selected, the types that are both brown midrib (bmr) and possess tannins are or primary interest. The target market for this material is the forage industry and they desired brown midrib for increased forage quality; the presence of tannins in the grain minimized the loss of grain to birds. All of these selections will be advanced for further evaluation next year.

In hybrid testing, the PCCMCA was coordinated by Rene Clara. A total of 12 locations were planted and grown throughout Central America. In El Salvador and Nicaragua, INTSORMIL collaborators conducted these PCCMCA trials. In 2007, the trial had 17 entries with approximately ½ of these entries coming from private industry and the remainder from INTSORMIL supported breeding activities. In these trials, the hybrid ESHG3 produced the highest yields in both 2005 and 2006. It was designated for commercial seed production studies that have been completed in the recent year.

Seed Production optimization for ESHG3 was evaluated in both El Salvador and Nicaragua. To determine optimum seed production the trial were designed as randomized blocks in a 3x2 factorial; the female:male ratios evaluated were: 3:1 and 4:1 (ICSA613 female: male 86EO361), and three planting dates 0x0 (simultaneous planting), 5x0 (female planted 5 days after the male), and 0x5 (male planted 5 days after the female). In both Nicaragua and El Salvador, differences in planting date did not affect seed yield, indicating that these parents have a good nick. Significant differences were detected for the ratio of female to male row numbers. Higher seed yields were produced in the R = 3:1 ratio (Table 1).

## Agronomy

*Testing of Line of PS Sorghum 99ZAM 911-3 Y 99ZAM 686-2 in association with maize in El Salvador*

Evaluation of two improved Macio-type photoperiod sensitive sorghums (varieties 99ZAM686-2 and 99ZAM911-3) was conducted in on farm trials. Production practices were typical maize/sorghum production (sorghum is planted 25 days after maize). Producers were selected from cooperating producers in different regions of the country where sorghum is grown (Chalatenango, San Miguel, Sonsonete, Ahuachapan). The area for each experimental variety was 500 m2, and each trial included the two experimental and a local check. The experiment was replicated across locations.

The results from 20 locations indicated that 99ZAM911-3 and 99ZAM686-2 yielded nearly the same and both exceeded the local check by an average of 12%. When considered in net revenue (from grain), the use of the improved Macios would net the producers 13% more than the traditional Macio. If the sales of seed are included, the increase of net revenue could be as high as 76%. The maize/sorghum system using these improved varieties even exceeds efficiency of land use on pure cultures of either maize or sorghum. The return on investment was calculated with the sales prices of grain in January, when prices are low and similar for

**Table 1. Datos obtenidos en el ensayo de producción de semilla del sorgo híbrido para grano, ESHG-3. Santa Cruz Porrillo, El Salvador 2007.**

| Planting Ratio (Relaciones de siembra) | Planting Time | Height Cms. | Days to Flowering | Seed Set % | Seed Yield kg/ha$^{-1}$ |
|---|---|---|---|---|---|
| 3:1 | 5x0 | 125 | 61 | 27 | 1025.7 |
| | 0x0 | 132 | 63 | 42.5 | 1571.2 |
| | 0x5 | 131 | 64 | 32 | 1038.8 |
| 4:1 | 5x0 | 128 | 57 | 24 | 691.32 |
| | 0x0 | 131 | 57 | 34 | 898.72 |
| | 0x5 | 133 | 57 | 24 | 640.88 |
| Mean | | 128.7 | 59.71 | 30.18 | 968.78 |
| Source | | | | | |
| Planting Ratio | | * | ns | ns | ** |
| Planting Date | | * | ns | ns | ns |
| Ratio x Date | | ns | ns | ns | ns |
| C.V. (%) | | 1.81 | 6.61 | 29.62 | 21.01 |

both sorghum and maize. If these were sold in months with higher prices, there would be a greater return.

Producers were surveyed regarding the varieties while on a tour of tests. A total of 50 surveys were returned. Producers responded that the height of the new varieties was acceptable (they were slightly lower, and this would facilitate harvest). From a forage perspective, producers preferred ZAM 911-3 to ZAM 686-2 as it had more leaf area early. The grain panicle of ZAM 911-3 was preferred over local checks and ZAM 686-2 as it was easier to thresh. Finally, the most important trait was grain color and flour color. Most all producers preferred ZAM 911-3 because of the white color of the grain and the white flour that the grain produces. From most all perspectives, ZAM 911-3 was the preferred variety from this test.

*Testing of the Photoperiod Sensitive Sorghum 99ZAM676-1 in monoculture and in association with Maize*

This test was designed to measure the performance of the photoperiod sensitive sorghum 99ZAM 676-1 in monoculture and maize/sorghum association in on farm trial. Cooperators were selected by extension agencies in areas where sorghum is grown (Chalatenango, Cabañas, San Miguel, Sonsonete, Ahuachapan, la Union). Experimental plots were 1000m2 , divided into 500m2 for 99ZAM 676-1 and 500 m2 with the local Creole variety. Seed of the improved variety was provided to the producer. Agronomic management was that typical for the producer. Grain and biomass yields were measured at typical harvest time by random sub-sampling of three spots in the larger plot.

The results obtained indicated that 99ZAM 676-1, exceeded the performance of local varieties for grain by an average of 877 kg/ha and biomass yield by an average of 1787 kg/ha. In addition, ZAM 676-1 was slightly shorter and easier to harvest than some local varieties. Economic analysis indicates that 99ZAM 676-1 has the best return and also the most cost-effective because for every dollar invested, it generates .67 cents greater return than the local variety. This would increase if the grain is sold later in the season when prices are high.

*Difusión de variedades mejoradas de millón para el sistema asocio con maíz, en las zonas secas de Las Segovias, Matagalpa y Chinandega.*

In Nicaragua, approximately 25,000 hectares of photoperiod sensitive sorghum are planted annually. These varieties typically have white grain and endosperm, they are tall and have an average yield of 1,500 kg/ha. Most of this crop is planted in association with maize and on small hillside farms. The sorghum is planted as security for rural families to feed themselves in areas where the yield of maize and beans are reduced by drought. To encourage production of improved Macios, three blocks of photoperiod sensitive sorghums (varieties EIME 119, ES 790 and 85 SCP 805) were grown to produce 25 quintals EIME 119, 28 quintals of ES - 790 and 37 qq 85 SCP 805, for a total of 90 quintals of seed.

In May 2008 this seed was distributed to 900 producers (individual and cooperative) in the departments of Esteli, Madriz, Chinandega and Matagalpa. The producers will use this seed to plant between 13,000 to 43,000 manzanas in in association with maize. In addition, local extension will assist producers in using this seed effectively to produce the next crop, partition a quantity to use as seed and market the remaining as either seed or grain.

*The effect of planting density and fertilization on forage yield sorghum forage variety INTA*

Four population densities of the Forage Variety INTA were evaluated (266,000, 332,500, 399,000 and 465,500 plants per hect-

**Table 2. Agronomic and compositional data for INTA Forrajero in Nicaragua in 2007.**

| Nombre | Days to Harvest | Height (cm) | Leaf/Stalk Ratio | Crude Protein % | Crude Fiber % |
|---|---|---|---|---|---|
| INTA FORRAJERO | 58 | 214 | 0.38 | 11.07 | 21.19 |

are). Each population was tested at four nitrogen levels (0, 65, 130 and 195 kg/ha).

No interactions were detected between population density and N level. There was no statistical difference in biomass yield based on population density. Nitrogen was a significant effect and with the best yields produced both the 130 and 195 kg/ha N rates. Because there was no statistical difference between these rates, use of the lower N rate was more cost effective, producing 55.6 and 21.8 Mg/ha fresh and dry weight, respectively (Table 2).

## Grain Utilization – Food Use

In 2007-2008, the cost of wheat flour quadrupled in El Salvador. Bakers across the country requested government solutions to the problem that consisted of subsidies, tax elimination, credits, etc. This situation provides an outstanding opportunity to promote and stimulate the use of sorghum flour as a substitute for part of the wheat flour in baked products. At the current price of wheat flour, sorghum is approximately ½ the cost. In response to this situation, in March CENTA, through the Food Technology lab published two newspaper articles and appeared on three different news broadcasts describing the use of sorghum as a flour substitute for wheat ( http://www.centa.gob.sv/Videos.aspx ; http://www.laprensagrafica.com/departamentos/1004993.asp ; http://www.laprensagrafica.com/economia /1004098.asp )

This promotion piqued the interest of many people from the food and bakery industries, and additional information and training was requested from CENTA's food lab. In the past year, CENTA food scientists have conducted four training sessions and educated approximately 100 participants. These demonstrations had two objectives: 1) to produce sorghum flour using a small mill (Omega VI) donated by INTSORMIL and 2) to demonstrate the utilization of sorghum flour as a substitute of wheat in different products.

As a result of trainings, big bakeries like Santa Eduviges, Pan Rey, and Monico located in San Salvador and surrounding areas, and many small and medium bakeries and productive groups from rural areas begin conducting trials with sorghum flour and actually they are using it to produce many of their products. "Pan Rey" a medium bakery located in Apopa, San Salvador, is producing its own flour, but is limited in their production by the limited supply of high quality sorghum grain. CENTA, through the INTSORMIL program is assisting them by identifying which hybrids they should buy. This has helped, but consistent supplies of good quality grain are difficult to find. They are using sorghum flour in a diversity of their products they are currently conducting trials right now with French bread formulation using 20% and 25% of sorghum flour. Consumer acceptance of their baked products with sorghum is good.

Another bottleneck to utilization of sorghum is milling capacity. Two Omega VI mills were purchased by INTSORMIL and our currently being used in El Salvador to produce sorghum flour. A small producer (Kris Duville) and CENTA's food lab are now providing this flour in a small scale. The Omega VI mill has a capacity of 2 pounds per minute. To get good particle size (flour pass through a mesh of 80) the flour must pass through the Omega VI at least four times but this is less than seven (what was required in a nixtamal mill). These mills, located in strategic points, will likely be more effective to supply sorghum flour than a large milling company in a single location, primarily because of transportation costs and logistics. There are efforts underway to increase and place these mills in appropriate locations.

La Colina a food processor specializing in Central American Ethnic Foods also requested training related to sorghum and flour production. A meeting with CENTA's cereal program personnel and the food lab personnel was conducted; CENTA is producing 3 hectares of food quality sorghum to be harvested in November, 2008; they will use the grain for flour production. GUMARSAL Company is going to mill all the sorghum produced and the flour is going to be used at La Colina's bakery to elaborate a diversity of sweet breads, cookies and healthy products to export to the USA. This company actually is exporting a diversity of products like frozen fruits, processed vegetables, chutneys, tamales, semitas and other Salvadorian ethnic foods. Last week CENTA's food lab provided La Colina with 200 pounds of fine flour to start conducting trials. CENTA's technicians will be involved in the trials. In addition to these examples, there are numerous other opportunities to use sorghum as a wheat substitute. CENTA is exploring and acting on these opportunities as appropriate. INTSORMIL is supporting this effort as well.

## Technology Transfer

*Seed production of released varieties of sorghum (Sorghum bicolor L. Moench)*

This project is conducted to increase seed of improved varieties of sorghum INTA RCV and INTA SR-16, INTA-Forrajero and release the seed to market as commercial varieties.

On April 29 two varieties (INTA RCV and INTA SR-16) were released by INTA. For each variety, phenotypic descriptors and seed (40 qq INTA RCV and 30 qq of INTA SR-16) were produced. This seed will be distributed to the Pacific zone of Nicaragua where the use of the grain is primarily for animal feeding. Each producer will be provided with approximately 20 lb of seed. The distribution should provide seed to approximately 3500 farmers to plant about 65,000 manzanas. This distribution should allow producers across the región to learn the new varieties.

*Production and Transfer of Improved Sorghums to Small Producers in El Salvador*

The objective of the Project is to improve the productivity and profitability of small producers in NE El Salvador. During the first year seed was produced for eight varieties (85SCP805, 790, 226, Soberano, RCV, CENTA S-2, CENTA S-3 and Jocoro). Extension training to use these varieties was in the New Conception area. Seed of these varieties was provided to establish 321 plots and 227 varieties insensitive sorghums, making a total 548 plots, using 10 pounds per plot. Yield and productivity was measured and summarize for 211 plots. Seed was also provided to small producers specifically to produce additional seed for sale. A total of 260.50 quintals of sorghum seeds were produced for use in extension agencies that have areas of influence in the northeastern part of the departments of Chalatenango, Cabanas, Cuscatlan, Morazán, San Miguel and Union.

## Networking

Several INTSORMIL collaborators attended and made presentations at the 53rd annual PCCMCA meetings held in Costa Rica in April 2008. INTSORMIL regional fund supported the travel of Vilma Calderon to the meeting to make a presentation. In addition, Salvador Zeledon won first place for his presentation at the meetings. Regional Coordinators Rene Clara and William Rooney traveled throughout Nicaragua, Honduras and El Salvador during harvest season to review programs and project activities. Ing. Nury Gutierrez of INTA traveled from Nicaragua to El Salvador to learn sorghum hybridization techniques from INTSORMIL supported CENTA staff. Drs. Joe Hancock and Lloyd Rooney traveled to the region to review and participate in collaborative research project related to animal feeding and food uses of sorghum. An agreement between CARE and INTSORMIL was formalized in the spring of 2008 to cooperate on the development and extension of sorghum into El Salvador for a period of two years.

Several releases of sorghum varieties were completed in 2007-2008. In El Salvador, CENTA released a series of sorghum forage varieties, highlighted by President Tony Saca, formally releasing the material at a field day at a dairy farm in El Salvador. INTSORMIL was recognized for their support in the development of this material. In Nicaragua in April 2008, INTA formally released INTA-RCV, INTA-SR16 and INTA Forrajero. In their release, the support of INTSORMIL in these releases was formally recognized.

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

## Gebisa Ejeta
## Purdue University

### Coordinators

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The Horn of Africa Regional Program now encompasses four countries of the Horn of Africa Region: Tanzania, Uganda, Kenya and Ethiopia. Scientists from the four countries and U.S. Collaborators met and participated in a planning workshop to discuss collaborative research for the Horn of Africa Region in September, 2008. The original Sorghum/Millet CRSP Grant program was closed after 27 years and the new Sorghum and Millet and Other Grains CRSP was initiated on September 29, 2006. As the Horn of Africa Regional Program goes forward, the planning workshop participants determined that we need take what has been accomplished and then develop a strategy to build on the strengths of the past. Declining human capacity is the biggest detriment to progress at the present time. This is due to lack of financial support and the cost of advanced training in the US.

### Institution Building and Networking

Examples of INTSORMIL trained scientists who have returned home include Dr Senayit Yetneberk of the Ethiopian Agricultural Research Organization (EIAR) who received Ph.D. training in Food Science at the University of Pretoria under the supervision of Prof. John Taylor and Prof. Lloyd Rooney of Texas A&M University. Dr. Yetneberk has now fully implemented a system for evaluating the injera making quality of new sorghum lines, a system that she developed during her Ph.D. studies. This quality evaluation system is proving invaluable as the cost of teff, the grain preferred for injera making, has increased dramatically in the past year, making it unaffordable to many Ethiopians. Hence, people are increasingly utilizing sorghum to make injera.

Dr. Tebkew Damte Belete, Debre Zeit Agricultural Research Center, Debre Zeit, Ethiopia received Ph.D. training in Entomology at West Texas A&M University under the supervision of Prof Bonnie Pendleton and returned home in December 2007.

### Capacity building support

- Support for M.S. degree training at Ohio State University (OSU tuition cost share) in AED Economics for one student from Tanzania starting in 2008. Ph.D. support for one faculty member from Sokoine University (SUA) in the SUA Ph.D. program
- Supported two M.S. students in agricultural economics at SUA

During this year Dr. Gebisa Ejeta has continued collaboration with EIAR scientists in conducting research on sorghum resistance to *Striga* in Ethiopia. Experimental sorghum hybrids with *Striga* resistance that have high yield potential have been identified, and can be utilized for catalyzing a seed business activity once their *Striga* resistance is confirmed in field tests in Africa.

Charles Wortmann and collaborators in Ethiopia, Uganda, and Tanzania working in the area of crop, soil and water management to optimize grain yield and quality for value-added markets met most of their research objectives including: enhancing information bases for tied-ridging in Ethiopia, skip-row planting in Ethiopia, fertilizer use in Ethiopia and Uganda, reviving research activities in Tanzania and enhancement of technology dissemination in Uganda. They did not address some sorghum grain utilization activities in the region but opted to focus resources on technology dissemination in expectation that increased regional demand for grain will lead to increased demand for production technology. Although, one graduate student was partly supported by the project, this level of training proved to be less degree training than intended.

