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INTSORMIL 2011

2011 Annual Report

INTSORMIL

Sorghum Millet and other Grains
Collaborative Research
Support Program CRSP

FRONT COVER

Children of Gouloumbo Village, Mopti Region, Northern Mali admiring the recently harvested bundle of pearl millet panicles which are ready for threshing by their mothers.

Photo Courtesy of Elvis Heinrichs, University of Nebraska

BACK COVER

Top: Gouloumbo Village woman winnowing threshed millet in the décrue area of Mopti Region in Northern Mali.

Bottom: Women of Gouloumbo Village, Mopti Region, Northern Mali threshing the recently harvested pearl millet (left) and sorghum (right) panicles which were harvested in the décrue area of Lac Korientzé.

Photo Courtesy of Elvis Heinrichs, University of Nebraska

INTSORMIL
Sorghum, Millet and Other Grains CRSP

2011 ANNUAL REPORT

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INTSORMIL INSTITUTIONS

Kansas State University
Ohio State University
Purdue University
Texas A&M University
University of Nebraska – Lincoln
West Texas A&M University

INTSORMIL institutions are affirmative action/equal opportunity institutions.

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Introduction and Program Review

The 2011 INTSORMIL Annual Report presents the progress and notable achievements by the Sorghum/Millet and Other Grains CRSP during the period of September 30, 2010 through September 29, 2011. These results are an outcome of partnerships between scientists at six U.S. Land Grant Universities (Kansas State University, University of Nebraska, The 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 sixteen 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 16 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, utilization and technology transfer for the mutual benefit of the Less Developed Sorghum and Millet Producing 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 enlarges 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 and small farmers. 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. The USAID Acquisition Officer Representative (SOR) serves as a voting member of the Board and provides advice and guidance to the ME and the Board in areas of policy, technical aspects, collaborating country coordination, budget management and review.

Education

During the period of 2010-2011, there were 46 students from 20 different countries enrolled in an INTSORMIL advanced degree program and advised by an INTSORMIL principal investigator. Approximately 65% of these students came from countries other than the U.S. The number of students receiving 100% funding by INTSORMIL in 2010-2011 totaled 13. An additional 33 students received partial funding from INTSORMIL. INTSORMIL places high priority on training of women. During the period 2010-2011, 50% of all INTSORMIL graduate participants were female.

Another important category of education which INTSORMIL supports is non-degree research activities, namely postdoctoral research and research of visiting scientists with INTSORMIL PI's in the United States. During this year, 10 host country scientists improved their education as either postdoctoral scientists (5) or visiting scientists (5). Their research activities were in the disciplines of agronomy, plant breeding, food science and plant pathology. These scientists came to the USA from Egypt, Guatemala, Ethiopia, Nigeria, Uganda and the USA. In addition to non-degree research activities there were 351 participants (156 male and 195 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 ASARECAIECARSAM in Africa, 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.

Regional Activities and Benefits

West Africa

The collaborating 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 to manage grain harvesting and storage practices. 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 for targeted environments.

Multi-institution, multi-disciplinary teams of agronomists, entomologists, food scientists, breeders, pathologists, poultry scientists, extension educators, and others from Burkina Faso, Mali, Niger, Nigeria, and Senegal are developing, evaluating, and transferring technologies to improve production and marketing of sorghum and millet and manage Striga in West Africa. The regional program with collaboration among scientists at IER in Mali, INRAN in Niger, INERA and IRSAT in Burkina Faso, ISRA and ITA in Senegal, University ofMaiduguri in Nigeria, universities in the U.S., volunteer organizations, and private industries is contributing to INTSORMIL objectives to increase stability and yield through crop and natural resource management; develop and disseminate information on stresses to increase yield and quality; enhance stability and yield through genetic technologies; facilitate markets; improve food and nutritional quality to enhance marketability and consumer health; and better the lives of people dependent on sorghum and millet.

Horn of Africa

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

Sorghum and millet constraints in the region continue to be low productivity and limited markets for the grain produced. Major production constraints include water deficits, stem borers, nitrogen deficiency, Striga, weeds and Quelea quelea (birds). Farm household interviews in Tanzania show a low rate of adoption for production technologies, often due to lack of knowledge and availability of technologies (e.g., seed of improved varieties) or market instability and seasonal price fluctuations. The market limitations are perpetuated by a general lack of reliable quality grain production. Storage and transport infrastructure deficiencies compound the product/market disconnect. The INTSORMIL regional project team continues to address these constraints from developing production technologies, extending these to farmers in the region and exploring new market outlets for sorghum and millet while enhancing and protecting profits for all involved in the supply chain. Studies of the sorghum based clear beer value chain in Tanzania is an excellent example of this holistic approach. The study included interviews with sorghum farmers, traders, transporters, processors, distributors and warehouse owners. There has been a modest increase (4%) of sorghum based product in the clear beer industry in the region over the last two years of the study. The study concludes that continued growth in the sorghum beer industry depends on potential demand of the buyers, consistent and high quality grain from farmers, adequate transportation and storage infrastructure, profitability for all chain members and trust and contract enforcement mechanisms. This study validates the INTSORMIL objectives for regional development.

Although not all planned activities for Year 5 of the individual projects comprising the Horn of Africa regional program were accomplished during 2011, there are clear indications that progress is being made in the region. Production technology development continues through breeding of Striga resistant sorghum hybrids, testing and optimization of agronomic practices adaptable to the region. Sorghum and millet constraints are then further addressed through analysis of technology adoption, detailed value chain studies, monitoring of market forces on commodity prices and new product development. The regional program reflects well the major objectives of supply chain/market development, IPM, genetic enhancement and building partnerships.

Through all these activities, students who are being trained provide the human capacity for development in the host countries.

Southern Africa

The southern Africa regional program is composed of 10 research projects directed by 13 scientists representing 7 agencies in 4 countries. Eleven U.S. based principal investigators collaborate with the regional scientists. Countries and agencies represented are:

Botswana	Botswana College of Agriculture
Mozambique	National Agrarian Research Institute
South Africa	University of the Free State
	University of Pretoria
	Medical Research Council
Zambia	Zambia Agricultural Research Institute
	University of Zambia

The scientists represent the disciplines of agronomy (1), breeding (3), socio-economics (2), entomology (2), food science (1), and pathology (2). 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. A regional planning meeting to identify and guide 2006-2011 activities developed the following 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". Regional scientists selected for the 2006-2011program have the expertise to contribute to the goal of improving sorghum and millet for the regions farmers and end-users. Each scientist is expected to specify where activities fall within the regional plan and to provide performance indicators and outputs. Collaborating scientists bring to INTSORMIL additional collaborators including Future Harvest Centers, NGOs, and other governmental or private organizations. Each has other programmatic funds - donors, grants and commodity organizations - for reciprocal leveraging of resources. Technical backstopping and logistical, material and additional operational support is provided by the U.S. collaborators.

Central America

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 productivity, profitability, economic growth and food security for producers and consumers as well. Since 1999, INTSORMIL program emphasis in Central America has been based in El Salvador and Nicaragua. In-region coordination is provided by lng. Rene Clara-Valencia and 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. However, additional support and activities are allowing the INTSORMIL program to extend throughout Central America.

Grain sorghum is the third most important crop in Central America (El Salvador, Guatemala, Honduras, and Nicaragua) after maize and beans. The area devoted to grain sorghum in 2003 was 225,000 ha- 1, and produced an average grain yield of 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.

Associate Awards

Mali 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 was modified in 2008 to provide four year funding at $1,250,000 per year (2008-2009 to 2011-2012) to expand all activities and to develop institutional capacity by adding a degree and short term training component to the Cooperative Agreement.

The Cooperative Agreement consists of four 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, 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 and 4) Academic Training led by Jess Lowenberg Deboer, Purdue University. Activities are conducted in collaboration with IER.

Significant progress was achieved in 2011 through meeting Project objectives as set forth in the workplan:

- Network establishment to enhance partnership development with relevant stakeholders and to develop stronger farmers' groups so as to enhance their marketing power.
- Facilitate adoption of production and marketing technologies to improve the productivity of sorghum and millet and increase farmer incomes.
- Develop alternative markets (human food and livestock and poultry feed) for sorghum and millet.
- Develop sorghum production technology for the "culture de decrue" system
- Upscaling the sorghum and millet seed production industry in collaboration with other agencies.
- Disseminate technology via workshops, field days and media (communications, publications and website).
- Build institutional (IER) technology development and transfer capacity through long term (academic) training and short term training of farmers' groups and food processor entrepreneurs.

Network establishment

There is an increasing level of integration between the three principal activities of the broader INTSORMIL Project and this level will be intensified further in 2012. With the food processing sector, Production-Marketing continues to advise them about the increasing availability of clean seed from our farmers' associations and the need of our farmers' associations for a price premium for quality. We also hold joint workshops of processors and farmers' associations to help build these commercial networks. Due to the lack of available technologies for décrue sorghum production the KSU program has emphasized research activities. Now that they have identified technologies that function well on the décrue, Production-Marketing will be collaborating with them to get the technology out to farmers following the integrated extension approach that Production-Marketing has been introducing. This will be operational in Kayes and Mopti in the 2012 agricultural year. The next step is to plug the KSU décrue sorghum program into the IICEM operation to increase the hectares of décrue sorghum under improved technologies/management practices.

Production-Marketing

The Production-Marketing project is also tied to the overall INTSORMIL program from which we draw scientific help. We have had visits combined with short courses for intensive chicken producers by Joe Hancock, animal nutrition scientist specializing in poultry at KSU. As we get yields of sorghum up we can compete with com in the rations especially for intensive poultry. Non-tannin sorghums have 95 to 97% of the feeding efficiency of maize so with prices at 95% or less of maize producers should substitute sorghum for maize in the ration. Chicken producers or feed mixers need the mixing machine to do this and the awareness of the substitutability between rations. Joe Hancock provides the necessary technical information and has been doing this for several years. The intensive poultry sector is growing rapidly. With good yields of Grinkan in 2012 we will be again competing with maize with respect to price. Thus we must follow up our workshops and advise chicken producers about relative prices at that time.

Décrue Sorghum System Production Technology

Décrue sorghum project activities include 1) Expansion of the sorghum varieties Saba Tienda and Saba Soto with more farmers involved in other regions of the décrue system, 2) Introduction of new cultivars in Gao, Mopti and Kayes through an adaptation test, 3) Training on insect identification and pest management for all technicians involved in extension and research of the décrue system, 4) A better understanding of the response to fertilizer of sorghum, through soil and plant analysis from experiments conducted in the décrue systems and a BMP (Best Management Practices) package for décrue sorghum developed. Technologies made available to farmers are a new cultivar, moderate inorganic fertilizers and improved agronomic practices. In 2012 the project will be expanded with participation of more farmers and we will be forming farmers groups to expand the area under the use of improved technologies.

Food Processing

Food Processing project activities focused on 1) further building capacity and providing technical support to entrepreneur partners in the Mopti/Gao region of northern Mali, and 2) completion, testing and final work on the Incubation Center at IER Sotuba in Bamako. These two parts of the Processing Project comprise activities in Mali concentrated on expanding markets for sorghum and millet. Other work relates to INTSORMIL training activities for Ms. Fatima Cisse, M.S. student at Purdue University who spent 3 months in Bamako conducting part of her research thesis work. Processors in the Mopti/Gao region are now generally functioning in terms of processing milled products that are being sold into the marketplace. The Incubation Center (IER Sotuba) building and milling, agglomeration and drying equipment was fully functional in June 2011. During the summer equipment was tested and procedures were further developed for processing of products. The Incubation Center was formally launched in September. Since the inauguration we have demonstrated the functioning of the Incubation Center in providing technical support for processing of quality competitive products.

Technology Transfer

Year 2010-2011 targets were surpassed with 3,986 ha under improved technologies, 4,130 farmers who have applied new technologies and received INTSORMIL supported short term food security training, and 3,900 rural households benefiting directly from INTSORMIL interventions. Targets for 2012 include 5,000 ha under improved technologies, 5,500 farmers who have applied new technologies and received INTSORMIL supported short term food security training, and 5,500 rural households benefiting directly from INTSORMIL interventions.

Institutional Capacity Building

The training component is managed Purdue University. This component is based on the need for competent technically qualified scientists in sorghum and miller food processing, agronomy, and agricultural economics in Mali. Five students were selected by IER for degree training in the USA. Two are currently studying economics at West Texas A&M; two are in agronomy in Kansas State University under Prof. Vara Prasad and one is at Purdue in Food Science under Prof. Hamaker. Two have completed short term training; one in agronomy under Prof. Prasad at KSU and another in breeding under Prof. Mitch Tuinstra at Purdue University. Abdou! Wahab Toure completed a short term training program at Kansas State University where he conducted studies on the mechanics of drought tolerance characteristics of décrue sorghum cultivars.

BMR Associate Award

A major constraint to further development of the Central American and Haitian dairy industry is the lack of sufficient good quality forage which results in low milk and meat production and an increase in production costs. Through the Feed the Future (FtF) initiative the bmr varieties developed by the CENTA/El Salvador sorghum breeding program are being distributed to farmers throughout the region through the support of a $1.1 million associate award from USAID/Washington. The project "Identification and Release of Brown Midrib (bmr) Sorghum Varieties to Producers in Central America and Haiti" aims to help farmers grow more productive forage sorghum crops. Forage sorghum is the green leafy material and stalk (not the grain) that farmers can use for feeding dairy and beef cattle. The highly digestible forage of bmr varieties increases both milk and meat production. This project has huge potential economic benefits. For the 388,000 sorghum farmers in Costa Rica, El Salvador, Guatemala, Haiti, Honduras, Nicaragua and Panama, bmr sorghum varieties can potentially increase their farm income by 15% or a total of $163,000,000.

Activities in Year 2011 included the evaluation of 16 bmr varieties developed by the CENTA program and four check varieties in:

- Costa Rica (INTA: Instituto de Tecnologia Agropecuaria)
- El Salvador (CENTA: Centro Nacional de Tecnologia Agropecuaria y Forestal)
- Guatemala (ICTA: Instituto de Ciencia y Tecnologia Agricolas)
- Haiti (Chibas Bionergy)
- Honduras (DICTA: Direcion de Ciencia y Tecnologia Agropecuaria)
- Nicaragua (INTA: Instituto Nicaraguense de Tecnologia Agropecuaria).
- Panama (IDIAP: Instituto de Investigaci6n Agropecuaria de Panama)

The top two varieties in each country were selected for further evaluation and seed multiplication in 2012. In 2013, seed will be widely distributed to dairy farmers in each of the collaborating countries.

The bmr sorghum variety, Sorgo CENTA S-2 bmr was commercially released at a ceremony held in a dairy farmer's sorghum field near San Miguel, El Salvador. This is the first bmr variety to be released in Central America. The release ceremony was sponsored by CENTA (Centro Nacional de Tecnololgia Agropecuaria y Forestale), Ministerio de Agricultura y Ganaderia (MAG), Agricultura Familiar, USAID/El Salvador and INTSORMIL. Sorgo CENTA S-2 bmr was developed by INTSORMIL/CENTA Central American Regional Coordinator Rene Clara Valencia through the support of Texas A&M University sorghum breeder Bill Rooney. CENTA S-2 bmr is a forage sorghum variety which is nutritionally superior and highly digestible by dairy cows resulting in about 20% higher milk production than non-bmr varieties.

The bmr varieties are targeted to the small scale dairy farmers who are part of the "Agricultura Familiar" program (family farmers) under the El Salvadoran government's "Plan de Agricultura Familiar" (PAF) (family agriculture). Thus, the bmr varieties are components of the program for food security of the rural family farmers as they will significantly increase rural income of the El Salvadoran dairy farmer and supports the CENTA/MAG motto, "Garantizando nuestra seguridad alimentaria," ("Guaranteeing our food security").

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. However, in an interview with Reuters, World Bank Agriculture Sector Manager for Africa Karen Brooks said, "Food price hikes are hitting Africa's urban populations harder now than in 2008 and pose a serious challenge to some of the continent's leaders, who face elections this year....

Brooks said investors were excited about African agriculture but that the continent was still missing out due to lingering fears over land rights, taxation and stability as private funds flow into Latin America and Central Asia. African leaders have committed to devoting 10 percent of their budgets to agriculture as part of efforts to bridge investment gaps. But Brooks said results were mixed.

Meanwhile, some African nations have made progress in adopting policies and most have recognized the urgency, but just a handful are meeting the 10 percent budget target. Better weather has supported harvests this year, but the deficit remains vast.... Brooks said the World Bank was focusing on four main issues: land and water management, technology, agricultural markets and infrastructure, and food security and vulnerability.... Poor infrastructure, weak financial services and concerns over land rights are among the key concerns the World Bank is trying to tackle to encourage investors to turn to Africa, rather than other regions where returns are quicker, she added." [Reuters/Factiva]

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 were expected to remain high in 2010111 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 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 31 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 3lyears 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

Sustainable Plant Protection Systems

INTSORMIL

Grain Molds, Mycotoxins and Stalk Rots of Sorghum and Millet

Project KSU 101

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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 mem-bers 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 breed-ing. 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 related species, and many cultures are misidentified, if identified at all. Many of these cultures al-so 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 in terms of pathogenicity, breeding materials often were challenged with an improper 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 a new species ("*Fusarium africana*") that has been clearly distinguished only recently and 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 *Fu-*

sarium 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 may produce mycotoxins that could contaminate grain. Identifying the toxins produced, if any, and their levels is particularly important for strains found on finger millet as this grain often is used to produce a weaning food for children. These children would be particularly susceptible to the reductions in mental and physical development that can result from sub-acute 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.
- 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 bacterial and most other fungal contaminants. These cleaned cultures are genetically purified by sub-culturing individual macro or microconidia (of uninucleate origin) 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/millet *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% difference 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 repeated 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 identified, 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.

Mycotoxin Production

In vitro assessment of mycotoxin production requires collaboration with other scientists who are equipped with the necessary apparati for chemical analyses. The presence of the fumonisin, beauvericin and fusaproliferin mycotoxins can be evaluated after growth on rice in laboratory culture for up to 30 days. The contents are extracted in acetonitrile:water, run through a clean-up column to remove contaminants, derivatized, if necessary, to enable detection, and finally quanti-fied by using an HPLC protocol.

Converted rice (usually the Uncle Ben's brand) commonly is used for these studies and the toxin levels produced can be high. Four mycotoxins were tested: fumonisin, fusaproliferin and beauvericin, and moniliformin. Fumonisins are important due to their association with esophageal cancer and neural tube defects in humans, their ability to cause a number of diseases in domesticated animals, and their effects as trade barriers. Fusaproliferin and beauvericin are not associated with a disease syndrome of humans or domesticated animals but are toxic to cells main-tained in cell culture. Beauvericin is insecticidal and yeasts that synthesize this compound have been used as biocontrol agents. Beauvericin also is very effective in permeabilizing cell membranes and thereby facilitating the entry of other mycotoxigenic molecules. Moniliformin is a very unusual compound that is known to be toxic to poultry and may be produced in massive amounts (up to 10% of the total mass of the culture) by in vitro cultures of some strains.

Strengthening Research Capacity

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

Research Results

Species Identification – Mali

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, and initial AFLP comparisons have been made. At this time there are at least 11 different species represented by multiple isolates, of these four have been previously described and the description of a fifth is in progress. Preliminary studies suggest some strains produce very large amounts of moniliformin, but that most make only limited amounts of fumonisins. Studies of other mycotoxins are not yet complete. In addition to 11 putative species with multiple representatives, there are an additional 17 strains with AFLP patterns that are sufficiently unusual to think that they may each represent an additional species. Analyzing banding patterns of individuals in the same species on a common gel has begun to begin the evaluation of the genetic diversity present.

Fusarium population characterization – Uganda.

Formal description of a new species, *F. intsormilium*, is complete, except for the photography required for the formal mycological description. This species was originally recovered from finger millet and is morphologically indistinguishable from *F. verticillioides*. Strains are usually highly fertile sexually and can produce beauvericin, but little or no moniliformin. We have analyzed a large sample of strains from maize growing in the same area from which *F. intsormilium* was first recovered. Although the species is present on maize, only about 1% of the isolates we examined were *F. intsormilium*. Thus, this species can colonize maize, but is not, at this time a major threat to maize, as is the closely related *F. verticillioides.* Conducting pathogenicity studies with these strains is difficult since they are not yet known to occur outside Uganda, which restricts their use in field trials outside Uganda. *F. intsormilium* and *F. verticillioides* account for only a portion of the Ugandan population from finger millet. With the characterizations of toxin production by these species within the population now more-or-less complete, our attention will shift to characterizing other species present in this population.

The tef-1 and tub-2 sequences are hypothesized to be nearly constant within a species, with variation often taken as an indication of the age of the population. Older populations usually contain more variation and are found closer to the center of geographic origin for the species. *F. verticillioides* has been predicted by some investigators to have originated in Africa, based on its phylogenetic relationships. However, this fungus is the most widespread of the *Fusarium* species on maize, a crop that did not originate in Africa. The strains from finger millet were used to test this hypothesis by sequencing both tub-2 and tef-1 in every strain. We found five different sequences for the tef-1 gene and two sequences for the tub-2 gene. Of the five tef-1 sequences, three are unique thus far to Uganda, with the other two being reported from numerous locations. For tub-2, neither of the two sequences were unique to this collection. The presence of so many alleles at the tef-1 locus, and the occurrence, relatively speaking, of so many unique alleles in such a small collection is consistent with the hypothesis that F. verticillioides originated in Africa, perhaps on a crop such as finger millet and jumped to maize at some later date. It also suggests that many of the other undescribed species of *Fusarium* from sorghum and millets in this region may have important roles on other hosts, and that an understanding of the selection pressures that resulted in the observed pathogenicity characters and toxin profiles of these closely related species could provide insights into the current mechanisms of pathogenicity and how these mechanisms might evolve in the future. Thus, the pathogens isolated from subsistence crops may hold a key to understanding how resistance works in some of the most important grain crops now cultivated for human food and animal feed, as well as providing insights into traits that could be selected to increase fungal resistance.

Tests of Toxin Production

We have been working with colleagues at the PROMEC unit of the Medical Research Council in Tygerberg, South Africa to test the ability of putative strains of *Fusarium proliferatum* to produce various toxins, but in particular fumonisins and moniliformin. This species is the most common of the known fumonisin-producing species found on sorghum, and all of the strains analyzed are from West Africa. The results of these studies are quite interesting and are described in more detail in their annual report. In brief, they found that strains isolated from maize and strains isolated from sorghum differed in their abilities to produce both fumonisins (Table 1) and moniliformin (Table 2) when grown on commercially purchased maize, sorghum (red or white), or finger millet. Five of the ten strains from maize and one of the seven strains from sorghum produced little, if any fumonisins on any of the ground grains, while the remaining strains all produced > 1000 mg/kg fumonisins on all of the substrates tested. For moniliformin, the results are similar with only the *F. proliferatum* strains capable of making high levels of fumonisins capable of producing significant levels of fumonisins.

When the study began, all strains were thought to be *F. proliferatum*, based on morphological characters. As some strains were not expressing the toxin phenotypes expected, all of the strains also were identified by using molecular characters. Tests conducted at K-State included sexual crosses, AFLP analyses and sequencing of tef-1 and tub-2. Based on these tests, a number of the isolates were reclassified. These identifications eased the analysis of the data and presented some clear patterns. *F. proliferatum* strains may, or may not, produce high levels of fumonisins or of moniliformin. *F. andiyazi, F. pseudonygamai* and the new *Fusarium* sp. produce relatively little fumonisin. Neither *F. andiyazi* nor the new *Fusarium* sp. produce much moniliformin, and so far seem to be of relatively minor toxicological importance. *F. pseudonyagami* strains are known to be capable of producing extremely high levels of moniliformin, as also reported here. Strains of *F. proliferatum* isolated from sorghum generally produce more of both fumonisin and moniliformin, regardless of the grain on which they are grown. An exception is MRC 8742, a strain of maize origin that synthesized > 17,000 mg/kg of fumonisin when grown on ground maize. Based on these data, it is not clear that

Table 1. **Fumonisin production by *Fusarium proliferatum*, *F. verticillioides*, *F. andiyazi*, *F. pseudonygamai* and a new species of *Fusarium* grown on maize, white or red sorghum, and millet (from PROMEC, Medical Research Council, South Africa).**

MRC number[1]	Species ID	Fumonisin level in grain patty (mg/kg)															
		Maize				White Sorghum				Red Sorghum				Millet			
		FB_1	FB_2	FB_3	Total	FB_1	FB_2	FB_3	Total	FB_1	FB_2	FB_3	Total	FB_1	FB_2	FB_3	Total
Maize (n=10)																	
MRC 8737	*F. proliferatum*	16	7	3	**26**	37	5	4	**46**	7	2	1	**10**	4	1	0	**5**
MRC 8738	*F. proliferatum*	3	0	0	**3**	4	0	0	**4**	1	0	0	**1**	2	0	0	**2**
MRC 8739	*F. proliferatum*	2	0	0	**2**	2	0	0	**2**	3	0	0	**3**	0	0	0	**0**
MRC 8740	*F. proliferatum*	1	0	0	**1**	0	0	0	**0**	1	0	0	**1**	0	0	0	**0**
MRC 8741	*F. proliferatum*	1	0	0	**1**	1	0	0	**1**	1	0	0	**1**	1	0	0	**1**
MRC 8742	*F. proliferatum*	13630	3385	413	**17428**	4633	1250	227	**6110**	2214	517	124	**2855**	2903	797	100	**3800**
MRC 8743	*F. proliferatum*	1907	527	149	**2583**	1482	473	214	**2169**	2041	652	185	**2878**	1627	433	163	**2222**
MRC 8744	*F. proliferatum*	1309	154	225	**1688**	2443	279	435	**3157**	1691	242	197	**2130**	1799	242	381	**2422**
MRC 8745	*F. proliferatum*	508	159	27	**694**	1414	276	69	**1759**	1060	232	59	**1351**	1811	414	72	**2297**
MRC 8746	*F. proliferatum*	3057	420	141	**3618**	2508	335	123	**2966**	2470	304	144	**2918**	2750	391	105	**3246**
Sorghum (n=9)																	
MRC 8724	*Fusarium* sp.	11	3	0	**14**	2	1	0	**3**	8	2	0	**10**	6	1	0	**7**
MRC 8725	*F. andiyazi*	15	7	1	**23**	1	0	0	**1**	11	7	0	**18**	55	37	3	**95**
MRC 8726	*F. proliferatum*	4040	2279	158	**6477**	3446	1898	139	**5483**	2852	1385	137	**4374**	3995	2328	146	**6469**
MRC 8727	*F. proliferatum*	1539	464	95	**2098**	1785	292	186	**2263**	2281	534	193	**3008**	2406	569	163	**3138**
MRC 8728	*F. proliferatum*	2078	1225	68	**3371**	1830	968	107	**2905**	4293	1973	212	**6478**	1664	873	59	**2596**
MRC 8729	*F. proliferatum*	2777	1169	74	**4020**	3214	1753	103	**5070**	3463	1264	115	**4842**	4040	1923	136	**6099**
MRC 8730	*F. proliferatum*	1525	557	56	**2138**	1880	805	78	**2763**	2556	869	99	**3524**	1890	623	91	**2604**
MRC 8731	*F. proliferatum*	6112	1306	974	**8392**	5675	1165	1052	**7892**	3992	818	925	**5735**	3117	683	592	**4392**
MRC 8732	*F. proliferatum*	24	16	1	**41**	22	9	2	**33**	24	8	2	**34**	21	8	2	**31**
Millet (n=1)																	
MRC 8723	***F. pseudonygamai***	2	1	0	**3**	19	6	1	**27**	29	12	2	**43**	3	1	1	**5**
Control (n=1)																	
MRC 826[3]	*F. verticillioides*	10335	2610	679	**13624**	5603	1803	696	**8102**	5221	1631	694	**7546**	6603	1904	581	**9088**

[1] Medical Research Council (MRC), PROMEC Unit culture collection number; 3MRC826 = high fumonisin producer; nd = not detected (detection limit < 1 mg/kg).

Table 2. Moniliformin profiles of *Fusarium proliferatum*, *F. andiyazi*, *F. pseudonygamai, F. napiforme,* and a new species of *Fusarium* grown on maize, white or red sorghum, or millet.

MRC number1	Species ID[2] (Previous ID)	Moniliformin levels in grain patties (mg/kg)			
		Maize	White Sorghum	Red Sorghum	Millet
Maize (n=10)					
MRC 8737	*F. proliferatum*	nd	nd	nd	nd
MRC 8738	*F. proliferatum*	nd	nd	nd	nd
MRC 8739	*F. proliferatum*	nd	nd	nd	nd
MRC 8740	*F. proliferatum*	nd	nd	nd	nd
MRC 8741	*F. proliferatum*	nd	nd	nd	nd
MRC 8742	*F. proliferatum*	nd	nd	nd	nd
MRC 8743	*F. proliferatum*	21	27	61	6
MRC 8744	*F. proliferatum*	1423	1963	1025	1616
MRC 8745	*F. proliferatum*	115	265	97	107
MRC 8746	*F. proliferatum*	924	1433	546	1440
Sorghum (n=9)					
MRC 8724	*Fusarium* sp.	2	31	9	10
MRC 8725	*F. andiyazi*	18	nd	7	46
MRC 8726	*F. proliferatum*	3555	5427	6110	1301
MRC 8727	*F. proliferatum*	86	648	557	852
MRC 8728	*F. proliferatum*	1197	4998	2844	4003
MRC 8729	*F. proliferatum*	4964	3028	4637	4094
MRC 8730	*F. proliferatum*	6102	4245	4011	8892
MRC 8731	*F. proliferatum*	1237	1747	1402	2268
MRC 8732	*F. proliferatum*	761	1174	1419	1101
Millet (n=1)					
MRC 8723	*F. pseudonygamai*	19220	22570	13840	21360
Controls (n=1)					
MRC 82792	*F. napiforme*	23020	27670	27304	33430

[1] Medical Research Council (MRC), PROMEC Unit culture collection number; 2MRC8279 = high moniliformin producer; nd = not detected (detection limit < 1 mg/kg).

any of these grains in ground form is particularly better or particularly worse for the synthesis of these toxins, although there certainly are differences amongst the strains recovered from both maize and sorghum.