The research led by Mark Erbaugh and Don Larson (OSU) is on target in terms of the activities planned and those accomplished in the past year. The technology adoption analyses have been completed and the papers written and revised and will be sent to journals for review and publication in the near future. The sorghum-based clear beer studies are well underway and the farm household surveys in the high potential areas have been completed. Data entry and cleaning have been completed. A procedure has been established to collect monthly price data for sorghum and millet for the years 2008 to 2011 to permit analysis of monthly price variability and opportunities to store grain on-farms to sell at higher farm prices in the post-harvest period.

A Tanzanian student (Joseph Mgaya) has started his M.S. studies at OSU. During this year, market development in support of sorghum and millet farmers in Tanzania was promoted. Results of smallholder technology adoption studies in sorghum areas showed that,

- Adoption rates of improved technology (improved seed varieties, manure/fertilizer, and tillage practices) are generally low in the study areas
- Sorghum yields are typically low in Tanzania, 338 kg/ha, but are substantially higher for adopters than non-adopters
- Adopters are generally better off economically compared to non-adopters of improved technologies
- Some demographics (education, sex, marital status), farm size, wealth (as measured by the dwelling index, off-farm income) were important factors explaining adoption
- Accessibility to all-weather roads was also an important factor affecting adoption
- Perception about the existence of production and marketing problems are important factors explaining adoption

Preliminary results of sorghum-based clear beer value chain studies show that,

- Lack of input availability for smallholder producers
- Low producer/farm prices at harvest time that increase substantially in the post harvest period
- Poor roads cause higher transport costs for smallholders
- Investors perceive high business risks in sorghum processing because of supply & market demand uncertainty
- Government policy interference, e.g. domestic food security versus export potential
- Contract enforcement challenges for larger scale producers and processors
- Value chain sustainability requires trust and profit opportunities for all members

Dr. David Jackson in year 2 of the project with Sokoine University in Tanzania initiated a point of strategic renewal and refocus. Support efforts based on clientele from the former INTSORMIL project were nearing their completion, as only 5-10 small business groups were actively receiving extensive one-on-one assistance. Therefore, new groups were identified (and surveyed) to receive initial workshop training and services in Year 3. The identification and survey process was designed to ensure that services were provided to those groups most likely to achieve success. In addition, specific planning for year 3 farmer workshops and a regional conference were initiated. The farmer workshops are poised to start in January 2009. In addition, to help achieving program sustainability and improveing human capital, two students were successfully recruited into degree programs in Food Science and Technology at the University of Nebraska.

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

## Gary C. Peterson
## Texas A&M University

### Coordinators

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### Regional Program Description

The Southern Africa program is composed of 14 investigators in 12 individual research projects representing 8 agencies from 4 countries. There an additional 8 U.S. principal investigators that collaborate with the regional investigators. The regional planning meeting held to develop a plan to guide activities from 30 September 2007 to 29 September 2011 developed the problem statement: Food security and incomes of sorghum and millet farmers in southern Africa remain low and productivity is constrained by a lack of appropriate technologies and farmer linkages with input and output markets. Enhanced collaboration among stakeholders will facilitate technology transfer, adoption, and improved productivity. Market incentives will drive technology adoption and productivity improvements.

Agencies represented include the Botswana College of Agriculture; the Mozambique National Agrarian Research Institute; in South Africa the University of the Free State, the ARC-GCI, the University of Pretoria, and the Medical Research Council, and in Zambia the Zambia Agricultural Research Institute and the University of Zambia. The investigators represent disciplines including:

agronomy (1), breeding (3), socio-economics (2), entomology (3), food science (1), and pathology (1). Regional investigators were selected with the expectation each has expertise that will allow the regional program to achieve the goal of improving sorghum and millet for the regions farmers and end-users.

Work plans are developed by each regional investigator using a format similar to the format for U.S. investigators. Each investigator is expected to specify where activities fall within the regional plan and to provide performance indicators and outputs. Progress listed in the individual annual reports will be used to evaluation progress and performance. Each collaborating investigator brings to INTSORMIL their own collaborators including Future Harvest Centers, NGOs, and other governmental or private organizations. Each also has other grant funds - other donors, grants and commodity organizations - that provide reciprocal leveraging of resources for each organization. Technical backstopping (as needed) and logistical, material and additional operational support is provided by the U.S. collaborators.

The goal of the collaborative program is to develop and transfer technology for increased production and use of pearl millet and sorghum. Component projects conduct research specific to the project goals but which has implications to research in other projects. Projects interact to develop new technology and the interaction will increase as additional opportunities and funding become available. The local scientists are encouraged to collaborate across country boundaries.

## Sorghum/Millet Constraints

Sorghum and pearl millet are major food crops in the Southern Africa region. Sorghum is also used to make opaque beer and as a livestock feed. Sorghum is the major cereal in Botswana and parts of Zambia and Mozambique while pearl millet is the major cereal in Namibia and parts of Mozambique, Zambia, and Zimbabwe. In many areas the stalks are used as forage for animal feed, to build fences and traditional storage facilities, and the juice of sweet sorghum as a source of sugar. In some areas sorghum and pearl millet are considered as food security crops, especially in regions where rainfall is a limiting factor for maize and rice production.

Constraints associated with low resource agriculture are present including low grain yield potential, infertile soils, variable moisture availability, numerous insect pests and diseases, poor grain quality, lack of improved seed, and poor distribution and market structures. Policy constraints frequently place sorghum and pearl millet at a disadvantage relative to other commodities. Improved crop genetics combined with better disease or insect management can economically address some constraints by increasing grain yield potential and stress resistance and by improving grain quality to meet end-use requirements. To increase end-use beyond the farm gate market channels should be improved as sorghum grain with the required quality to meet commercial requirements frequently has inconsistent production and supply. The inconsistent supply of quality grain is frequently cited as a major factor in deciding to use maize as opposed to sorghum. A major constraint to increased farmer production and productivity is the lack of adequate seed systems to distribute improved varieties. The adoption rate of improved varieties is largely unknown due to inadequacies of the seed system. Consequently farmers continue to use their local varieties which have low productivity potentials. 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 in development by national programs. Reduced stored grain loss, with some estimates of a 30 - 50% loss annually, will increase the availability of high quality grain. Exotic sorghums and pearl millets are continually introduced into the region as sources of needed traits. Identification of regionally adapted sorghum or pearl millet cultivars or hybrids with stable grain yield and multiple stress resistance will assist the NARS teams in developing lines, varieties, and hybrids for the diverse environments and production systems in each country and in similar environments. Research is on-going to improve disease and insect pest management and to improve sorghum and pearl millet processing techniques to improve use in value added foods.

Market channels need to be improved since sorghum varieties with the required quality to meet commercial consumer requirements frequently have inconsistent production and supply. The inconsistent supply of quality grain is frequently cited as a major factor in deciding to use maize as opposed to sorghum. Availability of a consistent supply of improved quality sorghum for processing into value added urban products is a major factor limiting utilization and development of commercial sorghum markets. Food companies will use but cannot consistently acquire sufficient quantities of high quality sorghums for processing. For example, Zambia Breweries= requirements of sorghum to produce Eagle larger is 40 B 60 tons per month, which cannot be met. A strong need exists for developing a system of identity preservation for production, marketing, and processing.

## Institution Building and Networking

### *Networking*

*Workshops and Meetings*

In November 2007 and September 2008 workshops were held in Pretoria, South Africa and Gothenburg, Sweden on the Science and Technology of Traditional Grains (sorghum and millets and pseudocereals). Each workshop was attended by some 40 delegates. The aim of the workshops was to increase the utilization of traditional grains. The workshops were organized by the University of Pretoria, the Swedish Food and Biotechnology Institute (SIK) and the International Foundation for Science (IFS), with the support of IFS. The workshops involved networking scientists from developing countries and established scientists working on traditional grains. The first workshop focused establishment of mentoring pairs between scientists and development of research project proposals. The second concentrated interaction with industry in Europe using traditional grains and practical learning of gluten-free baking technology.

A workshop for food processing entrepreneurs in southern Africa on Alternative Cereal Processing Technologies will take place in Botswana in November 2008. The workshop is being hosted by the Botswana National Food Technology Research Centre in collaboration with INTSORMIL and Cereal Science and Technology-Southern Africa.

In Mozambique demonstration plots and field days were carried out at Namialo, Namapa, Ocua and Katapua in Nampula and Cabo Delgado Provinces.

Participation by INTSORMIL collaborators in South Africa in meetings and activities of the Sorghum Forum (March 2008) and Sorghum Trust (October 2008) provide the opportunity to interact with commercial producers and discuss technology develop that is applicable to all sizes of farms.

Nearly 500 people attended a pearl millet field field day (Zambia) including representatives from the farming community, farmers= unions, seed companies, schools, NGOs, Ministry of Agriculture staff, Provincial and District Administrators and the public media.

Improved pearl milletvarieties were exhibited at District, Provincial and National shows

Crop production guides were made available to Extension staff in 7 districts.

### Research Investigator Exchanges

Dr. Lloyd Rooney (Texas A&M University) - November 2007. Visited South Africa for participation in the Traditional Grains Workshop and meeting with graduate students.

Dr. Medson Chisi (Zambia) visited the national program in Mozambique and evaluated sorghum and millet trials at several locations. Several germplasm lines were sent to Mozambique at their request.

Dr. John Yohe (INTSORMIL Program Director) and Dr. Gary Peterson (Texas AgriLife Research and INTSORMIL Regional Coordinator) - April/May 2008. Evaluation visits to Mozambique, South Africa (Bloemfontein, Potchefstroom and Pretoria), Botswana, and Zambia. Met with INTSORMIL collaborators and relevant administrators to review the current status of collaborative activity and plan future research and technology transfer activity.

Dr. Mark Erbaugh (Ohio State University) and Dr. Don Larson (Ohio State University) visited the Zambian sorghum breeding program at Golden Valley

Several scientists from Botswana and Namibia visited the Zambian sorghum breeding program at Golden Valley

In Mozambique, the national sorghum program received visits from Dr. Carlos Dominguez (ICRISAT-Mozambique), Dr. Mary Mgonja (ICRISAT-Kenya sorghum breeder) and Dr. Jane Ininda (AGRA Program Officer - Crop Improvement)

### Research Information Exchanges

Texas A&M University is working with the University of Pretoria to evaluate the brewing potential of the high protein digestibility lines developed in the Texas AgriLife Research sorghum program. Samples of lines that have been found to be promising in terms of improved yeast fermentation nutrition have been supplied to University of Pretoria for small-scale pilot-brewing trials.

### Germplasm Conservation and Distribution

The Zambian national sorghum program continued its work with the Food Diversification Project (FoDis) supported by JICA, Care International and Harvest Help in technology transfer as well as seed production and distribution. 2.5 tons of Kuyuma and 2.0 tons of Sima were produced at Nanga. This seed will be distributed in Rufunsa, Luangwa and Sinazongwe district. The program has, with the support of INTSORMIL, continued to increase seed of released varieties such as WP-13, Kuyuma, Sima and ZSV-15 when necessary.

The Zambian national pearl millet program produced 360 kg of Dola and 600 kg of Lubasi foundation seed. The production is adequate to plant 200 ha and produce 200,000 kg commercial certified or quality declared seed in 2008/09.

The Market Access Trade Enabling Policy (MATEP) would like 1,200 MT while Golden Valley Agricultural Research Trust (GART) is interested in funding commercial pearl millet production of Dola and forage types for Strengthening HIV/AIDSs and Food Security Mitigation Mechanisms.

The Mozambique national sorghum program planted seed increases at three locations to produce improved sorghum seed for distribution. In Namapa, 3.0 tons of Macia were produced. The seed will be supplied to farmers and the private sector through District extension services at a cost of $1.45/kg, equivalent to 35 meticals/kg. In Nampula, approximately 4.0 tons of foundation seed of Macia and Sima were produced. Part of the seed will be sold to assist farmer associations through the IKURU national NG). In Manica, 5 ha of Macia and 4.5 ha of pearl millet were planted but production data are not yet available.

### Spreading Research Results

In addition to workshops information distribution is also increasingly being achieved through posting of technical publications on the INTSORMIL website. During this past year the University of Pretoria has produced documents on: Developments in sorghum lager and stout sorghum brewing, Five Simple Methods for the Determination of Sorghum Grain End-Use Quality, Guide to Floor Malting of Sorghum and Millets and several posters about sorghum and millet science and technology.

Information is also spread through direct work with organisations and commercial companies. During the past year Prof . John Taylor spent two weeks in Ghana working with UNIDO on its project on Industrial Development of Sorghum Malt and Its Utilization in the Food Industry in West Africa. He also worked with two commercial companies malting and brewing with sorghum in Africa.

### *Examples of INTSORMIL Trained Scientists Who Have Returned Home*

Dr Senayit Yetneberk of the Ethiopian Agricultural Research Organization (EARO) received Ph.D. training in Food Science at the University of Pretoria under the supervision of Prof John Taylor and Prof Lloyd Rooney of Texas A&M University and returned home in 2004. Dr. Yetneberk has now fully implemented the system for evaluating the injera making quality of new sorghum lines that she developed during her Ph.D. studies. This quality evaluation system is proving invaluable as the cost of teff, the grain preferred for injera making, has increased dramatically in the past year, making it unaffordable to many Ethiopians. Hence, people are increasingly utilizing sorghum to make injera.

### *Human Resource Development Strategy*

For degree programs, the primary mechanism is to upgrade the research and sorghum and millet science skills of university lecturers and scientists in research institutes in sub-Saharan Africa. During the past year, there were nine such graduate students studying Food Science at the University of Pretoria.

For non-degree (short-term) programs, the University of Pretoria has a short course in sorghum malting technology and a certificate course in opaque beer brewing. The strategy is now to formalize this training. Discussions are ongoing with the Institute of Brewing and Distilling (IBD) to have a Sorghum elective in the IBD=s General Certificate in Brewing. Such an elective would help raise the human resources skills and status of the sorghum brewing industry, as well as to promote sorghum brewing in new regions.

Rebecca Lubinda, a faculty member in the Department of Agricultural Economics and Extension Education at UNZA, has decided to begin Ph.D. studies in agricultural economics this spring or next fall through the RUFORUM program located at Bunda College in Malawi. Her studies will be supported on a cost share basis between the OSU INTSORMIL/Zambia project and the Regional Universities Forum for Capacity Building in Agriculture (RUFORUM).

INTSORMIL supported students, and students affiliated with INTSORMIL collaborators, at the University of the Free State receive training in interdisciplinary research including plant pathology and breeding.

## Research Accomplishments

### *Entomology*

#### *Mozambique*

Twenty-five sweet sorghum varieties from ICRISAT (also evaluated in the sorghum breeding program) were screened for resistance to shoot fly and stem borer. A differential response to both pests was observed. For shoot fly, varieties with a low severity of attack and some level of resistance include ICSV 700 (1.0), ICSB654 (1.3), ICSB324 (1.3), and SPV1411 (1.7). Varieties with a high severity of attack and susceptibility include IESB91104DL (4.3), SPV422 (4.3), Ent#64 DTN (3.3) and E 36-1 (3.3). For stem borer, varieties with a low severity of attack and some level of resistance include S35 (1.0), ICSB654 (1.0) and ICSB324 (1.3). Varieties with a high severity of attack and susceptibility include SPV411 (3.0), IESB91104DL (2.7) and IESB940218DL (2.7). Two varieties - ICSB654 and ICSB324 - appeared to have resistance to both insect pests.

The Texas A&M University All Disease and Insect Nursery (ADIN) was evaluated for resistance to stem borer. Entries TAM428 (1.00), Sureno (1.50), Tx2911 (1.50), Tx2952 (1.50), and Tx2950 (1.75) had a low severity of attack and were classified as resistant to stem borer. Entries Tx2955 (3.25),6GCPOBS143 (3.25), Tx2959 (3.25), and B9955 (3.5) exhibited a high severity of attack and were classified as susceptible to stem borer.

### *Botswana and South Africa*

Primary collaborative research is on developing varieties resistant to the sugarcane aphid (*Melanaphis sacchari* [Zehntner]). Two trials were provided to collaborators at the ARC-Grain Crops Institute (Potchefstroom) and the Botswana College of Agriculture (BCA-Sebele). The first trial was composed of 50 entries which had not been previously evaluated for resistance to sugarcane aphid. At Potchefstroom the three replication trial was evaluated in a seedling stage greenhouse trial with artificial inoculation. Seedlings were inoculated 10 days after emergence and plants rated for aphid abundance and plant damage 21 days after infestation. Plants were rated on a scale of 1 (highly resistant) to 6 (highly susceptible). TAM428, the resistant check, was rated as a 1 for plant damage and aphid abundance while Segaolane, the susceptible check, was rated as a 5.7 for plant damage and 4.3 for aphid abundance. Analysis of the Potchefstroom data indicated that for plant damage on the experimental entries 18% (7) of the entries rated 1, 34% (13) rated 2, 2% (1) rated 3, 29% (11) rated 4, 16% (6) rated 5 (Table 1). None of the entries rated a 6 for plant damage. For aphid abundance 32% (12) of the entries rated 1 and highly resistant, 50% (19) rated 2 and highly resistant, 16% (6) rated 3 and resistant, and24% (1) rated 4 and slightly resistant. None of the entries rated as susceptible based on aphid abundance. In the field trial 26% (10) rated 1, 55% (21) rated 2, 18% (7) rated 3. In the field none of the entries were rated completely susceptible. In the field 20% (10) of the entries rated under 2.3 (resistant to highly resistant) and under 2.3 based on greenhouse ratings. At Sebele there were few aphid present at most entries were scored as a 1. At the BCA plots were also scored for percent of plants infested with shoot fly (*Atherigona soccata* [Rondani]) and sorghum stem borer (*Chilo partellus* [Swinhoe]). For shoot fly the percent of infested plants ranged from 0 to 33 and for stem borer from 0 to 59. Several experimental entries with excellent sugarcane aphid resistance also had no shoot fly or sorghum stem borers identified.

The second trial was a twenty-five entry three replication trial composed of 22 entries previously identified with a high level of resistance to sugarcane aphid and 3 local checks. The purpose of the trial was to identify entries with excellent adaptation and grain yield to the local production system. All experimental entries were rated as 1 or 2 for greenhouse damage and only two entries rated higher than a one for sugarcane aphid abundance (Table 2). The test average was 3.2 tons/ha with the local hybrid check producing 3.83 tons/ha, Tegemeo 2.78 tons/ha, and Macia 2.70 tons/ha. Five entries produced more grain than the hybrid check with yield ranging from 3.94 to 4.40 tons/ha. Only two entries produced significantly less grain than the local hybrid check, PAN 8420. Five entries produced more grain than PAN 8420 although the differences were not significant. Fifteen experimental entries produced more grain than the local check cultivars, Tegemeo and Macia although a significant difference was identified for only one experimental entry. Several entries were selected for on-farm trials during the next growing season at three locations to identify entries suitable for small-scale farmer market.

## Food Quality

Research is being undertaken to promote sorghum and millets within the health food niche market. Research by INTSORMIL supported M.Sc. student Constance Chiremba and by Ph.D. Student Muthulisi Siwela under the supervision of Prof. John Taylor and Dr. Gyebi Duodu of the University of Pretoria has shown that good quality cookies with high antioxidant activity can be produced from 100% sorghum and from finger millet blended with wheat. Similarly, work by Ph.D. graduate Nomusa Dlamini under the supervision of Prof Lloyd Rooney of Texas A&M University and John Taylor has shown that traditional African sorghum porridges and modern extrusion cooked ready-to-eat products from sorghum also have excellent antioxidant activity. Arising from this work, the largest sorghum food manufacturer in South Africa has now approached the University of Pretoria to determine the antioxidant activity of their sorghum raw materials and products.

Research conducted by Ph.D. graduate Martin Kebakile under the supervision of John Taylor, Dr. Riette de Kock (University of Pretoria) and Lloyd Rooney has shown that milling sorghum using the South African developed simple roller mill is much more efficient than the currently commonly used technology of dehulling, followed by hammer milling. As a result of this research, a major international brewing company is now evaluating this roller milling technology for milling its maize and sorghum adjuncts.

## Market Development

The adoption of improved technologies among smallholder growers of maize, millet and sorghum was studied using a household survey of smallholder farmers in a sorghum and millet growing district (Siavonga area) to identify factors that influence adoption of improved technologies (improved seed, deep tillage, and manure/fertilizer) in the production of maize, millet and sorghum. Progress toward indicators such as income growth, yield increases, and production increases will be measured against this baseline information. In addition to confirming that adopters are generally better off compared to non-adopters of improved technologies, the results indicate that some demographics (education, sex, marital status), farm size, wealth (as measured by the dwelling index, off-farm income), accessibility, and perception about the existence of production and marketing problems are important in explaining adoption in at least some of the crops. Besides the need to recognize the inherent heterogeneity among crops, broad-based investment in education, and marketing infrastructure and institutions could improve technology uptake.

A survey of sorghum and millet farmers in a high potential area was conducted in two blocks of Luanshya district north of Lusaka. Luanshya is a high potential sorghum producing area that also has market access advantages because of its close proximity (60 kilometers) to the Zambian Breweries Ndola facility that brews Eagle lager. Luanshya was selected after the researchers visited the Mumbwa area (the original high potential area selected) only to discover that very little sorghum is now grown there. Maize is the major crop now grown in the Mumbwa area. The change to maize is due in part to large government subsidies (60%) on maize seed and fertilizer prices. In the Luanshya survey, 170 households were visited, of which 164 were complete interviews. Data entry and cleaning has been completed.

The sorghum based clear beer supply chain analysis resulted in a progress report that identified the value chain players, from farmers to retailers of the clear beer. Interviews were conducted with various representatives of firms that form part of the chain on their activities and experiences in the chain. The producer of Eagle lager, Zambian Breweries, was the first organization to be visited and was the primary source of information on the other chain players. Interviews were also conducted with CHC commodities, the sole supplier of sorghum to Zambian Breweries, and two of the official distributors of Eagle lager, R.S. Distributors and Nenima Trading. Various retailers within Lusaka were also visited. For this year the main activity was the examination of the clear beer supply chain with interviews with retailers, wholesalers, brewers, warehouses, transporters, local buyers, farmers, and others. Information was required on supply chain players= operations, information flows, promotion flows, ownership flows, product flows, payment flows, constraints and the means for smallholders to sell in commercial markets. Estimates of future demand for the clear beer were also required to assess the growth potential of this market. The current analysis of the clear beer supply chain has concentrated on collecting more information that was not available last year and estimating the future demand for Eagle lager.

An interview at CHC commodities, a grain trading company, provided useful information on the flow of information on the quantities, quality and prices of sorghum required for production of clear beer as well as the ownership of the sorghum as it moves from the farmers= fields to Northern breweries. Further interviews are being conducted to collect actual prices of sorghum this year (including how they are determined) and how payments are made. Further interviews were also conducted with R.S Distributors on its operations and flow of clear beer from the brewers to the retailers. The main activity that remains to be done is the estimation of future demand for Eagle lager. Future demand estimates will be based on sales/production forecasts based on trends in sales and production of the beer since its introduction in 2005. Data will be obtained from Zambian Breweries in Lusaka.

## Pearl Millet Breeding (Zambia)

Although several seed companies operate in Zambia only 18% of the 523 released plant varieties are marketed. Only one pearl variety is >commercially= marketed but accurate information on seed demand/supply chain is not well documented. Demand for improved seed is increasing domestically and in neighboring countries, especially following the release of the improved bristled and bird-tolerant variety Dola. Thirty-eight exotic seed parents (i.e. 19 A1, A4, and A5 CMS and corresponding maintainer lines) as well as 51 other B-lines were evaluated, characterized and stored. An attempt was made to produce seed of 190 experimental cms based hybrids from 19 A-lines and 10 potential pollinators.

Through collaboration with the Food Science Department of the University of Zambia, some food quality traits were determined on 30 pearl millet varieties.

Five variety trials were conducted to evaluate the performance of experimental varieties versus released standard varieties. A32 entry trial composed of 13 released SADC varieties, 11 Zambian experimental varieties, 1 elite and 7 exotic varieties was planted at three dates to evaluate for grain yield. Statistically significant differences were obtained for grain yield in the November plantings. At the early planting date, Sepo, ZPMV20601, ZPMV 22601, ZPMV 22501, Tuso, ZPMV 20402 and Dola were best while ZPMV 22601, Sepo and ZPMV 20601 were superior in planting two weeks later. There was a 6% yield advantage with early planting, and late maturing varieties out-yield early maturing varieties when planted early and vice versa.

Twenty-two elite varieties were evaluated with 10 released ones that included the sorghum variety Kuyuma. Statistically significant differences were obtained for grain yield with ZPMV 20402 and ZPMV 21401 being equal to the check Lubasi. Other promising varieties were Taram, ZPMV 27401 and ZPMV 21402. Kuyuma produced less grain yield than 28 of the 31 pearl millet varieties tested.

Additional activities in the pearl millet breeding program included the regeneration of 23 Zambian or exotic varieties. Research was also conducted to pursue the development of both top-cross and population hybrids using cytoplasmic genetic male sterility (CMS) in top-cross hybrids and inter-varietal crosses in population hybrids. Nineteen pairs of A/B-lines of the Aa, A4 and A5 CMS system were evaluated. Results led to the conclusion that the lines could still be segregating and require additional inbreeding and selecting. Fifty-one potential B-lines from ICRISAT were evaluated for traits including flowering, maturity, height, size and shape of spikes, absence or presence of bristles, color of grain, tillering, lodging tolerance, threshing percent and grain yield. Based on the data collected 30 were selected for further evaluation and future use. Restorer hybrid parents were characterized and evaluated for potential use in Zambia. From several hybrid BC3 and BC4 inbred progenies, 18 diverse potential restorer hybrid parents were formed.

## Sorghum Breeding

### *Zambia*

Several varieties and management practices have been developed by the program. However technology adoption has been modest due to a number of reasons, primarily lack of seed availability. A study done several years ago on sorghum farmers on the availability of sorghum seed reported that forty-five percent cited lack of seed as a major reason for non-adoption, while 36 percent reported lack of information as a constraint. According to the same survey results, 40 percent of the adopters depended on NGOs for seed as compared to only 15 percent who depended on purchased seed from different sources, including Zambia Seed Company. Issues of seed production and distribution have continued to be a major hindrance to increased production of sorghum in Zambia and are largely due to government policy that is restricting access to publically released varieties by private seed companies.

Three of the major focus of the breeding program in Zambia are to ensure food security under the crop diversification policy by developing varieties and hybrids that are of acceptable quality to end users, to elevate sorghum from a subsistence crop to a commercial cash generating crop, and to increase technology transfer. Participatory approaches are used to achieve this goal. This has been achieved through establishing markets and value chain management. The increased production and use of sorghum is expected to provide household food security and increased income for subsistence farming sector. Seed of popular varieties was increased at Nanga and will be distributed in Rufunsa, Luangwa and Sinazongwe. The program in collaboration with various NGOs is involved in the promotion of improved varieties and management practices to farmers. In Siavonga during the 2007/2008 season 130 small holder farmers grew about 200 hectares of sorghum. Most importantly the farmers= average grain yield was 2.5 tons per hectare as opposed to their average of 0.5 tons per hectare. Most of the sorghum growers have moved from thatched huts to iron sheets, a measure of affluence in these communities.

Collaborative research with INTSORMIL has involved the exchange of germplasm and evaluation of trials with specific traits. A number of parental lines have been evaluated for combining ability and other desirable agronomic traits. This research has resulted in the development of sorghum varieties suitable for food, brewing, feed and forage. Varieties and hybrids including ZSV-15, WP-13, MMSH-625 and MMSH-1365 have been released to farmers with a fair amount of success in terms of acceptance. Collaborative activities in technology transfer continue in Kazungula and Siavonga under a sorghum commercialization project involving Care International (Zambia) and Harvest Help designed to promote sorghum production and consumption. With increased production of sorghum, it is expected that incomes and profitability of farmers will increase resulting in food security.

The 2007/2008 growing season was characterized by heavy rains at the beginning of the season and early cessation of the rains in early March. Multi-location trials were abandoned and where they were conducted the coefficients of variations were unacceptably high. However, the breeding nursery and some trials performed well. Field days conducted at GART and Masaiti in Ndola proved successful and the attendance by farmers was good. At GART significant differences were observed among the entries evaluated in the sorghum advanced variety trial and the preliminary hybrid trial. A number of lines were identified for additional evaluation in multi-location and on farm trials. ZSV-15-4. [Framida x SDS 3845]F6-5, ELT1-16 and derivatives of WP-13 are some of the lines selected for further evaluation. New hybrids ZSH-206, 208 and 205 had high yields and good agronomic scores at GART.

### *Mozambique*

Land-race varieties collected in the Central Sorghum Plateau-Gorongosa/Sofala Province (22 varieties) and the Northern Sorghum Plateau-Cabo Delgado Province (19 varieties) was evaluated for agronomic characteristics (including days to flowering, plant height, panicle exsertion), insect resistance (borers, midge, aphids) and disease resistance (downy mildew and head smut). Both collections were resistant to downy mildew and head smut (scored as 1 on a 1 = resistant to 5 = susceptible scale). Level of resistance to aphids (scored between 1 and 2) and midge (scored between 1 and 2) was generally excellent. Most entries exhibited a moderate level of susceptibility to borers. In collaboration with the University of the Free State (South Africa), the varieties will be grown in the next growing season for its characterization using DNA-finger print to determine genetic diversity, grain quality and nutritional value (in collaboration with the University of Pretoria-Department of Food Science).

Ten improved varieties from the Zambian national sorghum breeding program were evaluated for performance in Mozambique. Results indicated that all of the varieties performed well under local conditions. The varieties all scored a 1 (1 = resistant to 5 = susceptible) for downy mildew and head smut reaction. All varieties sustained little damage due to midge (all scored 1) and aphids (8 scored at 1 and 2 scored at 2). The varieties were moderately susceptible to damage by borers, usually scoring at 2 or3.

Twenty-five (25) sweet sorghum varieties developed by ICRISAT-Kenya were evaluated at 6 locations (Manica, Chokwe, Namialo, Montepuez, Oacua and Katapua) under rain-fed conditions. Brix percent (test mean = 11.9) ranged from 7.9 ICSB 324 to 14.5 for Ent #64DTN and S 35. The water limited environment resulted in reduced stalk yield and grain weight (test mean of 543.0 kg/ha).

Four sorghum trials from the Texas A&M University sorghum program were evaluated for agronomic traits, insect and disease resistance, and grain yield. The trials were the All Disease and Insect Nursery (ADIN), Drought Line Test (DLT), Grain Weathering Test (GWT) and Midge Line Test (MLT). Each test contains standards checks for the relevant trait(s) and resistant lines in an improved genetic background. Grain yield in the ADIN averaged 1.08 kg/ha (CV=14.7), 1.27 kg/ha (CV=13.05) in the DLT, and 1.61 (CV=12.67) in the MLT. Based upon the data collected for grain yield, agronomic traits, grain quality, and tolerance/resistance to drought, sorghum midge 9 lines were selected for pre-release increase and testing. Designation/pedigree of the lines are:

- 03CM15067 (((((Tx2880*(Tx2880*(Tx2864*(Tx436*(Tx 2864*PI550607)))))-PR3-SM6-CM3-CM1-CM2-CABK-CABK-CGBK
- 03CM15012 (85OG4300-5*Tx2782)-SM5-CM2-SM2-SM1-CABK-CMBK-CMBK
- 02CM1104 (((((Tx2880*(Tx2880*(Tx2864*(Tx2864*P I550610)))))-PR3-SM6-CM3-CM2-CG3-BGBK-CABK
- Sureño
- 01CS20538 (90LI9178 - (M84-7*VG153)-LBK-PR7-L4-L2
- 02CS30445 (99CA3019 - (VG153*(TAM428*SBIII))-23-B32-BE2-BE1)
- B409 (B1*(B7904*(SC748*SC630)))-HF17B
- 02CS5067 (B1*BTx635)-HF8
- 01CS19225 (B35*B9501)-HD9

During the 2008-2009 growing season in Mozambique and Texas multiple location data will be gathered on each line and selected local checks (such as Macia and Kuyuma). A release proposal will be developed and submitted to the Texas AgriLife Research Plant Release Committee. Intellectual property rights to the lines for use as varieties in Mozambique will be transferred to IIAM.