Strengthening Research Capacity

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

Networking Activities

Editorial and Committee Service (2010)

- Editor, Food Additives and Contaminants (2006-present)
- Editor, Mycological Research (2009-2010)
- International Society for Plant Pathology, Fusarium Committee (2000-2013)
- MycoRed External Advisory Committee (2007-2013)
- USDA/University of Hawaii, TSTAR Plant Protection Panel (2010-2011)

Research Investigator Exchanges (2011)

- Argentina – February 28 – March 15
- Australia – July 11-23
- Burkina Faso – May 17-23
- Italy – October 2-10
- Japan – November 23-26
- Malaysia – November 27 – December 4
- Norway – August 21-29
- Poland – September 18-24
- South Africa – October 23 – November 6
- South Korea – November 14-22
- Zambia – October 19-22

Other Collaborating Scientists (Host Country)

- Dr. Sofia Chulze, Dept. of Microbiology, National University of Rio Cuarto, Rio Cuar-to, 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. 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 2010 (other than collaborators)

- Peter Cotty, USDA-ARS, University of Arizona, Tucson, Arizona.
- Elettra Berni, Industrial Experiment Station for Food Preservation, Parma, Italy.
- Lakshmikantha Channaiah, Kansas State University, Manhattan, Kansas.
- David Geiser, Pennsylvania State University, University Park, Pennsylvania.
- Fungal Genetics Stock Center, University of Missouri-Kansas City, Kansas City, Missouri.
- Carla Klittich, Dow Agrosciences, Indianapolis, Indiana.
- Ralf Kristensen, Institute of Veterinary Medicine, Oslo, Norway.
- Kristian F. Nielsen, Danish Technical University, Lyngby, Denmark.
- Robert H. Proctor, Mycotoxin Research Unit, NCAUR, USDA-ARS, Peoria, Illinois.
- Anne Rigdon, Kansas State University, Manhattan, Kansas.
- Leire Molinero Ruiz, CSIC Institute for Sustainable Agriculture, Cordoba, Spain.
- Keith Seifert, Agriculture and Agri-Foods Canada, Ottawa, Ontario, Canada.
- Dilip Shah, Donald Danforth Plant Sciences Center, St. Louis, Missouri.

Publications and Presentations (2010)

Seminar, Workshop & Invited Meeting Presentations (International Locations)

MycoRed symposium, Univ. Nacional de Rio Cuarto, Rio Cuarto, Argentina – 03/10.

Royal Botanic Gardens – Sydney, Sydney, Australia – 07/10.

11th European Fusarium Seminar – Poznan, Poland (Keynote speaker) – 09/10.

Zambian Agricultural Research Institute, Lusaka, Zambia – 10/10.

FABI, University of Pretoria, Pretoria, South Africa – 10/10.

Kihara Institute, University of Yokohama, Yokohama, Japan – 11/10.

School of Forestry, Seoul National University, Seoul, Korea – 11/10.

International Society for Mycotoxicology Asian meeting, Penang, Malaysia – 12/10.

Science University of Malaysia, School of Biological Sciences, Penang, Malaysia – 12/10.

Journal Articles (2010)

Saleh, A. A., H. U. Ahmed, T. C. Todd, S. E. Travers, K. Zeller, J. F. Leslie & K. A. Gar-rett. 2010. Relatedness of Macrophomina phaseolina isolates from tallgrass prairie, maize, soybean and sorghum. Molecular Ecology 19: 79-91.

Summerell, B. A., M. Laurence, E. C. Y. Liew & J. F. Leslie. 2010. Biogeography and phylogeography of Fusarium: A review. Fungal Diversity 44: 3-13.

Voss, H.-H., R. L. Bowden, J. F. Leslie & T. Miedaner. 2010. Variation and transgression of aggressiveness among two Gibberella zeae crosses developed from highly aggressive parental isolates. Phytopathology 100: 904-912.

Book Chapters (2010)

Leslie, J. F. & J.-R. Xu. 2010. Fusarium genetics and pathogenicity. In: Cellular and Mo-lecular Biology of Filamentous Fungi (K. A. Borkovich & D. Ebbole, eds.), pp. 607-621. ASM Press, Washington, DC.

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

Project WTAMU 101
Bonnie B. Pendleton
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Principal Investigator

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Collaborating Scientists

Mr. Hamé Abdou Kadi Kadi – Entomologist, INRAN, B.P. 429, Niamey (location Kollo), Niger
Mr. Fernando M. Chitio – Entomologist/Zonal Director, IIAM, Box 36, Nampula, Mozambique
Dr. Niamoye Yaro Diarisso – Entomologist/Scientific Coordinator, IER, B.P. 258, Bamako, Mali
Dr. David C. Munthali – Entomologist, PP/Bag 0027, Botswana College of Agriculture, Gaborone
Dr. Gary C. Peterson – Sorghum Breeder, Texas AgriLife Research, Lubbock, TX 79401
Dr. Michael W. Pendleton – Electron Microscopist, Microscopy and Imaging Center, Texas A&M University, College Station, TX 77843-2257
Dr. Gerald J. Michels, Jr. – Entomologist, Texas AgriLife Research, Amarillo, TX 79106

Introduction and Justification

Entomologists, plant breeders, pathologists, and extension agents in Mali, Niger, Mozambique, Botswana, and the US are educating students and farmers in IPM and developing, evaluating, and transferring pest management technologies for insects of sorghum and pearl 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, and increase yield of food and feed for domestic use and income from marketing. Sorghum and millet are damaged by greenbug, Schizaphis graminum, in the US and sugarcane aphid, Melanaphis sacchari, in Africa that suck juice from leaves and vector viruses. Corn earworm, Helicoverpa zea, and fall armyworm, Spodoptera frugiperda, larvae feed on leaves, but cause most damage to sorghum by chewing on developing kernels. Larvae of sorghum midge, Stenodiplosis sorghicola, feed on the developing kernel and can cause 100% loss of grain. Larvae of millet head miner, Heliocheilus albipunctella, tunnel in millet spikes. Southwestern corn borer, Diatraea grandiosella, in the US and maize stalk borer, Busseola fusca; and spotted stem borer, Chilo partellus in Africa tunnel in stalks, causing susceptibility to disease and lodging. Insects annually destroy 35% of stored grain worldwide. The most damaging insect pests of stored grain include maize weevil, Sitophilus zeamais, and lesser grain borer, Rhyzopertha dominica.

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 Texas A&M University in the United States 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, farmer associations, volunteer organizations, and other agencies.

Specific objectives were to: 1) support entomology and IPM research and education of scientists in African countries; 2) collaborate to develop and deliver IPM strategies against insects that damage sorghum and millet in the field and storage by improved understanding of bioecology and population dynamics of insects and damage they cause; evaluation of potential arthropod pests; agronomic practices to prevent damage by insects and reduce pesticide use; cultivars with greater yield and resistance to biotic and abiotic stresses; 3) provide education for students in the US and African countries; and 4) develop partnerships with agencies engaged in improvement of sorghum and pearl 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 US.

Research Methodology and Strategy

Evaluating potential pests and understanding the life histories of insect pests and natural enemies. M.S. student Camilo Garzon used pheromones to monitor seasonal abundance and develop a predictive model of southwestern corn borer moths in Texas. Developing germplasm resistant to biotic constraints. The PI and African entomologists collaborated with breeding projects in Mali, Mozambique, Niger, and Texas, and with Monsanto for evaluating sorghum and pearl millet for resistance to millet head miner, sorghum midge, greenbug, sugarcane aphid, stalk borers, termites, and storage beetles. Studying pests of stored grain. Fernando Chitio in Mozambique and M.S. student Drissa Diarra from Mali evaluated resistance of stored sorghum grain to maize weevil. Scanning electron microscopy and energy dispersive spectroscopy were used to relate the depth of starch concentration in sorghum grain to resistance to maize weevil. Transferring insect pest management technologies. Mr. Chitio and Mr. Abdou Kadi Kadi assisted in transferring new sorghums to hundreds of farmers in Mozambique and Niger. Field demonstrations and workshops were used to teach farmers and extension to recognize pest problems and evaluate and implement IPM options. Undergraduate and graduate students from the US, Botswana, Mali, and Niger were educated in entomology and IPM.

Research Results

M.S. student Camilo Garzon counted beginning and maximum numbers of southwestern corn borer moths and generated a temperature-based degree-day model for cumulative numbers of male moths captured each week in pheromone traps on the Texas High Plains. Two peaks in numbers of moths occurred in late-June/early July and 12 August. Catches of first-generation moths began when approximately 90 degree-days had accumulated from 15 July and the peak coincided with 418 degree-days. Degree-day accumulations plotted against expected cumulative percentages of moths from the logistic function produced a sigmoidal curve. Degree-days of 288, 419, and 495 corresponded with 25, 50, and 75% cumulative moths. The model accurately predicted maximum numbers of moths. (Figure 1)

The PI collaborated with entomologists from Kansas, Nebraska, Oklahoma, and Texas to develop a sequential sampling plan and model for panicle-feeding caterpillars of sorghum.

The PI evaluated sorghum lines being developed by Monsanto and found 42 and 25% were as or more resistant than resistant checks to greenbug biotypes E and I, respectively.

Hamé Abdou Kadi Kadi assisted Dr. Kadri Aboubacar of Faculté d'Agronomie, Université Abdou Moumouni de Niamey, Niger, with field training of internship students. An intern at Kollo assessed resistance of 10 pearl millet varieties to damage by millet head miner. An intern at Konni surveyed knowledge of sorghum insect pests and control methods used by 80 farmers in four villages. An identification handbook was used to identify the insects. Visits to fields verified the farmers' answers. Data were discussed and validated at a village assembly. At Dibissou, Konni, 100, 55, 50, and 45% of farmers used cultural, chemical, traditional, and physical controls, respectively, against sorghum insect pests in the field. Only 30% used resistant sorghum. All farmers used traditional methods of repairing and cleaning granaries before storing sorghum panicles or grain. Chemicals, ash, and salt were used by 70, 40, and 15% of the farmers, respectively. Azadirachta indica, Boscia senegalensis, Annona senegalensis, and Balanites eagyptiaca leaves were used by 25, 15, 10, and 10% of the farmers surveyed. (Table 1)

At IIAM Namialo Agriculture Research Station in Mozambique, Fernando Chitio, entomologist, and Joaquim Mutaliano, breeder, found ICSV 93046 sorghum least damaged by stalk borers or termites. (Table 2)

At IIAM Mapupulo Research Station, Fernando Chitio and Joaquim Mutaliano found Macia, Sima, and GV Sima 710 E-2 least damaged by stalk borers, sugarcane aphids, and termites. In a second evaluation at Mapupulo, 02 CS 30445 and 02 CS 30932 sorghums were least damaged by stalk borers. (Table 3)

In the Entomology Laboratory at IIAM Nampula Agriculture Research Station, Mozambique, Fernando Chitio found 02 CM 19225, 02 CS 30331, 02 CS 30445, 02 CS 30932, 03 CM 15012 BK, 03 CM 15067 BK sorghums less damaged 4 months after infestation by maize weevil. (Table 4)

M.S. student Drissa Diarra from Mali evaluated stored sorghum grain for resistance to maize weevil. Five newly emerged

Table 1.

Application	Control method	Percentage of respondents
	Cultural	100
	Chemical	55
Field	Traditional	50
	Physical	45
	Resistant varieties	30
	Granary repair and cleaning	100
	Chemical	70
	Ash	40
Storage	Salt	15
	Leaves of *Azadirachta indica*	25
	Leaves of *Boscia senegalensis*	15
	Leaves of *Annona senegalensis*	10
	Ground leaves of *Balanites eagyptiaca*	10

Table 2.

Sorghum genotype	Score (1-5) of damage	
	Stalk borers	Termites
ICSV 93046	1.80 d	2.20 c
SDSL 90167	1.83 cd	2.60 a-c
SPV 1411	2.00 b-d	2.50 a-c
E 36-1	2.23 a-c	2.30 bc
IESB 92008 DL	2.07 b-d	2.53 a-c
IS 2331	2.07 b-d	2.57 a-c
MR#22xIS8613/1/2/3-1-3	2.00 b-d	2.67 a-c
IESB 92021 DL	2.17 b-d	2.60 a-c
IESB 91104DL	2.10 b-d	2.73 a-c
IESB 92165 DL	2.23 a-c	2.60 a-c
Ent#64DTN	2.07 b-d	2.80 a-c
IESB 92028 DL	2.10 b-d	2.80 a-c
ICSV 700	2.10 b-d	2.97 a-c
Karimtama	2.07 b-d	3.03 a-c
S 35	2.07 b-d	3.10 a-c
Sima	2.23 a-c	2.97 a-c
NTJ 2	2.27 ab	2.93 a-c
ICSB 324	2.33 a-c	2.97 a-c
SPV 422	2.27 ab	3.30 a
IESB 94021 DL	2.67 a	3.13 ab

Table 3.

Sorghum genotype	Score (1-5 scale) of damage		
	Stalk borers	Sugarcane aphid	Termites
Macia	1.67 b	1.73 b-e	1.10 b
Sima	1.97 ab	1.53 de	1.07 b
GV Sima 710 E-2	1.93 ab	1.50 e	1.17 ab
Elite-16/705 E-7	2.43 a	1.60 c-e	1.20 ab
SDS-1958-1-3-2/724 E-5	2.20 ab	1.90 a-d	1.27 ab
Kuyuma/708 E-10	2.43 a	2.03 a-c	1.00 b
ICSV-93010-1/708 E-9	2.30 ab	1.93 a-c	1.27 ab
ZSV-15/709 E-1	2.27 ab	1.73 b-e	1.5 a
ZSV-15-4/723 E-3	2.33 ab	2.13 a	1.10 b
Elite-17/707 E-6	2.43 a	1.90 a-d	1.23 ab
(SDS-5006*USV-187) E-4	2.23 ab	2.10 ab	1.33 ab
SDS-3047/722 E-8	2.67 ab	1.90 a-d	1.13 b
02 CS 5067	1.70 b-d	1.97 c	1.03 c
04 CM 884-5-1	1.76 b-d	1.97 c	1.03 c
02 CS 30932	1.60 cd	2.23 a-c	1.00 c
02 CS 30445	1.63 cd	2.07 bc	1.20 a-c
04 CM 798-7-1	1.90 a-d	2.03 bc	1.10 bc
02 CS 30331	1.87 a-d	2.23 a-c	1.00 c
04 CS 523-2-1	1.93 a-d	1.97 c	1.20 a-c
Macia	1.90 a-d	2.17 a-c	1.07 bc
03 CS GWT 115	2.03 a-c	2.23 a-c	1.00 bc
04 CS 452-2-1	1.87 a-d	2.13 bc	1.30 ab
04 CS 573-3-1	1.97 a-d	2.27 a-c	1.10 bc
02 CM 19225	1.97 a-d	2.37 a-d	1.07 bc
03 CM 1104 BK	2.10 ab	2.40 ab	1.10 bc
03 CM 15067 BK	2.33 a	2.17 a-c	1.10 bc
04 CS 608-6-1	2.03 a-c	2.27 a-c	1.43 a
Sima	2.23 a	2.07 bc	1.63 c
03 CM 15012 BK	2.33 a	2.57 a	1.03 c

Table 4.

Sorghum genotypes	Damage (1-5 scale) by maize weevil
02 CM 19225, 02 CS 30331, 02 CS 30445, 02 CS 30932, 03 CM 15012 BK, 03 CM 15067 BK	2.33 d
Sima, Macia, 02 CS 5067, 04 CM 452-4-1, 04 CS 884-5-1, 25 V 15/709 E-1	2.67 cd
03 CS GWT 115, GVS 17/710 E-2, ZSV 15-4/723 E-3	3.00 b-d
04 CS 608-6-1, 043 CS 573-3-1, SDS 1458-1-3-2/724 E-5, SDS 5006 WSV 187/E-4	3.33 a-c
ICSV 93010-1/708 E-9, 03 CM 1104 BK, 04 CS 798-7-1	3.67 a-c
04 CS 523-2-1, Elite 16/705 E-7	4.00 a

weevils were put with 5.0 g of grain in each of 10 vials maintained at 27ºC and 65-70% relative humidity. Each grain in the 10 vials of a genotype of sorghum was evaluated for damage on a scale of 1-5. Live and dead weevils were counted and grain in each vial was weighed every 3 weeks. The study will continue until 105 days after infestation, but at 63 days, 06BRON274 (Tegemeo*Tx2783)-HW5-CA1 was least damaged, and grain of Sureno weighed only 2.2% less than the original weight, while Tx430 had a damage score of 1.2 and weighed 13% less. (Table 5)

Dr. Michael Pendleton developed a technique using iodine vapor to indicate the depth of starch from the surface of sorghum kernels that graduate students and the PI found to be resistant to maize weevils. He previously found that the depth of starch from the surface of a sorghum kernel correlated with resistance to maize weevils that chew into kernels to feed and deposit eggs. The left image produced with a SEM secondary image detector shows the surface of a fractured kernel of resistant Sima after cryo-freezing with liquid nitrogen. The image on the right is an energy dispersive spectroscopy (EDS) map of the same area showing a yellow dot where iodine (indicating starch) was located. The brighter dots showed the concentration of starch in the layers of cells under the empty cells in the left image. Starch was concentrated approximately 50 µm in from the surface of the grain. (Figure 2)

Dr. Michael Pendleton developed a technique using epoxy to better preserve cell contents of kernels in original configuration. A kernel of moderately resistant Segaolane sorghum fixed, embedded in epoxy, sectioned with an ultra-microtome, and imaged with

Table 5.

	Live weevils/g		Damage score (1-5 scale)		Grain weight/g	
Sorghum genotype	**42**	**63**	**42**	**63**	**42**	**63 days**
Sureno	0.6	2.2	1.06	1.10	1.00	0.98
TAM428	0.8	1.2	1.08	1.13	1.00	0.97
07BRON288 (B8PR1059*B8PR1013)-PR10-CA3-CA2-CC2-LIBK-LIBK	0.8	1.0	1.09	1.13	1.00	0.96
06BRON274 (Tegemeo*Tx2783)-HW5-CA1	0.6	1.0	1.05	1.07	1.00	0.96
Macia	0.6	1.2	1.08	1.20	0.99	0.95
Tx2952 96GCPOBS124/GR134B-LG56-BG1-L2-BG1-LGBK	0.8	1.6	1.11	1.14	0.99	0.94
SRN39	1.0	1.6	1.06	1.11	0.99	0.94
Segaolane	1.0	1.2	1.68	1.16	0.99	0.94
B.HF8	0.8	1.4	1.08	1.14	0.99	0.94
(Segaolane*WM#322)-LG2-LG2-(03)BG1-LG1-LBK-PRBK	1.0	1.2	1.08	1.09	0.99	0.93
Tegemeo	1.0	2.2	1.08	1.15	0.99	0.93
(Macia*TAM428)-LL9	1.0	2.0	1.07	1.16	0.99	0.92
Ent62/SADC	0.8	2.2	1.09	1.19	0.99	0.92
01BRON195 (91BE146*Tx2864)-LG12	0.8	2.6	1.07	1.14	0.98	0.90
06BRON287 (Sureno*(6OB172/88CC445*Tx2862))-LG4-CG2-CG1-CA1-LIBK-LIBK	0.8	3.2	1.11	1.21	0.98	0.89
Tx430	0.8	2.2	1.13	1.20	0.97	0.87

Figure 1.

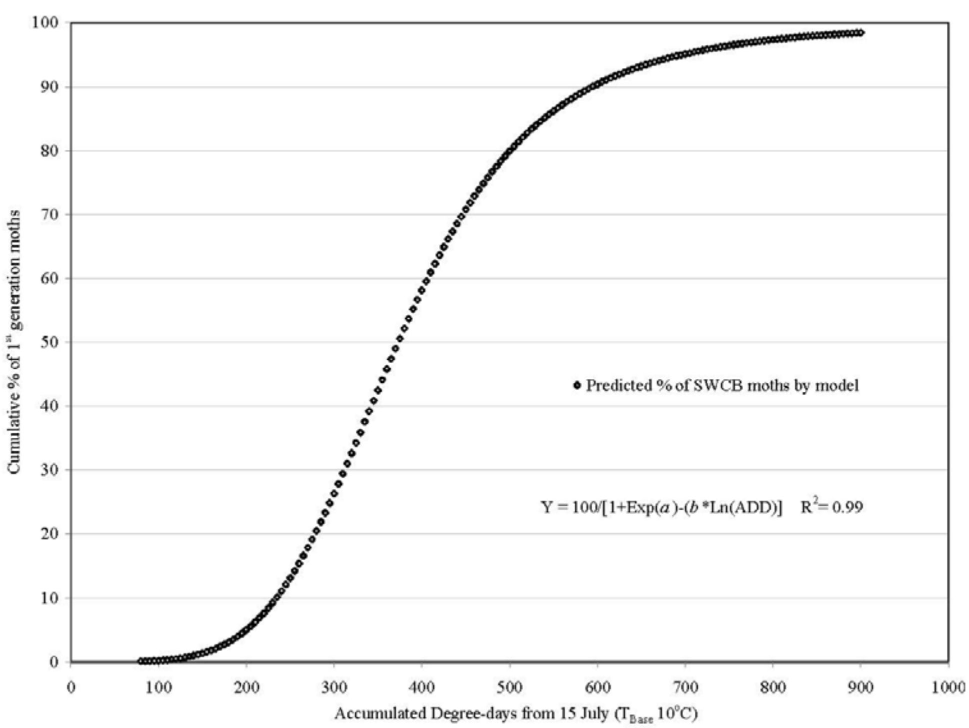


Figure 2.

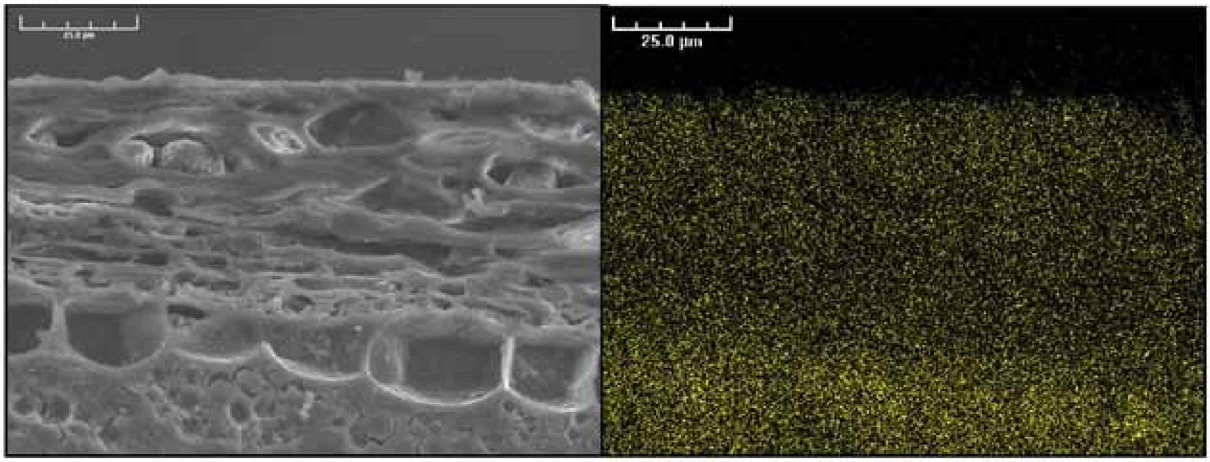


Figure 3.

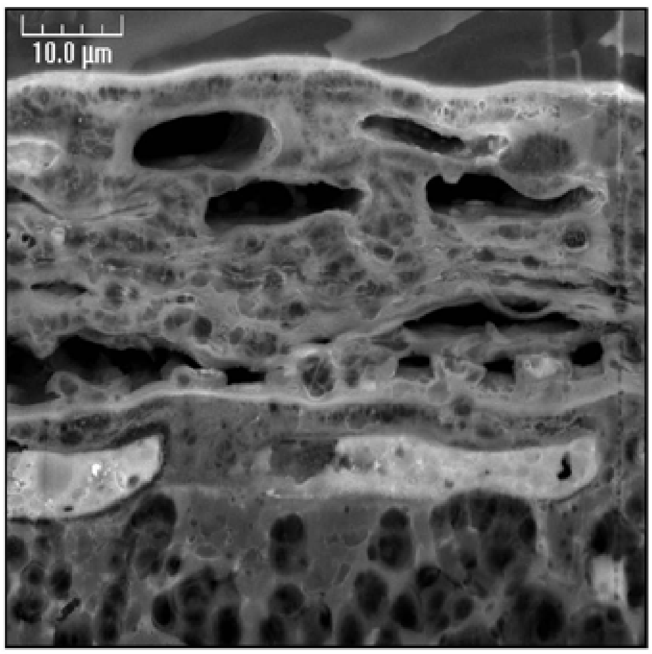
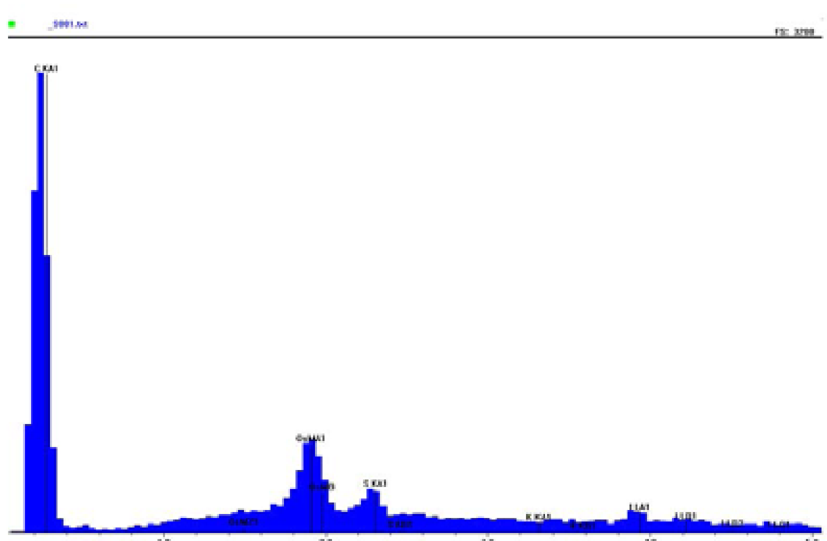


Figure 4.



a SEM backscatter detector showed brighter areas in contrast at approximately 28 µm from the surface of the grain. (Figure 3)

An EDS plot of elements shown by using a non-rastered beam in the bright area of the backscattered SEM image of a Segaolane kernel revealed two iodine (I) peaks indicating starch [sulfur (S)

and carbon (C) occur naturally in sorghum and osmium (Os) was in the fixative solution added before embedding and sectioning by ultramicrotome]. (Figure 4)

An EDS plot of elements shown by using a non-rastered beam in the dark area of the backscattered SEM image of the Segaolane kernel showed no iodine (I) peak, so starch was not present in the dark areas. (Figure 5)

Dr. Niamoye Diarisso assessed at Sotuba, Mali, germination of Grinkan, Niachitiama, Seguifa, Tiandougou, and Tiandougou coura sorghum after storage in polyethylene or triple bags. The sorghums were ready for release. (Figure 6) Once each month from February through August 2011, whole kernels and those damaged by Rhyzopertha dominica or other storage insects were counted and weighed. Seguifa, which seemed very resistant, had more than 90% germination and was less than 6% damaged after storage in triple or polyethylene bags. But, in general, sorghum grain was much less infested and germination was greater after storage in triple than polyethylene bags. Germination of Grinkan was greatest in May (80%). Damage to Grinkan in August was less than 10% in a triple bag but three times greater in a polyethylene bag. (Figure 7) Most germination of Tiandougou occurred in April after storage in a triple bag (65%) while most germination after storage in a polyethylene bag was 60% in May. Greatest germination of Niachitiama was 50% in June in a triple bag and 45% in May in a polyethylene bag. Infestation of Niachitiama or Tiandougou in triple bags was only 5% in July, July, and August but 12-15% in June and increased to 35% in August in polyethylene bags. Percentage of germination of Tiandougou coura stored in a triple bag was greatest in May (85%) and decreased to 65% in August; germination after storage in a polyethylene bag was greatest in April (75%) but decreased to 38% in July (Figure). Tiandougou coura was not infested by insects in a triple bag but was 75% infested in August in a polyethylene bag.

Networking Activities

Workshops and Meetings

The PI, collaborators, and students presented research at the Entomology Science Conference, 2-4 November 2010, College Station, TX; Texas Plant Protection Conference, 6-7 December 2010, College Station, TX; Annual Meeting of the Entomological

Figure 5.

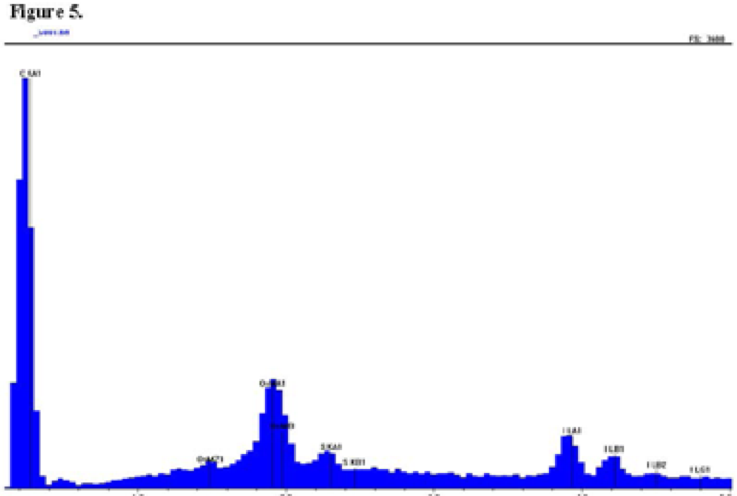


Figure 6.