## Plant Pathology

Root efficiency remains a critical component of low input agriculture and is essential in ensuring that limited soil moisture and nutrients are used optimally so as to ensure sustainable crop production. A Ph.D. thesis was completed and included aspect on pathogenisis, resistance, seed treatments and the role of edaphic factors on disease severity. An M.Sc. study has been initiated to continue aspects studied during the Ph.D. study. A new collection of root pathogens was initiated that covered a wider production area than the previous study and included forage, grain and wild sorghums. These are being used to define pathogen aggressiveness and the stability of resistance using different pathogen spectra. In an initial study, 60 isolates, provisionally classified as Fusarium oxysporum, root efficiencies, based on visible root rot and root volume, were reduced by 15-38 %. Additional isolates of other genera are currently being evaluated. Isolates will be used in line screening, winter greenhouse trials to determine isolate x genotype interactions and lines will also be used to determine histological and physiological relationships within the host x pathogen response. Isolates used in the evaluations will be sequenced to confirm the identity of the pathogens. Trials were planted at Cedara including lines obtained from the Texas A&M program for the evaluation of resistance to root rots in B and R populations. Root rot severities ranged from 8.3 to 72.1 % based on visible discoloration and most lines were susceptible to root rots. Only one of 323 lines yielded root rot severities <10 % while 268 line yielded severities >30 %. There was a tendency for more resistant lines to produce smaller root volumes, which ranged from 4.4 to 128.3 ml. Of the 7 lines that produced root volumes in excess of 100 ml, only two old lines ie. A 3739 and ICSV-LM 90364 yielded root rot severities <20 %.

On-going trials were planted in Greytown, Klerkdorp, Cedara and Bethlehem (all in South Africa) to evaluate new releases for cold tolerance and ergot susceptibility. These trials are aimed at preventing susceptible cultivars from entering the market and a re-occurrence of 1980=s epidemics. Data were analyed using the regression methodology developed to quantify ergot susceptibility x weather interactions (McLAREN, N.W. (1992) Quantifying resistance of sorghum genotypes to the sugary disease pathogen (*Claviceps africana*). Plant Disease 76: 986-988). Of the 72 potential releases, 31 were identified as high ergot risk cultivars and will not be marketed.

Sorghum nurseries received from the Texas A&M sorghum program were evaluated for sources of resistance and adaptability to the major foliar diseases at Cedara (KwaZulu-Natal Province). Most lines were white, tan genotypes although some red grained lines were also included. Foliar disease severities in these trials were relatively low due to nurseries being received late. Particular emphasis was placed on grain molds which remain a major concern to processors, both due to the effect on grain quality (milling and discolorations) and the potential health hazard due to mycotoxins. Grain molds were evaluated in trials at Cedara and Potchefstroom (North-West Province). Selections were made to serve both commercial and small scale production. Most lines were however rejected based on extreme susceptibility to grain molds. In the ADIN nursery four lines (Tegemeo, Macia, Sureño and BTx635) were selected to be included in a small farmer evaluation trial in collaboration with INTSORMIL during 2008/09 (Table 3). Similarly, in the Sugarcane Aphid Trial (Table 1) and SCA Yield Trial (Table 2), a number of entries were identified for the small farmer program. Selected lines will be evaluated on-farm during 2008/09 to determine adaptability to low input conditions.

## Agronomy

Several trails were conducted on nutrient management in Mozambique. 1) Trials to verify and fine-tune promising practices and to strengthen technology dissemination were conducted on-station and on-farm in northern Mozambique in collaboration with Zonal Research Centers in Nampula and Manica and with CLUSA. 2) Various treatments to evaluate the effect of green manure in rotation with sorghum were evaluated. The treatments include sorghum fertilized with standard fertilizer (Urea + NPK), sorghum fertilized with urea, cowpea, sorghum without soil amendment, and sole crotalaria. 3) The effect of different foliar application rates of monthly fertilized is being evaluated. 4) To understand current sorghum, millet and other small grain production systems as well as farmer=s soil nutrient management practices for restoration soil fertility of sorghum and millet a questionnaire was developed for farmer interviews. Data from all of the studies is currently being analyzed.

## Publications


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**Table 1. Sugarcane aphid damage, shoot fly and stem borer infested plants, plant color and grain color, disease resistance ratings in the 2008 Sugarcane Aphid Test, Potchefstroom and Cedara, South Africa and Sebele, Botswana.**

| Source | Designation/Pedigree | Plant Color † | Grain Color ‡ | Potchefstroom Seedling Damage§ | Potchefstroom Adult Damage¶ | Sebele Adult Damage ¶ | Sebele Shootfly Infested Plants | Sebele Stemborer Infested Plans | Leaf Blight # | Rust # | Zonate # | Anthracnose # | Grain Mold† † | Grain Mold† † |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | % | % | | | | | Cedara | Potch |
| 5 | TAM428 | P | W | 1.0 | 1.0 | 1.0 | 4.9 | 0.0 | 2.8 | 0.3 | 0.0 | 0.7 | 3.5 | 2.2 |
| 6 | WM#177 | P | W | 1.0 | 1.0 | 1.0 | 3.7 | 17.8 | 2.2 | 2.2 | 0.0 | 0.7 | 3.5 | 2.3 |
| 8 | Ent62/SADC | T | W | 1.0 | 1.0 | 1.0 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 0.8 | 1.8 | 3.5 |
| 13 | (9MLT176/(MR112B-92M2*Tx2880)*Segaolane)-CG1-LG1-CA1 | T | W | 1.0 | 1.0 | 1.0 | 0.0 | 0.0 | 1.8 | 0.0 | 0.0 | 0.0 | 3.8 | 2.7 |
| 18 | (Sureno*Tegemeo)-BE3-CA1-CCBK-CABK | T | W | 1.0 | 3.0 | 1.0 | 0.0 | 16.7 | 2.2 | 0.3 | 0.0 | 0.0 | 4.5 | 3.8 |
| 20 | (Dorado*Tegemeo)-HW13-CA1-CC2-LGBK | T | W | 1.0 | 1.3 | 1.0 | 0.0 | 0.0 | 1.5 | 0.0 | 0.0 | 0.3 | 3.3 | 3.5 |
| 21 | (Dorado*Tegemeo)-HW10-CA1-CC2-CABK | T | W | 1.0 | 2.3 | 1.0 | 22.2 | 16.7 | 0.5 | 0.0 | 0.0 | 0.2 | 3.0 | 3.2 |
| 22 | (M50009/VG15*TAM428)-HW1-CA1-LGBK-LGBK | T | W | 1.0 | 2.3 | 1.0 | 21.4 | 4.8 | 1.2 | 0.2 | 0.0 | 0.5 | 3.7 | 3.2 |
| 25 | (Tegemeo*WM#322)-CA2-CC2-CABK | T | W | 1.0 | 2.0 | 1.0 | 0.0 | 0.0 | 1.5 | 0.2 | 0.8 | 1.3 | 4.2 | 3.7 |
| 20 | (Dorado*Tegemeo)-HW10-CA1-LGBK-CABK | T | W | 1.0 | 3.3 | 1.1 | 6.7 | 12.0 | 1.2 | 0.0 | 0.0 | 0.3 | 3.3 | 3.5 |
| 1 | Kuyuma | T | W | 2.3 | 1.7 | 1.1 | 8.3 | 9.3 | 0.2 | 2.2 | 0.0 | 0.8 | 3.2 | 3.5 |
| 3 | Macia | T | W | 2.3 | 2.0 | 1.2 | 12.3 | 18.9 | 1.7 | 0.8 | 0.0 | 0.8 | 2.7 | 2.0 |
| 9 | SDSL89426 | T | W | 2.3 | 1.3 | 1.0 | 8.3 | 17.9 | 0.8 | 0.2 | 2.2 | 0.0 | 3.7 | 3.2 |
| 16 | (9MLT176/(MR112B-92M2*Tx2880)*A964)-LG8-CABK-LGBK-LGBK | T | W | 2.3 | 2.3 | 1.0 | 0.0 | 25.0 | 1.5 | 0.7 | 0.0 | 0.0 | 3.8 | 2.2 |
| 17 | (LG35*WM#322)-BE40-LG1-CA1-LGBK-CABK | T | R | 2.3 | 2.0 | 1.0 | 5.5 | 12.2 | 1.2 | 0.0 | 0.0 | 0.0 | 2.5 | 2.7 |
| 24 | (Dorado*Tegemeo)-HG15-CA1-LGBK-CABK | T | W | 2.3 | 2.0 | 1.0 | 0.0 | 11.1 | 1.8 | 0.2 | 0.0 | 0.0 | 4.5 | 3.3 |
| 41 | (5BRON151/(7EO366*GR107B-90M16)*Tegemeo)-HG1-LGBK-CABK | T | R | 2.3 | 2.0 | 1.0 | 0.0 | 21.7 | 1.5 | 0.0 | 0.0 | 0.2 | 1.7 | 2.2 |
| 43 | (6BRON168/6OB172/(88CC445*Tx2862)*Tegemeo)-HG5-CC2-LGBK | T | R | 2.3 | 3.3 | 1.8 | 15.9 | 11.4 | 2.3 | 0.2 | 0.0 | 0.7 | 3.5 | 3.2 |
| 44 | (Tx2883*Tegemeo)-HG17-CC2_LGBK | P | W | 2.3 | 1.3 | 1.0 | 8.3 | 17.9 | 1.8 | 0.0 | 0.0 | 0.8 | 3.8 | 2.3 |
| 47 | (Tegemeo*ICSR-939)-CA6-CC1 | T | W | 2.3 | 3.3 | 1.8 | 15.9 | 11.4 | 2.2 | 0.2 | 0.0 | 0.0 | 3.8 | 3.2 |
| 11 | A964 | T | W | 2.7 | 3.0 | 1.0 | 12.2 | 16.7 | 0.2 | 0.2 | 0.0 | 0.2 | 3.7 | 2.8 |
| 19 | (Dorado*Tegemeo)-HW4-CA1-CCBK-CABK | T | W | 2.7 | 2.0 | 1.9 | 16.7 | 4.8 | 2.0 | 0.3 | 0.0 | 0.0 | 3.5 | 3.0 |
| 26 | (A964*P850029)-BE9-CA1-LGBK | T | W | 2.7 | 3.3 | 1.1 | 21.4 | 4.8 | 0.3 | 1.0 | 0.0 | 0.0 | 3.5 | 3.3 |
| 27 | (A964*P850029)-HW6-CA1-CC1-LGBK | T | W | 2.7 | 1.3 | 1.0 | 0.0 | 20.0 | 0.8 | 0.2 | 0.0 | 0.7 | 4.2 | 4.0 |
| 31 | (Kuyuma*LG35)-CA6-CC2-CABK | T | W | 2.7 | 3.0 | 1.3 | 11.1 | 11.1 | 0.2 | 0.0 | 0.0 | 0.0 | 2.3 | 3.0 |
| 38 | (Tegemeo*ICSB12)-CA12-CC1-LGBK | T | W | 2.7 | 3.3 | 2.2 | 11.1 | 22.2 | 1.0 | 0.2 | 0.0 | 0.2 | 3.2 | 3.5 |
| 42 | (5BRON151/(7EO366*GR107B-90M16)*Tegemeo)-HG7-CC2-CABK | T | W | 2.7 | 2.3 | 1.0 | 0.0 | 0.0 | 1.7 | 0.0 | 0.0 | 1.2 | 2.0 | 2.8 |
| 37 | (Tegemeo*ICSB12)-CA2-CC1-CABK | T | W | 3.3 | 1.3 | 1.0 | 33.3 | 0.0 | 2.3 | 0.2 | 0.0 | 0.0 | 3.3 | 3.5 |
| 10 | EPSON2-40/E#15/SADC | T | W | 3.7 | 1.7 | 1.0 | 4.8 | 25.0 | 0.2 | 1.8 | 0.0 | 1.3 | 3.2 | 2.3 |
| 7 | SRN39 | T | LY | 4.0 | 2.0 | 1.0 | 0.0 | 59.2 | 0.0 | 2.2 | 0.0 | 0.0 | 3.5 | 2.3 |
| 15 | (9MLT176/(MR112B-92M2*Tx2880)*A964)-LG8-CABK-LGBK-CA | T | W | 4.0 | 2.3 | 1.0 | 0.0 | 0.0 | 1.5 | 0.0 | 0.0 | 1.2 | 3.5 | 3.3 |
| 29 | (Tegemeo*5BRON139)-HW15-CA1-LD2-CABK | T | R | 4.0 | 2.7 | 1.0 | 0.0 | 11.1 | 2.2 | 0.0 | 0.0 | 0.2 | 2.8 | 3.3 |
| 30 | (R.88B928*Tegemeo)-HW1-CA1-LGBK-CABK | T | W | 4.0 | 1.7 | 1.2 | 11.1 | 11.1 | 2.3 | 0.3 | 0.0 | 0.0 | 3.7 | 3.3 |
| 32 | (Kuyuma*LG35)-CA10-LGBK-CABK | T | R | 4.0 | 2.3 | 1.3 | 13.3 | 0.0 | 2.2 | 0.2 | 0.0 | 0.2 | 2.5 | 3.7 |
| 33 | (Kuyuma*LG35)-CA12-CC1-LGBK | T | W | 4.0 | 2.7 | 1.0 | 0.0 | 0.0 | 1.5 | 0.0 | 0.0 | 0.3 | 3.7 | 2.2 |
| 36 | (Tegemeo*ICSR-939)-CA7-CC1-CABK | T | W | 4.0 | 2.3 | 1.0 | 0.0 | 22.2 | 2.8 | 0.2 | 0.0 | 0.0 | 3.5 | 3.5 |
| 46 | (Tegemeo*ICSR-939)-CA5-CC2 | T | W | 4.0 | 3.0 | 1.0 | 3.3 | 8.3 | 2.7 | 0.8 | 0.0 | 0.2 | 3.2 | 3.5 |
| 48 | (Tegemeo*ICSR-939)-CA7-CC1 | T | W | 4.0 | 1.7 | 1.1 | 0.0 | 32.2 | 1.8 | 0.5 | 0.0 | 0.3 | 3.7 | 3.0 |
| 50 | (Tegemeo*ICSR-939)-HG2-CC1 | T | W | 4.0 | 1.7 | 2.0 | 0.0 | 15.1 | 1.8 | 0.7 | 0.0 | 0.0 | 3.5 | 2.5 |

**Table 1. (cont'd)** **Sugarcane aphid damage, shoot fly and stem borer infested plants, plant color and grain color, disease resistance ratings in the 2008 Sugarcane Aphid Test, Potchefstroom and Cedara, South Africa and Sebele, Botswana.**

| Source | Designation/Pedigree | Plant Color† | Grain Color‡ | Potchefstroom Seedling Damage§ | Potchefstroom Adult Damage¶ | Sebele Adult Damage¶ | Sebele Shootfly Infested Plants | Sebele Stemborer Infested Plans | Leaf Blight# | Rust# | Zonate# | Anthracnose# | Grain Mold†† | Grain Mold†† |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | % | % | | | | | Cedara | Potch |
| 23 | (Dorado*Tegemeo)-HW15-CA1-CC2-LG1 | T | W | 4.3 | 2.0 | 1.0 | 8.3 | 6.7 | 1.5 | 0.0 | 0.0 | 0.2 | 4.3 | 2.3 |
| 28 | (CE151*Sureno)-HW3-CA1-LG1-CABK | T | W | 4.3 | 1.0 | 1.0 | 0.0 | 44.4 | 0.7 | 0.0 | 0.0 | 0.0 | 3.2 | 3.3 |
| 4 | Tegemeo | T | W | 5.0 | 3.0 | 1.1 | 0.0 | 23.4 | 2.5 | 0.0 | 0.0 | 0.5 | 3.3 | 2.2 |
| 45 | (Tegemeo*ICSR-939)-CA3-CC2 | T | W | 5.0 | 2.0 | 1.0 | 11.1 | 9.7 | 2.3 | 0.0 | 0.0 | 0.0 | 3.8 | 3.2 |
| 49 | (Tegemeo*ICSR-939)-CA10-CC1 | T | W | 5.0 | 1.7 | 1.0 | 5.6 | 44.4 | 0.8 | 0.2 | 0.0 | 1.3 | 3.8 | 3.2 |
| 14 | (9MLT176/(MR112B-92M2*Tx2880)*A964)-CA3-CABK-CCBK-CA | T | W | 5.3 | 2.7 | 1.0 | 33.3 | 13.3 | 1.2 | 0.2 | 0.0 | 0.2 | 2.8 | 2.7 |
| 40 | (5BRON139/(6EO361*GR107-)*Kuyuma)-HG7-LG2-CA BK | T | R | 5.3 | 2.7 | 1.0 | 8.3 | 26.8 | 0.8 | 0.3 | 0.0 | 0.7 | 2.5 | 2.8 |
| 12 | Segaolane | P | W | 5.7 | 4.0 | 2.5 | 25.0 | 12.4 | 1.5 | 0.2 | 0.0 | 0.2 | 3.2 | 3.0 |
| 34 | (Kuyuma*5BRON155)-CA5-CC1-CABK | T | R | 5.7 | 1.7 | 1.3 | 15.0 | 0.0 | 0.7 | 0.0 | 0.0 | 0.7 | 2.8 | 3.2 |
| 39 | (5BRON139/(6EO361*GR107-)*Kuyuma)-HG3-LD2-CA BK | T | W | 5.7 | 2.7 | 1.1 | 22.2 | 0.0 | 0.3 | 0.2 | 0.0 | 0.5 | 3.8 | 1.8 |
| 2 | CE151 | T | W | | | 1.0 | 13.9 | 13.3 | 1.8 | 0.2 | 0.0 | 0.3 | 3.7 | 3.7 |
| | MEAN | | | 3.0 | 2.1 | 1.2 | 9.3 | 13.6 | 1.5 | 0.3 | 0.1 | 0.4 | 3.4 | 3.0 |
| | LSD.05 | | | 2.7 | 1.1 | | | | 0.4 | 0.28 | 0.33 | 0.25 | 0.47 | 0.74 |

†P = purple plant color, T = tan plant color.
‡R = red grain color, W = white grain color.
§ Scored on a scale of 1 = 0-10% leaf necrosis, 2 = 11-25%, 3 = 26-50%, 4 = 51-70%, 5 = 71-90%, 6 = 91-100% leaf necrosis.
¶ Scored on a scale of 1 = 0=10% leaf tissue covered by aphids, 2 = 11-25%, 3 = 26 - 50%, 4 = 51-70%, 5 = 71-90%, 6 = 91-100% leaf tissue covered by aphids.
# Scored on a scale of 0 = no disease symptoms up to 5 = heavy infestation and near total leaf death.
†† Score on a scale of 0 = no grain mold up to 5 = heavy infestation and blackened grain.