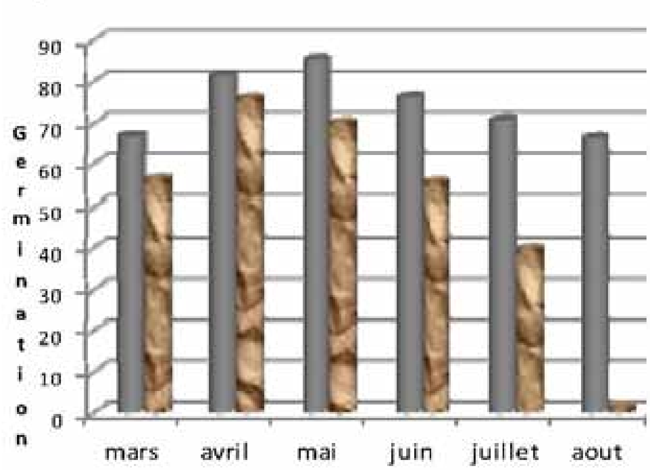
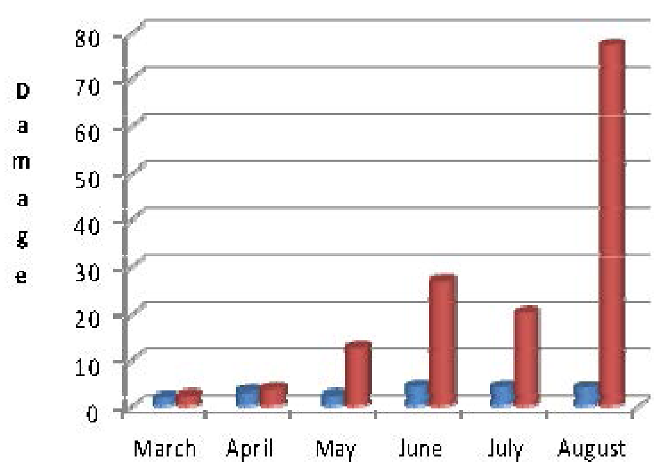


Figure 7.



Society of America, 12-15 December 2010, San Diego, CA; Annual Meeting of the Southwestern Branch of the Entomological Society of America and Society of Southwestern Entomologists, 7-10 March 2011, Amarillo, TX; Texas Society for Microscopy Annual Meeting, 8-9 April 2011, Fort Worth, TX; Microscopy and Microanalysis Meeting, 7-11 August 2011, Nashville, TN; and Great Plains Sorghum Conference and Biennial Sorghum Research and Utilization Conference, 12-14 September 2011, Stillwater, OK. The PI and IER collaborators Dr. Niamoye Yaro Diarisso, entomologist; Dr. Mamourou Diourté, plant pathologist; and Abdoul Wahab Touré, agronomist, organized a management workshop on 29-30 June for trainers of decru sorghum farmers in Mali. Hamé Abdou Kadi Kadi from Niger attended workshops on climate change, farming systems modeling, food security, and nutrition in West Africa.

Research Investigator Exchanges

From 18 December 2010 - 4 January 2011, the PI traveled to Mali and Niger and met with and discussed INTSORMIL research with scientists at IER and INRAN. In Niger, the PI and Hamé Abdou Kadi Kadi visited farmers and extension agents at Madaoua who were testing and very enthusiastic about new sorghum INRAN developed for resistance to sorghum midge. From 24 June - 7 July 2011, the PI traveled to Mali to discuss and review research and collaborate with IER scientists in presenting a workshop to teach trainers to train farmers how to manage decru sorghum.

Research Information Exchange

Sorghums developed for resistance to greenbugs were evaluated for Monsanto in the US. Eighty farmers in four villages in Niger were trained to identify and manage sorghum insect pests. A workshop was used to educate 26 trainers of decru sorghum farmers in Mali. Supplies and funding were provided to Mr. Chitio in Mozambique, Dr. Yaro in Mali, Mr. Abdou Kadi Kadi in Niger, and Dr. Munthali in Botswana.

Germplasm Distribution

Hame Abdou Kadi Kadi was involved in release of sorghum midge-resistant SSD-35 to hundreds of farmers in Madaoua and Birni N'Konni, Niger.

Publications and Presentations

Journal Articles

Pendleton, M.W., B.B. Pendleton, E.A. Ellis, G.C. Peterson, F.M. Chitio, and S. Vyavhare. 2011. Use of scanning electron microscopy and energy dispersive spectroscopy to correlate the arrangement of starch with resistance to maize weevil (Coleoptera: Curculionidae) in sorghum grain. Microscopy and Microanalysis 17: 250-251.

Pendleton, M.W., B.B. Pendleton, E.A. Ellis, G.C. Peterson, F.M. Chitio, and S. Vyavhare. 2011. Using scanning electron microscopy and energy dispersive spectroscopy to determine if resistance of sorghum grain to maize weevil (Coleoptera: Curculionidae) is correlated to the arrangement of starch within the sorghum grain. Texas Journal of Microscopy 42: 11.

Vyavhare, S., and B.B. Pendleton. 2011. Maturity stages and moisture content of sorghum grain damaged by maize weevil. Southwestern Entomologist 36:331-333.

Proceedings

Eder, Z., and B.B. Pendleton. 2011. Development and infestation characteristics of yellow sugarcane aphid (Hemiptera: Aphididae) on sorghum. P. 38. In Proceedings of the 59th Annual Meeting of the Southwestern Branch of the Entomological Society of America. Amarillo, TX. 7-10 March 2011.

Pendleton, B.B., M.W. Pendleton, E.A. Ellis, G.C. Peterson, F. Chitio, and S. Vyavhare. 2011. Use of scanning electron microscopy and energy dispersive spectroscopy to correlate resistance to maize weevil (Coleoptera: Curculionidae) to the arrangement of starch in sorghum grain. P. 39-40. In Proceedings of the 59th Annual Meeting of the Southwestern Branch of the Entomological Society of America. Amarillo, TX. 7-10 March 2011.

Thesis

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Presentations

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Sustainable Production Systems

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

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 compared and tested several available soil, water, plant and nutrient management practices in different crop mixtures and crop rotations to understand interaction(s) and assess their long-term impact on yields and economic stability. Our research will help in developing a of package of practices that will improve productivity of sorghum and millet cropping systems. As a part of training and capacity building, two graduate students (one MS from Ghana and one Ph.D. student from Mali) started graduate degree programs at K-State and will complete their programs by Fall 2012.

Objectives and Implementation Sites

The main objectives during this year were to:

- Test and transfer improved crop, soil and water management practices in farmers field;
- Understand the impact of drought and high temperature stress on sorghum and millet;
- Study the response of sorghum genotypes to nitrogen application; and
- Continue long-term training for host country scientists

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

1. Ghana: Silbelle, Sorbelle, Piisi and Nakor; 2. Niger: Kallapate and Kollo region; 3. Burkina Faso: Gourcy, Saira, and Zondoma; 4. Mali: Sotuba, Cinzana, Fansirakoro and Konobougou; and 5. US: Manhattan, Ottawa, Hays, Kansas.

Research Methodology and Strategy

Host Country: Ghana

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; and (ii) quantify contribution of cowpea to yield improvement in sorghum.

Treatments and Experimental Design: Experiment was 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). Conventional tillage consisted of disc ploughing and harrowing while in the no-till treatment, a pre-emergence herbicide was used to kill weeds before sowing directly into the residue followed by the application of a post-emergence herbicide. In the conventional tillage system, weeds were controlled manually using hoes.

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: 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). Conventional tillage consisted of disc ploughing and harrowing while in the no-till treatment, plots were sprayed with glyphosate to kill weeds before sowing followed by hand weeding to control any weeds that emerge. The N fertilizer rates were applied in two doses at 2 and 6 weeks after sowing, using urea as N source.

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; and (ii) quantify contribution of cowpea with and without P fertilizer to succeeding sorghum crops.

Treatments and Experimental Design: The experiment was conducted in two communities Piisi/Nakor and Silbelle/Sorbelle in Upper West Region of Ghana. These communities were selected based on earlier farmers' participatory surveys. The experiment was arranged in a factorial combination of three 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 10 farmers' fields at each location.

Host Country: Niger

Experiment 1: On-Farm Demonstration of Improved Technology (Tied Ridges, Fertilizer Application and High Planting Density) on Sorghum

Objectives: The main objective of this experiment was to demonstrate the benefits of tied ridges, fertilizer application and planting density on sorghum yield under on-farm conditions.

Treatments and Experimental Design: This research was conducted in three different agro ecological zones: a low (200-300), medium (300 - 500) and high (>500) rainfall (mm year-1) environment. The package was composed of tied ridge, manure (5 t/ha), urea (50 kg/ha), density of 31,250 hills/ha and three plants/hill. Experimental design was a randomized complete block design, with ten replications.

Experiment 2: On-Farm Demonstration of Improved Technology (Micro-dose, Fertilizer Application and Planting Density) on Pearl Millet

Objectives: The main objective of this experiment was to demonstrate the impact of additional fertilizer application and plant population on productivity millet.

Treatments and Experimental Design: The treatments comprised of two technologies (combination of densities and fertilization) - A: low technology (no input), 10,000 plant ha-1, no fertilizer; B: Improved technology-1, 17,000 plant ha-1, micro-dose (6 g NPK), triple super phosphate 20 kg P2O5 ha-1 and 30 kg N ha-1. Experimental design was a randomized complete block design, with ten replications.

Host Country: Burkina Faso

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 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.

Host Country: Mali

No reports were submitted for this year.

United States of America

Experiment 1: Impact of High Temperature Stress on Finger Millet

Objectives: The main objective of this experiment was to study the effects of high temperature stress on growth, development and yield of finger millet.

Treatments and Experimental Design: Finger millet genotype (271670 SD) was grown in controlled environments. After emergence plants were exposed to three day/night temperatures (32/22ºC; 36/26ºC; and 38/28ºC). Experimental design was a randomized block design with 10 replicates (pots) for growth and yield.

Experiment 2: Response of Sorghum Genotypes to Nitrogen

Objectives: The objectives of this experiment were to quantify the effect of high temperature during reproductive stages and to test if genotypes varied in their response to high temperature stress.

Treatments and Experimental Design: Twelve sorghum genotypes (six hybrids: 26056, 99480, 95480, 95207, 23012, CSR1114/R45, TX3042/TX2737; and six inbred lines: B35, SC35, SC599, TX430, TX2783, and TX7000) were grown at three N rates (0, 45 and 90 k N ha-1) under field conditions at Manhattan, Hays and Ottawa. Experimental design was a split plot design with four replications. Main plots were the N rates; and sub-plots were the genotypes.

Research Results

Host Country: Ghana

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

Cowpea: There was significant main effect of tillage on cowpea growth and yield in 2010. Pod and grain yields were significantly higher under no-till than under conventional tillage (Table 1). Cowpea relay cropped with sorghum or intercropped with sorghum had higher pod and grain yields than sorghum-cowpea rotation. Application of 40 kg N ha-1 or 26 kg P ha^{-1} significantly increased cowpea stover compared with no fertilizer or combined application of N and P fertilizer.

Sorghum: Sorghum stover, panicle and grain yields were significantly higher under conventional tillage (CT) than under no-tillage (NT, Table 1). Sorghum following cowpea in relay had lower stover and panicle yield than continuous sorghum and sorghum intercropped with cowpea. Sorghum grain yield following cowpea in relay were significantly lower than continuous sorghum and sorghum intercropped with cowpea. Application of fertilizer significantly increased stover, panicle and grain production compared with the control of no fertilizer. There was no significant difference between fertilizer rates on sorghum stover yield. Combined application of N and P fertilizer gave higher panicle ield compared with only N or P application. There was no significant difference between 40 + 26 (N + P) kg ha^{-1} or 26 kg P ha^{-1} alone, however, both treatments had significantly higher grain yield compared to 40 N or no fertilizer control.

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

Sorghum grown under no-till produced significantly higher grain yield than sorghum grown under conventional tillage (Table 2). The local variety, Chere, produced significantly higher stover yield than the two improved varieties, Kapaala and Dorado. The variety Dorado produced significantly higher grain yield than variety Kapaala and Chere. The local variety Chere significantly out yielded Kapaala in terms of grain yield. Fertilizer application significantly increased stover, panicle and grain yield compared with no fertilization (Table 2). There was no significant effect of increasing N rate on stover yield although there was a trend of increasing stover weight with increasing N rate. Grain yield increased with increasing N rate up to 60 kg N ha^{-1} and then decreased with higher N rate (Table 2).

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

Cowpea: As in previous years, there was no significant effect of tillage system on cowpea biomass, pod and grain yield (Table 3). There were significant effects of cropping system and P fertilizer application on cowpea biomass, pod and grain yield. Cowpea following sorghum in rotation produced significantly higher biomass than when relay or intercropped with sorghum. Pod and seed yields were significantly higher when cowpea was relay cropped with sorghum than in annual rotation or when intercropped with sorghum (Table 3). As in previous years, application of 26 kg P ha-1 increased cowpea biomass yield compared with no P application (Table 3).

Sorghum: Tillage system had no effect on sorghum stover and grain yield but increased panicle weight (Table 3). Cropping system significantly influenced sorghum stover, panicle and grain yield. Sorghum following cowpea in relay had significantly higher stover and grain yields than sorghum intercropped with cowpea. There was a significant increase in sorghum stover, panicle and grain yields with P fertilizer application (26 kg P ha-1) (Table 3).

Host Country: Niger

Experiment 1: On-Farm Demonstration of Improved Technology (Tied Ridges, Fertilizer Application and High Planting Density) on Sorghum

Grain yield of sorghum increased by about 10 fold with improved technology compared to traditional cultural practices. Farmers now realized that the chronic sorghum poor production was mainly due to lack of or improper soil and water management. Most farmers are convinced of the importance of the new technology and like to apply it in their field. However, its adoption has some constraints. Sorghum producers indicated that the adoption of the tied ridge technique required some tools which necessary for making ridges. They indicated that the use of animal traction can help adoption of this technology than making them by hand (as practiced currently). They were advised to use animal traction equipment. Introduction of animal drawn implements will greatly help in the adoption of the tied ridge practice in the region, and will consequently improve sorghum production in the region.

Experiment 2: On-Farm Demonstration of Improved Technology (Micro-dose, Fertilizer Application and Planting Density) on Pearl Millet

During the last two growing seasons, demonstration trials were conducted in several regions with extremely poor sandy soil to show to farmers of these regions a new cultural practice which can help them improved pearl millet productivity. Results

Table 1. Effects of tillage, cropping system and fertilizer on cowpea and sorghum in 2010 at Wa, Ghana

Main Effects	Cowpea yield (CP)			Sorghum yield (SG)		
	Stover	Pod	Grain	Stover	Panicle	Grain
	kg ha^{-1}			kg ha^{-1}		
Tillage system						
Conventional Tillage	930a	1250b	763b	2731a	2042a	808a
No Tillage	847b	1514a	978a	1499b	1156b	676b
Cropping system						
Continuous SG				2550b	1922b	805a
SG - CP rotation	802	1182c	766b			
CP - SG intercrop	980	1620a	948a	3048a	2187a	841a
CP - SG relay	822	1344b	897a	748c	688c	581b
Fertilizer rate (kg ha^{-1})						
0	772b	1514	896	1459b	1063c	445c
40 N	977a	1389	927	2163a	1563b	790b
26 P	1000a	1375	867	2146a	1667b	837a
40 +26 (N+P)	803b	1250	819	2697a	2104a	897a

Means within a column followed by similar letters are not significantly different at $P<0.05$.

Table 2. Main effects of tillage, variety and N fertilizer rate on stover and grain yield of sorghum during 2010 at Wa, Ghana.

Treatments	Stover yield (kg ha^{-1})	Grain yield (kg ha^{-1})
Tillage system		
CT	3932a	444b
NT	3970a	523a
Variety		
Kapaala	2025c	408c
Dorado	3165b	583a
Local (*Chere*)	6663a	460b
Fertilizer (kg ha^{-1})		
0	1655b	370c
30	4001a	453b
60	4017a	542a
90	4061a	478b
120	4852a	575a

Means with similar letters are not significant at $P<0.05$.

Table 3. Main effects of tillage, cropping system and P fertilizer on cowpea (CP) and sorghum (SG) in farmers fields during 2010 at Wa, Ghana.

Main Effects	**Cowpea yield (CP) (kg ha^{-1})**			**Sorghum yield (SG) (kg ha^{-1})**		
	Biomass	**Pod**	**Grain**	**Stover**	**Panicle**	**Grain**
Tillage system						
Conventional Tillage	1198	1483	941a	2428	1415a	783
No Tillage	1289	1493	939b	2499	1670b	880
Cropping system						
Continuous SG						
SG - CP rotation	1377a	1405c	870c			
CP - SG intercrop	1122c	1485ab	938b	2053b	1255b	698b
CP - SG relay	1233b	1575a	1012a	2873a	1830a	964a
P fertilizer (kg P ha^{-1})						
0	1103b	1453	911	2320b	1405b	668b
26 P	1385a	1523	969	2606a	1680a	994a

Means within a column followed by similar letters are not significantly different at $P<0.05$.

of demonstration trials, always showed large yield benefits from improved technology. Farmers conducting the demonstration trials liked to practice informed others. Many millet producers in these areas started to apply this technology. This season was not good for millet production in the whole country because of crops failure caused mainly by drought. The performance of this technology is not visible this year due environment problems. However, millet producers engagement in the use of the technology has not changed. The technology is recognized as appropriate to farming in poor sandy soils. There were clear benefits to yield in a normal year (see Photo 1 and 2 from harvests from 2010).

Host Country: Burkina Faso:

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

Sorghum produced higher yield when grown in rotation than grown continuously in all water conservation techniques. Grain yield of the improved sorghum variety Sariaso 14 grown in rotation with cowpea was increased by 76 to 118% than the same variety grown continuously. Similarly, grain yield of the local landrace Nongomsoba grown in rotation with cowpea was higher than the same variety grown continuously by 45 to 101%. The response of improved genotype was greater than the local genotype. For the various water conservation techniques, use of stone rows or grass strips produced greater yield of both genotypes either grown continuously or in rotations system, the response was similar in both cropping systems. Stone were slightly superior than the grass strips in 2010.

Host Country: Mali

No reports were submitted for this year.

United States: Manhattan, Kansas

Experiment 1: Impact of High Temperature Stress on Finger Millet

Finger millet plants grown at 32/22°C performed better in terms of growth and yield than plants grown at 36/26°C and 38/28°C. There were no significant effects of high temperature stress on leaf photosynthesis. High temperatures (36/26 or 38/28°C) significantly increased stomatal conductance, transpiration rate, and leaf temperature from. However, chlorophyll a fluorescence (indicative of photosynthetic efficiency) and leaf chlorophyll content was significantly decreased by high temperatures. High temperature stress delayed panicle emergence, flowering and physiological maturity. High temperature stress significantly decreased plant height, internode length, leaf area; however, numbers of leaves were significantly increased by high temperature stress (Table 4). Finger millet yield traits (panicle numbers, finger numbers, finger length, number of seeds, seed weight) were significantly decreased by high temperature stress.

Experiment 2: Response of Sorghum Genotypes to Nitrogen

There were significant effects of nitrogen (Figure 1) and genotypes (Figure 2) on grain yield across all locations. Maximum grain yield was obtained at 90 kg N, followed 45 kg N, and lowest in 0 N kg ha^{-1}. Performance of hybrids was generally superior to the inbred lines of all traits. Sorghum hybrids 26506 and 99480 produced maximum grain yield across all locations. While inbred SC35 had the lowest grain yield.

There were significant differences among genotypes for all NUE traits at Ottawa and Manhattan (Table 5). Across genotypes N uptake efficiency ranged from 56 to 82, utilization efficiency from 31 to 55, recovery from 2 to 52, total NUE from 18 to 35 and NHI from 43 to 71 %. Among the genotypes, 99480 and 26506 both known to be post–flowering drought tolerance were high in NUE and component of N use. While genotypes B35 and SC35 were the lowest in NUE and components of N use. Components of nitrogen use efficiency were greater at 0 N compared to 45 or 90 kg N ha^{-1}. Overall, our data suggest that there were significant differences for NUE traits in sorghum hybrids and inbred lines. There are opportunities to breed for higher NUE in grain sorghum.

Photo 1. Manually made tied ridges in Niger.

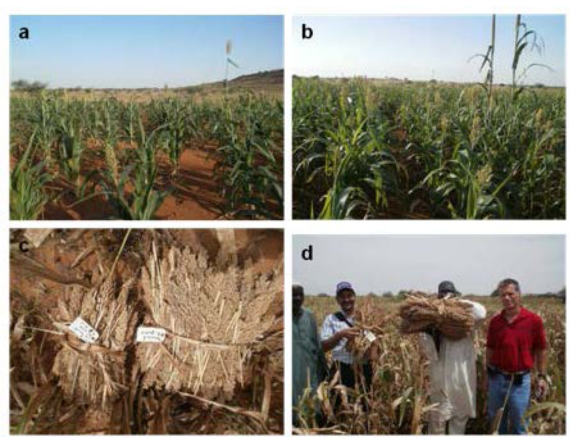


Photo 2. (a) On-farm sorghum fields without tied ridges - showing poor growth; (b) with tied ridges - showing improved growth (c) and (d) lower yield (left bundle) without and higher yield (right bundle) with tied ridges in each photo.

Table 4. Effect of temperature stress on phenology, growth and yield traits of finger millet grown under controlled environment conditions.

Traits	Opt-Temp. 32/22°C	High Temp. 1 36/26°C	High Temp. 2 38/28°C	LSD
Days to panicle emergence	52	68	-	-
Days to flowering	64	85	-	-
Days to physiological maturity	130	158	-	-
Plant height (cm)	75	54	34	3.79***
Internode length (cm)	8.5	5.3	2.7	0.51***
Number of tillers plant^{-1}	6.5	11.2	6.1	0.62***
Number of leaves plant^{-1}	13.2	15.9	17.3	1.43***
Leaf area (cm^{-2} plant^{-1})	350	361	283	47.49*
Panicle dry weight (g plant^{-1})	14.3	4.5	2.9	1.37***
Panicle numbers (plant^{-1})	8.2	6.0	6.2	0.56***
Finger numbers	7.4	6.0	6.6	0.53***
Finger length (cm)	6.8	5.4	4.8	0.43***
Seed numbers	162	107	74	7.56***
100 seed weight (g)	0.46	0.28	0.22	0.05***

*, **, ***, Significant at P<0.05, 0.01 and 0.001, respectively.

Table 5. Influence of different treatments on components of nitrogen use efficiency during 2010 in Ottawa and Manhattan.

	Ottawa			Manhattan (Unit 7)		
Treatments	**Uptake Efficiency**	**Utilization Efficiency**	**Total N Use Efficiency**	**Uptake Efficiency**	**Utilization Efficiency**	**Total N Use Efficiency**
Genotypes						
Hybrids						
26506	64.8a	55.8a	35.4a	68.3bcd	39.5bcd	32.2bcde
99480	64.5a	54.3a	33.9a	82.6a	52.9a	42.7a
95207	64.9a	54.5a	33.4a	64.8bcd	38.8vcd	31.7bcde
23012	63.5a	51.0ab	32.6a	72.4abc	46.1ab	37.6ab
CSR1114/R45	63.7a	50.3ab	32.2ab	71.5abc	41.7bc	34.6bc
TX3042/TX2737	58.1b	42.4cd	24.6cb	65.2bcd	45.6ab	36.3ab
Inbred Lines						
SC35	62.6a	33.7e	22.3de	74.9ab	46.7ab	37.3ab
SC599	56.2b	34.1e	18.2e	58.2d	32.2d	25.3e
TX430	56.3b	39.6de	18.1e	60.3dc	35.1cd	28.9cde
TX2783	65.1a	42.8cd	27.9bc	65.1bcd	42.4bc	32.6bcd
TX7000	62.9a	46.2bc	26.2cd	26.1de	31.7d	53.9cd
				61.7cd	42.7bc	34.0bc
N Levels (kg ha^{-1})						
0	100	41.4b	41.4a	100a	50.3a	50.3a
45	49	46.8a	23.2b	50.1b	32.8b	24.4b
90	37	49.4a	18.1c	52.5b	40.8b	25.2a
F Test Probability						
Genotypes (G)	*	**	**	*	**	**
Nitrogen (N)	**	**	**	*	**	**
G x N	**	**	**	NS	NS	NS

*, **, ***, Significant at P<0.05, 0.01 and 0.001, respectively.

Figure 1. Grain yield at different N levels during 2010 at four locations in Kansas.

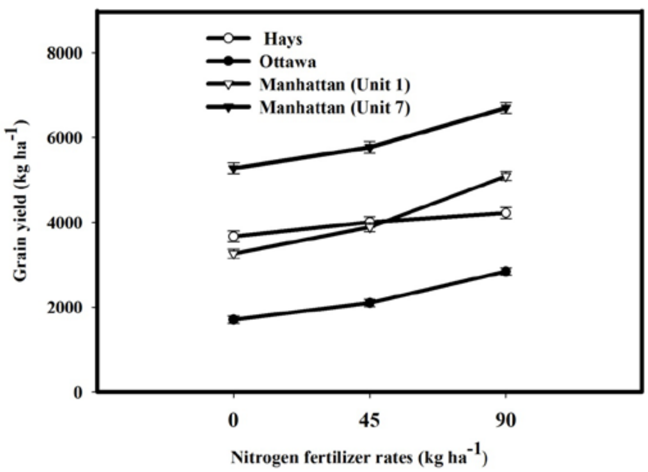
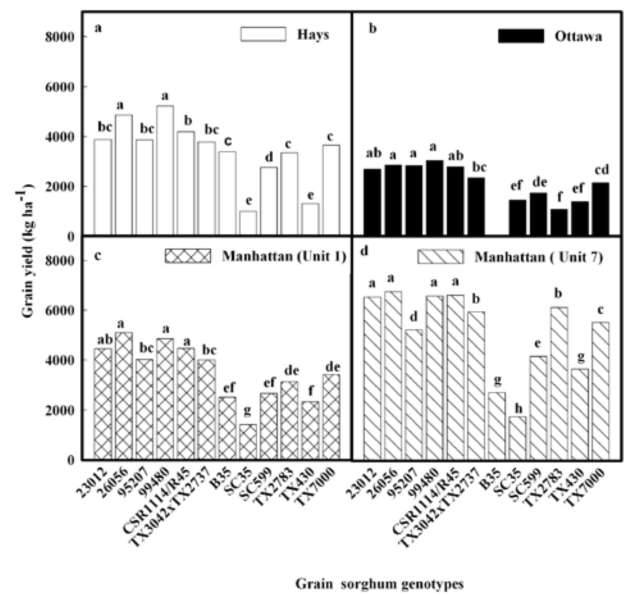


Figure 2. Grain yield of different sorghum genotypes during 2010 at four locations in Kansas.



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 several components of ICSM components and tested in on-station and on-farm conditions. All of these component technologies have shown significant improvements in grain yield under on-farm conditions, and have shown adoption by farmers. Some of these technologies included: use of phosphorus application (26 kg ha^{-1}) in cowpea – sorghum intercropping or crop rotations in Ghana; use of micro-dose and additional fertilizer 20 kg P ha-1 and 30 kg N ha^{-1} to improve productivity of millet; use of tied ridges to improve productivity of sorghum and millet in Niger; and use of improved cultivar in combination with contour ridging, and micro-dose + enhanced fertilizer application for improved sorghum and millet yields in Mali; and use of stone rows for water harvesting, zai system and improved cultivar of sorghum and cowpea in Burkina Faso. In addition, we enhanced our knowledge on impacts of abiotic stresses (high temperature stress) on millet, and high temperature and drought on grain sorghum. Sorghum genotypes for high temperature and drought tolerance were identified; and sorghum genotypes with greater nitrogen use efficiency were identified.

Training (Degree and Non-Degree)

Degree Training: Three students (one each from Mali, Ghana and Burkina Faso) are undergoing degree training.

1. Mali: Mr. Alassane Maiga, has completed his course work, research and preliminary exam in 2010. He is currently writing his research and expected to complete next semester. His research focuses on development improved crop management practices (planting dates, planting densities, fertilizer nitrogen) on productivity of grain sorghum. He is developing color chart to identify N deficiency and management option.

2. Ghana: Mr. George Mahama Yakuba, completed his MS research work. He is working on improving nitrogen use efficiency of sorghum. He is screening sorghum cultivars and hybrids for nitrogen use efficiency. He is currently writing his MS thesis and is expected to complete next semester.

In addition, two students from Kenya (Mr. Raymond Mutava and Ms. Rachel Opole) are continuing with PhD programs at KSU (leveraging money from other sources – Kansas Grain Sorghum Commission and Center for Sorghum Improvement). Rachel is working on understanding impact of high temperature stress on finger millet. Raymond is focusing his research on screening sorghum germplasm for drought tolerance and understanding mechanisms of tolerance.

Networking Activities

We have initiated ties with local and regional institutes including several NGO for conducting on-farm and on-station research and extension activities. These include networking activities with Production, Marketing and transformation of Sorghum (INTSORMIL project in Mali). SANREM CRSP on developing Conservation Agriculture Production Systems in Ghana and Mali. Up-scaling contour-ridge tillage project funded by the USAID Mission of Mali; and minimum tillage and cover crop project funded by EMBRAPA in Mali.

Publications and Presentations

Journal Articles

Ananda N, Vadlani PV, Prasad PVV. 2011. Evaluation of drought and heat stressed grain sorghum (Sorghum bicolor) for biofuel production. Industrial Crops and Products 33: 779-782

Mutava RN, Prasad PVV, Tuinstra MR, Kofoid KD and Yu J. 2011. Characterization of sorghum genotypes for traits related to drought tolerance. Field Crops Research 123: 10-18

Prasad PVV, Vu JCV, Boote KJ, Allen LH Jr. 2011. Longevity and temperature response of pollen as affected by elevated growth temperature and carbon dioxide in peanut and grain sorghum. Experimental and Environmental Botany 70: 51-57.

Singh, RP, Prasad PVV, Sharma AK, Reddy KR. 2011. Impact of High Temperature Stress and Potential Opportunities for Breeding. In S.S. Yadav, R.J. Redden, J.L. Hatfield, H.L. Campen and A.E. Hall (eds). Crop Adaptation to Climate Change. Wiley-Blackwell, Oxford, UK. 166-185.

Abstracts and Presentations

Mahama G, Prasad PVV, Mengel DB, Staggenborg SA, Tesso T. 2011. Nitrogen use efficiency in grain sorghum genotypes. Annual Meeting of ASA-CSSA-SSSA, 16 – 19 Oct., San Antonio, TX, USA.

Maiga A, Roozeboom K, Prasad PVV. 2011. Effect of planting practices on light interception, growth and yield of grain sorghum. Annual Meeting of ASA-CSSA-SSSA, 16 – 19 Oct., San Antonio, TX, USA.

Mutava RN, Prasad PVV, Staggenborg SA, Yu J, Roozeboom KL. 2011. Evaluating variability in water use efficiency of some selected genotypes. Annual Meeting of ASA-CSSA-SSSA, 16 – 19 Oct., San Antonio, TX, USA.

Mutava RN, Prasad PVV, Staggenborg SA, Yu J, Roozeboom KL. 2011. Influence of drought stress on root growth and development of sorghum genotypes. Sorghum Improvement Conference of North America, 13 – 14 Sep., Stillwater, OK, USA.

Mutava RN, Prasad PVV. 2011. Screening sorghum genotypes for canopy temperature using field based infra-red sensors. Annual Meeting of ASA-CSSA-SSSA, 16 – 19 Oct., San Antonio, TX, USA.

Narayanan S, Aiken RM, Prasad PVV, Xin Z, Kofoid KD, Yu J. 2011. Allometric model to quantify sorghum canopy formation. Annual Meeting of ASA-CSSA-SSSA, 16 – 19 Oct., San Antonio, TX, USA.

Narayanan S, Aiken RM, Xin Z, Prasad PVV, Kofoid KD, Yu J. 2011. Canopy architecture and transpiration efficiency in sorghum. Keystone Symposium: Plant Abiotic Stress Tolerance Mechanisms, Water and Global Agriculture, 17 – 22 Jan., Keystone, CO, USA.

Opole R, Prasad PVV, Staggenborg SA, Roozeboom KL. 2010. Effect of seeding rate and nitrogen fertilizer application rate on field performance of finger millet. Annual Meeting of American Society of Agronomy, 31 Oct. – 03 Nov., Long Beach, CA, USA.

Prasad PVV, Djanaguiraman M. 2011. Effect of high temperature stress on pollen viability: role of reactive oxygen species and phospholipids. Annual Meeting of ASA-CSSA-SSSA, 16 – 19 Oct., San Antonio, TX, USA.

Prasad PVV, Naab JB, Doumbia MD, Dalton TD. 2011. Conservation agricultural practices in West Africa: challenges and opportunities. International Conference on Sustainable Agriculture and Food Security: Challenges and Opportunities, 27 – 28 Sep., Bandung, Indonesia.

Prasad PVV. 2011. Impact of climate change and climate variability on productivity of food grain crops. Asian Crop Science Association Conference, 27 – 30 Sep., Bogor, Indonesia.

Yahaya I, Hashim I, Naab JB, Prasad PVV, Dalton TD. 2011. Knowledge of households, cropping systems, perceptions on conservation agricultural practices in Upper West region of Ghana. Proceedings of Second International Conservation Agriculture Workshop and Conference in Southeast Asia, 4 – 7 July 2011, Phnom Penh, Cambodia.

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

Project UNL 101
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Introduction and Justification.

Research and extension activities were implemented in Ethiopia, Uganda, Mozambique, and Nebraska supporting the INTSORMIL objective of improving crop, soil, and water management for increased and more stable yields. Promising practices have been identified and 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 climate variability. Research on skip-row planting of sorghum and maize was continued in the Central Rift Valley with a component of planting a short-season pulse crop in the skip-row area. Extension (transfer of technology, TOT) activities continue to promote soil management technology in Ethiopia with financial support from IDRC. In striga-infested eastern and northern Uganda, TOT continued in 10 sub-counties and was initiated in another 4 sub-counties through diverse partnerships promoting tillage and soil fertility management practices developed, fine-tuned, or verified with INTSORMIL support; longer term sustainability of these practices is being studied as part of a MS thesis. Three INTSORMIL-supported sorghum varieties were released in Uganda and >2 t of seed has been disseminated to farmers. Complementary funding from AGRA enabled development of yield response functions to application of applied fertilizers for six crops and of a fertilizer optimization tool for choice of crop-nutrient-application rate combinations for maximization of net returns on investment. Dr. Kaizzi Kayuki was a visiting scientist at UNL for 6 weeks for analysis of research data and to plan for the future. Collaboration in Mozambique has continued with field and lab preparations for Ricardo Maria's PhD research addressing issues of fertilizer N profitability and use efficiency. Angela Kasozi and Feyera Liben have continued their MS studies with their field research in Uganda and Ethiopia, respectively. One journal paper was published and two accepted for publication.

Objectives and Implementation Sites

The goal of this project is to improve food security and market development of sorghum, pearl millet, and teff 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 US through graduate degree and short-term training, and technical support; 2) Increased productivity of sorghum and teff based cropping systems through better management. Activities in Ethiopia during 2010-11 included: the verification and/or TOT in Ethiopia of tied-ridge and skip-row planting and research on intercropping bean in the skip-row areas of sorghum and maize, and in collaboration with IWMI, research on water productivity and determination of genetic components of important varieties for crop growth modeling; research on teff management practices was not conducted because Mr. Brhane was away for PhD study. Activities in Uganda included: research and TOT on tillage, soil fertility, and varieties for striga affected areas; variety development/release/dissemination; a baseline study; and a marketing study. Preparations were made for an N use study and study of soil and leaf tissue analytical procedures in Mozambique. 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 broached with the release of two white grained varieties: brewing quality was verified, grain supply to Nile breweries was facilitated, and preparations are underway to work with Maganjo Millers on baking bread with white-grain sorghum substituting for some of the wheat flour. 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 in 2010-11 were in Ethiopia, Uganda, Tanzania and Mozambique including: Central Rift Valley (Melkassa and Mieso) and Tigray in Ethiopia; eastern and northern Uganda through Kawanda ARI; Central (Dodoma and Singida Regions) Tanzania; and Nampula, and Manica in Mozambique.

Research Methodology and Strategy

The interdisciplinary team. Tewodros Mesfin and Gebreyesus Brhane (agronomy) continued as the main collaborators in Ethiopia; other collaborating agronomists in Ethiopia include Jibril Mohammed and Tenau Workayehu; Feyera Liben completed his M.S. course work at Haramaya University and is conducting his thesis research. Dr. Kaizzi Kayuki (soil science) continued to lead collaborative activities in Uganda with a research and TOT on nutrient supply and tillage for water conservation and promotion of new varieties; Angela Kasosi continues her M.S. studies at Makerere University, conducting her field research in 2011-12. Ricardo Maria (soil scientist) has completed the course work for his Ph.D. at UNL and is conducting his thesis research in Mozambique. John Ebiyao (plant breeder) completed multi-location testing and release of three striga resistant or tolerant varieties in Uganda. NASECO, a seed company, has been a partner in dissemination of the new varieties in Uganda. Makerere University economist, Dr. Elepu (Elepu et al., 2011) conducted baseline and sorghum marketing studies in Uganda and concluded that farmers who participated in INTSORMIL activities had 30% more yield per ha, twice as much profit, and less production cost per ton of grain produced compared with non-participating farmers. The Nebraska team, including Richard Ferguson (soil scientist) and Drew Lyon (agronomist), are working with APSIM modelers at the University of Queensland (Graham Hammer et al., physiologists and modelers) to improve APSIM for simulation of the effects of skip-row planting and to apply it for extrapolation of trial results across the U.S. Great Plains. Outreach partners are numerous including the Teso Diocese Development Organization (TEDDO) working in five districts of Uganda, the Soroti Catholic Diocese, several farm field school groups which are supported by several donors including FAO and Norweigian Aid, and various government and non-government extension partners and community-based organizations.

Research Results

Host Country : Ethiopia

Climate variability in Ethiopia. The complex decision process of farmers, in consideration of recent and developing weather conditions, documented in 2009-10 in Bosset and Meisso districts in the Central Rift Valley of Ethiopia, is a basis for current field and modeling research.

Feyera Liben's M.S. research addresses various aspects of dry soil planting in response to more variable on-set of the rains and the importance of early crop establishment for crop yield and water use efficiency. A field study, with one of two sets of trials completed at two locations, investigates survival of sorghum and maize seed in dry soil at different soil depths and the effect of a small rain followed by a dry period (false on-set) on seedling emergence and vigor. An analysis of historical rainfall data will provide probabilities for excessive delay in onset, false on-set, and true on-set of rains following different planting dates. The third component uses the DSSAT model to investigate the probability of increased yields with dry soil planting at different dates compared with planting following true on-set of rains.

Progress for enhanced use of crop growth simulation models in response to climate variability was achieved. Two varieties each of sorghum and maize are being characterized for estimating of genetic coefficients in APSIM and DSSAT CropGro. Tewodros Mesfin has started his Ph.D. at the Univ. of Sydney with non-INTSORMIL funding intending to use an APSIM model simulation directed approach in conducting cropping systems research in Ethiopia for his dissertation. We are collaborating with Dr. Graham Hammer of University of Queensland in improving APSIM for skip-row planting, a practice with potential to improve stability of crop productivity with increased variability in cessation of rains.

In collaboration with the International Water Management Institute team in Addis Ababa, water use efficiency of sorghum, maize, and bean is being studied. Rainy season trials were conducted in the 2011 season on rainfed, deficit irrigation, and full irrigation. Dry season trials are planned for deficit and full irrigation only. The results will improve understanding of opportunities to improve water productivity and will be used to improve the calibration of crop growth models.

Information of best management practices derived from INTSORMIL-supported research is being disseminated through an IRDC-funded project for technology transfer.

Host country – Mozambique

Preparations were made for the Ph.D. research of Ricardo Maria. Three field sites in the Manica area were identified and planted to sorghum, maize, or soybean in 2011 to meet the previous crop requirement of his research plan. Preparations are underway for November-December planting. Improvements in the soil analysis laboratory were made in preparation for his research.

Host country – Uganda

Dr. Kaizzi Kayuki was a visiting scientist at UNL for six weeks to analyze data and interpret results of fertilizer research that was primarily funded by AGRA and partly by INTSORMIL. Grain sorghum response to N reached a plateau at less than 50 kg/ha N for most of the 11 site-seasons (Table 1). Mean sorghum yield and plant N uptake with no N applied (N0) were 0.69 Mg $ha^{-1}$and 31.3 kg ha^{-1}, respectively, but these increased to 2.78 Mg ha^{-1} and 75.9 kg ha^{-1} with N application (Table 2). The mean economically optimal N rates (EONR) were 34 to 18 kg ha^{-1} N and mean EOPR were 11 to 2 kg ha^{-1} P; this was based on fertilizer use cost to grain price ratios ranging from 10 to 30 for N and 10 to 50 for P, respectively (Fig. 1). Sorghum did not respond to K application. Grain N concentration, N harvest index, and internal NUE at EONR were

Table 1. Nitrogen and phosphorus application effect on sorghum grain and stover yield across 11 trials conducted in Uganda. There were no N or P rate by site-season interactions.

	N rate, kg ha^{-1}					P rate (with N applied), kg ha^{-1}				
Location	0	30	60	90	*P>F*	0	30	60	90	*P>F*
	Grain yield, Mg ha^{-1}					Stover yield, Mg ha^{-1}				
Grain†	0.69	2.11	2.22	2.31	***	1.94	2.23	2.33	2.28	***
Stover	3.31	5.48	5.69	5.73	***	5.10	5.22	5.57	5.61	ns

ns, no significant effect at $P \le 0.05$.
*** Significant effect at $P \le 0.001$.
† The yield response functions for N and P (with N applied), respectively are:
Grain yield = $2.27 - 1.58*0.932^N$
Grain yield = $2.305 - 0.362*0.839^P$.

Table 2. Mean effect of N rate on components of N use efficiency across all P and K rates by sorghum for 11 site-seasons in Uganda.

		N rate, kg ha^{-1}					
Component	**Units**	**0**	**30**	**60**	**90**	***P>F***	**EONR†**
Grain N concentration	g kg^{-1}	16.3	16.9	17.4	17.2	***	16.7
Plant N content	kg ha^{-1}	31.3	67.9	74.7	75.9	***	64.7
Harvest index	kg kg^{-1}	0.222	0.300	0.306	0.305	***	0.300
N harvest index	kg kg^{-1}	0.448	0.537	0.538	0.521	***	0.532
Recovery efficiency	kg kg^{-1}		1.221	0.723	0.496	***	1.352
Agronomic efficiency	kg kg^{-1}		46.5	25.7	16.9	***	52.0

†The EONR (economically optimal N rate) was 24 kg ha^{-1} for a fertilizer N use cost to farm-gate grain price ratio of 20.
ns, no significant effect at $P \le 0.05$.
*** Significant effect at $P \le 0.001$.

Figure 1. Economically optimal N rates at different fertilizer use cost to grain price ratios (CP) for sorghum in Uganda.

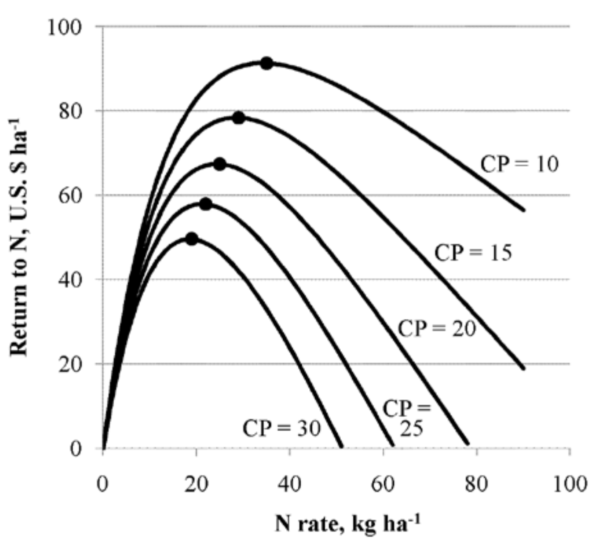

Table 3. Results from 215 on-farm sorghum on-farm trials in Uganda.

	2010A	*2010B*
	n = 118	**n = 97**
Treatments	**Grain yield, Mg ha^{-1}**	
Control	0.98a	0.90a
2.5 t ha^{-1} FYM	1.95b	1.37b
(15 kg N + 7.5 kg P + 2.5 t FYM) ha^{-1}	2.58c	1.79cd
(30 kg N + 15 kg P) ha^{-1}	2.69c	1.91de
(30 kg N + 15 kg P + 30 kg K) ha^{-1}	3.56d	2.12e
Mucuna	2.05b	1.69c

1.67%, 53.2% and 31.8 kg kg-1, respectively, and higher than for N0 (Table 2). Mean N recovery efficiency was very high and equal to 135% of applied N at EONR indicating that N application boosted root growth sufficiently to recover soil N that was otherwise lost, likely to leaching or denitrification, in addition to fully using the equivalent of the applied N. Agronomic efficiency at EONR was high with 52 kg kg-1 increased grain yield per kg of N applied. The results are reported in Kaizzi et al. (2011a).

In addition to determining sorghum response to N, P and K, response functions were determined for 12 other crop-nutrient combinations (Kaizzi et al., 2011b; Kaizzi et al, 2011c). The response functions for the 15 combinations were integrated into a fertilizer optimization tool with the relevant economic analyses. The tool is constructed in Excel with the add-on Solver. Input data include expected hectares and price or value of each crop (sorghum, maize, upland rice, bean, soybean, and groundnut), fertilizer prices, and money available for fertilizer purchase (Fig. 2). The fertilizer optimizer then runs the calculations and reports the fertilizer rates for each crop and the mean expected effects on yields and net returns.

INTSORMIL supported activities are underway in Tororo, Palissa, Busia, Kumi, Pader, Soroti, Lira, and Apac districts. To improve input supply, the project subsidizes fertilizer suppliers from major towns to supply 'dealers' in targeted sub-counties with fertilizer for retail sale to farmers on a pilot basis. Fertilizer prices are high, e.g. U.S. $1.40 per kg urea-N, while grain prices following a good harvest were low (<$0.14 for brown-grain sorghum but $0.36 for white grain sorghum purchased by Nile Breweries). Available data indicates mean returns of >$2 per $1 invested in up to 25 kg ha^{-1} fertilizer N applied to sorghum. In six extension meetings with a total attendance of ~300, mostly women, fertilizer use issues were discussed. Demonstrations and on-farm trials, a total of 215, were conducted with many of these sites serving as fieldday sites which had a total attendance of ~1600 farmers (Table 3). Farmers recognize the need to better manage soil fertility and express willingness to use fertilizer. Posters and leaflets addressing fertilizer and manure use were prepared in local languages and reviewed with farmers. Needed revisions were identified.

Three INTSORMIL-supported sorghum varieties were released in Uganda in 2011 (Ebiayu et al., 2011): SESO 1 (SRN39; M91057 (SESO 2); and IS25403 (SESO 3). SESO 1 and 2 are white grained and were found by SAB-Miller Nile Breweries to be of high quality for clear beer production, while SESO 3 has a relatively high tannin content and consider of good quality for local, opaque beer brewing. All have tolerance or resistance to striga and shoot fly.

Networking Activities

Dr. Kayuki Kaizzi came to UNL as a visiting scientist for six weeks to analyze data and to prepare publications. A TOT network in Uganda was expanded to more districts and non-government organization partners. An IDRC project in Ethiopia has been important in dissemination of results of INTSORMIL supported research. INTSORMIL collaborators have linked with NASECO to increase and market seed of newly released varieties and they have linked with the Nile Brewing Company to use grain of new white grain varieties for brewing.

Publications

Journal Articles

Abunyewa, A.A., R.B. Ferguson, C.S. Wortmann, D.J. Lyon, S.C. Mason, S. Irmak, and R.N. Klein. 2010. Grain sorghum water use with skip-row configuration in the Central Great Plains. Agric. Biol. J. North Amer. Published.

Workayehu, T. and C.S. Wortmann. 2011. Maize-bean intercrop suppression of weeds and profitability in southern Ethiopia. Agron J. 104:1058-1063.

Book Chapter

Wortmann, C.S., and T. Regassa. 2011. Sweet sorghum as a bioenergy crop for the US Great Plains. In Dr.-Ing. Marco Aurélio dos Santos Bernardes (Ed.). Economic Effects of Biofuel Production. InTech Publications. Rijeka Croatia. In press. 225-240.

Miscellaneous Publications

Ebiyau, J., H. Okurut-Akol, T.E. Areke, C. Wortmann, and K. Kaizzi. 2011. Evaluation of five genotypes for agronomic performance, striga and pest resistance, and brewing qualities to meet market demands. NARO Technical Report.

Elepu, G., J.M. Erbaugh, and D.W. Larson. 2011. Sorghum production technology transfer project in eastern and northern Uganda: a baseline survey. Final report.

Decision making strategies of farmers in evolving climate change. Melkassa Agricultural Research Center.

Germplasm Enhancement and Conservation

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

Project PRF 101
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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 thought 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:

- Evaluating integrated *Striga* management (ISM) wherein cultivation of Striga resistant sorghum was combined with

water conservation tillage (tie-ridging) and nitrogen fertilizer at two *Striga* infested areas of Ethiopia.
- Exploring the effects of agronomic manipulation on sorghum carotenoid contents at selected stages of kernel maturation and light exposure.

Research Methods

Evaluating ISM Under Heavy Striga Infestation in Ethiopia

The objectives of the study were to assess the potential of integrating different Striga control options to suppress Striga and improve crop productivity and to compare relative efficacy of individual control options in areas where *Striga* is a major biotic constraint on sorghum grain production.

The study was conducted during the 2002 and 2003 cropping seasons at Sirinka and Kobo experiment stations in northern Ethiopia. The Sirinka site is located at 11°45'08'' latitude and 39°36'45'' longitude and is surrounded by a chain of mountains. The elevation at this site is 1850 m above sea level. The soils are well-drained Andosols with generally low nutrient and organic matter content. The Kobo site is located on the Kobo plain further north of the Sirinka location. It is situated at 12°08'38'' latitude and 39°38'30'' longitude at an elevation of 1480 m above sea level. Soils at the Kobo site are predominantly vertic clay type. Because of its altitude Kobo tends to have higher temperature and receives generally less rainfall than Sirinka. Both areas have suffered from recurrent drought and severe infestation by *S. hermonthica* for decades. Continuous planting of susceptible varieties has resulted in heavy and uniform buildup of *Striga* seeds in the soils; thus, artificial infestation was not necessary for this experiment.

The treatments consisted of a combination of three improved and another three traditional practices used by small-scale farmers. The three improved practices were a resistant variety, N fertilizer application and tied-ridge tillage. The corresponding traditional practices were a local variety, no N fertilizer application and flat bed planting. The resistant variety (P-9401) used in this study has low germination stimulant production and incompatible response mechanisms. It is a white-seeded cultivar bred at Purdue University and released for use in Striga infested areas in Ethiopia and Eritrea. The susceptible cultivar (Jigurte) was a tall red-seeded cultivar adapted to northern Ethiopia and largely recognized by its characteristic large seeds and stiff stalks. The varieties were tested with and without N fertilizer either on flat seed bed or on tie-ridge bed. For treatment combinations that involved N fertilizer, a 32 kg ha–1 N in the form of urea was split-applied by broadcasting, half of the dose at the time of planting and the remaining at 30 d after planting. Tie-ridges were constructed with a tie-ridger fitted on a local implement and were tied every 2.5 m. Hand hoes were used to reform broken ridges and incomplete ties when necessary. The combined treatments were:

- Local variety + zero N fertilizer + flat bed planting
- Local variety + zero N fertilizer + tied ridging
- Local variety + N fertilizer + flat bed planting
- Local variety + N fertilizer + tied ridging
- Resistant variety + zero N fertilizer + flat bed planting
- Resistant variety + zero N fertilizer + tied ridging
- Resistant variety + N fertilizer + flat bed planting
- Resistant variety + N fertilizer + tied ridging

The experiment was arranged in a randomized complete block design with four replications. Plots consisted of six 5-m-long rows spaced 0.75 m apart. Plots were monitored closely for *Striga* emergence.

Grain yield and biomass production were determined from the central four rows of each plot. Thousand kernel weight, referred to as "kernel weight" here after, was recorded for each plot from the bulk sample of harvested grain. Grain moisture content was determined at harvest using a moisture meter, and weights were adjusted to 12.5% before statistical analysis. The number of emerged *Striga* (NES) and *Striga* vigor (SV) were recorded from the central two rows of each plot starting at 15 days after the first Striga seedling emerged aboveground. The SV was scored on a 5-point scale with "1" representing the weakest *Striga* plant and "5" representing the most vigorous plant. The scale took into account the average height and the extent of branching of Striga plants. Both scores were taken four times at 15-d intervals, referred to as scoring dates.

Agronomic Manipulation can Influence Carotenoid Content of Whole Grain and Decorticated Yellow Endosperm Sorghum Porridge

The objectives of this study were to develop insight into how agronomic manipulation, traditional milling and preparation would impact carotenoid content, stability and bioaccessibility from model porridge foods produced from milled fractions of yellow-endosperm sorghum. This report focuses on the impact of bagging panicles of yellow-endosperm sorghums.

Two sorghum varieties (P1222 and P88) were selected on the basis of their yellow-endosperm kernel characteristics and highest carotenoid contents based from preliminary assessment conducted on grains selected from the 2005 and 2006 sorghum crops. Variety P1222 is an inbred variety of sorghum derived from a yellow-endosperm germplasm introduction from Thailand. P88 is derived from the well known group of yellow endosperm introductions from Nigeria (known as "Korggi"). The two varieties along with an inbred maize variety Becks-5856 (control) were grown in different un-replicated single-row plots in 2007 at Purdue's Agronomy Center for Research and Education (ACRE). Several randomly selected plants from each designated variety were bagged (brown paper bag) and unbagged and tagged at 50% anthesis. Tagged panicles from each set (bagged and unbagged) were randomly harvested at 30 days after half bloom (DAHB), 50 DAHB along with mature unbagged maize, transported, stored and dried.

Five different panicles from each variety of bagged, unbagged at 30 and 50 DAHB and Becks-5856 that were free from apparent weathering and molding were selected. Each sample was equally divided and designated whole grain and decorticated flour. The designated grains were mechanically decorticated in order to obtain endosperm and bran rich fractions. The designated whole and decorticated grain fractions were subsequently milled and stored frozen at −80°C under nitrogen.

Grain samples were handled, extracted and analyzed under minimal light conditions and with yellow lights when needed to minimize photo-oxidative reactions. Moisture content for each sub-sample was determined following the American Association of Cereal Chemists recommendations. Carotenoid extractions from grain fractions were then performed and analyzed by liquid chromatography.

Research Results

Evaluating ISM under heavy Striga infestation in Ethiopia

Treatment effects in the combined analysis of variance were significant for both grain yield and biomass production but not significant for kernel weight. Similarly, grain yield both at Sirinka and Kobo and biomass production at Sirinka were also significant but kernel weight was not significant at either locations. The interaction between component factors and between the factors and environment were not significant for grain yield, biomass yield and kernel weight. Partitioning the treatment into main effects showed that all factors were significant for grain yield. The effects of variety on biomass yield and fertility management on kernel weight were also significant. The N fertilizer and tillage main effects in the combined analysis, N fertilizer effect at Sirinka and tillage effect at Kobo were also significant for grain yield. However, both factors did not significantly affect biomass production and kernel weight except N fertilizer application in the combined data and tillage at Kobo that were significant for kernel weight. The environment effect for grain yield and kernel weight and environment × treatment interaction effect for grain yield and biomass production were also significant. However, the interaction among component factors and between the factors and environment were not significant for any of the traits.

Mean grain yield for N fertilized treatments was 1.36 Mg ha $^{-1}$ compared with 0.95 for unfertilized treatments. Yield under tied-ridge tillage was 1.35 Mg ha $^{-1}$ while under flat beds the yield was 0.95 Mg ha $^{-1}$. Mean grain yield in the resistant cultivar was 11% higher than that of the susceptible cultivar. However, at Sirinka the yield difference between the resistant and susceptible cultivars was not significant while at Kobo the yield was 30% more for the resistant variety. In contrast, mean biomass production was 37% less in the resistant variety and was consistent across locations. Kernel weight was higher in the local cultivar at Sirinka, but was not significantly different at Kobo and in the combined analysis. Nitrogen fertilizer had no effect on kernel weight, while tied-ridge tillage had positive effect at Kobo but not at Sirinka.

The highest grain yield of (1.68 Mg ha $^{-1}$) was recorded for the treatment combination involving the resistant cultivar with N application and tied-ridge tillage. This treatment was 121% higher than the local practice (local variety planted on flat bed without N fertilizer application). This result was fairly consistent across locations with few exceptions. At Sirinka, treatments involving fertilizer application without tied-ridges yielded higher than those that involved tied-ridges without N fertilizer. The opposite was true at Kobo. On the other hand, the highest biomass production was obtained with the treatment combination involving fertilizer application and tie-ridge, while the kernel weight was highest when the local variety was grown under improved soil moisture with or without fertilizer application. Similar to grain yield, both biomass and kernel weight were lowest at Kobo, most probably due to the more severe drought and higher *Striga* infestation at this location.

The treatment and variety effects were significant for NES for all of the scoring dates and tillage and tillage × environment interaction effects for the second through the fourth scoring dates. Other interaction effects were not significant for NES. *Striga* vigor rating was affected by the variety and variety × environment interaction effects on the second through the fourth scoring dates. Tillage effect was significant for first and fourth scoring dates and tillage × environment interaction for first scoring date. Treatment × environment interaction effect was also significant for all scoring dates. Three way interactions of N × variety × environment for first scoring date and tillage × variety × environment for first and third scoring dates were also significant.

Similar to the grain yield and biomass, the treatment effect was significant for NES at all scoring dates but SV was not significantly affected by the treatment combination. The resistant variety had lower NES for all scoring dates and less SV for the last three scoring dates compared with the susceptible variety. Tillage had an inconsistent effect on NES but SV was often less with tied-ridges compared with flat bed tillage. Nitrogen application had no significant effect on both NES and SV for all scoring dates. Therefore, combining different practices was much less important for reducing NES and SV than was for grain yield. Only variety had a great and generally consistent effect on NES and SV. At physiological maturity, mean NES was 23 times higher in the susceptible local cultivar compared with the resistant cultivar. Kobo had much higher NES than Sirinka. Tied-ridge tillage also reduced NES by two to three times on the last three scoring dates and significantly lowered SV on the first and last scoring dates but both were not affected by N fertilizer application.

Mean NES was significantly different between treatments, and there was a consistent trend for all scoring dates. Treatments involving the resistant variety had significantly lower infestation than those involving the susceptible local cultivar. The pattern was consistent across the scoring dates and between the two locations, but the intensity varied, with infestation at Kobo consistently exceeding that at Sirinka. The level of Striga infestation at both locations, however, was lower than expected.

Our results indicate that combining host plant resistance with tied-ridge tillage and N application enhanced sorghum yield on Striga-infested soils. Nitrogen application and tillage had more influence on yield than the resistant variety contributing an average yield increase of 43 and 42%, respectively. Unlike the grain yield, the greatest proportion of Striga control was attributed to the resistant variety. The markedly low NES and SV in the resistant variety as compared to the susceptible cultivar are attributable to the genetic differences between the varieties. The resistant variety possessed genetic traits that might have limited the production of root exudates that stimulate Striga germination and attachment, and the low NES was probably due to this factor. Certain resistant varieties also produce low amount of post-attachment signals that influence growth and development of the parasite. Although there is no evidence to indicate that the resistant variety used in our study produced low amount of post-attachment signals, factors related to post-attachment interaction between the host and the developing parasite may have accounted for reduced vigor of the parasite in the resistant variety. Consistent with the results of many previous studies N fertilizer in the present study did not have any effect on Striga infestation.