**Table 2. Grain yield (tons/ha), sugarcane aphid damage, selected agronomic characteristics and disease evaluation in the 2008 Sugarcane Aphid Yield tests at Potchefstroom and Cedara, South Africa, and Corpus Christi, Texas.**

| PEDIGREE | Plant Color | Grain Color | Potchefstroom Seedling Damage† | Potchefstroom SCA Abundance‡ | Potchefstroom Adult Plant Damage† | Potchefstroom Grain Yield | Corpus Christi Height | Corpus Christi Exsertion | Corpus Christi Midge Damage Rating§ | Corpus Christi Grain Weathering¶ | Leaf Blight# | Sooty Stripe# | Anthracnose# | Grain Mold†† | Grain Mold†† |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | tons/ha | cm | cm | | | | | | Cedara | Potch |
| (SV1*Sima/IS23250)-LG15-CG1-BG2-(03)BGBK-LGK | T | W | 1 | 1 | 1 | 4.40 | 65 | 1 | 9 | 3.5 | 0.8 | 1.7 | 0.5 | 1.8 | 3.5 |
| (Macia*GR128-92M12)-HM20-CA2-CG1 | T | W | 1 | 1 | 1 | 4.02 | 50 | 4 | 4 | 3.5 | 0.3 | 0.8 | 1.2 | 1.7 | 3.5 |
| (SDSL89426*6OB124/GR134B-LG56)-lg5-cg1-(03)BG2-BG1 | T | W | 1 | 1 | 1 | 3.98 | 50 | 0 | 9 | 3.5 | 0.5 | 0.7 | 2.2 | 2.7 | 3.5 |
| (A964*FGYQ336)-LG4-LG2-(03)BG1-BG3-LBK | T | W | 1 | 1 | 1 | 3.95 | 38 | 0 | 6 | 3.5 | 0.2 | 0.3 | 2.3 | 3.5 | 3.5 |
| (SV1*Sima/IS23250)-LG15-CG1-BG2-(03)BGBK-LBK | T | W | 1 | 1 | 1 | 3.94 | 65 | 2 | 7 | 3.5 | 0.5 | 2.0 | 0.3 | 2.2 | 3.5 |
| PAN84201 | P | R | 1 | 1 | 1 | 3.83 | | | | | 2.2 | 1.0 | 0.0 | 2.5 | 3.5 |
| (6OB128/(Tx2862*6EO361)*CE151)-LG4-CG1-(03)BGBK-CCBK-LBK | T | W | 1 | 1 | 1 | 3.80 | | | 9 | 3.5 | 0.2 | 0.8 | 1.7 | 1.8 | 3.5 |
| (CE151*TAM4280)-LG15-LG1-BG1- | T | W | 1 | 1 | 1 | 3.76 | 62 | 4 | 9 | 3.5 | 2.2 | 1.5 | 1.5 | 2.2 | 3.5 |
| (Macia*TAM428)-LL9 | T | W | 1 | 1 | 1 | 3.53 | 42 | 0 | 2 | 3.5 | 1.0 | 1.3 | 1.5 | 1.8 | 3.5 |
| (6BRON171/(7EO366*Tx2783)*CE151)-LG5-CG2-(03)BG1-BG2-LBK | T | LY | 1 | 1 | 1 | 3.50 | 42 | 2 | 7 | 3.5 | 0.0 | 1.7 | 2.2 | 3.0 | 3.5 |
| (Segaolane*WM#322)-CG1-(03)BGBK-CCBK-LBK | RP | W | 1 | 1 | 1 | 3.46 | 50 | 2 | 1 | 3.5 | 1.5 | 2.8 | 1.8 | 3.2 | 3.5 |
| (5BRON131/(80C2241*GR108-90M30)*SDSL9426)-LG6-LG1-BG1-BG2-LBK | T | R | 1 | 2 | 1 | 3.38 | 47 | 4 | 2 | 2.5 | 0.3 | 1.5 | 1.2 | 3.7 | 2.5 |
| (Segaolane*WM#322)-LG2-LG2-(03)BG1-LG1-LBK | RP | W | 1 | 1 | 1 | 3.36 | 55 | 3 | 3 | 3.5 | 1.7 | 1.0 | 0.0 | 3.5 | 3.5 |
| (Macia*TAM428)-LL2 | T | W | 1 | 1 | 1 | 3.35 | 43 | 1 | 7 | 2.5 | 2.3 | 0.3 | 2.0 | 1.8 | 2.5 |
| (6BRON161/((7EO366*Tx2783)-HG54*CE151)-LG1-(03)BGBK-CCBK-LBK | P | W | 1 | 1 | 1 | 3.09 | 40 | 0 | 1 | 2.5 | 1.3 | 1.2 | 2.8 | 3.8 | 2.5 |
| (6BRON161/(7EO366*Tx2783)*CE151)-LG5-CG2-(03)BG1-BG2-LBK | T | LY | 1 | 1 | 1 | 2.79 | 40 | 2 | 7 | 3.0 | 0.3 | 1.7 | 2.7 | 3.2 | 3.0 |
| Tegemeo | T | W | 6 | 3 | 2 | 2.78 | 48 | 1 | 3 | 3.5 | 1.8 | 1.2 | 1.5 | 3.2 | 3.5 |
| Macia | T | W | 6 | 3 | 3 | 2.70 | 50 | 2 | 6 | 3.5 | 0.2 | 0.3 | 2.3 | 3.5 | 3.5 |
| (6OB128/(Tx2862*6EO361)*CE151)-LG16-CG1-LGBK-LG2-LBK | T | R | 1 | 1 | 1 | 2.69 | 41 | 1 | 9 | 3.5 | 0.3 | 2.2 | 2.2 | 1.8 | 3.5 |
| (SDSL89426*6OB124/GR134B-)-LG5-(03)CCBK-CCBK-LBK | RP | WB | 1 | 1 | 1 | 2.63 | 45 | 4 | 2 | 3.5 | 1.8 | 1.3 | 2.7 | 2.2 | 3.5 |
| (6BRON161/(7EO366*Tx2783)-HG54- | T | W | 1 | 1 | 1 | 2.61 | 47 | 2 | 9 | 3.5 | 0.2 | 1.3 | 2.0 | 1.8 | 3.5 |
| (6OB128/(Tx2862*6EO361)*CE151)-LG19-(03)CCBK-CCBK-LBK | T | W | 1 | 1 | 1 | 2.60 | 26 | 0 | 6 | 3.5 | 1.8 | 1.5 | 1.8 | 3.2 | 3.5 |
| (6BRON126/((87BH8606-14*GR107-90M46)-HG10)*CE151)-CG1-(03)BGBK-CCBK-LBK | T | W | 1 | 1 | 1 | 2.31 | 43 | 3 | 3 | 3.5 | 1.0 | 2.2 | 2.0 | 2.8 | 3.5 |
| (EPSON2-40/E#15-SADC*TAM428)-LG3-BG1-BG1-LBK | T | W | 1 | 1 | 1 | 2.07 | 38 | 1 | 5 | 3.5 | 0.2 | 2.3 | 0.2 | 3.5 | 3.5 |
| (CE151*TAM428)-LG1-(03)BGBK-CCBK-LBK | RP | W | 1 | 2 | 1 | 1.68 | 42 | 0 | 8 | 3.5 | 0.8 | 1.3 | 0.2 | 1.5 | 3.5 |
| Mean | | | 1.4 | 1.3 | 1.2 | 3.20 | | | | | 0.9 | 1.4 | 1.5 | 2.6 | 2.4 |
| LSD.05 | | | 0.20 | 0.50 | 0.50 | 1.30 | | | | | 0.6 | 0.6 | 0.4 | 0.5 | 0.73 |

† Scored on a scale of 1 = 0-10% leaf necrosis, 2 = 11-25%, 3 = 26-50%, 4 = 51-70%, 5 = 71-90%, 6 = 91-100% leaf necrosis.
‡ Scored on a scale of 1 = 0=10% leaf tissue covered by aphids, 2 = 11-25%, 3 = 26 - 50%, 4 = 51-70%, 5 = 71-90%, 6 = 91-100% leaf tissue covered by aphids.
§ Scored on a scale of 1 = 0-10% aborted kernels, 2 = 11-20% aborted kernels, up to 9 = 81-100% aborted kernels.
¶ Scored on a scale of 1 = Seed bright, free from mold damage, 2 = Moderately resistant to mold and seed slightly discolored, 3 = Moderately susceptible and considerable seed discoloration, 4 = susceptible with extensive seed discoloration and deterioration, 5 = Very susceptible with extensive seed deterioration.
# Scored on a scale of 0 = no disease symptoms up to 5 = heavy infestation and near total leaf death.
†† Score on a scale of 0 = no grain mold up to 5 = heavy infestation and blackened grain.

**Table 3. Leaf blight, anthracnose and grain mold ratings for entries in the ADIN at Cedara, KwaZulu-Natal, South Africa.**

| Entry | Designation | Plant Color† | Grain Color‡ | Leaf Blight | Anthracnose | Grain Mold |
|---|---|---|---|---|---|---|
| 1 | B35 | P | LY | 0.30 | 0.00 | 4.50 |
| 2 | SC326-6 | P | W | 0.00 | 0.00 | 4.00 |
| 3 | SC414-12E | P | W | 0.50 | 0.00 | 4.30 |
| 4 | 86EON361 | T | W | 1.80 | 0.80 | 2.80 |
| 5 | Tegemeo | T | W | 0.30 | 0.30 | 1.80 |
| 6 | Macia | P | W | 0.00 | 0.50 | 3.00 |
| 7 | Tx2880 | P | W | 1.30 | 1.00 | 4.50 |
| 8 | Tx2911 | P | R | 2.00 | 1.30 | 2.80 |
| 9 | Malisor 84-7 | T | W | 0.30 | 0.80 | 2.30 |
| 10 | SRN39 | T | R | 1.80 | 0.30 | 3.80 |
| 11 | Sureno | T | W | 1.80 | 0.00 | 2.30 |
| 12 | Tx436 | T | W | 1.30 | 0.00 | 3.80 |
| 13 | Tx2783 | P | R | 2.80 | 0.30 | 2.80 |
| 14 | BTx635 | T | W | 2.00 | 0.80 | 2.00 |
| 15 | BTx623 | RP | W | 2.30 | 0.00 | 3.30 |
| 16 | BTx631 | T | W | 0.80 | 0.30 | 3.80 |
| 17 | Tx430 | P | W-YE | 1.80 | 0.00 | 3.50 |
| 18 | TAM428 | P | W | 1.80 | 0.00 | 1.80 |
| 19 | Tx7078 | P | R | 2.80 | 0.00 | 4.50 |
| 20 | BTx378 | P | R | 0.80 | 0.00 | 4.30 |
| 21 | 99GWO92 | T | R | 0.00 | 0.30 | 3.80 |
| 22 | B.HF14 | T | W | 1.00 | 0.00 | 3.50 |
| 23 | B.LD6 (wxy) | T | W | 0.30 | 1.30 | 3.80 |
| 24 | 02CA4624 | T | W | 0.00 | 1.00 | 4.30 |
| 25 | Tx2963 | T | R | 0.00 | 1.80 | 2.80 |
| 26 | Tx2961 | T | R | 0.00 | 1.30 | 3.30 |
| 27 | Tx2957 | T | W | 0.80 | 1.38 | 2.30 |
| 28 | Tx2950 | T | R | 1.00 | 0.30 | 2.00 |
| 29 | Tx2952 | T | R | 1.00 | 0.50 | 2.50 |
| 30 | Tx2955 | T | R | 0.00 | 0.80 | 3.00 |
| 31 | 01BRON186 | T | W | 0.30 | 0.00 | 3.30 |
| 32 | 01BRON195 | T | W | 1.80 | 0.30 | 4.50 |
| 33 | 03BRON172 | T | R | 2.30 | 0.80 | 3.30 |
| 34 | 04BRON267 | T | R | 1.30 | 0.00 | 2.30 |
| 35 | 04BRON275 | T | R | 1.80 | 0.00 | 3.50 |
| 36 | R.01122 | T | R | 3.50 | 0.00 | 2.50 |
| 37 | R.01302 | T | R | 2.80 | 0.30 | 3.00 |
| 38 | R.02107 | T | R | 2.50 | 0.80 | 4.30 |
| 39 | R.04060 | P | R | 2.50 | 0.80 | 4.30 |
| 40 | R.04064 | T | R | 2.00 | 0.00 | 0.80 |
| 41 | R.04153 | T | R | 2.00 | 0.30 | 3.00 |
| 42 | B.9883 | T | W | 0.30 | 0.50 | 4.00 |
| 43 | B.01021 | P | R | 2.80 | 0.00 | 1.80 |
| 44 | B01035-CS2-WF1 | T | W | 2.00 | 0.00 | 3.30 |
| 45 | B01046-CS2-WF2 | P | W | 3.00 | 0.50 | 2.80 |
| 46 | B.01067 | P | R | 2.80 | 0.80 | 3.30 |
| 47 | B.01074-CS2-WF1 | T | R | 2.50 | 0.30 | 3.00 |
| 48 | B.01362 | T | W | 1.30 | 0.00 | 3.50 |
| 49 | B.03289bmr | T | W | 1.00 | 1.00 | 2.80 |
| 50 | B.03290bmr | T | W | 0.00 | 1.30 | 4.30 |
| | Mean | | | 1.40 | 0.40 | 3.20 |
| | LSD (P>0.05) | | | 0.66 | 0.43 | 0.83 |

† P = purple; RP = reddish-purple; T = tan.
‡ R = red; W = white; W-YE = White-yellow endosperm; LY = lemon yellow

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


## Bruce Hamaker and Bonnie Pendleton
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### Introduction and Justification

Multi-agency, multi-disciplinary teams of agronomists, entomologists, food scientists, plant breeders, plant pathologists, poultry scientists, extension educators, and others from Burkina Faso, Mali, Niger, Nigeria, Senegal in West Africa are developing, evaluating, and transferring technologies to improve production and marketing of sorghum and pearl millet and manage *Striga*. Agronomic and pest management technologies include use of resistant cultivars, crop rotation, intercropping, fertilizer, and herbicides to manage such pests as anthracnose and other diseases, millet head miner, sorghum midge, panicle bugs, stalk borers, storage weevils, and *Striga*. FAO estimates $7 billion annual crop losses from *Striga* that affects 100 million people in Africa. Losses of 10-100% occur and result in abandonment of arable land. Pest-resistant cultivars and improved crop, soil, water, and pest management will reduce pesticide use, conserve soil and water, more efficiently use fertilizer, and increase food and feed for domestic use and income from marketing. Development and adoption of high-yielding, quality sorghum and millet with increased nutritional value can improve nutrition and health. Work in the marketing sector links farmers to output markets involving assistance to cereal processors to develop high quality, competitive products for urban consumers and advancing sorghum and millet for poultry feed and broiler operations. Partnerships among host-country scientists, NGOs, international agencies, extension, and farmers will ensure transfer of technologies for improved agricultural production and marketing. Greater, more stable yields will better the livelihood of people dependent on sorghum and millet and help end hunger in Africa by increasing farm incomes and agricultural development.