Agronomic Practices can Enhance Carotenoid Content of Yellow-Endosperm Sorghums

Consistent with previous results, whole maize fractions were generally found to have a significantly ($P<0.05$) higher carotenoid content than sorghum fractions ranging from 10.69 to 13.66 mg/kg compared to 2.90–13.70 mg/kg, respectively. For both grains, (all-E)-lutein and (all-E)-zeaxanthin were the most abundant species in all fractions accounting for >70% of the total carotenoid content in each fraction. In general, the carotenoid levels in these sorghum varieties are comparable to carotenoid contents reported previously for similar yellow-endosperm fractions. As with maize, (all-E)-lutein and (all-E)-zeaxanthin were the predominant carotenoid species in milled fractions. In addition, appreciable levels of α-cryptoxanthin and provitamin A β-cryptoxanthin were detected in all milled sorghum fractions, ranging from 0.03 to 0.35 mg/kg (sorghum) and 0.58–2.98 mg/kg (maize). Carotene levels ranged from 0.009 to 1.23 mg/kg (sorghum) and 0.16–0.90 mg/kg (maize). (Z)-Isomers of lutein + zeaxanthin and β-carotene in milled sorghum samples accounted for ~10–13% of the total carotenoid content of these fractions, compared to ~12–13% in maize. These values are consistent with previous reports of carotenoid isomers in fresh and processed sorghum and maize products and fractions. Overall, the total carotenoid content of the sorghum varieties screened in this study compares to other grains and pulses including wheat (6.60 mg/kg), peas (31.60 mg/kg), and cowpea (44.74 mg/kg), suggesting that these grains can be a significant dietary source of carotenoids. However, it is important to note that these levels remain substantially lower than commonly consumed carotenoid-rich fruits and vegetables including carrots (135 mg/kg) and spinach (175mg/kg).

Differences were observed in carotenoid content of milled fractions. For maize, total carotenoid content of decorticated bran fractions (17.99 ± 1.14 mg/kg) was significantly lower than decorticated flour fractions (30.75 ± 1.48 mg/kg) and whole grain maize meal (22.52 ± 4.97 mg/kg). For sorghum, both meal and bran fractions were generally higher in total carotenoids compared to flour fractions. The highest carotenoid levels were observed in milled bagged decorticated bran fractions (9.87–13.70 mg/kg), followed by milled whole grain meals (3.98–10.00 mg/kg), respectively, with decorticated flours (2.90–7.36 mg/kg) having the lowest carotenoid content among yellow-endosperm sorghum milled products.

Observed differences between maize and sorghum fractions may be related to differences in specific macronutrient profile of milled fractions. The higher carotenoid content of sorghum decorticated bran may be partially explained by a higher protein content reported for sorghum bran compared to maize bran (~7% relative to 4%). Additionally, sorghum has been reported to have a much higher proportion of peripheral endosperm compared to maize. A higher proportion of corneous and peripheral endosperm may be partitioned with the bran fraction during milling sorghum relative to maize bran which is more readily separated from the kernel. Therefore, unlike for maize, decortication of sorghum grain may negatively impact the total carotenoid content of sorghum meals and flours used to make porridge or other products. It is critical to note that this may depend on specific milling techniques and setting suggesting that further research is required to better understand how processing conditions may impact final carotenoid content of milled sorghum fractions.

In addition to milling, carotenoid content appears to be impacted by specific agronomic practices. Over the years, several traditional agronomic approaches have been used to modulate grain's chemical composition including bagging and harvesting prior to full maturity. Consistent with previous findings, harvesting sorghum variety P88 at 30 DAHB compared to full maturity (50 DAHB) resulted in significantly higher carotenoid content in whole grain meal. This effect was significant ($p < 0.05$) for cryptoxanthins, β-carotene as well as total carotenoid content. Additionally, bagging of sorghum panicles generally resulted in a positive effect on carotenoid accumulation for both sorghum varieties with the exception of meals and flours from P88 variety at 30 DAHB. An increase of ~8–184% in total carotenoid content was observed among milled fractions prepared from bagged versus unbagged sorghum. Decorticated bran fractions were most impacted by bagging with increases of ~256% for cis-xanthophylls and 184% for total carotenoids in P88 30 DAHB. The increase in provitamin A carotenoids was particularly interesting with an increase of 68% in β-carotene for P88 varieties at 30 DAHB, compared to 47% at 50 DAHB. Similarly, a 121% increase was observed for provitamin A β-cryptoxanthin for the same maturation period. For P1222 variety, changes are more limited. However, there were increases in β-carotene at 50 DAHB 8% and 11% for β-cryptoxanthin.

On average, the observed increase in total carotenoid content of bagged sorghum grains is consistent with previous observations that carotenoid content increased by 77% when bagged after pollination compared to standard unprotected open flower heads. The increase in carotenoid content of bagged sorghum may be a result of reduced exposure to light and a lower degree of photo-oxidation of endogenous carotenoids. Similar increases in carotenoid content of leafy vegetables grown under UV protective polyethylene roofing at maturity have been reported. The bagging of sorghum panicles in some way mimics these treatments by protecting the kernels from light stress while potentially inducing heat stress and providing similar increases in carotenoid accumulation.

Quantitatively, provitamin A β-carotene content in sorghum varieties at 30 and 50 DAHB was comparable to maize fractions. β-carotene content ranged from 0.63 to 1.82 mg/kg in sorghum fractions. Levels of β-carotene in sorghum meal and flour appeared to be enhanced, albeit not significantly for all fractions, by harvesting at 30 DAHB. Bagging appeared to result in slight enhancement of β-carotene content particularly in bran fractions of sorghum. These levels are consistent with those previously reported for yellow-endosperm sorghum which range from 0.024 to 1.10 mg/kg. While encouraging, provitamin A β-carotene comprises only a small portion of the total carotenoid content in milled sorghum fractions. While background levels in these sorghum varieties remains relatively low, it compares well to standard yellow maize and is promising for future biofortification and breeding efforts targeting enhancement of elevated provitamin A content.

Training (Degree and Non-Degree)

Luis Rivera from Peru is a Ph.D. student supported on our INTSORMIL project. His research is in the area of the genetics and agronomy of sorghum as a biofuel crop. Luis is making good progress towards his degree objective.

Networking Activities

The principal investigator, Gebisa Ejeta, continues to spend a great deal of time on speaking engagement globally as the 2009 World Food Prize Laureate. In his travels around the world, Dr. Ejeta speaks at universities and other scientific conferences, and addresses government and international organizations concerned with global food security issues. He advocates the need for scientific research in global development and promotes science that benefits humanity particularly in areas of the world where hunger prevails.

Publications and Presentations

Amusan, I.O., P.J. Rich, T. Housley and G. Ejeta. 2011. An in vitro method for identifying post-attachment Striga resistance in maize and sorghum. Agronomy Journal 103:1472-1478.

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Satish K, Z. Gutema, C. Grenier, P. Rich and G. Ejeta. 2011. Molecular tagging and validation of microsatellite markers linked to the low germination stimulant gene (lgs) for Striga resistance in sorghum [Sorghum bicolor (L.) Moench]. Theoretical and Applied Genetics (online first - http://dx.doi.org/10.1007/s00122-011-1763-9).

Lab: Biotechnological Approaches to Genetic Analysis and Exploitation of Striga Resistance in Crop Plants

Project PRF 105
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Introduction and Justification

The parasitic weed, *Striga*, is the most important biotic stress in semi-arid tropical Africa. *Striga* infestation is most severe on marginal lands where soil nutrients and moisture are limited. Nearly 100 million hectares of field crops including sorghum, millets, and maize are infested annually with *Striga* in sub-Saharan Africa (SSA). Crop losses to *Striga* are disproportionately borne by subsistence farmers of SSA growing sorghum and millet because these are the cereals most adapted to poor soils of the marginal lands they inhabit. It has been our goal to aid these farmers by providing them with *Striga* resistant crop germplasm.

This INTSORMIL project specifically supports the Purdue Parasitic Weed Containment Facility, which is vital to our continuing efforts to improve *Striga* resistance in sorghum and other cereals. The Purdue University Parasitic Weed Containment Facility (located in Lilly Hall room 2-320B) was designed under the Containment Guidelines for Noxious Weeds and Parasitic Plants outlined by USDA-APHIS-PPQ. It was inspected by APHIS and approved in 2000 for reception, use and storage of Striga seed for research purposes. It is inspected by USDA-APHIS personnel at least once every three years.

The Purdue University Parasitic Weed Containment Facility is designed for use by Dr. Ejeta and other university research groups who carry out studies involving very small seeded parasitic plants declared noxious weeds by the USDA. These principally include parasitic species of the Orobanchaceae family, particularly Striga asiatica and Striga hermonthica, for which we currently have a USDA-APHIS-PPQ import permit (#P526-09-01788). All work in the Facility is done according to the USDA-APHIS approved standard operating procedures. The research began with the development of a simple and rapid method of screening individual seedlings of cereal host cultivars for the capacity of their root systems to produce and exude a chemical signal required to trigger germination of *Striga* seeds. The method has been utilized to select breeding materials leading to the development of *Striga*-resistant sorghums released and widely distributed across Africa. Following on this success, the objectives have broadened to include elucidation of additional host-produced signals influencing subsequent stages in the *Striga* life cycle, with the aim of developing crops with stable genetic resistance to this devastating pest. We are currently introgressing into selected landraces and improved sorghum cultivars potential resistance mechanisms based on newly acquired knowledge of host mitigated interactions beyond the germination of weed seed. These include mechanisms controlling initiation of haustoria and post-attachment establishment of the parasite. The containment facility is vital to discovery and transfer of *Striga* resistance mechanisms because it allows controlled and observable infection of host plants with parasitic weeds.

Research Objectives

The requested funding is primarily intended for operation and maintenance of the Facility, which according to the conditions of our USDA-APHIS-PPQ permit, must be staffed with a containment officer (Dr. Patrick Rich). Activities in the Facility include screening of breeding materials for specific *Striga* resistance characters. It has also been and will continue to be used for training of students and visiting African scientists for investigations of parasitic weed interactions with host cereals. Although this project is really intended to support research of other projects, such as PRF-101, some specific activities conducted in the Facility are listed below:

In this project period, we focused on fine mapping of the gene responsible for the Striga resistance trait of low germination stimulant (lgs) activity and set out to identify robust molecular markers for lgs that would be useful for *Striga* resistance breeding. The results of this work were published in the journal Theoretical and Applied Genetics at the end of 2011.

Molecular tagging and validation of microsatellite markers linked to the low germination stimulant gene (lgs) for *Striga* resistance in sorghum

Research Methods

Genetic Material

A recombinant inbred line population (RIL) consisting of 354 lines, developed by crossing SRN39 (low stimulant), an African caudatum and Shanqui Red (high stimulant), a Chinese kaoliang line, was utilized in this study. The parental lines differ significantly in field resistance to *Striga* as well as in *Striga* germination stimulant activity. SRN39 is a low germination stimulant producing line which exhibits excellent field resistance. In addition to low germination stimulant activity, SRN39 shows an incompatible response to *Striga* at the post-attachment stage. Shanqui Red has high *Striga* germination stimulant activity and is highly susceptible to *Striga* in the field. A set of nine advanced inbred lines derived from SRN39 and 14 sorghum cultivars from different geographic regions and contrasting for *Striga* germination stimulant activity were used to validate the markers tightly linked to the lgs gene. The details of genotypes used for marker validation are provided in Table 1.

Striga asiatica seed collected from various cereal hosts (maize, sorghum and rice) was obtained from the USDA station in Oxford, NC, USA. *Striga hermonthica* seed was collected from a sorghum host in Mali.

Phenotyping

The two parental lines of the recombinant inbred line (RIL) population, 354 RILs and a total of 23 diverse sorghum genotypes including eight advanced inbred lines derived from SRN39 were evaluated for S. asiatica germination stimulant activity trait using the agar gel assay (AGA) in a simple lattice design blocked over batches and time with six replications. The 23 sorghum genotypes used for marker validation were also phenotyped for *S. hermonthica* germination stimulant activity. All entries were replicated six times and MGD values for each genotype were averaged across the six replications. Sorghum entries were classified as having low and high Striga germination stimulant activity according to the 10mm threshold established previously.

PCR Amplification, Electrophoresis, and Genotyping

Genomic DNA from the RILs was extracted using the CTAB method. DNA for the marker validation portion of this study was extracted using a high throughput method. The RIL population was genotyped by both the Diversity Array Technology® (DArT) and simple sequence repeat markers (SSRs or microsatellite markers). The genomic DNA of 354 RILs was sent to DArT P/Lc, Yarralmula, Australia for DArT marker genotyping. Genotyping of additional SSR markers was done in our laboratory to aid in matching of linkage groups to sorghum chromosomes. Details of the PCR reactions are described in the published write up of this work (Satish et al. 2011). The amplicons of all SSR markers were separated on 3 % high-resolution agarose gels. The SSR alleles in RILs were manually scored either as A (SRN39 allele) or B (Shanqui Red allele). In case DArT markers, the dominant scores generated by the DArT system (1 present; 0 absent) was translated to A (SRN39 allele) or B (Shanqui Red allele). All DArT markers genotyped and mapped in this study were abbreviated as DM (for example DM77). The mapped SSR makers with the prefix 'Pustri' are newly developed markers in our study. The 'Xtxp' series markers are SSR markers developed by Bhattramakki et al. (2000) and 'SB' series are SSR markers developed by Yonemaru et al. (2009). For bulk segregant analysis (BSA), equal amounts of genomic DNA from 12 low stimulating and 12 high stimulating lines randomly chosen from the RIL population were pooled to make the bulks. Both the bulks along with the two parents of the population were screened to identify markers showing polymorphisms clearly among the four samples. The polymorphic markers identified in BSA were subsequently genotyped in the full RIL population for further linkage analysis.

Linkage Analysis and Genetic Mapping

A Chi-square test was applied to test for the significance of the expected 1:1 ratio for single gene inheritance for Striga germination stimulant activity in the RILs. RILs were scored as SRN39 (A type) allele if the MGD was less than 10 mm and as Shanqui Red (B type allele) if MGD was above 10 mm. Detailed linkage analysis and genetic linkage map was constructed by using the Joinmap 3.0 software. The Kosambi function was used to convert recombination frequency into the genetic distance (centimorgans, cM). The graphical representation of the genetic map was drawn using the Mapchart software and chromosomal nomenclature was followed according to Kim et al. (2005). To further confirm the mapped position of the lgs gene based on binary data, actual MGD data was subjected to QTL analysis using MQM mapping method to identify the major genomic region associated with *Striga* ger-

Table 1. Phenotyping and validation of the microsatellite markers associated with the *lgs* gene in diverse sorghum accessions

Accession	Pedigree of developed lines or origin of source lines	Phenotypic data (MGD)*		*Striga* germination stimulant activity	Field reaction to *Striga*	Genotyping†		
		S. asiatica	*S. hermonthica*			SB 3344	SB 3346	SB 3352
Shanqui Red	China	19.8±3.0	19.6±5.2	High	**Susceptible**	+	+	+
SRN39	Sudan	1.9±1.8	0.1±0.2	Low	**Resistant**	–	–	–
P954063	United States	13.6±1.3	11.8±2.0	High	**Susceptible**	+	×	–
P9401	SRN39×P954063	2.0±1.1	0±0	Low	**Resistant**	–	–	–
P9402	SRN39×P954063	0.4±0.7	1.0±1.5	Low	**Resistant**	–	–	–
P9403	SRN39×P954063	14.7±2.7	13.1±2.5	High	**Resistant**	+	×	–
P9404	SRN39×P954063	18.3±4.4	11.2±3.4	High	**Resistant**	+	×	–
P9405	SRN39×P954063	0.7±1.0	0±0	Low	**Resistant**	–	–	–
P9406	SRN39×P954063	13.2±2.3	14.0±2.3	High	**Resistant**	+	×	–
P9407	SRN39×P954063	17.6±3.1	12.9±2.6	High	**Resistant**	+	×	–
P9408	SRN39×P954063	24.8±3.6	23.0±7.0	High	**Resistant**	+	×	–
Brhan	Framida×SRN39	4.0±2.7	1.2±1.7	Low	**Resistant**	–	–	–
Framida	South Africa	0.2±0.4	1.1±1.4	Low	**Resistant**	–	–	–
555	India	0.5±0.5	1.3±2.2	Low	**Resistant**	+	×	+
SAR33	GPR148×Framida	0.7±0.7	4.2±3.2	Low	**Resistant**	–	–	–
IS9830	Sudan	1.0±1.6	0.3±1.0	Low	**Resistant**	–	–	–
ICSV1006	India	0.3 ± 0.4	0±0	Low	**Resistant**	–	–	–
ICSV1007	Burkina Faso	1.2 ± 0.6	0.9±1.7	Low	**Resistant**	–	–	+
CK60A	United States	11.8±2.2	14.3±3.1	High	**Susceptible**	×	+	+
Tetron	Sudan	4.3±1.5	1.4±1.9	Low	**Resistant**	–	–	–
N13	India	17.1±1.9	12.8±1.0	High	**Resistant**	×	×	+
IS4225	China	18.8±0.7	12.7±2.6	High	**Susceptible**	×	×	+
PQ-434	Sudan	0±0	1.2±1.2	Low	**not tested**	×	×	+

*MGD = maximum germination distance (mm) as measured in the agar gel assay (see text); MGD ≥ 10mm indicates high *Striga* germination stimulant activity; MGD < 10mm indicates low germination stimulant activity. Values are means of measures (mm) ± 1 standard deviation.

†Allele symbols: + indicates the Shanqui Red (wildtype) allele; – indicates the SRN39 (mutant) allele; × indicates a third allele. Approximate allele sizes for SB3344: + = 190 bp, – = 170 bp, × = 195 bp; SB3346: + = 285 bp, – = 300 bp, × = 290 bp; SB3352: + = 700 bp, – = 230 bp.

mination stimulant activity both with and without mapping of the lgs phenotype score (high or low) using the MapQTL 5 software.

Research Results

Genetic Analysis

The parental lines of the mapping population differed significantly for germination stimulant activity toward both Striga species. The low stimulant parent SRN39 showed an average MGD value of 0.4 contrasting to a MGD value of 19.7 of high stimulant parent Shanqui Red with S. asiatica. Out of 354 RILs screened with S. asiatica, 187 were classified as having low germination stimulant activity (MGD < 10 mm) and 167 had high germination stimulant activity (MGD ≥ 10 mm). The Chi-square test for goodness of fit for 1:1 expected for single gene inheritance was highly significant, thus confirming the single genic inheritance of the low germination stimulant activity previously reported. The frequency distribution for this trait in the RILs showed a bimodal type of distribution, further supporting single genic inheritance of the trait. Two distinct classes, high and low, were clearly separated by the AGA in the RIL population (Fig. 1)

Linkage Analysis and Fine-Mapping of the lgs Gene

Prior to the linkage analysis and mapping, the low quality DArT markers with large numbers of missing data points and segregation distortion were removed. Genotyping data on a total of 335 DArT markers, 15 SSR markers and *Striga* germination stimulant activity binary score were subjected to linkage analysis with the Joinmap® software. Initial linkage analysis mapped the lgs gene on to the tip of SBI-05 chromosome. The constructed linkage map consisted of 12 linkage groups for ten sorghum chro-

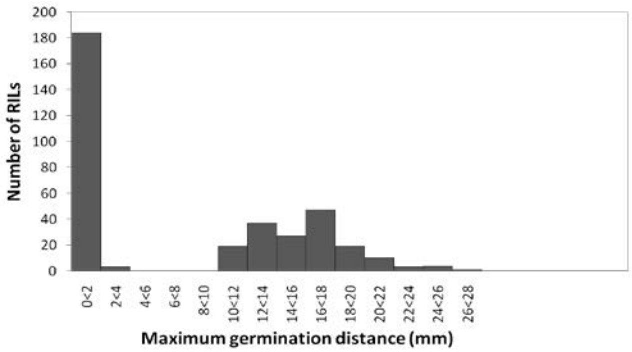

Figure 1. Frequency distribution in RILs of the cross SRN39 × Shanqui Red for maximum germination distance MGD) data

mosomes, including two linkage groups for chromosome SBI-01 and one unknown linkage group.

The QTL analysis in our study for the actual MGD values measured in the AGA identified only one major QTL near the lgs gene without any minor QTLs, highly supporting the hypothesis of a single major gene influencing the trait. Different studies have reported the association of low germination stimulant activity and Striga field resistance in sorghum. Analysis of QTL regions with multiple field evaluations under *Striga* infestation using a sub-set of the RIL population we used for mapping in the present study showed that one of the major and consistent QTLs common to both *S. asiatica* and *S. hermonthica* field resistance is associated again with the lgs locus. However, the identification of additional QTLs in both the QTL experiments with field measurements of Striga resistance stongly suggests the involvement of some additional resistance mechanisms controlled by other genes.

Low *Striga* germination stimulant activity, encoded by a single recessive gene (lgs), is one of several resistance traits identified in sorghum. The mutated version of lgs gene results in low Striga germination stimulant activity. It is the best characterized and most widely exploited resistance character. By a detailed linkage analysis of this trait in a large RIL population using a high density genetic linkage map, we precisely tagged and mapped the gene (lgs) to the short arm of sorghum SBI-05. Through fine-mapping, the region containing the lgs gene was delimited to a 5.9 cM interval with a total of eight mapped microsatellite markers. The three tightly linked microsatellite markers SB3344, SB3346 and SB3343 co-segregating with the trait phenotype were spaced with genetic distances of 0.5 cM, 0.7 cM and 0.9 cM, respectively, from the lgs gene on the same side. On the opposite side of the gene, the nearest co-segregating flanking marker was SB3352 with a genetic distance of 1.2 cM. Furthermore, the validation of tightly linked markers in diverse sorghum accessions showed their potential utility and application in MAS and identification of low germination stimulant activity in source materials. Generally, markers linked at a distance <5 cM to the target gene, validated in diverse genotypes, as those obtained in the present study, can be effectively utilized for indirect selection. Moreover, the efficiency of MAS can be increased by employing the markers flanking the gene of interest for recombinant selection. Thus, a set of eight microsatellite markers associated with the fine-mapped lgs gene in the present study in a total interval of 5.9 cM could be effectively used for foreground and recombinant selection in a MAS program for efficient transfer of the lgs gene into new and existing cultivars targeted for Striga endemic areas. A partial genetic map of sorghum with the fine-mapped lgs region on SBI-05 is provided in Fig. 2.

The mapping position of lgs based on binary phenotypic data was further confirmed by two rounds of initial QTL analysis with MQM mapping using the genetic maps with and without presence of the lgs locus. The two rounds of QTL analysis showed the same major QTL peak on the tip of SBI-05 (70% R2 and 82 LOD), thus confirming the presence of major gene in this genomic region. A third round of QTL analysis including the fine-mapped lgs region with 8 additional markers showed again only one major QTL peak exactly on the lgs locus with the R2 of 90% and 191 LOD value. No additional minor QTLs were identified for this trait though the distribution of MGD data for high stimulating RILs suggested the possibility of minor or modifier genes influencing in the trait expression reflected by their MGD values.

Validation of Tightly Linked Markers

The potential and utility of tightly linked markers identified in our study for the lgs gene was further validated using a set of 23 diverse sorghum accessions, including nine advanced *Striga* resistant lines developed at Purdue and released in various African

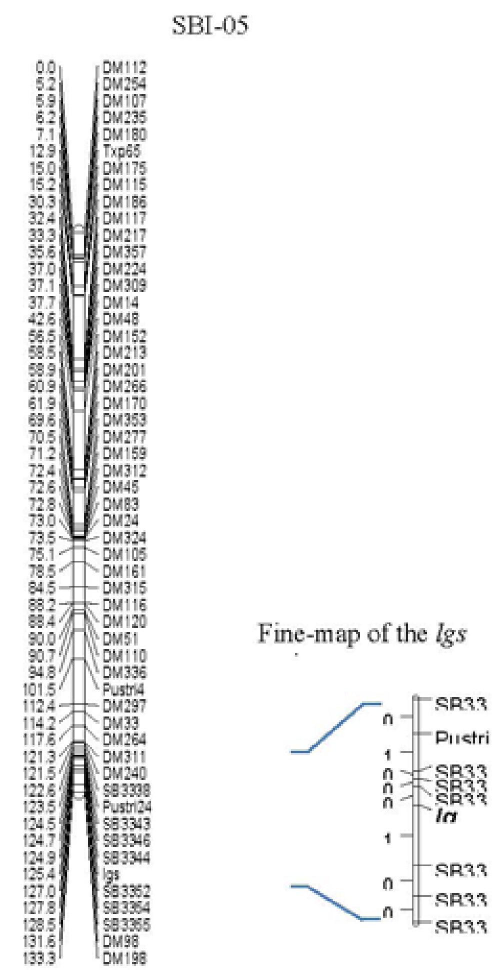

Figure 2. A partial genetic map of sorghum showing the fine-mapped *lgs* gene on SBI-05 chromosome

countries derived from SRN39 (low *Striga* germination stimulant activity). Eight of these (P9401-P9408) are derived from the cross SRN39 (low) × P954063 (high) and one accession, Brahan, was derived from SRN39 and Framida (another line with low *Striga* germination stimulant activity). In addition to these 11 accessions and the parents of the RIL population used to map lgs, ten diverse accessions with previously reported germination stimulant activity and field reaction to *Striga* were included in the validation test (Table 1). Although the 354 RILs used to map lgs were not screened with *S. hermonthica*, we found the parents of this population (Shanqui Red and SRN39) and the other accessions included in the validation study to have similar germination stimulant activity toward both *Striga* spp., that is, an entry showing low germination stimulant activity toward the *S. asiatica* seed source used in the AGA also showed low germination stimulant activity toward the *S. hermonthica* seed source. Using the same 10mm threshold, those accessions classified as high stimulators showed high germination stimulation activity toward both *Striga* species, though the actual MGD values sometimes differed between the two. The tightly linked markers SB3344 and SB3346 clearly distinguished all accessions with low *Striga* germination stimulant activity from high stimulant activity accessions, with the exception of two, 555 and the wild sorghum (*S. bicolor drummondii*) PQ-434. Among the SRN39 derivatives, the markers were always associated with the the trait; those with low *Striga* germination stimulant activity in all cases showed the SRN39 type allele. A gel image showing the validation of tightly linked marker SB3344 for *Striga* germination stimulant activity in the 23 sorghum accessions is presented in Fig. 3. The complete details on genotyping and phenotyping of these lines for both *Striga* spp. are provided in Table 1.

Validation of markers associated with a gene or QTL is an essential requirement for MAS in resistance breeding programs. We did not include SB3343 marker in the validation test, although it was tightly linked, due to dominance scoring of the markers in the RILs. Based on the marker genotyping, we found that the alleles corresponding to low *Striga* germination stimulant activity in the donor parent SRN39 were shared by nearly all other low stimulant lines. 21 out of 23 lines could be distinguished based on the marker allelic banding pattern (Table 1, Fig. 3). Nine lines used in the validation were SRN39 derivatives (P940_series and Brahan) which were released as *Striga* resistant varieties in several African countries. Some of these lines have inherited the low *Striga* germination stimulant activity, while others possess only the other resistance trait from SRN39, incompatibility, independently inherited from the low stimulant trait. Among these nine SRN39 derivatives, all four with low *Striga* germination stimulant activity carry the SRN39 type alleles. This suggests that these tags could be successfully used to introgress the low stimulant resistance trait into new and existing sorghum varieties.

Among the unrelated sources of low *Striga* germination stimulant activity, Framida, 555, SAR33, IS9830, ICSV1006, ICSV1007, Tetron, and the wild sorghum accession PQ-434, all carried the SRN39 marker alleles for the lgs gene except 555 and PQ-434 The most surprising accession was 555, which, together with Framida, has been extensively used as a source of low germination stimulant based resistance. We determined through genetic tests that the low *Striga* germination stimulant activity of 555 is recessive and allelic to SRN39, based on the high stimulant activity of the F1 hybrid of the cross Shanqui Red × 555 (MGD = 10.3). A cross between both low stimulant parents [(SRN39 × 555)F1] has a low stimulant phenotype showing an MGD of 2.0 (unpublished results) indicating that no complementation has occurred and so the mutations must affect the same gene. But SRN39 clearly has different alleles at the lgs associated markers than 555 (Table 1, Fig. 3). Hence, we hypothesize that 555 contains an independent mutation in lgs which occurred in a background coupled with different alleles at the marker satellites. Similar to 555, the low Striga germination stimulant accession PQ-434 did not share the SRN39 type alleles for any of the associated markers. Genetic tests confirmed that this mutant lgs phenotype, like SRN39, is recessive since a high germination stimulant activity is restored in hybrids of this line with high stimulant lines. The MGD of F1 hybrid between CK60 (high stimulating) and PQ-434 (low stimulating), for instance, is 10.1 (unpublished results). In crosses of PQ-434 with lines carrying mutant (SRN39 type) alleles at lgs, however, wild-type function is restored, [the MGD of (SRN39× PQ-434)F1 = 10.2 (unpublished results)]. Because complementation occurs in the F1, the mutations likely involve different genes in both SRN39 and PQ434 genotypes. Genetic mapping of this possible second lgs locus is currently underway.

It appears that the recessive alleles at lgs, and those at the mutated gene in PQ-434, result in low germination stimulant activity toward both *S. asiatica* and *S. hermonthica.* The phenotyping and genotyping of the 23 diverse accessions of the validation portion of this study showed similar MGD values in the AGA, regardless of which Striga spp. was used. This suggests that the markers would be broadly applicable to Striga populations.

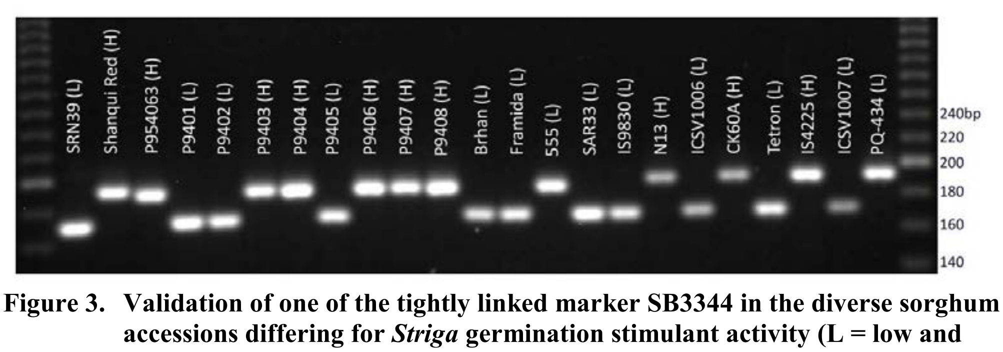

Figure 3. Validation of one of the tightly linked marker SB3344 in the diverse sorghum accessions differing for *Striga* germination stimulant activity (L = low and H = high)

Training (Degree and Non-Degree)

Much of the phenotyping and genotyping of the RILs with *Striga asiatica* was generated by Zenbaba Gutema, a doctoral student from Ethiopia as part of his dissertation research. Zenbaba was supported by INTSORMIL funds during his graduate studies. He received his Ph.D. from Purdue in 2008. Dr. Satish Kanuganti, an Indian post doctoral associate working in the Ejeta laboratory performed the QTL analysis and fine mapping of lgs that led to the publication of the cumulative results of all of this work.