### Objectives and Implementation Sites

This regional program with collaboration among scientists at Institut D'Economie Rurale (IER) in Mali, Institut National de la Recherche Agronomique du Niger (INRAN) in Niger, INERA and IRSAT in Burkina Faso, Institut Sénégalais de Recherches Agricoles (ISRA) and Institut de Technologie Alimentaire (ITA) in Senegal, the Lake Chad Research Institute and University of Maiduguri in Nigeria, universities in the US, volunteer organizations, and private industries is contributing to INTSORMIL objectives to facilitate markets; improve food and nutritional quality to enhance marketability and consumer health; increase stability and yield through crop and natural resources management; develop and disseminate information on stresses to increase yield and quality; enhance stability and yield through genetic technologies; and better the lives of people dependent on sorghum and pearl millet.

Ababacar N'Doye, food scientist for ITA, Senegal, coordinate the processing and marketing systems component of Project 1 "Increasing farmers' and processors' incomes via improvement in sorghum, pearl millet, and other grain production, processing, and marketing systems" that focuses on processed food and animal-feed markets and their expansion through development of high-quality, competitive millet and sorghum-processed products and expanded use of sorghum in poultry feed. The overall goal is to enhance urban markets for improved and hybrid sorghum and millet cultivars for farmers to sell surplus grain with emphasis on development and transfer of food technologies to farmers, NGOs, and food processing and marketing entrepreneurs and consumers.

Mamourou Diourte, plant pathologist for IER in Mali, coordinates the production component of Project 1. The goals are to: 1) disseminate the best existing cultivars in combination with fertilizer and other crop management options; 2) identify storage pests and control measures to manage grain harvesting and storage practices; 3) develop base populations of adapted sorghum and millet cultivars resistant to pests and drought; and 4) generate new dual-purpose varieties and hybrid parental lines adapted to target environments.

Hamidou Traore with INERA in Burkina Faso is coordinator for Project 2 "Integrated *Striga* and nutrient management for sorghum and pearl millet." The goals of Project 2 are to identify and characterize *Striga*-resistant sorghum and millet; characterize and implement integrated *Striga* management systems for millet that incorporate fertilizer and crop rotation or intercropping millet and cowpea; characterize and implement integrated *Striga* management systems for sorghum rotated with cotton; assess effects of herbicidal seed treatments on crop performance and *Striga* management; evaluate ALS-resistant genotypes; and transfer *Striga* control methods to increase yield of sorghum and millet and the incomes of farmers across West Africa.

## Research Methodology and Strategy

The processing and marketing systems component of Project 1 coordinated by Ababacar N'Doye, food scientist from Senegal, involves food scientists Boniface Bougouma from Burkina Faso, Iro Nkama from the University of Maiduguri in Nigeria, Moussa Moustapha and Kaka Saley from Niger; and Salissou Issa, poultry scientist from Niger. The project focuses on processed food and animal-feed markets and their expansion through development of good-quality, competitive millet- and sorghum-processed products and greater use of sorghum in poultry feed. Activities focus on processed products that contribute to development of markets for sorghum, millet, and fonio by development and transfer of technologies to entrepreneurs. Technologies for production of breads and other products based on sorghum, millet, and fonio will be diffused; local processing groups will be assisted to diffuse new processing technologies and initiate businesses; and sorghum, millet, and fonio will be characterized as "functional foods" for health. Additionally, research from Purdue University has shown the potential of using sorghum grain proteins as active viscoelastic components of composite bread so that sorghum flour can be incorporated at high levels with wheat flour. The goal is to have new competitive composite flours and other products in the marketplace. For animal feed, use of sorghum in poultry feed in West Africa is being validated and education provided on availability of low-tannin varieties and aflatoxin-free sorghum grains, with the goal to increase use of sorghum grain for poultry.

The production component of Project 1 is coordinated by Mamourou Diourte, plant pathologist in Mali, and involves pathologist Adama Neya in Burkina Faso; agronomists Jean B. Taonda in Burkina Faso, Abdoul Wahab Toure in Mali, and Seyni Sirifi in Niger; entomologists Niamoye Yaro Diarisso in Mali and Hame Abdou Kadi Kadi in Niger; and plant breeders Niaba Teme in Mali, Souley Soumana in Niger, N'Diaga Cisse in Senegal, and Ignatius Angarawai at Lake Chad Research Center in Nigeria. The scientists are using seed multiplication, on-farm testing, and exchange of varieties of sorghum and millet with the goal of disseminating the best cultivars in combination with fertilizer and other crop management options such as legumes in crop rotations and crop protection options. They also are identifying storage disease and insect pests and control measures. They are developing base populations of cultivars of sorghum and millet with known adaptation, stability, and acceptability through multi-environment experiments and resistance to pests and drought. They are using conventional and/or marker-assisted recurrent selection to generate adapted dual-purpose varieties, open-pollinated varieties, and hybrid parental lines.

Project 2 on "Integrated *Striga* and nutrient management for sorghum and pearl millet" is coordinated by Hamidou Traore from Burkina Faso. Involved are Mountaga Kayentao from Mali, Nouri Maman and Souley Soumana from Niger, and Moctar Wade from Senegal. The scientists are identifying *Striga*-resistant sorghum and millet; combining and implementing methods such as fertilizer, rotation of sorghum with cotton, and intercropping millet and cowpea to control *Striga*; evaluating herbicidal seed treatments; evaluating ALS-resistant genotypes; and transferring control technology packages for farmers.

## Research Results

Funds were not distributed to the scientists under the new project until May 2008. Most sorghum and millet will not be mature or harvested until October or later, so yield data were not yet available.

### *Project 1 - Increasing Farmers' and Processors' Incomes Via Improvement in Sorghum, Pearl Millet, and Other Grain Production, Processing, and Marketing Systems*

For the processing and marketing component of Project 1, Moustapha Moussa reported 1.5 tons of Sepon 82 and MR732 sorghum grains obtained from INRAN Maradi 2007 sorghum nursery production and 1 ton of millet grain purchased from the market by processing groups were processed to quality sorghum flour and agglomerated products (couscous, degue and boulettes) using the optimized cereal processing pilot unit at the INRAN food technology laboratory through funding from INTSORMIL. Four women's associations (Marie Tout, Lakal Kaney, Multimetiers, and Eden) with 20 members each that process and market sorghum and millet foods in Niamey were involved. After testing for quality and safety, 2 tons of sorghum and millet products (flour, couscous, degue, and boulettes) were marketed with collaboration of processors working with the project.

INRAN contracted with 2 farmers at N'Konni and 1 at Maradi to grow 15 tons of good-quality grain of SS-D35, Sepon 82, and IRAT204 sorghum for making agglomerated products, instant flour, and composite bread. The grain will soon be harvested, processed, and marketed with the collaboration of the processing groups involved in the project. INRAN scientists are training sorghum- and millet-based processing groups in Niamey in processing and business planning to help develop and expand processing activities.

At ITA in Senegal, the baking group tested a sorghum high digestible mutant developed at Purdue in composite flour breads. This grain has the storage protein, kafirin, in a form whereby proteins can interact with wheat glutens. Initial testing shows a potential to mobilize the kafirin proteins to participate in dough and bread development. Further testing is ongoing between ITA and Purdue laboratories.

For the production component of Project 1, Hame Abdou Kadi Kadi in a survey with 290 men and 30 women farmers from 16 villages in 2 regions, 14 extension agents, and 4 interns from University Abdou Moumouni of Niamey, identified storage insects, evaluated facilities, and assessed botanicals and cultural methods to prevent damage to millet and sorghum. The storage facilities differed by region; Andropogon was used for cylindrical granaries covered with grass at Maradi and bricks with grass were used at Tahoua. Dry spikes and/or panicles were stored. Grain was stored in barrels, burlap bags, plastic bags, and storage houses. (Table 1)

Niamoye Yaro Diarisso in Mali assisted farmers with evaluating Andropogon gayanus in 3 border rows 50 cm apart and 30 cm between plants on 7 and 8 July 2008 at Finkolo and Zanradougou, respectively, in the Sikasso region of Mali, to draw stalk borers away from millet. Andropogon was selected based on use and economic return by farmers during a Participatory Rural Appraisals and Structured Socio-economic Survey. Andropogon was attractive to stalk borers and/or parasitoids in a study funded by UNEP through ICIPE. A randomized complete block with 5 farms was used. Millet was planted on 17 and 18 July in 15 x 10-m plots 2 m apart at Zanradougou and Finkolo. Millet was surrounded by Andropogon or millet (check). Pests and natural enemies were sampled on 10 plants of millet and Andropogon 30, 70-80, and 100-110 days after emergence. Percentage of deadhearts and numbers of larvae and pupae were determined on 6 and 7 September 2008, 30 days after emergence at Zanradougou and Finkolo. Damage was greater at Finkolo than Zarandougou. Millet was less damaged surrounded by Andropogon (1.7%) than millet (5.3%). Damage scores were 5.8, 4.4, and 1.7 for millet surrounded by millet, Andropogon, and millet surrounded by Andropogon, respectively, at Finkolo. Damage scores at Zanradougou were 4.7 for millet surrounded by millet, 2.2 for Andropogon, and 1.7 for millet surrounded by Andropogon. Damage will be assessed again at harvest. (Table 2)

Hame Abdou Kadi Kadi, with help from Dr. Kadri Abooubacar and an intern from the University Abdou Moumouni of Niamey, evaluated at Kollo resistance to millet head miner of millet developed with Issaka Ahmadou, INRAN millet breeder. Genotypes were HKB, H 80-10 GR, TARAM, SOSAT–C, MANGARANA, HKP-GMS, ICMV IS 89305, ZATIB, MANGARANA x ICMV IS 89305, SOSAT-C x HKB, SOSAT-C x ZATB, and TCHOUMO. A completely randomized block with 3 replications was used. Each sub-plot 12 m2 had 4 rows 3 m long, with 1 m between rows and 1 m between hills. The millet was not harvested and yield data not available yet.

Hame Abdou Kadi Kadi helped introduce sorghum midge-resistant 99-SSD35 and its parent Mota Maradi (early maturing from Niger) at farms in 5 villages of 2 regions of Niger. The activity involved 4 extension agents, 12 men and 4 women farmers from 4 villages and a farmer's association ("TAYMAKO") of 74 men and 6 women. The group conducted 4 tests with 2 planting dates at 1 site. The group is eager to continue testing and be involved in seed production. Farmers are producing SSD35 in many fields at 1 site. The farmers' association and FAO grew 60 and 30 hectares of 99-SSD35 to give to farmers. The sorghum was not harvested and yield data are not available yet.

Mamourou Diourte reported results from preliminary evaluation in an anthracnose nursery in Mali indicated only 07CZF5P-56, 07CZF5P-11, 07SIRF5P-143, 07KEGIIT-122, 07SBF3DT-64, and 07SIRF5T-16 of the 45 breeding accessions scored no more than 5% (less than 2 on a 1-9 scale) of foliar disease severity at physiological maturity. Almost all 45 accessions are fairly resistant.

The ongoing crossing program in Mali assures improvement of breeding stock through recombination of the best materials. Crosses were made at Sotuba. New crosses will be made in the off-season nursery. Crossing will be done to maintain A/B lines.

Single-plant selections of F2 families at multiple locations in Mali were advanced by the pedigree method. A total of 34 F2, 201 F4, and 210 F5 progeny lines was evaluated. Early F4 progenies were evaluated at Béma and Cinzana, medium at Sotuba and Kolombada, and late at Farako and Kita. Early F5 were selected at Béma and Cinzana and late at Longorola and Kita.

Advanced elite early varieties were evaluated in a randomized complete block at Bema and Cinzana in Mali. Each plot had 4 rows 0.75 m apart and 5 m long. Farmers compared 20 early-maturing sorghums to a local check. Each plot was 500 m2 with rows 0.75 m apart and 5 m long. Yield of 25 GI and 18 GII agronomically elite, medium-maturing varieties and local check were evaluated in a randomized complete block at 3 stations in the Sudan Zone of Mali. Each plot was 4 rows 0.75 m apart and 5 m long. Ten medium-maturing breeding lines were compared to local checks by farmers at Bancoumana and Kafara and at Katibougou station. Each plot was 22.5 m2; 6 rows were 0.75 m apart and 5 m long. Yields of 23 agronomically elite, late-maturing breeding lines and 3 local checks of GI and 20 lines and 2 local checks for GII were evaluated at 3 locations in a randomized complete block in Mali. Each plot had 4 rows 0.75 m apart and 5 m long. Seven late-maturing varieties were compared by farmers to the local check at Kita. Each plot was 21 m2, with rows 0.75 m apart and 5 m long. At harvest, the cultivars will be evaluated for maturity, yield, agronomic desirability, and food quality.

**Table 1.**

| Pest | Botanical plant/method of use | Inert |
|---|---|---|
| Grain moth, Sitotroga | Cowpea, Vigna inguiculata, leaves repulse storage pests; | Ash, |
| cereallella; | Zouray, Boscia Salicifolia, leaves under spikes or panicles during drying, | |
| Confused flour beetle, | leaves superposed between tied spikes or panicles within granary; | Salt, |
| Tribolium confusum; | Yakuwa, Hibiscus sabdariffa,leaves and branches pounded and put on | |
| Red flour beetle, | granary poles; | Ash and |
| Tribolium castaneum; | Karanguia, Cenchrus biflorus, spiny fruit used on path of mice and rats; | salt mix |
| Lesser grain borer, | Komeya, Erasgrostis tremula, threading of the superior part of Erasgrotis | to control |
| Rhyzopertha dominica; | and superposed between tied spikes or panicles in granary; | termites |
| Grain trogoderma, | Dorowa, Parkia biglobos, fruit pounded and powder used around granary | and ants, |
| Trogoderma granarium; | poles; | |
| Flour pyralid, Ephestia | Rumfu, Cassia singueana, and neem, Azadirachta indica, flowers of | Fine sand, |
| kuehniella; | Cassia and leaves of neem mixed with seeds of cereals; | |
| Birds; | Houda Sartche, Caralluma dalzielli, leaves and branches pounded and put | Sun |
| Mice; | in granary poles; | drying |
| Rats; | Onion, Allium cepa, and garlic, Allium sativum, powder to prevent | |
| Mold; | damage | |
| Humidity | | |

**Table 2.**

| Village | Farmer | % vegetative plants with deadhearts by stalk borers | | |
|---|---|---|---|---|
| | | Millet surrounded by *A. gayanus* | Millet surrounded by millet | *Andropogon gayanus* |
| Finkolo | Diakalia BALLO | 1.5 | 10.3 | 2.0 |
| | Issouf BALLO | 1.5 | 4.3 | 3.0 |
| | Abdoulaye KONE | 2.8 | 5.2 | 5.5 |
| | Seybou KONE | 2.3 | 6.6 | 7.1 |
| | Oumar TRAORE | 0.5 | 2.5 | 4.6 |
| Zanradougou | Nouhoum DJOURTHE | 3.7 | 0.0 | 1.2 |
| | Siaka DJOURTHE | 0.0 | 12.5 | 3.0 |
| | Tidiani SANOGO | 1.5 | 1.5 | 2.4 |
| | Adama SONOGO | Plants damaged by animals | | |
| Mean damage | | 1.7 | 5.3 | 3.6 |

Grinkan caudatum-guinea sorghum distributed to 42 farmers in Kaniko village in Mali was extremely infested by panicle bugs but had hard grain and was not damaged. The sorghums are not mature or ready to harvest yet.