Networking Activities

The principal investigator, Gebisa Ejeta, continues to spend a great deal of time on speaking engagement globally as the 2009 World Food Prize Laureate. In his travels around the world, Dr. Ejeta speaks at universities and other scientific conferences, and addresses government and international organizations concerned with global food security issues. He advocates the need for scientific research in global development and promotes science that benefits humanity particularly in areas of the world where hunger prevails.

Publications and Presentations

Amusan, I.O., P.J. Rich, T. Housley and G. Ejeta. 2011. An in vitro method for identifying post-attachment Striga resistance in maize and sorghum. Agronomy Journal 103:1472-1478.

Tesso, T.T. and G. Ejeta. 2011. Integrating multiple control options enhances Striga management and sorghum yield on heavily infested soils. Agronomy Journal, 103: 1464-1471.

Satish K, Z. Gutema, C. Grenier, P. Rich and G. Ejeta. 2011. Molecular tagging and validation of microsatellite markers linked to the low germination stimulant gene (lgs) for Striga resistance in sorghum [Sorghum bicolor (L.) Moench]. Theoretical and Applied Genetics (online first - http://dx.doi.org/10.1007/s00122-011-1763-9).

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

Project 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 goal of this project focuses on research and training activities to deploy genetic technologies that will enhance the value and performance of farmer-accepted sorghum varieties in developed and developing sorghum production regions. These efforts will be accomplished through collaborative programs with sorghum breeders and researchers in U.S. universities and national agriculture research systems throughout West Africa (WA) including Niger, Burkina Faso, Mali, and Nigeria and through interaction with private industry partners including DuPont Crop Protection and private seed industry partners.

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%. 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 beer (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 combine grain quality and end-use requirement traits with key defensive traits (e.g., Striga and weed management) needed to maximize production potential. These efforts will facilitate the growth of the rapidly expanding markets for sorghum and millet, improve food and nutritional quality to enhance marketability and consumer health, increase the stability and yield of the crop through use of genetic technologies, and contribute to effective partnerships with national and international agencies engaged in the improvement of sorghum (Tuinstra, 2008).

Objectives and Listing of Implementation Sites

The goal of this project is to develop and deploy genetic technologies that will enhance the value and performance of farmer-accepted sorghum cultivars in developed and developing sorghum production regions. Specific objectives include efforts to combine traits and strategies to more effectively manage problematic weeds including Striga in varieties with improved grain quality characteristics, especially cultivars with improved food and feed quality traits (e.g., tan-plant, white-grain, … etc.) and mine genes associated with improved sorghum performance from the sorghum gene pool.

The objectives, collaborators, and implementation sites to address these constraints include:

1. Develop sorghum varieties and hybrids having improved grain quality and production characteristics. This objective focuses on development of sorghum varieties and hybrids having improved food- and feed-quality characteristics for use in West Africa and the United States. Key collaborators and implementation sites include:
- Daniel Aba, IAR, NIGERIA
- Gebisa Ejeta, Purdue University, USA

2. Deploy traits that enhance resistance to biotic stresses in locally adapted varieties and hybrids with excellent grain quality.

This objective focuses on deployment of Striga resistance and herbicide tolerance traits into locally-adapted varieties and hybrids with excellent grain quality attributes. Key collaborators and implementation sites include:

- Daniel Aba, IAR, NIGERIA
- Soumana Soumana, INRAN, NIGER
- Hamidou Traore, INERA, Burkina Faso
- Mountaga Kayento and Abocar Traore, IER, MALI
- Reginald Young, Olumide Ibikunle, and John Beitler, DuPont Crop Protection, USA
- Kay Porter, Pioneer Hi-Bred International, USA

3. Identify and mine genes and alleles associated with improved sorghum performance from the natural sorghum gene pool. An Association Mapping (AM) panel of 300 sorghum lines and varieties selected to represent the genetic diversity of sorghum from around the world has been developed to identify genes and genetic diversity for important food, feed, industrial, and performance traits. Key collaborators and implementation sites include:

- Jianming Yu, Kansas State University, USA
- Dr. Guri Johal, Purdue University, USA
- Dr. Clint Chapple, Purdue University, USA

This project and approach directly contribute to the vision of the INTSORMIL CRSP for 2007-2011. Development of improved, locally-adapted, sorghum varieties and hybrids having enhanced food and feed quality traits will increase availability of high-quality grains. Improved access to these grains will facilitate market development 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 contribute to integrated management of the most important biotic pests through use of genetic technologies. Finally, the use and conservation of sorghum genetic resources will be improved through use of new biotechnology 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

The international sorghum breeding and crop research emphases of this project target countries in West Africa and are supported through short- and long-term training programs, germplasm exchange and evaluation, and basic research. The overarching goal of this project is to develop and deploy genetic technologies that improve sorghum production, performance, and value through plant breeding. The germplasm sources needed to create new breeding populations were identified or developed through evaluations of elite U.S. and tropical germplasm in the target regions. The populations are advanced and selected in summer and winter nurseries and then transferred to the target region for evaluation in conference with collaborating institutions.

Efforts to develop and commercialize new traits that enhance resistance to biotic stresses are being conducted in collaboration with scientists from NARS in Nigeria, Niger, Burkina Faso, and Mali, DuPont Crop Protection, and Pioneer Hi-Bred. This objective focuses on deployment of Striga resistance and herbicide tolerance traits into locally-adapted varieties and hybrids with excellent grain quality attributes including both hybrids and open-pollinated varieties. Researchers from the NARS conduct in-country testing and provide production expertise for cultivation of the new varieties, DuPont scientists contribute herbicide technology and business development capacity, and researchers from Pioneer Hi-Bred facilitate foundation and hybrid seed production of new cultivars. Elite inbred lines and varieties with ALS herbicide tolerance are being developed at Purdue University. This collaboration is allowing evaluation of seed treatments that combine herbicides, fungicides, and insecticides for efficacy in improving sorghum productivity in the region.

Sorghum exhibits an incredible array of natural genetic diversity. Much of this diversity is not utilized for crop improvement because potentially useful alleles of genes are hidden in otherwise inferior genetic backgrounds. New association gene mapping strategies coupled with massively parallel DNA sequencing capacity are being used to search for genes and alleles at a population level using natural diversity rather than through individual bi-parental crosses. These tests evaluate 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 represents much of the natural genetic variation of sorghum. The PI is using this collection and experimenting with new DNA sequencing technologies to create and identify unique alleles that contribute to improved food and feed-quality traits.

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 (Tuinstra, 2008). 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 food quality, but these types of sorghum tend to be more susceptible to mold than sorghum varieties with a red pericarp.

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 Burkina Faso to Senegal. Some progress has been made in use of these germplasms to produce locally adapted varieties with improved grain quality. The food-grade guinea sorghum variety Wassa is being used extensively to produce breeding populations for development of new varieties and inter-racial guinea hybrids. Plant breeding efforts in Nigeria and Niger focus more on hybrid variety development using caudatum sorghums. Crop improvement efforts in these environments focus on development of very large-seeded hybrids for food production and use in the malting industries. Numerous new sources of very large seed size coupled with long grain fill duration were introduced into production environments in Niger and Nigeria. These large seeded germplasms are generating considerable interest for use in the brewing and malting industries.

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

Sorghum researchers and producers in the U.S. and WA indicated that weed infestations including parasitic witchweeds (*Striga* spp.) are among the most important production constraints of sorghum production. 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. Efforts to breed for improved Striga resistance have had some success; however, no single technology is completely effective in controlling Striga or containing its spread.

One new Striga management technology being developed in this project involves use of herbicide tolerance traits for managing this weed. Low-dose metsulfuron seed coatings applied to herbicide tolerant varieties have been shown to be highly effective in controlling Striga infestation in field and greenhouse trials (Tuinstra et al., 2009). In 2010 and 2011, Purdue conducted collaborative research trials with scientists from Nigeria, Niger, Burkina Faso, and Mali, DuPont Crop Protection, and Pioneer Hi-Bred. These trials were designed to test ALS herbicide resistant hybrids developed at Purdue combined with herbicide seed treatments developed at DuPont. Plant breeding to develop additional ALS herbicide tolerant guinea and non-guinea sorghum hybrids adapted in the West Africa region are ongoing.

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

The goal of this project is to identify useful genetic variation in the sorghum gene pool using the genome sequence as a tool to identify and relate variation in specific genes with phenotypic variation. This information is being used to target genes for selective modification to enhance sorghum performance.

Stable Dwarf Cultivars of Sorghum

Sorghum plant height is a quantitative trait controlled by four major genes (Dw1:Dw2:Dw3:Dw4). Nearly all of the grain sorghum grown in the developed world is produced using semi-dwarf cultivars (Quinby 1974, 1975). These semi-dwarf cultivars commonly are called "3-dwarf" sorghums since they utilize recessive dwarfing alleles at three of the four major dwarfing genes (dw1:Dw2:dw3:dw4).

Dw3 is the only height gene that has been cloned in sorghum (Multani et al., 2003). The wild-type allele for Dw3 encodes an auxin efflux transporter involved in stem internode elongation (Multani et al., 2003; Brown et al., 2008). The recessive allele of this gene (dw3) is used to reduce plant height in nearly all commercial grain sorghum cultivars. This allele was originally identified and characterized by Karper (1932). Karper noted that the dw3 mutation produced a useful dwarf phenotype, but also noted that the dw3 allele was unstable and reverted to wild-type Dw3 at a frequency of approximately 1 in 600 plants. These revertant plants are generally termed "height mutants". Farmers dislike height mutants because these off-types are unsightly in commercial grain production fields. Commercial seed producers do not like height mutants because of the effort and cost required to rogue these plants from seed production fields. These management efforts increase the "cost-of-goods" for F1 hybrid seed.

The objectives of this research were to identify and characterize stable alleles of the dw3 locus that could be used to correct the problem of height mutants in commercial sorghum cultivars. DNA samples were extracted from plants representing a sorghum diversity panel. A PCR assay was developed to screen these samples for genomic variation in the Dw3 locus. Using this assay, genotypes with the dw3 allele should produce a 1960 bp product and genotypes with the Dw3 allele should produce a 1078 bp product (Figure 1). DNA sequencing was used to characterize genotypes that produced polymorphic PCR fragments when compared with the Dw3 or dw3 alleles. These experiments identified 46 accessions with unique DNA sequence haplotypes. Comparative DNA analyses indicated numerous haplotypes that were characterized by several different deletions, an insertion, and numerous SNPs.

New dw3 mutants defined by deletions or insertions were of particular interest as potential sources of a stable dw3 phenotype (Table 1). These mutants were evaluated in grow-out experiments in Puerto Rico – 2010 and Indiana – 2011 (Table 2). Mutants de-

igure 1. PCR markers used to screen for haplotypes of *Dw3* in the sorghum diversity panel.

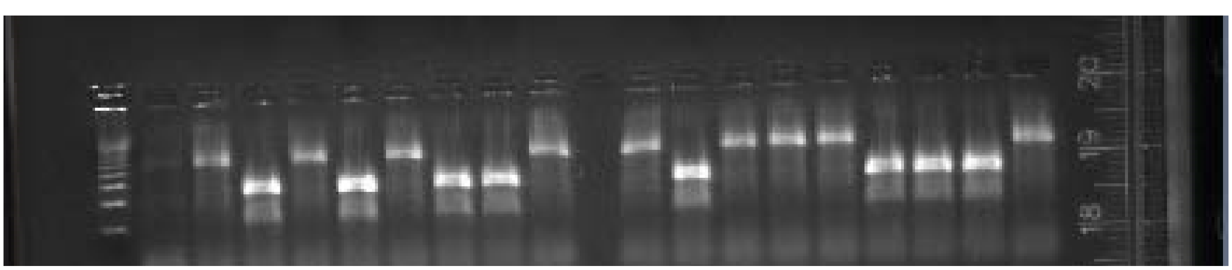

Table 1. New *dw3* mutants of sorghum defined by insertions and deletions.

Mutation	PCR Fragment
6-bp deletion	1072-bp
82-bp deletion	996-bp
6-bp insertion	1084-bp
15-bp deletion	1063-bp

Table 2. Genetic stability of *dw3* mutants of sorghum measured by frequency of height mutants in growout experiments.

Mutation	Observed Mutations	Frequency of Height Mutants
6-bp deletion	0 in 55,860 plants	0
82-bp deletion	0 in 2,808 plants	0
6-bp insertion	0 in 2,432 plants	0
Tx430 - Control	5 in 1,496 plants	0.334 %

fined by the 6-bp deletion, 82-bp deletion, and 6-bp insertion were shown to be completely stable with no observed height mutants under field conditions (Table 2). Another deletion mutant haplotype defined by a 15-bp deletion has not yet been evaluated in grow-out experiments but may represent another stable dw3 allele (Table 1).

PCR markers can be used to differentiate stable dw3 alleles from the unstable dw3 allele. The stable alleles produce PCR products that are 996-1084 bp in length and the unstable allele produces a 1960 bp product (Table 1). These markers provide an important tool in the development of stable dwarf cultivars and breeding populations because plants with stable alleles cannot be differentiated from plants with the unstable allele (dw3) by visual inspection of individual plants. However, analyses of plant DNA using the PCR protocol described above will indicate the plants that carry the stable allele.

Low-HCN Forages

Several important crop plants including sorghum, barley, and cassava are cyanogenic; able to release cyanide (HCN) upon tissue disruption. HCN renders the consumption of plant materials containing cyanogenic glycosides toxic to humans and most animals. The goal of this project is to identify genes and novel alleles that interfere with dhurrin metabolism and study the impact these mutations have on plant health and nutritional quality.

Biochemical analyses of 300 diverse sorghum genotypes indicated 5-fold variation in dhurrin content. We are using this natural genetic diversity to identify the genes that contribute to quantitative variation in dhurrin content and to study the role of dhurrin in plant health. The assessment of natural genetic variation for dhurrin production is being complemented by mutation screening in an EMS mutant population of 12,000 M2 families. A high-throughput HCN assay is being used to identify plants that are compromised in dhurrin metabolism. This mutation screen has identified numerous mutants impaired in dhurrin biosynthesis or catabolism. Development of dhurrin-free sorghum forages has the potential to replace corn and other forage crops that require more water and other inputs than sorghum.

Networking Activities

Workshops and Meetings

Sorghum Improvement Conference of North America. 12-14 September 2011, Stillwater, OK.

APS-IPPC Joint Meeting. 6-10 August 2011, Honolulu, Hawaii.

International conference on crop improvement, ideotyping, and modelling for African cropping systems under climate change. 7-9 February 2011, University of Hohenheim, Euro-Forum, Stuttgart, Germany.

Corn & Sorghum and Soybean Seed Research Conference. 8-10 December 2010, Chicago, Illinois.

2010 ASA-CSSA-SSSA Meeting. 1-3 November 2010, Long Beach, CA.

Research Information Exchange

Dr. Olumide Ibikunle from DuPont Crop Protection-NIGERIA was hosted on a short visit to Purdue University to discuss commercialization of herbicide seed treatments to control Striga infestation of sorghum and maize in West Africa on 22-27 September 2011.

Researchers from Purdue University, DuPont Crop Protection, and Pioneer Hi-Bred toured collaborative research plots in Northern Nigeria on 18-28 October 2010.

Germplasm Conservation and Distribution

Replicated herbicide seed treatment experiments were distributed to collaborators in Niger, Burkina Faso, Nigeria, and Mali to evaluate control of Striga under diverse environmental conditions.

A set of 16 large-seeded, food-grade sorghum breeding lines was distributed to Dr. Daniel Aba at the IAR in Nigeria for evaluation in sorghum malting trials.

A nursery of 250 ALS herbicide resistant sorghum breeding lines was distributed to collaborators from DuPont and IAR in Nigeria to evaluate adaptation, efficacy of herbicide seed treatments, and host-plant resistance to Striga.

Samples of several food-grade sorghum hybrids were distributed to collaborators in Naples, Italy for evaluation in food-grade sorghum production and utilization trials.

Publications and Presentations

Journal Articles

Mutava RN, Prasad PVV, Tuinstra MR, Kofoid KD, Yua J. 2011. Characterization of sorghum genotypes for traits related to drought tolerance. Field Crops Research 123: 10 -18.

Tesso TT, Kershner K, Ochanda NW, Al-Khatib K, Tuinstra MR. 2011. Registration of 34 Sorghum Germplasm Lines Resistant to Acetolactate Synthase–Inhibitor Herbicides. Journal of Plant Registrations 5: 215-219.

Hennigh DS, Al-Khatib K, Tuinstra MR. 2010. Response of acetolactate synthase resistant grain sorghum to nicosulfuron plus rimsulfuron. Weed Technology. 24: 411-415.

Hennigh SD, Al-Khatib K, Currie RS, Tuinstra MR, Geier PW, Stahlman PW, Claassen MM. 2010. Weed control with selected herbicides in acetolactate synthase-resistant sorghum. Crop Protection 29: 879-883.

Tesso T, Ochanda NW, Little CR, Claflin LE, Tuinstra MR. 2010. Analysis of host plant resistance to multiple Fusarium species associated with stalk rot disease in sorghum [Sorghum bicolor (L.) Moench]. Field Crops Research 118: 177-182.

Hennigh SD, Al-Khatib K, Tuinstra MR. 2010. Postemergence Weed Control in Acetolactate Synthase Resistant Grain Sorghum. Weed Technology 24: 219-225.

Book Chapters

Yu J, Hamblin MT, Tuinstra MR. 2011-in press. Association Genetics Strategies and Resources. In AH Patterson (ed.) Genetics and Genomics of Saccharinae, Vol. 11. Springer Inc., New York.

Presentations

Bergsma B, Barrero-Farfan I, Johal G, Tuinstra MR. 2011. Genetic Diversity of Dw3 in Sorghum and Phenotypic Effects of dw3 and br2 on Sorghum and Corn Development. Abstract 91-17. ASA-CSSA-SSSA Annual Meetings, 16-19 October 2011. San Antonio, TX.

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

Project TAM 101
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Introduction And Justification

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 Sureno 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 culti-

vars 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. 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). Advanced lines have been selected in El Salvador and these lines are now in advanced testing in multiple locations and production systems.

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.

Forage Sorghum Breeding

Forage sorghums have become increasingly important in the Central American region; development of new varieties and hybrids with improved forage quality are important. Specific improvement involves incorporation of the brown midrib trait into existing and improved cultivars. Segregating progenies have been grown and selections made from these populations in both Texas and El Salvador; these lines are currently in evaluation in both line per se and hybrid combinations. Most of these selections are brown midrib. Several hybrids and lines have been produced and are being sold and/or distributed within the region.

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. These breeding efforts have resulted in the development of a set of brown midrib lines that were selected and are adapted to the Central American region. These fifteen lines possess the bmr-12 allele in the background of commonly grown cultivars grown in Central America. Through the Feed the Future initiative, we have funding to conduct the testing across Central America to identify the best genotypes for each area. The entries in these studies are listed in Table 1 and this evaluation will be initiated in 2010-2011.

The value of brown midrib is in the improved forage quality associated therewith. Because variation in quality is detectable among brown midrib varieties, it is critical to continue to monitor forage quality. Over many years, animal nutritionists and plant scientists have developed rather efficient lab protocols to measure the forage quality of plant biomass. These figures provide relative estimates of protein, digestible fiber, non-digestable fiber using the measurements of ADF, NDF and crude protein (Weiss, 1994). Our program has acquired and now used NIR technology to estimate forage quality in sorghum. Samples from all tests in the Feed the Future activity and the breeding program will have access to this capacity in coming years.

In addition to the development of bmr sorghum varieties, our program is active in the development of forage sorghum hybrids (both normal and brown mid-rib). Experimentally lines have been developed that produce high yielding forage hybrids with quality equal to or better than those currently commercialized (Table 2). Experimental data clearly indicate the value of photoperiod sensitivity in increasing forage yield. Further analysis to identify those with good quality is currently underway.

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 dis-

Table 1. Mean performance of fifteen brown midrib experimental varieties and four normal and commonly grown sorghum varities in six Central American environments in 2010 and 2011.

Pedigree	Biomass	Pl ht	Lignin	TDN
	kg ha-1	cm	%	%
Centa S-3	12,106	202	6.6	57.6
CI 0916 bmr	11,339	200	5.9	57.0
Centa S-2	11,295	211	7.2	57.8
CI 0947 bmr	10,996	202	5.0	58.6
CI 0932 bmr	10,856	217	5.4	57.4
CI 0910 bmr	10,588	208	6.7	56.6
VG 146	10,482	205	6.9	57.7
Centa-RCV	10,427	189	7.5	57.4
CI 0943 bmr	10,119	196	6.2	57.4
CI 0929 bmr	9,948	203	6.4	56.7
CI 0936 bmr	9,805	201	6.1	57.2
CI 0968 bmr	9,771	200	5.8	57.8
CI 0938 bmr	9,555	200	5.4	58.3
CI 0925 bmr	9,144	190	5.9	57.1
CI 0970 bmr	8,738	182	6.1	57.5
CI 0973 bmr	8,682	198	5.9	57.1
CI 0914 bmr	8,650	184	5.9	57.7
CI 0972 bmr	8,287	180	6.0	57.7
CI 0919 bmr	7,853	179	6.1	57.4
LSD	1,568	14	0.2	0.2

Table 2. Yield data from selected and top yielding experimental forage sorghum hybrids developed in the Texas Agrilife sorghum research program and evaluated in two locations in Texas.

PEDIGREE	Plant color	Maturity at harvest	Plant height	Desir-ability	Lod-ging	Yield
	color		m			T acre^{-1}
ATx623(bmr)/F06451	P	V	2.88	1.8	1.0	56.38
ATx623/TX2910	P	V	2.87	1.3	1.0	56.08
ATx645/BTx2752//Tx2910	P	V	2.73	2.0	1.8	52.29
ATx623/Tx2909	P	V	2.87	1.3	1.0	48.96
ATx631/Tx2909	T	V	2.93	1.3	1.0	47.70
ATx623bmr/F07314bmr	P	V	3.07	3.2	1.3	46.59
ATx645/BTx2752//F06451	P	V	2.83	2.3	1.2	42.98
ATx631/TX2910	T	V	2.80	2.2	1.0	42.80
ATx623bmr/F08331bmr	T	V	2.31	2.2	1.2	42.67
ATx623bmr/F08338bmr	P	M	2.86	3.3	1.3	37.50
ATx623bmr/F08336bmr	P	V	2.07	2.2	1.2	34.85
ATx623bmr/F07310bmr	P	M	2.72	3.7	1.5	33.18
ATx623bmr/F08317bmr	P	M	2.67	3.2	1.3	32.72
ATx623bmr/F07321bmr	P	M	2.78	3.7	1.2	32.30
ATx623bmr/F08327bmr	P	M	2.81	4.5	2.0	32.07
ATx631/Tx2785	T	M	2.77	3.7	1.5	30.82
ATx623bmr/F08322bmr	P	M	2.76	2.7	1.0	30.44
ATx623bmr/F08325bmr	P	M	2.47	3.0	1.0	30.44
ATx623/Tx2784	P	M	2.86	3.5	1.2	30.30
ATx623bmr/F07312bmr	P	M	2.89	4.5	1.5	30.14
ATx623bmr/F08337bmr	P	M	2.85	5.3	2.3	29.86
ATx623bmr/F07327	P	M	2.80	4.8	3.3	29.85
ATx631/Tx2784	T	M	2.75	4.0	1.7	28.26
ATx623bmr/F07329	P	M	2.80	5.2	3.2	27.97
ATx623bmr/F07334	P	M	2.78	4.5	1.3	27.62
ATx623bmr/F08318bmr	P	M	2.73	5.7	4.3	27.60
ATx631bmr12/F08317bmr	T	M	2.54	2.7	1.0	27.60
ATx623bmr/F08328bmr	P	M	2.93	5.5	2.5	27.28
ATx623bmr/F08321bmr	P	M	2.64	5.0	2.7	26.80
ATx623bmr/F07307bmr	P	M	2.91	5.5	2.0	26.78
ATx623bmr/F07331	P	M	2.84	4.7	2.5	26.51
ATx623/Tx2785	P	HD	2.94	4.3	1.3	26.36
ATx623bmr/F08330bmr	P	M	2.73	5.5	3.2	26.36
Average			2.68	3.92	1.83	30.61

Plant color was either purple (P) or tan (T). Maturity at harvest was either mature (M), hard dough (HD), or vegetative (V). Desirability is presented on a scale of 1 (most desirable) to 9 (least desirable). Lodging is rated on a scale of 1 (no lodging) to 9 (completely lodged).

ease 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).

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. One population (with SC748-5 as the source of anthracnose resistance) was evaluated in 2010 in two US locations. Analysis revealed one major QTL and three minor QTL influencing anthracnose resistance. The major QTL was present in the same general region as described in Perumal et al. (2008) (Klein et al., unpublished results).

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. As part of the breeding and selection process, our program has developed approximately 20 sudangrass pollinator lines that have potential to produce sorghum sudangrass hybrids that will be of value in Central America. These lines have good yield potential in hybrid combination, acceptable forage quality and they possess resistance to downy mildew in both the line and hybrids.

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). Our program has evaluated experimental hybrids in replicated yield trials in multiple 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. Based on these trials several higher yielding black sorghum genotypes have been identified and are being prepared for release (Tables 3 and 4). From these trials, it is apparent that both genotype and environment influence antioxidant compound production and degradation and that productivity of specific compounds is maximized in specific genotypes.

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

Table 3. Grain composition of Tx3362 and four grain sorghum pollinator lines (Tx430, Tx436, Tx2783, and SC103-12E) grown in College Station and Halfway Texas in 2011. All components were estimated using NIR analysis on a Foss XDS system using calibration curves developed by the sorghum breeding and grain quality programs of Texas Agrilife Research.

Trait	Tx3362	Tx430	Tx436	Tx2783	SC103-12E	L.S.D. (P<.05)
College Station						
Starch (%)	62.5	65.8	67.0	65.7	67.0	2.0
Protein (%)	15.3	11.5	10.6	12.7	11.7	2.4
Fat (%)	1.9	2.9	3.7	3.0	3.1	0.3
Fiber (%)	2.4	2.1	1.8	2.0	2.1	0.3
Ash (%)	1.2	1.2	1.3	1.3	1.3	ns
Moisture (%)	10.3	10.4	10.2	10.3	10.3	ns
Phenols (mg GAE/g)†	15.6	2.5	1.4	4.0	13	3.0
Tannins (mg CE/g)‡	26.6	0.0	1.2	4.1	32	10.0
3-DOA Abs/mL/g)§	177.5	17.3	4.7	27.7	28	12.0
Halfway						
Starch (%)	63.8	67.9	68.3	69.2	67.6	1.8
Protein (%)	15.6	10.0	9.5	9.4	11.7	2.5
Fat (%)	3.0	3.6	3.4	3.5	4.2	0.2
Fiber (%)	2.3	2.0	1.9	1.8	1.8	0.2
Ash (%)	1.0	1.1	1.1	1.0	1.0	ns
Moisture(%)	10.4	10.5	11.0	10.5	10.4	ns
Phenols (mg GAE/g)	23	3	2	4	12	8.0
Tannins (mg CE/g)	55	0	0	9	28	22.0
3-DOA(Abs/mL/g)	153	7	6	11	15	40.0

† GAE = gallic acid equivalents;
‡ CE = catechin equivalents
§ 3-DOA = 3-deoxyanthocyanin

Table 4. Agronomic trait means of hybrids of Tx3363 and Tx3364 compared with three commercial check hybrids grown in College Station and Halfway Texas in 2009.

Trait	ATx3363/RTx3362	ATx3364/RTx3362	Pioneer 84G62	ATx2752/RTx437	ATx642/Tx2953	L.S.D (P<.05)
Days to Anthesis (d)						
College Station	63	67	69	64	71	1
Halfway	60	61	65	59	62	1
Moisture content (%)						
College Station	12.3	12.6	14.3	12.3	13.5	0.5
Halfway	14.4	14.1	15.3	14.3	13.6	0.5
Test weight (kg hl^{-1})						
College Station	55.5	53.1	60.9	70.0	67.3	1.8
Halfway	67.7	68.4	73.0	72.7	77.5	1.5
Plant height (cm)						
College Station	116.8	99.1	124.5	134.6	119.4	4.0
Halfway	139.7	129.5	127.0	139.7	147.3	3.5
Grain yield (kg ha^{-1})						
College Station	2,853	1,904	4,762	4,738	4,278	470
Halfway	4,843	3,415	6,182	5,397	4,650	390

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; it has been extremely difficult to identify acceptable and interested potential students. Mr. Ostilio Portillo, a Honduran joined our program in January 2010 to pursue a Ph.D in plant breeding; he is conducting research in both grain quality and forage productivity within the Central American region.

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 is a native of Africa and evolved in the diverse environments of the continent. Ample genetic diversity provides sorghum the opportunity to play a major role in increasing food security and decreasing production risk, especially with climate change impacting production of other grains. Sorghum is a major food grain in the semi-arid tropics and a major feed grain in the U.S. Demand as a food grain or nutraceutical is slowly increasing in the U.S. Efficient water use, tolerance to high temperatures, multitude of uses (food, feed, forage, biomass), ability to produce harvestable grain yield in diverse cropping systems, and performance in rotations sorghum ideally suited to marginal semi-arid environments. Sorghum production is reduced due to less than desired yield, biotic (insect pests and disease pathogens) and abiotic (primarily pre- and post-flowering drought) stress susceptibility, and lower value and quality of grain and forage. The overall objective of this project is to develop germplasm, parental lines and cultivars with enhanced adaptation, increased grain yield potential and resistance to multiple abiotic and/or biotic stresses.\

U.S. research is directed toward development of germplasm (including parental lines) suitable for use as hybrid seed parents. Germplasm, either R- (pollinators) or A-/B- pairs (female seed parent and maintainer) is selected for stress resistance, wide-adaptation, disease resistance, and improved weathering resistance. Replicated observation and grain yield trails are used to identify germplasm with improved combining ability for increased grain production. This project uses traditional breeding methodology and diverse environments to select for traits of interest. The genetic diversity within the breeding program is maintained through continuous introduction and crossing of exotic germplasm with traits of interest into the available gene pool.

Research for host countries is directed primarily at developing populations that can be selected in the U.S. and provided to host country collaborators for selection. Primary emphasis has been on sorghum midge resistance, disease resistance, grain wreathing resistance and post-flowering drought tolerance. For example, in Mozambique experimental breeding lines have been identified for possible release as varieties. The lines are in multi-location replicated trials to evaluate for adaptation and grain yield potential. The lines represent different pedigrees and were selected from nurseries developed for resistance to sorghum midge, grain weathering, and drought tolerance. In South Africa and Botswana, potential new varieties express a high level of resistance to sugarcane aphid and grain yield potential at least equal to the standard checks.

Objectives and Implementation Sites

- Develop sorghum genetic technology (germplasm, inbred lines and cultivars) resistant to selected biotic stresses
- Develop sorghum genetic technology resistant to pre- and post-flowering drought stress
- Develop sorghum genetic technology with improved grain quality and grain mold/weathering resistance
- Develop sorghum genetic technology with improved grain yield and adaptation for diverse cropping systems and environments

- Evaluate forage and sweet sorghums for biomass and potential use in cellulosic ethanol production
- Contribute to host-country institutional human capital development through short-term (non-degree) and long-term (M.S. and Ph.D.) educational opportunities

Segregating populations are developed, selected and evaluated in Texas for adaptation and resistance to specific diseases or insects, post-flowering drought tolerance, and grain mold/weathering resistance. Appropriate germplasm is provided to host country collaborators for evaluation in indigenous cropping systems for traits of interest and adaptation. The multi-disciplinary research team includes plant breeders, entomologists, plant pathologists, and food scientists with the expertise and programs to develop and deliver new technology. Texas nursery sites provide geographic diversity for selection and evaluation, and include the Coastal Bend for tropical adaptation and resistance to grain weathering, sorghum midge and disease(s) and the semi-arid temperate Southern High Plains for yield potential and drought tolerance. The Puerto Rico winter nursery provides an extra growing season to reduce development time for new germplasm and the opportunity to advance segregating lines an extra generation. Southern Africa locations provide additional evaluation environments - yield potential and adaptation nurseries in Zambia (Golden Valley Agricultural Trust at Chisamba), Mozambique (Nampula), Botswana (Botswana College of Agriculture, Sebele), and South Africa (Cedara), and disease resistance evaluation at Cedara (anthracnose, grain mold, and ergot). Cereal quality laboratories at the Univ. of Pretoria will provide the opportunity to analyze advanced germplasm for milling qualities in comparison with local checks.

Research Methodology and Strategy

Primary breeding methodology is the pedigree system. Segregating populations, advanced lines and hybrids undergo multi-location testing to identify the best genetic combinations for the trait(s) of interest. Selection in diverse environments will identify widely adapted genotypes with resistance to multiple stresses.

For southern Africa primary traits are adaptation to indigenous cropping systems, seedling and adult plant stage resistance to sugarcane aphid, and resistance to sooty stripe, leaf blight, anthracnose, and grain mold with sorghum midge resistance incorporated as necessary. 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, and drought. Advanced lines are evaluated as hybrid parents 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 facilitate identification and evaluation of new genetic technology. New genetic technology will be available to private industry through material transfer agreements.

Research Results

Replicated trials were provided to collaborators at the University of the Free State and the Botswana College of Agriculture. The trials provided the basis for collaborative research, and supplicated on-going research within each program. The sugarcane aphid (Melanaphis sacchari (Zehntner)) trial provided to collaborators at the University of the Free State and the Botswana College of Agriculture was a 24 entry trial. The All Disease and Insect Nursery (ADIN – 50 entries x 2 replications) and the Genetics of Pericarp Nursery (20 entries x 3 replications) were also provided to the University of the Free State to plant at Cedara.

Growing the sugarcane aphid yield trial at three locations (Sebele, Botswana; Cedara, South Africa; Lubbock, TX) provides the opportunity to evaluate the experimental entries for different traits in the appropriate environment (Table 1). Analysis of the data for number of sugarcane aphid, and the sugarcane aphid damage rating, led to the conclusion that an excellent level of resistance to the pest has been incorporated into elite adapted lines. The sugarcane aphid is not a U.S. sorghum pest and all pest evaluations are conducted by Dr. D. Munthali at the Botswana College of Agriculture. A differential response was noted for the lines although most were rated as expressing a high level of resistance (1 or 2 on the damage rating scale). Grain mold is major constraint to growing sorghum with white grain in Southern Africa. Generally, white color grain is more susceptible to weathering than red color sorghum. Evaluation at Cedara, South Africa is an outstanding environment to determine the grain mold response of sorghum. The location is also a good environment for evaluation for anthracnose (*Colletotrichum sublineolum* (Henn., Kabat cc. Bub.) and leaf blight (*Exserohilum turcicum* Leo and Sug.) (*Helminthosporium turcicum* Pass.) . Entries were scored for disease response by Dr. N. McLaren, University of the Free State plant pathologist. All entries were at least moderately susceptible to grain mold. Several entries expressed moderate (scored as 2-3) to high resistance (scored as 1) to anthracnose and leaf blight. Entries were evaluated for grain yield as either grain mass per panicle (Botswana) and per hectare (Lubbock). Entries express a differential yield response based on location. Generally the entries that produced the most grain at Lubbock did not perform well in Botswana, and vice versa. Segaolane, a Botswana cultivar, produced the mean grain yield 3458 kg/HA at Lubbock but was a higher yield cultivar in Botswana110.9g/panicle. Four of the higher grain yield cultivars in Botswana were among the higher grain yield cultivars at Lubbock. For grain yield in Botswana, measured as grain mass per panicle, the standard check Ent62/SADC produced the most grain per panicle as it did in the previous year.

The purpose of the sugarcane aphid resistance breeding program is to develop improved cultivars suitable for small-holder production systems with resistance to sugarcane aphid. New cultivars should be tan plant and white grain with excellent resistance to aphid and foliar disease, grain yield at least equal to local checks, and good grain mold resistance. Results indicate that sug-

Table 1. Grain yield, leaf disease resistance and insect resistance for the Sugarcane Aphid Test at Lubbock, TX, Cedara, South Africa and Sebele, Botswana, 2010-11.

SOURCE	PEDIGREE	YIELD	DESIRABILITY†	UNIFORMITY‡	ANTHRACNOSE§	GRAIN MOLD¶	GRAIN PER PANICLE	NUMBER OF SUGARCANE APHIDS	SUGARCANE AHPID DAMAGE#
09LI6454	Segaolane*WM#322)-LG2-LG2-(03)BG1-LG1-LBK-PRBK	4876	2.4	1	2.3	3.0	95.7	39.1	2.0
09LI6443	(LG35*WM#322)-BE40-LG1-CA1-LGBK-CABK-CABK	4361	2.3	2	1.7	3	104.0	64.4	4.0
09LI6453	(SV1*Sima/is23250)-LG15-CG1-BG2-(03)BGBK-LBK-PRBK	4333	2.4	1	1.3	3	82.9	12.8	1.0
09LI6021	Macia	4284	2.6	1	0.8	2.3	92.3	29.6	2.0
09LI6455	(6BRON/(7EO366*Tx2783)*CE151)-LG5-CG2-(03)BG1-LBK-PRBK	4187	2.4	1	1.5	3.7	51.4	33.3	2.0
07LI3545	Ento62/SADC	3973	2.5	2	0.8	2.7	132.6	30.0	2.0
09LI6452	(Macia*TAM428)-LL9	3819	2.4	1	2.0	3.7	61.6	34.4	2.0
09LI6024	SRN39	3682	2.7	2	0.0	2.9	75.7		
09LI6442	(9MLT176/(MR112B-92M2*Tx2880)*A964)-LG8-CABK-LGBK-LGBK-CABK	3623	2.3	1	0.0	3.0	120.4	27.7	2.0
09LI6018	Segaolane	3458	2.2	1	0.0	3.0	110.9	64.4	4.0
09LI6450	(5BRON151/(7EO366*GR107B-90M16)*Tegemeo)-HG7-CC2-CABK-CABK	3335	2.4	1	1.2	2.4	88.8	57.2	3.0
09LI6441	(9MLT176/(MR112B-92M2*Tx2880)-CA3-CABK-CCBK-CABK-CABK	3264	2.5	2	0.2	2.8	103.6	64.1	4.0
09LI6456	(Macia*TAM428)-LL2	2980	2.6	1	2.3	4.0	96.4	31.1	2.0
09LI6451	Tegemeo	2929	2.5	1	0.0	4.0	98.5	35.6	2.0
09LI6446	(Dorado*Tegemeo)-HW15-CA1-CC2-LG1-CABK	2906	2.4	1	0.2	3.3	126.0	29.6	2.0
09LI6448	(Kuyuma*5BRON155)-CA5-CC1-CABK-CABK	2705	2.4	1	0.7	3.0	110.8	33.3	2.0
	MEAN	3444	2.4						
	LSD.05	1498	0.3						

†Rated on a scale of 1 = most desirable (excellent grain yield potential) up to 5 = least desirable (no grain yield potential).
‡Rated on a scale of 1 = uniform up to 5 = very uneven.
§Rated on a scale of 1 = no tissue loss up to 5 = plant death.
¶Rated on a scale of 1 = no grain deterioration up to 5 = 100% grain deterioration.
#Rated on a scale of 1 = no leaf tissue necrosis up to 5 = plant death.

arcane aphid resistance has been incorporated into elite cultivars with excellent grain yield.

The goal of the sorghum midge resistance breeding program is to develop germplasm with high resistance to sorghum midge, good foliar traits, and acceptable grain yield potential. The scope of the sorghum midge resistance program has shifted to develop germplasm of potential use as varieties. The varieties should be taller and preferably have tan plant with white grain. Advanced entries are evaluated yearly for resistance at Corpus Christi, TX, and for adaptation (in the absence of the pest) at Lubbock, TX. In 2010 the midge line test was composed of 49 entries, 34 experimental entries and 15 checks (partial results shown in Table 2. Sorghum midge density was low with none of the susceptible checks sustaining 100% seed loss. Previous research has shown that entries with excellent resistance with low to moderate sorghum midge population density may be susceptible with high population density. In many environments a moderate population density may be the norm and therefore genotypes expressing moderate resistance may be usable directly as varieties. Many entries were identified with a high (scored as a 1 or 2) or moderate (scored as 3 or 4) resistance level. Grain yield at Lubbock was poor due to the environmental conditions. However, there are experimental lines with excellent resistance and acceptable grain yield that could be used as source lines to develop improved resistance varieties with higher grain yield. Additionally, the entries may express higher grain yield potential in host country production systems.

The B-/R-line Observation Nursery (BRON) is planted at several locations in Texas to evaluate for adaptation, stress (disease or drought) resistance, and grain weathering resistance. The nursery contains unreleased germplasm of use to either the U.S., host countries, or both. The parentage of lines in the nursery frequently includes exotic introductions. Many lines in the nursery are tan plant with either red or white grain. Partial results of the evaluation of selected entries are presented in Table 3. In 2010, very good ratings were obtained for grain weathering resistance and resistance to anthracnose, as well as preliminary assessment of post-flowering drought tolerance. For grain weathering reaction lines were evaluated on a scale of 1 = seed bright, free from mold damage; 3 = moderately susceptible, considerable discoloration; up to 5 = very susceptible, seed essentially all dead, embryos dead and endosperm deteriorated. Grain mold damage was severe at Corpus Christi with only 9 entries rated as moderately resistant (2.5) with some seed discoloration. Weathering damage scores for those 9 entries at the other locations (Weslaco and Halfway) indicated the lines expressed a good level of resistance (rated at 1.5 – 2.0). Only one entry, 10BRON280, expressed good resistance to both grain weathering and anthracnose (rated as 1 on a scale 1 = resistant to 9 = susceptible, leaf necrosis). Post-flowering drought stress at Lubbock in 2010 was less than desired due to excessive rainfall approximately 5 weeks after planting. The rainfall filled the soil profile and plant stress was less than desired. Most entries expressed a moderate to high level of post-flowering drought resistance with ratings of 1.5 to 2, indicating no more than 25% leaf necrosis.

The Mozambique national sorghum breeding program continues to evaluate the grain yield of germplasm from Texas A&M University sorghum trials provided to the National Agrarian Research Institute (IIAM). In 2009-10 15 lines were evaluated in replicated yield trials at three locations (Mapupulo, Namialo and Sussundenga) grain yield, adaptation and biotic (disease and insect) resistance. Included as standard checks are Macia and Sima. Designation/pedigree of the eight lines from the Lubbock program 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* PI550610)))))-PR3-SM6-CM3-CM2- CG3-BGBK-CABK
- Sureno
- 02CS30445 (99CA3019 - (VG153*(TAM428*SBIII))-23-B32-BE2-BE1)
- B409 (B1*(B7904*(SC748*SC630)))-HF17B
- 02CS5067 (B1*BTx635)-HF8
- 01CS19225 (B35*B9501)-HD9

The national sorghum program anticipates proposing lines for release following an additional year of testing in 2011-2012.

To evaluate hybrid combining ability and grain yield potential of new germplasm releases and advanced experimental lines replicated yield trials were planted at the Texas AgriLife Research Center, Lubbock, in 2010. The trials were not harvested due to poor stands as a result of unfavorable weather during germination and plant emergence. The remaining plans also sustained significant bird damage with most of the grain destroyed. The yield trials were planted for the 2011 growing season. Even with harsh conditions (extreme heat and drought in 2011) the trials were very good. The data will be reported in the next annual report.

Research continued to develop sweet sorghums with improved adaptation to semi-arid production systems. Selections were made in the F2 through F5 generations. New segregating populations are developed each year to provide opportunities to select germplasm with better adaptation. Selections were made to incorporate the brown midrib trait into both sweet sorghum and three-dwarf grain lines. Emphasis is being placed on developing new A-lines (hybrid females) with higher Brix.

Research conducted by the TAMU Cereal Quality Laboratory on lemon yellow grain with enhanced levels of the flavonones eriodictyol and naringenin, compounds with potential benefit as nutracueticals, was published. B-line selections are currently being sterilized to produce corresponding A-lines for hybrid production. Selections were made in new B- or R-line segregating populations to for lemon yellow grain color and better agronomic traits. Additional laboratory research will be conducted when new lines (and hybrids) are available with increased grain yield potential.

The inheritance of grain traits that contribute to improved quality of sorghum for use in beer brewing and malting need to be understood. The southern Africa cultivar 'Barnard Red' was crossed to elite local cultivars Macia and Kuyuma to develop populations for this research. Each population was grown in the 2010-11 winter nursery and 2011 Lubbock to advance a generation. Selections will be planted in the 2011-12 winter nursery so that both

Table 2. Grain yield and other agronomic traits of selected entries in the 2010 Midge Line Test at Corpus Christi and Lubbock, TX.

ENTRY	PEDIGREE	Plant Color	Grain Color	Midge Damage Rating†	Desirability‡	Plant Height cm	Panicle Exsertion cm	Leaf And Plant Death§	Uniformity¶	Desirability‡	Grain Yield Kg/HA
						Corpus Christi				Lubbock	
27	(MB108B/P.G.*((MR112-92M2*Tx2880)-SM17-))-LM3-CM1-CM2-CM2-CM1	P	W	3.7	2.4	155	7	70	2.0	2.2	3094
43	((90EO343/(Tx2895*(SC170*R4671)))*MB108B/P.G.)-BE27-CA2-CM2-CM1	T	R	6.3	2.3	153	4	65	1.0	2.4	2943
20	(Tx2882*((Tx2782*MB108B/P.G.)-CM10-SM1-CM2-CMBK))-CM20-CM1-CA3-CA2-CMBK-CMBK	RP	W	2.3	2.2	121	9	30	1.0	2.2	2655
31	(9MLT176/(MR112B-92M2*Tx2880)*A964)-CA3-CABK-CG1	T	W	2.3	2.5	167	1	15	1.0	2.4	2565
7	BTx640	P	R	1.3	3.0	111	14	40	1.0	2.5	2343
35	(Tx2880*(97M1/(PM12713*Tx2766)))-BE3-CA1-CA2-CMBK-LM1	T	W	4.3	2.6	126	7	75	1.0	2.4	2305
21	(Tx2755*8PR1013/MB120A)-LM7-CM1-CM2	RP	W	1.7	1.8	123	0	20	1.0	1.9	2300
16	(Tx2880*(Tx2880*(Tx2864*(Tx436*(Tx2864*PI550607)))))-PR3-SM6-CM3-CM1-CM2-CABK-CABK	P	W	1.0	2.2	115	5	35	1.0	2.2	2106
18	(Tx2880*(97M1/(PM12713*Tx2766)))-BE24-CM2-CM2	T	W	1.7	2.1	134	5	60	1.0	2.2	1957
40	((R.9519/((SC120*Tx7000)*Tx2817))*MB108B/P.G.)-BE9-CA2-CM2-CM1	T	W	4.0	2.2	150	3	60	3.0	2.2	1953
9	Tx2880	RP	W	1.3	2.6	94	0	35	1.0	2.6	1906
44	((90EO343/(Tx2895*(SC170*R4671)))*MB108B/P.G.)-LG17-CA1-CM2-CM2	RP	R	4.0	2.4	130	7	50	1.0	2.4	1840
25	(9MLT176/(MR112B-92M2*Tx2880)*Dorado)-CA4-CA2	T	W	3.3	2.5	140	9	55	1.5	2.4	1823
17	(Tx2880*(97M1/(PM12713*Tx2766)))-BE22-CA1-CA3	T	W	1.3	2.1	124	6	75	1.0	2.5	1788
22	(MB108B/P.G.*(MR112-90M5*87EO366))-HM9-CM1-CM2	RP	W	2.3	1.9	116	0	45	1.0	2.4	1698
11	Tx2883	RP	W	2.0	2.7	101	1	70	1.0	2.7	1636
39	(Tx2880*(97M1/(PM12713*Tx2766)))-CA3-CA2-CM1-LM1	T	W	1.7	2.1	120	2	40	2.0	2.6	1588
42	((90EO343/(Tx2895*(SC170*R4671)))*MB108B/P.G.)-BE11-CA1-CM1-LM1	T	W	4.0	2.1	133	2	40	1.5	2.2	1553
34	(Tx2880*(GR127-90M39*(Tx2862*(Tx2864*PI550607))))-PC1-SM1-SM1-CM2-CG2-BGBK-CABK-CGBK-LGBK-CABK-CM1-C	RP	W	2.0	2.3	128	10	30	1.5	2.3	1540

Table 2. – cont'd Grain yield and other agronomic traits of selected entries in the 2010 Midge Line Test at Corpus Christi and Lubbock, TX.

ENTRY	PEDIGREE	Plant Color	Grain Color	Midge Damage Rating†	Desirability‡	Plant Height cm	Panicle Exsertion cm	Leaf And Plant Death§	Uniformity¶	Desirability‡	Grain Yield Kg/HA
30	(9MLT176/(MR112B-92M2*Tx2880)*SV1)-CM9-CM1-CMBK	T	W	1.0	2.7	122	11	95	1.0	2.7	1495
36	(Tx2880*(97M1/(PM12713*Tx2766)))-BE5-LG2-CA2-CM2-CMBK	T	W	1.3	2.3	151	9	88	2.0	2.4	1490
37	(Tx2880*(97M1/(PM12713*Tx2766)))-BE31-CM2-CM2-CMBK-CMBK	T	W	1.0	2.1	107	2	95	1.0	2.6	1414
26	(Tx2883*(Tx2737*(Tx436*(Tx2783*PI550607))))-PC1-SM1-SM1-CM1-SM1-CABK-BGBK-CGBK-CABK-	P	W	1.7	2.3	117	4	45	1.0	2.4	1327
19	(Tx2880*(97M1/(PM12713*Tx2766)))-BE31-CM2-CM2	T	W	1.7	2.1	107	2	95	1.0	2.5	1307
28	(9MLT176/(MR112B-92M2*Tx2880)*SV1)-BE9-CM2-CM1-CMBK	T	W	1.0	2.6	138	7	60	1.5	2.5	1291
29	(9MLT176/(MR112B-92M2*Tx2880)*SV1)-CA3-CABK-CMBK	T	W	1.0	2.6	116	7	78	1.0	2.5	1223
46	(Tx2883*Tegemeo)-H2-CM1-CM1	RP	W	1.0	2.4	149	5	55	2.0	2.8	1213
33	(9MLT176/(MR112B-92M2*Tx2880)*WM#322)-BE35-LG2-CM3-CM2	T	W	1.0	2.4	129	2	75	1.0	2.7	1196
3	BTx643	P	W	6.0	2.5	101	4	35	1.0	2.4	1185
49	((B.HF14/(B1*BTx635))*B8PR1011)-BE8-CA1-CG1-LM2	T	W	1.0	1.9	98	3	55	1.0	2.5	1146
32	(9MLT176/(MR112B-92M2*Tx2880)*WM#322)-BE11-CA1-CM1-CMBK	T	W	2.0	2.6	155	9	50	2.0	2.9	1130
45	((90EO343/(Tx2895*(SC170*R4671)))*MB108B/P.G.)-LG27-CA1-CM1-CM2	RP	W	2.3	1.9	123	0	35	2.0	2.1	991
24	(Macia*(MR112-90M5*87EO366))-HM16-CA2-CM1-CM1	T	W	1.7	2.1	151	2	30	1.5	2.4	936
4	RTx430	P	W	7.3	2.5	112	0	20	1.0	2.4	835
	MEAN			2.8	2.4	124	5	52	1.3	2.5	1628
	LSD.05			1.9	0.4	16.1	4.1	25.0	0.9	0.3	1560

†Rated on a scale of 1 = 0-10% damaged grain, 2 = 11-20% damaged grain, up to 9 = 81-100% damaged grain.
‡Rated on a scale of 1 = most desirable (excellent) yield potential up to 5 = least desirable (no yield potential).
§Percent of leaf tissue necrosis.
¶Rated on a scale of 1 = very uniform up to 5 = very uneven.

Table 3. Ratings for post-flowering drought stress, grain weathering, desirability, and anthracnose for selected entries in the B/R-line Observation Nursery, 2010.

PEDIGREE	Plant Color†	Grain Color‡	Post Flowering Drought Stress§	Desirability¶	Grain Weathering#	Desirability	Anthracnose	Desirability	Grain Weathering	Desirability	Grain Weathering	Desirability
			Lubbock		Halfway		College Station		Corpus Christi		Weslaco	
RTx430	P	W	1.5	2.2	3.0	2.2	6	2.2	4.5	2.2	3.0	.355
Tx436	T	W	2.0	2.2	2.0	2.5	2	2.5	4.0	2.2	1.5	2.2
BTx2752	P	R	2.0	2.7	2.5	2.7	1	2.7	3.0	2.7	1.5	2.5
BTx643 (B1)	P	W	2.0	2.0	2.5	2.5	2	2.5	3.5	2.2	1.2	2.7
BTx631	T	W	2.0	2.2	2.5	2.2	1	2.7	3.5	2.7	2.0	2.2
02BRON173/(Tx436*(Tx436*(GR127-90M39*(Tx436*(Tx430*(Tx430*PI550610)))))-PR4-LG3-CG2-LG2-LG1-CG1-LIBK	T	W	1.5	2.2	2.0	2.5	1	2.0	4.0	2.5	3.0	2.5
04BRON257/(95BRON131*((Tx2862*(Tx2868*PI550607))-LG53-CG3))-LG1-CG1-CG3-LIBK	T	R	2.0	2.7	2.5	2.5	1	2.3	3.5	2.5	1.2	2.2
04BRON273/((R9120/(80C2241*Tx433))*((Tx2862*(Tx2868*PI550607))-LG9-CG2)-CG30-CG2-CG2-CG3-LIBK	T	W	1.5	2.2	2.0	2.5	1	2.3	4.0	2.2	2.5	2.2
05BRON279/(Tx2880*(86EO361*(Tx2880*PI550607)))-PC1-PR10-LG2-CG2-CM2-CGBK-CM1-LGBK-CG1-LGBK-LIBK	T	W	1.5	2.2	3.0	2.2	2	2.2	3.5	2.0	3.0	2.0
05BRON287/(Tx2880*(86EO361*(Tx2880*PI550607)))-PC1-PR10-LG13-CG2-LG2-LGBK-LG1-BG1-CA2-LIBK	T	W	1.5	2.2	3.0	2.2	5	2.7	3.5	2.2	3.0	2.5
06BRON274/(Tegemeo*Tx2783)-HW5-CA1-LIBK	T	W	2.0	2.5	2.5	2.2	3	2.2	3.5	2.5	3.5	2.0
06BRON277/(Sureno*5BRON139)-BE6-CA1-LIBK	T	R	1.5	2.7	1.5	2.5	4	2.7	2.5	2.2	1.5	2.7
07BRON255/(Segaolane*KS115)-HW3-CA3-LD1-LIBK	P	W	2.0	1.8	2.5	2.7	3	1.8	3.5	1.5	1.5	1.5
07BRON269/(6OBS124*Dorado)-HW22-CA3-LD2-LIBK	P	W	1.5	2.2	2.0	2.0	3	2.5	4.0	1.8	1.2	2.0
07BRON273/((99CA1422/(B1*(B7904*(SC748*SC630))))*(8PR1051/Tx631*GB102))-LG37-CG1-CA2-CA2-CC1-LIBK	T	W	2.0	2.2	1.5	1.8	2	2.5	3.5	1.8	2.0	1.8
07BRON274/(Sureno*LG35)-LG39-CA2-CA3-LG1-LIBK	T	W	2.0	2.3	1.5	2.2	5	2.3	3.5	1.8	1.5	2.2
07BRON280/(92B1941/(SC719-11E*SC630-11E)*6OB124)-LG5-LG1-CA3-LGBK-LIBK	P	DR	1.5	2.5	2.0	2.7	6	2.7	2.5	2.2	1.2	2.5
07BRON283/((92B1941/(SC719-11E*SC630-11E))*(9BRON125/((R2241*(R5646*SC326-6))*GR107-90M18)-LG94))-LG13-LG1-LG1-LG1-LIBK	P	DR	1.5	2.0	2.0	2.0	6	1.8	2.2	2.2	1.2	2.2
07BRON285/((92B1941/(SC719-11E*SC630-11E))*(9BRON125/((R2241*(R5646*SC326-6))*GR107-90M18)-LG94))-LG17-CA1-LG1-CCBK-LIBK	T	DR	1.5	2.2	1.5	2.0	2	2.0	3.0	2.2	1.2	2.5
07BRON287((92B1941/(SC719-11E*SC630-11E))*(9BRON125/((R2241*(R5646*SC326-6))*GR107-90M18)-LG94))-LG24-CG1-CA3-LG3-LG1-LIBK	T	DR	1.5	2.2	1.5	2.0	5	2.2	2.5	2.0	1.0	1.5
07BRON288/(B8PR1059*B8PR1013)-PR10-CA3-CA2-CC2-LIBK	T	W	2.0	2.2	2.0	1.8	5	2.2	4.0	2.0	2.5	2.5
07BRON299/((8BRON122/(GR127-90M37*GR107-90M18))*MB108B/P.G.)-LG38-CA2-LG2-LIBK	P	W	1.5	2.5	1.5	2.0	3	1.8	3.0	1.5	1.0	1.8
07BRON300/((90EO328/Sureno*BDM499)*(98BRON122/(GR127-GR107))-HW3-CA3-CC2-LIBK	T	R	1.5	2.7	1.5	2.5	1	3.0	3.5	2.7	2.5	2.5
08BRON277/(Tx635*B8PR1013)-BE16-CA1-CA2-LG2-LG1-CABK	T	W	1.5	2.2	2.0	2.0	2	2.0	3.5	1.5	1.2	1.8
08BRON278/(B8PR1051*B8PR1011)-BE5-LG2-CA3-CC1-CA1-CABK	T	W	2.0	2.2	2.0	1.8	3	2.0	3.5	1.5	2.5	1.8
08BRON289/((9BRON125/((R2241*R5646*SC326-60)*GR107-90M18))*MB108B/P.G.)-BE17-CA2-CC1-CA2-CABK	T	W	2.5	2.0	2.0	1.8	1	2.0	.4	2.0	2.5	2.0
08BRON290/((9BRON125/((R2241*R5646*SC326-60)*GR107-90M18))*MB108B/P.G.)-LG8-CA2-CC1-LG3-CABK	T	W	1.5	2.2	2.5	1.8	1	2.5	4.0	2.2	1.2	2.5
08BRON291/((R.9120/(80C2241*Tx433))*MB108B/P.G.)-BE3-CA3-CC1-LG1-CABK	T	W	2.5	2.5	3.0	2.5	1	2.5	3.5	2.5	1.2	2.2

Table 3. – cont'd Ratings for post-flowering drought stress, grain weathering, desirability, and anthracnose for selected entries in the B/R-line Observation Nursery, 2010.