N'Diaga Cisse from Senegal reported that Foundation seeds of CE151-262 and F2-20 sorghum varieties were produced and harvested by ISRA in October 2007. The seeds were made available for certified seed production to ANCAR, EWA, and CPFP organizations that are respectively an extension service, a NGO, and a training center for producers. CPFP produced CE151-262 on 1hectare during 2008. The field was visited by 44 producers from 10 farmer organizations. One ton of seed will be distributed to seed producers for a second production before large-scale production. EWA distributed CE151-262 and F2-20 to 3 cooperatives it organized. These varieties were planted on 7 and 1 hectares, respectively. As many as 10,000 farmers can benefit from multiplication of seeds of these sorghums. Seeds of F2-20 produced on 4 hectares this season with ANCAR supervision will be available to farmers' communities participating in the INTSORMIL production and marketing project. The F2-20 seeds produced last year were used for the program this year.

Yields of 52 new sorghum lines to improve quality of current varieties were evaluated by ISRA at Bambey Station. Lines with good yield potential (3-4 tons per hectare) were observed. The lines were divided into 3 maturity classes: less than 65, 65-69, and more than 70 days to flowering. These classes had 15, 20, and 20 entries, respectively, and were introduced in 3 experiments at Bambey and Nioro stations. The plants are now being harvested, and yield data soon will be available.

S. J. B. Taonda, agronomist for INERA in Burkina Faso, trained technicians of the Hunger Project NGO and farmers in technology of micro-dose; technical characteristics and techniques for using improved varieties of sorghum, millet, and cowpeas in tests; and warrantage. The training scheme involved indigenous resource people who diffused the technology in their core communities. After the courses by the research team, a research technician was assigned to provide supervision to the village. Farmers trained in the field school plots transmitted knowledge and skills to at least other 4 farmers. Two endogenous leaders were identified to benefit training of trainers and technicians of the Hunger Project. They effectively train other farmers. (Table 3)

Following the project, the Hunger Project NGO took over and asked for research expertise to continue to train farmers for adoption of micro-dose technology in all agricultural areas of Burkina Faso. (Table 4)

Twenty tests were used in 2008 at Nagreongo, Burkina Faso, to compare Sariasso11 and local "Raoumdé" sorghum varieties in combination with no or micro-dose of 15:15:15 NPK fertilizer. Following training, farmers with their own funds or financial support through implementation of the new warrantage system of micro-credit from the Hunger Project adopted micro-dose technology in fields at Nagreongo. (Table 5)

Adama Neya, plant pathologist for INERA in Burkina Faso, was involved in: (a) advanced screening sorghum lines/varieties for disease resistance; (b) a field day; (c) using on-farm tests to transfer new technologies to farmers; (d) and training farmers and technicians. An advanced screening experiment was started in July 2008 at Farako-Ba using the 6 best sorghum lines from the INERA breeding program and 5 best lines from the Mali breeding program. Most sorghum lines had good resistance to diseases under natural and high disease pressure (using susceptible infector rows).

A Field Day at Farako-Ba Station in Burkina Faso in October 2007 demonstrated 7 improved varieties (Framida, Sariaso 01, Sariaso 02, Sariaso INI-20, Sariaso INI-24, ICSV 111, and Sariaso 03) and the effect of seed treatment with Calthio DS chemical against cover smut on sorghum. More than 160 people (farmers,

**Table 3.**

| Training theme | Participants | | |
|---|---|---|---|
| | Male | Female | Total |
| Micro-dose technology | 79 | 71 | 150 |
| Characteristics and technical itinerary of sorghum, millet, and cowpea improved varieties | 80 | 72 | 152 |
| Warrant credit system (negotiation, purchase, storage techniques, maintenance of stock, credit monitoring) | 82 | 28 | 110 |
| Field day | 104 | 80 | 184 |
| TOTAL | 345 (58%) | 251 (42%) | 596 (100%) |

**Table 4.**

| Province/zone | Epicenter/site | Participants | | |
|---|---|---|---|---|
| | | Male | Female | Total |
| Bam (Kongounssi) | Loaga | 64 | 36 | 100 |
| Gourma (Fada) | Diapangou | 44 | 16 | 60 |
| Balé (Boromo) | Vy | 48 | 22 | 70 |
| Boulgou (Tenkodogo) | Bissiga | 38 | 22 | 60 |
| Houet (Bobo) | Yéguérésso | 68 | 32 | 100 |
| Kouritenga (Koupéla) | Liguidimalguem | 32 | 28 | 60 |
| TOTAL | | 294 | 156 | 450 |
| Percentage | | 65 | 35 | 100 |

**Table 5.**

| Village | Crop | Number of farmers | Cultivated land (hectares) |
|---|---|---|---|
| Nahartenga | Sorghum | 36 | 53 |
| | Millet | 28 | 27 |
| Nagreongo | Sorghum | 72 | 150 |
| | Millet | 52 | 78 |
| Tanghin | Sorghum | 30 | 44 |
| | Millet | 22 | 11 |
| V2 | Sorghum | 44 | 48 |
| | Millet | 16 | 8 |
| V5 | Sorghum | 86 | 160 |
| | Millet | 54 | 84 |
| Saraogo | Sorghum | 38 | 58 |
| | Millet | 22 | 36 |
| Kologkoom | Sorghum | 24 | 14 |
| | Millet | 20 | 12 |
| TOTAL | | 544 | 783 |

students, processors, extension workers, and leaders of farmer`s organizations) viewed the plots. The same plot was used at Farako-Ba to transfer new technologies to end-users in July 2008.

Since July 2008, a technology transfer test was used in Karangasso-Vigueé and Klesso villages in western Burkina Faso to show performance of 4 white improved sorghum varieties (Sariaso 01, Sariaso INI-20, Sariaso INI-24, and ICSV111) and seed treatment with Calthi WS to control seed-borne diseases. More than 260 people, mostly farmers and extension workers, visited the on-farm tests. All are willing to adopt the new improved sorghum varieties. They will be provided seed for the next rainy season. In May 2008, 3 extension agents and 32 farmers from Karangasso-Vigué, Bio, Bio-Djosso, Wara, and Klesso villages in western Burkina Faso were trained in impact and control of diseases of sorghum and millet. Production and control were by improved varieties and chemical treatment by Apron Star against downy mildew of millet and Calthio WS against covered smut on sorghum. Activities are on-going to identify methods to control storage pests on farms.

A student from the Polytechnic University of Bobo Dioulasso in Burkina Faso was trained for 2 months in the plant pathology laboratory at Farako-Ba in using laboratory tests for chemical control of sorghum seed-borne diseases.

Ignatius Angarawai, millet breeder with Lake Chad Research Institute in Maiduguri, Nigeria, worked to improve productivity and yield stability of millet in semi-arid zones of Nigeria that will spill over to neighboring West African countries. He identified SOSAT-C88 as resistant to downy mildew. Hybrid 25B-4 X SOSAT-C88 was very resistant to downy mildew and may be advanced. He identified PS563 monodii as a source of a *Striga* resistance gene and deployed it to the Ex-Borno cultivar. He found the hybrid of Ex-Borno x PS563 very resistant to *Striga* emergence. It was backcrossed to BC3F1. Results were disseminated in on-farm experiments, with 17 experimental varieties for selection by farmers in 12 villages each with an average of 200 farm families.

### *Project 2 – Integrated Striga and Nutrient Management for Sorghum and Pearl Millet*

For Project 2, Souley Soumana reported effects of herbicidal seed treatments on crop performance and *Striga* management at Sotuba and Samanko in Mali, Konni in Niger, and Kamboinse in Burkina Faso. ALS-herbicide tolerant, food-grade sorghum was evaluated in replicated experiments with metsulfuron-methyl seed treatments in *Striga*-infested plots. The experiment was a randomized complete block with 6 replications. Treatments were evaluated in single-row plots (3 x 1.6 m). Ten seeds of sorghum and *Striga* seeds were planted per hill. Traits measured for each plot were: day when the first *Striga* emerged, numbers of *Striga* plants at 60 days and 90 days after planting, and day when 50% of sorghum was flowering. Treatments were: 0, 0.003, 0.006, 0.0125, and 0.025 mg ai MET/seed.

Souley Soumana also helped characterize the most resistant sorghum varieties in the region and develop and transfer an integrated *Striga* management system for guinea sorghum and non-guinea zones of West Africa. Fifteen genotypes provided by the PIs were evaluated at IER, Sotuba, Mali; Konni, INRAN, Niger; Bambey, Senegal; Kamboinse, Burkina Faso; and ICRISAT, Mali. Genotypes were F220, CEF322/35-1-2, SARIASO-14, SARIASO-9, ICSV1049, SRN-39, Brhan, Mota Galmi, WASSA, SEGUETANA, CSM388, Malisor 92-1, Linea3, CE145-66-V, and SL246. A randomized complete block with 3 replications in 1-row plots 3 x 1.6 m was used. The same data as for the herbicide seed treatment will be collected.

Sorghum breeding lines from SRN-39 or Brhan that combine tolerance to ALS herbicides with resistance to Striga were evaluated. Sixty ALS herbicide-resistant genotypes that segregate for low-germination stimulant production were evaluated in 1-row plots (3 x 1.60 m) with 2 replications. The same data as for the *Striga* experiment will be collected.

Sorghum for the 3 experiments was planted on 30 June at Konni Station in Niger. Plants were thinned to 3 on 20 July. To ensure uniform infestation, 0.55 g of *Striga* seed collected from the previous year were planted with the sorghum seeds in each hill. Plots were hand-weeded to control non-target weeds 14 and 30 days after planting and as needed later. *Striga* was counted on 29 August and 30 September in all plots.

During 2008, more than 200 F1 are being grown to produce F2 seeds in Niger. The F3 and F4 generations were evaluated and selections advanced by the pedigree method. The backcross program was continuous for development of new adapted A lines. Seeds of parental lines of N223A*N223B, TX623A*TX623B, and 150A*150B were increased.

In Mali, advanced sorghum breeding lines were evaluated under artificial infestation by *Striga*. Six replications of 4 doses of herbicide and a check were used to evaluate the effectiveness of herbicide doses in treating sorghum seed against *Striga* at Sotuba. To develop an IPM package to control *Striga* in different agroecological zones of West Africa, 15 genotypes from Burkina Faso, Mali, Niger, Senegal, and ICRISAT Bamako were grown with 3 replications at Sotuba. Sixty lines derived from SRN39 and Brhan sorghum tolerant to herbicide resistance to *Striga* were grown at 2 research stations. *Striga* plants per plot were estimated 60 and 90 days after planting. In general, infestation by *Striga* was low probably because of sufficient rain during 2008. The sorghum plants have not been harvested yet.

Moctar Wade from Senegal reported the extent and intensity of infestations by *Striga* hermonthica have increased and threaten production of cereals in the peanut belt. A Farmers' Field School was used for participatory diffusion of integrated *Striga* management. During 2008, a Farmer Field School was implemented in one field-school village (Tounghor) 30 km from Bambey. Extension workers previously trained in Farmer Field School techniques (2005 and 2006) acted as facilitators. The facilitators held a field school once per 15 days.

Three plots 400 m² were delimited in a field naturally infested by S. hermonthica: one for the innovations suggested for integrated *Striga* management (Souna millet with 2.5 tons/hectare of sheep or goat organic manure, 150 kg/hectare NPK, 100 kg/hectare of urea, and mechanical weeding at 15, 35, and 65 day after planting), another for usual farmer practices (Souna millet and mechanical weeding at 15 and 35 days after planting), and the third for niébé IS86-283:Mélakh false host (suicidal germination) of *Striga*.

Weekly activities at the Farmer Field Schools were: (1) agroecosystem analysis, (2) implementation of agroecosystem analysis decisions, (3) special topics, (4) data collection, (5) icebreaker, (6) evaluation, and (7) planning for the Farmer Field School the following week. In addition to the 2 weekly Farmer Field Schools, exchange visits were organized between farmers to allow those from other villages to find solutions to their *Striga* problems through the Farmer Field School and confront their knowledge and exchange experiences in *Striga* control and agricultural production. There were 27 participants from 5 villages. Thirty non-participant farmers from other villages visited the Farmer Field School experiments. The program made farmers better able to understand the *Striga* life cycle (germination to flowering and seed production); understand cereals and false host cropping and *Striga* management strategies for more sustainable production; understand how false hosts like cowpea (IS86-283:Melakh) deplete the *Striga* seed bank in the soil while producing food and improving soil fertility; and develop technical skill for using integrated *Striga* management. Participants were convinced nutrients such as sheep or goat manure, NPK fertilizer, and urea significantly delay *Striga* emergence and enhance plant growth and increase millet productivity.

Methods to control *Striga* were demonstrated in fields of 20 farmers -- 4 per the villages of Daadack, Baaback, Batal, Ngoye, and Ngayokhème in the peanut belt near Bambey. The same treatments as used at the Farmer Field School site were used on plots 500m². Visits and training meetings for farmers were once a month. The plots were Souna millet with 2.5 tons per hectare of sheep or goat manure, 150 kg per hectare of NPK, 100 kg per hectare of urea, and mechanical weeding 15, 35, and 65 days after planting; Souna millet weeded mechanically 15 and 35 days after planting; and a niébé IS86-283:Mélakh false host. Cultivated were 1,500m² x 20 = 30,000 m². Twenty farmers were taught integrated *Striga* management. Fifty farmers from the village and surrounding villages visited the demonstration fields. Field demonstrations require less time and funds and are a good tool for diffusing technologies but are less effective than Farmer Field Schools.

Sorghums F220, CEF322/35-1-2, SARIASO14, SARIASO9, ICSV1049, SRN39, Brhan, Mota Galmi, WASSA, SEGUETANA CZ1, CSM388, MALISOR 92-1, Lina3, CE145-66-V, and SL246 from Burkina Faso, Mali, Niger, Senegal, and ICRISAT were evaluated in a *Striga*-infested area of the field and pots in Senegal. The plot was 3 x 1.6 m = 4.8 m². In both field and pot culture, CEF322/35-1-2 (Burkina Faso), Brhan (Niger), Lina3 (ICRISAT), and SL246 (Senegal) were resistant. All 11 genotypes were susceptible to the *Striga* Senegalese race, with 50-100 *Striga* per square meter. Experiments are ongoing until harvest. Resistant lines accepted by farmers will be cultivated at several locations next year.

## Networking Activities

Workshops and Meetings. The PI and collaborators presented research and discussed workplans at the Sorghum, Millet and Other Grains West Africa regional meeting, Bamako, Mali, 14-16 April 2008. Hame Abdou Kadi Kadi taught farmers in the field in Niger identification, biology, and ecology of millet head miner and sorghum midge. Information on sorghum was provided to researchers, extension, NGOs and development project personnel, private sector, and farmers at an ICRISAT/INRAN open house.

### *Research Investigator Exchanges*

The scientists met for a Sorghum, Millet and Other Grains West Africa regional meeting in Bamako, Mali, 14-16 April 2008. Information on sorghum was provided for researchers, extension, NGOs and development project personnel, private sector, and farmers at an ICRISAT/INRAN open house.

### *Research Information Exchange*

Ignatius Angarawai was a team member for marker-assisted selection in pearl millet for downy mildew resistance, in collaboration with ICRISAT Nairobi, sponsored by Syngenta Foundation. Several scientists, including Niamoye Yaro Diarisso in Mali, Hame Abdou Kadi Kadi in Niger, Eva and Fred Rattunde with ICRISAT in Mali, and Alain Ratnadass with CIRAD/ICRISAT in Niger planned collaborative research for the “Cereals for the Drylands” proposal to the Gates Foundation.

### *Germplasm Conservation and Distribution*

Fifteen tons of sorghum grain and tons of sorghum and millet products were produced and marketed in Niger. Hectares and tons of seeds of sorghums were produced for farmers in Mali, Niger, and Senegal. Resistant millet was disseminated to 200 farm families in Nigeria. Bougouna Sogoba with AMEDD NGO in Koutiala assisted with transferring seeds of resistant sorghums to farmers in villages in Mali.

## Training

Ignatius Angarawai completed Ph.D. training at Federal University of Technology, Yola, and participated in molecular training, University of Georgia, USA, in collaboration with Professor Katrien Devos, sponsored by the National Science Foundation.

## Publications and Presentations

Journal Articles – Angarawai, I.I, A.M. Kadams and D. Bello. 2008. Gene effects controlling heritability of downy mildew resistance in Nigerian elite pearl millet lines. International Digital Organization for Scientific Information (IDOSI) Publications P-100, St. # 7, Sohailabad, Peoples Colony No 2, Faisalabad, Pakistan.

Angarawai, I.I, A.M. Kadams, D. Bello and S.G. Mohammed. 2008. Quantitative nature of downy mildew resistance in Nigerian elite pearl millet lines. Journal of Semi Arid Tropical Agricultural Research, Patancheru, AP, India.

Wilson, J.P., M.D. Sanogo, S.K. Nutsugah, I. Angarawai, A. Fofana, H. Traore, I. Ahmadou, and F.P.Muuka. 2008. Evaluation of pearl millet for yield and downy mildew resistance across seven countries in sub-Saharan Africa. African Journal of Agricultural Research 3: 371-378.

### *Presentations*

Host-country and U.S. PIs reported at the Sorghum, Millet and Other Grains West Africa regional meeting, 14-16 April 2008, Bamako, Mali.

# Educational Activities

INTSORMIL

# 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, 41 students were enrolled in an INTSORMIL advanced degree program. Approximately 80% of these students come from countries other than the U.S. which shows the emphasis placed on host country institutional development (Figure 1).

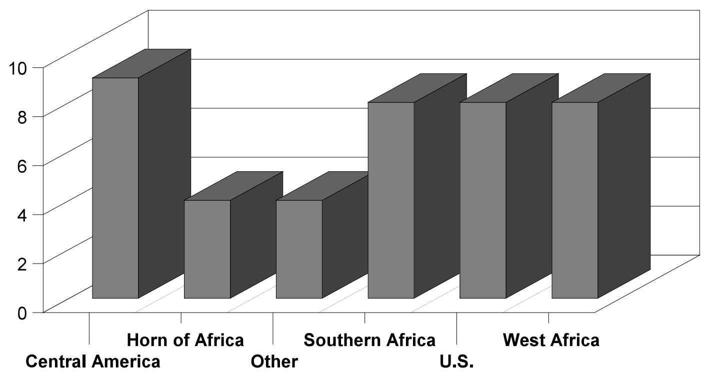


**Figure 1. Degree Participants by Region**

INTSORMIL also places a high priority on training women which is reflected in Figure 2. From 2007-2008, 44% of all INTSORMIL graduate participants were female. Thirty-seven of the 41 students received partial INTSORMIL funding and 4 received full INTSORMIL scholarships.

All 41 students worked directly with INTSORMIL principal investigators on INTSORMIL projects. These students are enrolled in graduate programs in seven disciplinary areas, agronomy, animal nutrition, breeding, economics, entomology, food science, and pathology.

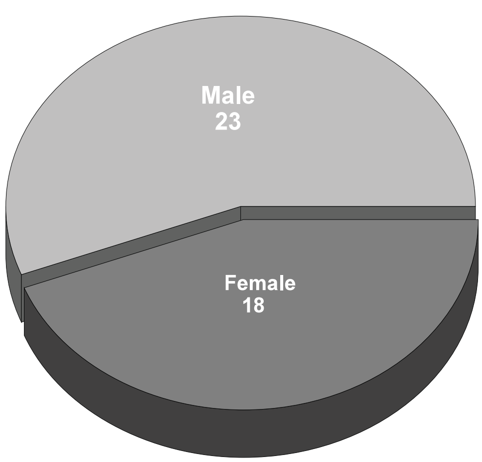


**Figure 2. Degree Participants by Gender**

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 2007-2008 there were 16.

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. Three postdoctoral scientists and ten visiting host country scientists were provided the opportunity to upgrade their skills in this fashion from 2007-2008.

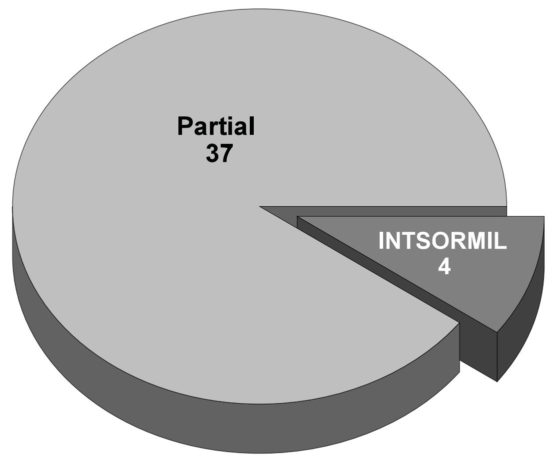


**Figure 3. Degree Participants Funding**

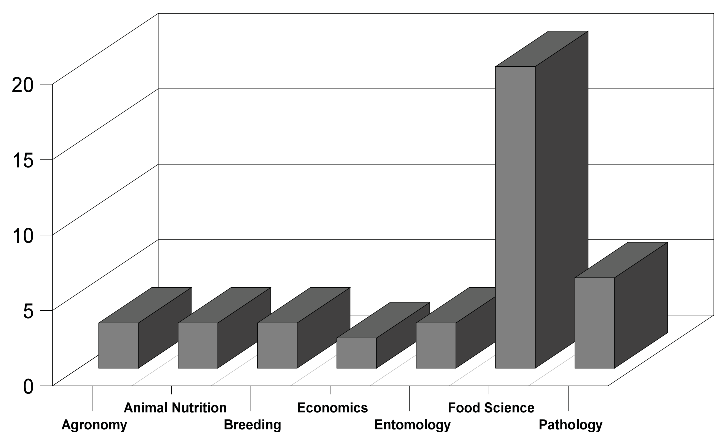


**Figure 4. Degree Participants by Discipline**

**Year 2 INTSORMIL Degree**
**Training Participants**
**September 30, 2007 – September 29, 2008**

| Name | Country | Univ. | Discipline | Advisor | Degree | Gender | Funding |
|---|---|---|---|---|---|---|---|
| Abunyewa, Akwasi | Ghana | UNL | Agronomy | Charles Wortmann | Ph.D. | M | P |
| Maiga, Alassane | Mali | KSU | Agronomy | Vara Prasad | Ph.D. | M | I |
| Opole, Rachel | Kenya | KSU | Agronomy | Vara Prasad | Ph.D. | F | P |
| Sawadogo, Boukare | Burkina Faso | KSU | Agronomy | Vara Prasad | M.S. | M | P |
| Feoli, Carolina | Costa Rica | KSU | Animal Nutrition | Joe Hancock | Ph.D. | F | P |
| Issa, Salissou | Niger | KSU | Animal Nutrition | Joe Hancock | Ph.D. | M | I |
| Monge, Cynthia | Costa Rica | KSU | Animal Nutrition | Joe Hancock | M.S. | F | P |
| Corn, Rebecca | USA | TAM | Breeding | William Rooney | Ph.D. | F | P |
| Hayes, Chad | USA | TAM | Breeding | William Rooney | M.S. | M | P |
| Packer, Dan | USA | TAM | Breeding | William Rooney | Ph.D. | M | P |
| Baquedano, Felix | Nicaragua | PRF | Economics | John Sanders | Ph.D. | M | P |
| Mgaya, Joseph | Tanzania | OSU | Economics | J. Mark Erbaugh/ Donald Larson | M.S. | M | P |
| Garzon, Camillo | Colombia | WTAM | Entomology | Bonnie Pendleton | M.S. | M | P |
| Telly, Madani | Mali | WTAM | Entomology | Bonnie Pendleton | M.S. | M | P |
| Belete, Tebkew Damte | Ethiopia | WTAM | Entomology | Bonnie Pendleton | Ph.D. | M | P |
| Barrion, Stephen | Namibia | U of Pretoria | Food Science | John Taylor | M.S. | M | P |
| Boswell, Sara | USA | TAM | Food Science | Lloyd Rooney | M.S. | F | P |
| Calderon, Vilma Ruth | El Salvador | TAM | Food Science | Lloyd Rooney | M.S. | F | I |
| Cardenas, Ana | Mexico | TAM | Food Science | Lloyd Rooney | M.S. | F | P |
| Chiremba, Constance | Zimbabwe | U of Pretoria | Food Science | John Taylor | M.S. | F | P |
| Gritsenko, Maria | Russia | TAM | Food Science | Lloyd Rooney | M.S. | F | P |
| Guajardo, David | Mexico | TAM | Food Science | Lloyd Rooney | M.S. | M | P |
| Mella, Onesmo | Tanzania | UNL | Food Science | David Jackson | M.S. | F | P |
| Mugode, Luke | Zambia | U of Pretoria | Food Science | John Taylor | M.S. | M | P |
| Poland, Nathan | USA | TAM | Food Science | Lloyd Rooney | M.S. | M | P |
| Taleon, Victor | Guatemala | TAM | Food Science | Lloyd Rooney | M.S. | M | P |
| Asif, Muhammad | Pakistan | TAM | Food Science | Lloyd Rooney | Ph.D. | M | P |
| Diarra, Mohamed | Mali | U of Maiduguri | Food Science | Iro Nkama | Ph.D. | M | P |
| Dilek Austin | USA/Turkey | TAM | Food Science | Lloyd Rooney | Ph.D. | F | P |
| Dykes, Linda | USA/Canada | TAM | Food Science | Lloyd Rooney | Ph.D. | F | P |
| Guajardo, Sara | Mexico | TAM | Food Science | Lloyd Rooney | Ph.D. | F | P |
| Hikeezi, Doreen | Zambia | U of Pretoria | Food Science | John Taylor | Ph.D. | F | P |
| Kebakile, Martin | Botswana | U of Pretoria | Food Science | John Taylor | Ph.D. | M | P |
| Mkandawire, Nyambe L. | Zambia | UNL | Food Science | David Jackson | Ph.D. | F | I |
| Njongmeta, Nenge L.A. | Cameroon | TAM | Food Science | Lloyd Rooney | Ph.D. | F | P |
| Fuentes, Irazeuma | USA | KSU | Pathology | John Leslie | M.S. | F | P |
| Lee, Jungkwan | Korea | KSU | Pathology | John Leslie | Ph.D. | M | P |
| Mpofu, Leo | Zimbabwe | U of Free State | Pathology | Neil McLaren | Ph.D. | M | P |
| Nor, Nik | Malaysia | KSU | Pathology | John Leslie | Ph.D. | M | P |
| Parau, Jose | South Africa | U of Free State | Pathology | Neil McLaren | M.S. | F | P |
| van Rooyen, Danielle | South Africa | U of Free State | Pathology | Neil McLaren | M.S. | M | P |

**I = Completely funded by INTSORMIL** **P = Partially funded by INTSORMIL** **IC = InterCRSP funding**

**KSU = Kansas State Univ.** **TAM = Texas A&M Univ.** **USDA = Tifton, Georgia**
**OSU = Ohio State Univ.** **TTU = Texas Tech Univ.** **WTU = W. Texas A&M Univ.**
**PRF = Purdue Univ.** **UNL = Univ. of Nebraska - Lincoln**

## Year 2 INTSORMIL Non-Degree Training Participants September 30, 2007 – September 29, 2008

| Name | Country | Univ. | Discipline | Advisor | Activity | Gender | Funding |
|---|---|---|---|---|---|---|---|
| Letayo, Elias | Tanzania | UNL | Agronomy | Wortmann | VS | M | P |
| Mesfin, Tewodros | Ethiopia | UNL | Agronomy | Wortmann | VS | M | P |
| Dighe, Nilesh | India | TAM | Breeding | W. Rooney | PD | M | P |
| Li, Guiying | China | TAM | Breeding | W. Rooney | VS | M | P |
| Diatia, Aminata | Tanzania | PRF | Food Science | Hamaker | VS | F | P |
| Galindo-Perez, Cesar | Guatemela | TAM | Food Science | L. Rooney | VS | M | P |
| Ndoye, Ababacar | Senegal | PRF | Food Science | Hamaker | VS | M | P |
| Lee, Jungkwan | Korea | KSU | Pathology | Leslie | PD | M | P |
| Saleh, Amgad | Egypt | KSU | Pathology | Leslie | PD | M | P |
| Chulze, Sofia | Argentina | KSU | Pathology | Leslie | VS | F | P |
| Fogle, Paul | USA | KSU | Pathology | Leslie | VS | M | P |
| Hachibamba, Twambo | Zambia | KSU | Pathology | Leslie | VS | F | P |
| Manani, Tinna | Malawi | KSU | Pathology | Leslie | VS | F | P |

**VS = Visiting Scientist PD = Post Doctoral**

## Year 2 INTSORMIL Conference/Workshop Activities September 30, 2007– September 29, 2008

| Name | Location | Date | Participants: Male | Female | Total |
|---|---|---|---|---|---|
| Scientific Research Ethics | Korea | May 21, 2008 | 40 | 44 | 84 |
| Scientific Writing Workshop | Malaysia | June 18, 2008 | 58 | 68 | 126 |
| Fusarium Laboratory Workshop | Malaysia | June 22-27, 2008 | 14 | 20 | 34 |
| Scientific Writing Workshop | Malaysia | June 30, 2008 | 51 | 42 | 93 |
| ISPA/ISM Mycotoxin Training Workshop | Bari, Italy | Sept. 28-Oct. 3, 2008 | 11 | 13 | 24 |
| Tewdros Mesfin | Houston, TX | Aug. 18-21, 2008 | 1 | 0 | 1 |
| Elias Letayo | Houston, TX | Aug. 18-21, 2008 | 1 | 0 | 1 |
| Tebkew Damte Belete | Fort Worth, TX | Feb. 23-26, 2008 | 1 | 0 | 1 |
| **TOTAL** | | | **177** | **187** | **364** |

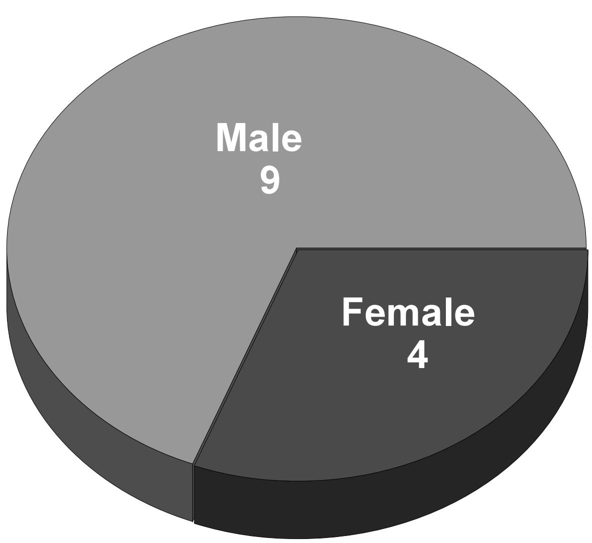


**Figure 5. Total Non-Degree Participants by Gender**

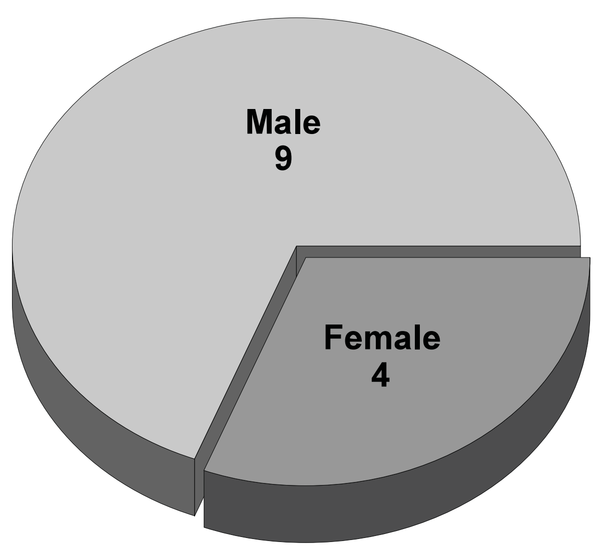


**Figure 6. Total Conference/Workshop Participants by Gender**

# Appendices

## INTSORMIL Sponsored and Co-Sponsored Workshops 2007-2008

| Name | Where | When |
|---|---|---|
| Building a Supply Chain for Millet and Sorghum Food Processing | Bamako, Mali | March 12-14, 2008 |
| INTSORMIL West Africa Regional Workshop | Bamako, Mali | April 15-17, 2008 |
| INTSORMIL Horn of Africa Regional Meeting | Nairobi, Kenya | September 22-24, 2008 |

# 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 |
| GART | Golden Valley Agricultural Research Trust |
| 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 |
| 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 |