08BRON292/((Tx2862*(Tx2868*PI550607))-LG35-CG3-CG3-PR1-LI1-PR1/98LI159*ICSB12)-CA3-LG1-LG1-CABK	T	R	2.0	2.5	3.0	2.7	1	1.8	3.5	2.2	1.2	1.5
10BRON252/(9MLT176/(MR112B-92M2*Tx2880)*Dorado)-BE1-CA1-CA2-CC2-LGBK-CA2	T	W	2.5	2.5	1.5	2.5	3	2.5	3.5	2.5	1.2	2.2
10BRON253(9MLT176/(MR112B-92M2*Tx2880)*Dorado)-CA4-CA1-CC2-CABK-LGBK	T	W	2.0	2.7	2.5	2.5	1	2.5	3.0	2.7	1.2	2.2
10BRON254(Kuyuma*LG35)-CA6-CC2-CABK-CABK	T	W	2.0	2.5	2.0	2.5	3	2.5	3.5	2.7	1.5	2.5
10BRON255/(Kuyuma*LG35)-CA10-LGBK-CABK-LG1	T	R	2.0	2.2	2.0	2.0	1	2.2	3.0	1.8	1.2	2.0
10BRON256(Kuyuma*5BRON155)-CA5-CC1-CABK-CA1	T	R	2.5	2.5	2.0	2.5	1	2.2	3.5	2.0	1.2	2.2
10BRON259/(Macia*Dorado)-HD12-HW1-HW1-CA1	T	W	2.0	2.5	2.0	2.2	1	2.2	4.5	2.7	1.5	2.7
10BRON260/(99GWO92*(EO361*Macia)-HD19)F3-HF80-4-HW2-HW2-LG1	T	W	2.0	2.3	2.0	2.2	2	2.0	4.0	2.7	2.5	2.2
10BRON261/((Macia*88BE2668)-HD9*(Macia*Dorado)-LL2)F2-HW3-HW1-LG1	T	R	2.0	2.5	2.0	2.5	1	2.3	4.0	2.7	3.0	2.5
10BRON267(6OBS124/GR134-/(GR104*((Tx432*CS3541)*SC326-6))*Soberano)-HG11-CC1-CA2-CA1	T	R	2.0	2.5	2.0	2.5	3	2.5	4.0	2.5	1.0	2.2
10BRON272/(89CC443*LG35)-LG22-CA1-CA1-LG1-CA1-LG2	T	R	2.0	2.2	1.5	2.5	7	2.5	4.0	2.5	1.0	2.2
10BRON276/((6OB172/(88CC445*Tx2862))*MB108B/P.G.)-BE4-CA3-CC1-CA2-CA1	T	R	2.0	2.2	1.5	1.8	3	2.0	4.0	2.2	1.0	2.2
10BRON278/((8BRON122/(GR127-90M37*GR107-90M18))*MB108B/P.G.)-LG20-CA2-LG1-CA1-LG1	T	R	1.5	2.2	1.5	2.0	7	2.2	2.5	2.2	2.0	1.8
10BRON280/(LG70*(GR127*(3*7#56)))F3/98PR507-1D(I&II)-PR4-LG3-LD2-LD2-LG2-LG1	P	W	1.5	2.2	2.5	2.2	1	2.5	2.5	2.7	1.5	2.5
10BRON282/(B8PR1059*B35)-LG12-LD2-CC1-LG2-CA1	T	W	1.5	2.5	3.5	2.5	1	2.3	3.0	2.5	1.5	2.5
10BRON283/(B8PR1059*B35)-LG14-CA3-LG1-CA1-LG2	T	R	1.5	2.2	2.0	2.5	8	2.5	2.5	2.5	1.2	2.5
10BRON286/((6OBS160/(Bvar*GB102-))*B8PR1011)-BE6-CA3-CC1-CA1-LG2	T	W	2.0	1.8	1.5	1.8	7	2.2	3.5	1.8	1.2	1.5
10BRON287/((B8PR1051/(BTx631*GB102))*B8PR1011)-LG4-CA1-CC1-CA2-LG2	T	W	2.0	1.8	2.0	2.2	5	2.2	3.5	1.8	1.2	1.8
10BRON289/(9MLT176/(MR112B-92M2*Tx2880)*Segaolane)-CG1-LG1-CA1-CC2-CA2-CA2-LG1	T	W	2.0	2.5	2.0	1.8	2	2.2	3.5	1.8	1.2	2.2
10BRON292/((Macia*2668)-HD9*(Macia*Dorado)LL2)F2-HW12-HW1-LG1-LG2	T	W	2.0	2.2	3.0	2.0	1	2.5	3.5	2.2	1.2	2.7
10BRON295/(5BRON155/((87BH8606-4*GR127-90M46)-HG30)*Jocoro)-HG11-LG1-LG1-CA2	T	R	2.0	2.3	2.0	2.2	6	2.5	2.5	2.5	1.2	2.5
10BRON296/(5BRON155/((87BH8606-4*GR127-90M46)-HG30)*Jocoro)-HG11-LG1-LG1-LG1	T	R	1.5	2.3	2.0	2.0	5	2.5	2.5	2.5	1.2	2.5
10BRON297(7BRON187/(GR127-90M37*GR108-90M30)-LG23-CG1-CG1-CG2-CGBK*Soberano)-HG2-CA2-LG2-LG2	T	W	1.5	2.5	3.0	2.0	1	2.5	4.0	2.7	3.0	2.7
10BRON300/(98CD187*90L19037/(M84-7VG153))F3-HF12-HW2-HW1-LG1-CA2	**T**	W	1.5	2.5	2.5	2.0	1	2.5	3.0	2.5	1.0	2.0

† P = purple, T = tan
‡ R = red, W = white
§ Rated on a scale of 1 = leaves and plant completely green; 2 = approximately 25% of leaf area dead; 3 = approximately 50% of leaf area dead; 4 = over 50% of leaf area dead and possibly some completely dead; to 5 = entire plant (leaves and peduncle) dead
¶ Rated on a scale of 1 = most desirable, excellent yield potential up to 5 = least desirable with no panicl# Rated on a scale of 1 = seed bright, free from mold damage; 2 = moderately resistant to mold, seed slightly discolored; 3 = moderately susceptible, considerable discoloration; 4 = susceptible, extensive discoloration and deterioration of seed; 5 = very susceptible, seed essentially all dead, embryos dead and endosperm deteriorated

populations will be at the appropriate stage to initiate research in 2012. A Ph.D. graduate student from Zambia has been identified to conduct the research. An assistantship offer cannot be extended until INTSORMIL is officially renewed for five-years. The earliest the student will be able to begin is probably January, 2013.

The Puerto Rico winter sorghum nursery contributes to research progress. The nursery is used to produce seed for new segregating grain or sweet sorghum populations, to incorporate the brown midrib (bmr) traits in grain populations, to grow F1 cross seed, make additional backcrosses for sterilization of potential new A-lines, and increase A-line seed used to produce hybrids. The nursery provides a location to develop populations for use in graduate research.

Achievement of Activities Proposed in Work Plan

Activities proposed in the Work Plan were only partially accomplished. For the U.S., activities included: increase lines and exotic cultivars useful in developing new populations; evaluate and select segregating germplasm for resistance to selected biotic (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; develop new segregating populations based upon results of trials; distribute to collaborators 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; distribute seed of released lines; and select forage and sweet sorghum populations for adaptation to a semi-aired production system. Drought breeding nurseries (including breeding plot and observation plots) were destroyed by Round-Up herbicide drift from a nearby farmers' field. This resulted in the loss of approximately 2000 plots and will hinder research progress for the next 2-3 years. Although selection and observation nurseries will be replanted a years research will be lost.

For southern Africa 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 trials of germplasm potentially useful in the indigenous cropping system(s); develop new segregating populations based on research findings; select germplasm for use in local production systems.

Relationship and contribution to INTSORMIL Strategic Plan objectives, target, benchmarks and indicators

OBJECTIVES

Networking Activities

Participated in the Texas Seed Trade Association Production and Research Conference, February 7-8, 2011, Austin, TX

Participated in the INTSORMIL Board of Directors conference call, February 17, 2011

Participated in the INTSORMIL Technical Advisory Committee meeting, May 11-12, 2011, Lincoln, NE

Participated in the Sorghum Research and Extension Symposium, July 21, 2011, Lubbock, TX

Participated in the INTSORMIL Board of Directors meeting, August 23-24, 2011, Kansas City, MO

Participated in the SICNA/Great Plains Sorghum Conference September 13-14, 2011, Stillwater, OK

Zambia, November 30 – December 12, 2011. The Sorghum Food Enterprise and Technology Development in Southern Africa workshop was held at the Hotel Golfview, Lusaka, December 6-10, 2011. The workshop was attended by 64 participants from Southern Africa, Nigeria and Ethiopia. The workshop agenda included 25 presentations on various aspects of sorghum and sorghum food processing, and included an on-site visit to National Breweries, Lusaka to observe production of Chibuka beer. Made invited presentation on "Breeding Sorghum Cultivars for Processing".

Mozambique, South Africa, Botswana and Zambia, March 26 – April 15, 2010. In Mozambique met with Joaquim Mutaliano (sorghum breeding) and Fernando Chitio (entomology) to discuss status and development of their respective research programs. In discussions with Dr. Calisto Bias, IIAM Director General, reviewed the IIAM/INTSORMIL program and future graduate training opportunities for IIAM scientists. In South Africa participated in the MycoRed AFRICA 2011 Conference in Cape Town. Discussions with Medical Research Council collaborators reviewed current research activity. Met with Dr. Neal McLaren, University of the Free State plant pathologist and INTSORMIL collaborator, to discuss research progress and plan graduate degree programs. In Botswana met with Dr. David Munthali, Botswana College of Agriculture entomologist, to discuss research progress and future opportunities. In Zambia met with Dr. Medson Chisi and F.R. Muuka from the Zambia Agricultural Research Institute (ZARI) Sorghum and Millet Improvement Program, and reviewed status of the regional program. Discussed INTSORMIL status with ZARI staff selected for graduate programs at either University of the Free State or Texas A&M University.

Seed of the following nurseries/tests 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 provided to private companies as requested under terms of a Materials Transfer Agreement (MTA).

Publications and Presentations

Dykes, L., G.C. Peterson, W.L. Rooney and L.W. Rooney. 2011. Flavonoid composition and lemon-yellow sorghum genotypes. J. Agric. and Food Chemistry 128(1):173-179.

McLaren, N.W. and G.C. Peterson. 2012. Evaluation of sorghum genotypes for grain mold resistance. Crop Sci. (accepted for publication).

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

Project KSU 102
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Kansas State University

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Collaborating Scientists

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Ing. Reneé Clará, Sorghum Breeding, Centro Nacional, de Technologia, Agricola de El Salvador, San Salvador, El Salvador
Ing. Francisco Vargas, Sorghum Production and Utilization, ANPROSOR, Managua, Nicaragua
Dr. Salissou Issa, Animal Nutrition and Husbandry, INRAN Rainfed Crops Program, INRAN, Niamey, Niger
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Dr. Ayao Missohou, Veterinary Medicine and Animal Nutrition, Dept. of Biological Sciences, School of Veterinary Medicine (EISMV), Université Cheikh Anta Diop, Dakar, Senegal
Ing. Miguel Rios, Animal Production, National School of Agriculture (UNA), Managua Nicaragua
Dr. Carlos Campabadahl, Animal Nutrition and RAPCO Director for Central America, Centro de Investigaciones en Nutricion Animal, Universidad de Costa Rica, San Jose, Costa Rica
Dr. Leland McKinney, Feed Science, Dept.of Grain Science and Industry, Kansas State University, Manhattan, KS
Dr. Keith Behnke, Feed Science, Dept.of Grain Science and Industry, Kansas State University, Manhattan, KS
Dr. Lloyd Rooney, Food Science and Cereal Chemistry, Texas A&M University, College Station, TX
Mr. Ababacar Ndoye, Food Science and Cereal Chemistry, Institut de Technologie Alimentair, Dakar, Senegal
Dr. Iro Nkama, Food Science and Cereal Chemistry, University of Maiduguri, P.M.B. 1069, Borno State, Nigeria
Dr. John Sanders, Economist, Dept.of Agricultural Economics, Purdue University, West Lafayette, IN

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 slightly less than two in a broiler vs three in a pig vs 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 and 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 the developing regions of the world.

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. Research activities to ensure improvements in sorghum grain quality and utilization are an integral part of that strategy. We have worked, are working, and will continue to work to integrate pathology/grain weathering, breeding for improved nutritional value, and feed processing technologies into experiments targeting poultry nutrition and production. Specifically for the 2010-2011 fiscal year, we followed up with producers touched by our Poultry Road Show from the previous year. The objective of this follow up was to re-emphasize the nutritional merits of locally produced sorghum grain especially when properly milled. Salissou Issa (former Ph.D. student at Kansas State and now Animal Production Specialist with INRAN) spent the 2010-2011 fiscal year communication with our various country collaborators in Senegal, Mali, Burkina Faso, Niger, and Nigeria, organizing additional regional research protocols and planning for a second Poultry Road Show for summer of the 2011-2012 fiscal year. Additionally, Hancock made two extended visits to El Salvador, Honduras, and Nicaragua, with the assistance of Jael Jean (graduate student for Dr. Timothy Dalton at KSU) to identify core research leaders for a similar type of activity in Central America.

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:

We were able to work with plant breeders (e.g., Clara, Tesso, and Rooney) in El Salvador, Nicaragua, Kansas, and Texas to identify genetic materials with superior agronomic and nutritional merit that will be used in feeding experiments for West Africa and Central America.

The input of cereal chemists (e.g., Nkama, Rooney, and Bean) in West Africa, Texas, and USDA/Kansas was 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 West Africa, Central America, and Kansas. That project was proposed to the National Sorghum Checkoff Board for additional funding.

The expertise of economists (e.g., Sanders, Ouendeba, and Dalton) in West Africa, Indiana, and Kansas was solicited to facilitate discussion of economic constraints on the poultry industry in West Africa and Central America.

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, Central America, and Kansas during the foreseeable future.

Interaction with animal nutritionists (e.g., Issa, Traore, Hien, Sangare, Missohou, Rios, Gernat, and Corea) in West Africa, Central America, and Kansas remains an essential component of our diet formulation strategies and conduct of chick-feeding experiments.

Specific sites utilized for our 2010-2011 activities included EISMV in Senegal, CRRA in Mali, INERA and CIRDES is Burkina Faso, INRAN in Niger, the University of Maiduguri in Nigeria, UNA in Nicaragua, El Zamorano in Honduras, the University of El Salvador, and, of course Kansas State University.

Research Methodology and Strategy

Active participation of host country scientists was a core component of our project during the 2010-2011 fiscal year. Collaborators form Senegal, Mali, Burkina Faso, Niger, and Nigeria finalized manuscript preparation from data generated from our region-wide project. These same collaborators agreed to participate in a second Poultry Road Show planned for the coming fiscal year. As for the Americas, planning with Vargus (of AMPROSOR, the National Sorghum Producers Association of Nicaragua) and Rios (at UNA) was expanded to include key scientist from Honduras and El Salvador as related to a regional project in Central America. Finally, at Kansas State, Chad Paulk completed his M.S. degree with our sorghum research as the core of his thesis.

Research Results

Specifically for the 2010-2011 fiscal year, Issa coordinated the initiation of additional regional research activities with our collaborators 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). These effort is imperative to the long-term viability of this INTSORMIL project for which a key component is development of a team of researchers to serve the poultry/sorghum industries in West Africa.

As for Central America activities, planning for our collaborative research activities were expanded beyond just Rios and Vargas in Nicaragua to include Dr. Able Gernat (Professor at El Zamorano in Honduras) and Elmer Edgardo Corea (Profesor de Nutricion y Reproduccion Animal, Departamento de Zootecnia, Facultad de Ciencias Agronomicas, Universidad de El Salvador). Also, contact was made with a small technical school near Ocotal, Nicaragua that seems to be an ideal location for outreach programs in this depressed region of that country.

Our overall objective and expected outcome for this INTSORMIL 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. For this next fiscal year we plan 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 were quite extensive during the 2010-2011 fiscal year. On-site supervision of our West Africa activities by Issa solidified the core research team set to meet the need for information among West African poultry farmers. Additionally, two extended visits to Central America were used to ensure formation of an equally impressive team of scientists, industry personnel, and sorghum farmers in El Salvador, Nicaragua, and Honduras. Hancock and his graduate students also were active in promoting sorghum with presentations and seminars given in other regions around the globe (e.g., Asia, Europe, and the United States).

Publications and Presentations

The Merits of Sorghum Grain as the Primary Cereal Grain in Diets for Swine and Poultry, USGC Sorghum Promotion Activity in Hanoi and Ho Chi Minh City, Vietnam, Kuala Lumpur, Malaysia, and Jakarta, Indonesia, July-August, 2011.

Status of Educational and Research Efforts as Related to Sorghum Utilization in the United States, USGC Sorghum Promotion Activity in Tokyo, Japan, June 2011.

Sorghum as a Feed Ingredient for Pigs …. Milling and Nutritional Considerations. USGC Sorghum Promotion Activity for the Colombian Swine Producers Association, Northern Crops Institute, Fargo, ND, June, 2011.

Sorghum as a Preferred Ingredient in Swine Diets. USGC Sorghum Promotion Acitivity in Santiago de Compostela, Spain, and Fatima, Portugal, April, 2011.

Feed Processing and Formulation Strategies to Improve Profitability in Pork Production …. Where Does Sorghum Fit In? USGC Spanish Sorghum Usage Workshop, Manhattan, KS, January, 2011.

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 Tanzania and Zambia through the identification of new market opportunities and related constraints in the value 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. Improving technology and linking producers to markets can be important parts of the solution to the problem. Improving production and marketing technology will lead to greater productivity and higher incomes for sorghum and millet producers and lower food costs for consumers.

Approval of the no-cost time extension until September 29, 2012 has enabled the researchers to continue work that was in progress at the end of September 2011. The major achievements in the past year were the following activities in Tanzania and Zambia. These included (1) studies of the sorghum based clear beer value chain, (2) analyzing the baseline farm household surveys in high potential areas, (3) writing a journal article on the improved seed value chain in Zambia and presenting a paper on the results of the improved seed value chain study in Tanzania; (4) initiating an intervention to improve market linkages between smallholder sorghum farmers and processors in Tanzania; (5) continuing the collection and analyzing of the monthly retail, wholesale and farm price information; (6) completion of M.S. degree in agricultural economics at The OSU in June 2011 by Bernadette Chimai from Zambia. Her thesis research titled "Determinants of Technical Efficiency in Smallholder Sorghum Farming in Zambia" analyzed the Luanshya farm household data. The project supported two M.S. students in agricultural economics at SUA and two senior research projects at UNZA. Salome Maseki completed her M.S. thesis research on the improved seed value chain at SUA in January, 2011.

The combined studies were designed to identify and quantify gaps in the impact chain (supply chain) for new and/or rapidly growing sorghum and millet markets for clear beer, food, and feed concentrate markets. These value added markets 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/encourage smallholders to adopt improved technologies to increase yields, production, and incomes. Studies on improved seed value chains examine constraints on the availability and adoption of this critical yield-enhancing technology.

Objectives and Implementation Sites

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

These activities are centered on INTSORMIL/SMOG 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. The strategy has been to focus on linking producers to markets as an incentive for farmers to increase technology uptake and production. A value chain approach is used to identify constraints and suggest interventions that can strengthen market linkages for sorghum and millet farmers.

Farm household technology adoption: Studies of farm household technology adoption have been reported in previous annual reports. Papers from these studies have been submitted for publication to refereed journals. The Tanzanian adoption paper is forthcoming in the Sokoine University of Agriculture Journal of Agricultural Economics and Development (JAED). The Zambian adoption paper has been accepted by the editor of the University of Swaziland journal (UNISWA) Research Journal of Agriculture, Science, and Technology.

Sorghum-based clear beer studies: In both countries studies are examining the entire sorghum-based clear beer value chain to identify ways to remove constraints. Important features of the value chain that are being analyzed are the linkages between farmers and processors that ensure sufficient quantities and quality and a reliable and timely supply of sorghum at competitive prices that benefit the farmer and processor. Value chain linkages between farmers and processors are analyzed to help ensure a reliable and timely supply of quantity and quality sorghum at competitive prices that benefit farmers and processors. Makindara is completing his dissertation research on this value chain in Tanzania. Chimai and Tembo presented a paper titled “Sorghum Clear Beer Value Chain” at the Sorghum Food Enterprise and Technology Development in Southern Africa Workshop, Golf view Hotel, Lusaka, Zambia, December 6-9, 2010.

Improved seed value chain studies: An improved seed value chain study was completed in Zambia and a similar study was completed in Tanzania. A paper titled: “Constraints on the Adoption of Improved Sorghum Seed in Tanzania: A Value Chain Approach” was presented at the 27th Annual Conference of the Association of International Agriculture and Extension Education (AIAEE), July 5 – 7, 2011 in Windhoek, Namibia. Hamukwala presented results of the Zambia study in a paper titled “Sorghum and Pearl Millet Seed Value Chains in Zambia: Opportunities and Challenges for Smallholder Farmers” at the Sorghum Food Enterprise and Technology Development workshop in Lusaka, December 6-9, 2010.

Feed concentrate value chains: Feed concentrates are an emerging market for sorghum and other grains as consumers demand more meat, especially poultry and dairy products, in their diet. Markets for eggs, broilers, and dairy products are growing rapidly as population and incomes grow in Tanzania and Zambia. We examine this value chain as another way to link smallholders to markets. A feed concentrate value study was completed in Tanzania and a value chain study proposal was developed for Zambia in 2012. Joseph F. Mgaya, Emmanuel R. Mbiha, Donald Larson, Fredy T. M. Kilima, and Mark Erbaugh presented a paper titled “Feed Concentrates Market and Prospects for Increased Sorghum and Millet Utilization in Tanzania” at the Sorghum Food Enterprise and Technology Development in Southern Africa Workshop, Golfview Hotel, Lusaka, Zambia, December 6-9, 2010.

Seasonal price variability studies: Small farmers are often forced to sell their crops at harvest when crop prices are frequently at the lowest level. Crop prices may increase substantially during the remainder of the marketing year when supply is low. Data collection of the monthly price changes, costs of storage and household seasonal cash flows continued in 2011. Price analyses have begun to identify ways farmers can sell at higher prices in the post-harvest season. Selected results for Tanzania are presented below.

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, Gebisa 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 September 30, 2010 to September 29, 2011 were to: (1) To complete a study of improved seed value chain, (2) To complete a study of the feed concentrate value chain, (3) Complete a study of sorghum based clear beer value chain, (4) To continue with monthly price data collection, and (5) Initiate an intervention to improve market linkage between smallholder sorghum farmers and processors.

Study of Improved Seed Value Chain

Ms. Salome Maseki, completed her M.Sc. in Agricultural Economics at Sokoine University of Agriculture, Department of Agricultural Economics and Agribusiness. Her thesis was titled “Economic Analysis of the Seed Value Chain in Tanzania: A Case Study of Millet and Sorghum in Singida Region.” The main objective of her study was to identify value chain factors that affect the use of improved sorghum and millet seed in Singida region. She completed a survey of 97 smallholders in Singida region plus three focus group discussions (at least 12 persons per group) in selected villages and key informant interviews with other seed value chain actors including researchers/breeders, certifiers and multipliers, and stockists. A paper titled: “Constraints on the Adoption of Improved Sorghum Seed in Tanzania: A Value Chain Approach” was presented at the 27th Annual Conference of the Association of International Agriculture and Extension Education (AIAEE), July 5 – 7, 2011 in Windhoek, Namibia.

Study on Feed Concentrate Value Chain

Mr. Joseph Mgaya, who was sponsored by the project, completed his M.Sc. in Agricultural Economics at The OSU in June 2010. The main objective of this research was to identify new market opportunities and constraints for sorghum and millet in the animal feed industry. Questionnaires were completed with 23 feed manufacturers and 58 livestock keepers in five regions of Tanzania (Dodoma, Arusha, Dar es Salaam, Pwani and Morogoro) in 2009/10. In addition, the researcher interviewed several government officials from the Ministry of Livestock and Fisheries and the

Ministry of Agriculture, Food Security and Cooperatives. Joseph F.Mgaya, Emmanuel R. Mbiha, Donald Larson, Fredy T. M. Kilima, and Mark Erbaugh presented results of his research in a paper titled "Feed Concentrates Market and Prospects for Increased Sorghum and Millet Utilization in Tanzania" at the Sorghum Food Enterprise and Technology Development in Southern Africa Workshop, Golfview Hotel, Lusaka, Zambia, December 6-9, 2010.

As population and incomes grow, the demand for livestock products (such as meat, milk and eggs) will grow (Figure 1). Egg production had the highest average rate of annual increase (24.9%) over the last ten years; milk production had the second highest average rate of annual increase (10.3%); Pig production had an average growth rate of 6.8%; and chicken meat production had an average annual rate of growth of 6.4%. Beef and lamb production are last with average growth rates of 3.2% and 1.7%, respectively. As a consequence, the demand for animal feed is expected to increase at an annual rate of 10 percent or more in the future.

Examine the Value Chain for Sorghum-Based Clear Beer

Jeremia Makindara, a faculty member and PhD candidate at SUA has been conducting the sorghum-based clear beer supply chain analysis. The objective of the study was to assess the emerging market for the sorghum-based clear beer as a new market opportunity for small holder sorghum producers. Interviews with farm households (107), traders (60), transporters (60), distributors and warehouse owners in the Arusha region have been completed. He expects to complete his PhD dissertation on this study by the end of this year or early next year.

Specifically, the study assessed the potential actors in the sorghum based clear beer value chain; determined value chain success factors; assessed the influence of consumers and farmers on the value chain; simulated sorghum beer demand and assessed distribution dynamics among the players in the value chain.

The findings show that both small holders in Singida Rural and commercial farmers in Simanjiro are the main suppliers of sorghum in the chain. These suppliers are linked with Tanzania Breweries Limited (TBL) through sub-contracted traders and contracted commercial farmers. TBL receives sorghum and stores sorghum at a National Milling storage facility in Arusha. TBL then produces sorghum based clear beer (Eagle) and distributes to consumers in Arusha and the Kilimanjaro region. The value chain success factor indices developed were 46 percent for traders; 44 percent for transporters and 58 percent for warehouse operators. This results show that the potential for developing a sustainable sorghum based clear beer value chain is much better under the current sorghum storage system than for the traditional trading and transportation systems.

In general, sorghum is produced on small plots of land, with recycled seed and with minimal use of fertilizers. The yields for these small holders are very low; 370 to 880 kg per hectare due to pests and diseases, unavailability of inputs, erratic rainfall, birds, lower prices, lack of marketing information and other supporting services. However, gross margin results of 34 percent provide hope for establishing a profitable sorghum value chain in the two districts. Production costs, farm location, interaction between production costs and farm gate price as well as the interaction between the varieties used and fertilizer applied are statistically significant in influencing sorghum farmers' profitability. The interaction of farmers, transporters and consumers all influence value chain competitiveness.

Young people between 19 to 31 years are the demographic group that prefers sorghum based clear beer due to the reasonable price and taste. However, most consumers shifted to Eagle beer from other TBL brands, and that according to the manufacturer's marketing strategy poses a challenge.

The findings show that return on sales are higher for farmers than transporters or traders. However, return on assets is higher for traders than for farmers or transporters. Despite the challenges faced, value chain development potential is there. Therefore it is recommended that the challenges can be addressed by involving the government, private people and researchers in developing a sustainable and a profitable value chain. The public sector role would be to provide knowledge and perhaps credit to farmers so that they could adopt production enhancing technologies.

Continue the Collection of Information on Price Variability

One of the ongoing activities for the project is data collection in Singida and Dodoma regions for analyzing seasonal variability of sorghum and millet prices over the entire project period. Using the data collection protocol, the Tanzanian collaborators have sub-contracted two local staff (one in each region) to accomplish the following tasks:

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

Methodology

The local contact persons in Dodoma and Singida regions, supported by the Tanzanian collaborators in Department of Agricultural Economics and Agribusiness (SUA), were responsible for data collection in their respective regions. The data are collected twice every week and entered into a standard form that has been translated into Swahili. The local contacts were instructed on how to complete the form. Completed forms are collected at the end of each contract period. Figure 2 presents a preliminary analysis of the sorghum data collected from Singida during the period July 2008 to December 2009. A similar analysis will be conducted for all data collected in Dodoma and Singida.

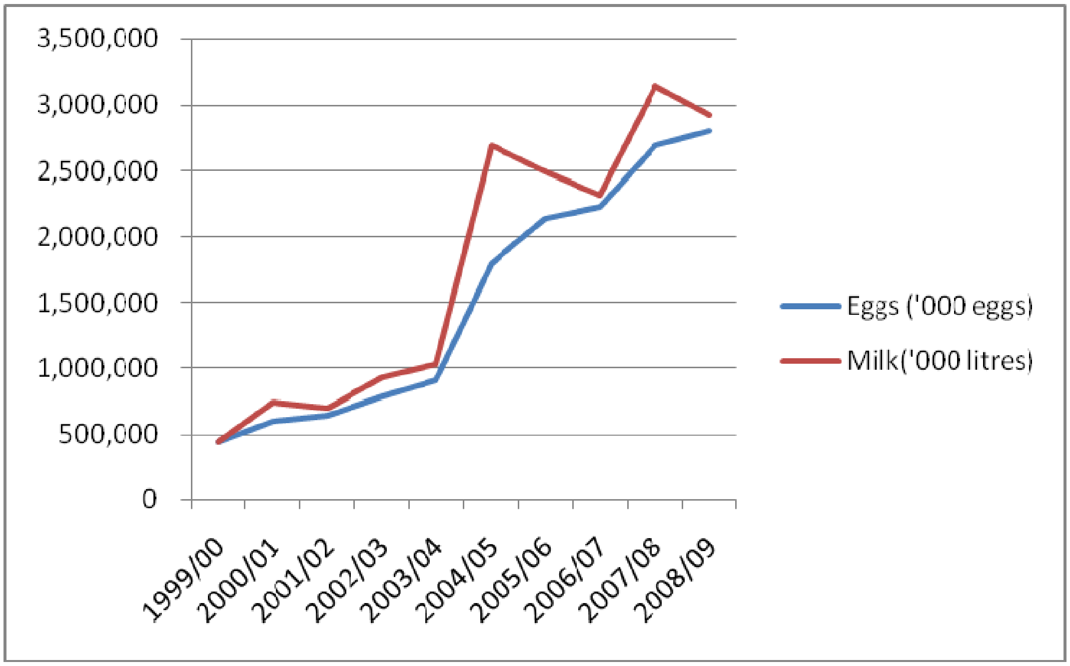
Calculation of Seasonal Indices

The 12-month cantered moving average approach was used to calculate a seasonal index for each month of the time series and was calculated as:

$$SI_{tm} = P_{tm} / CMA_{tm}$$

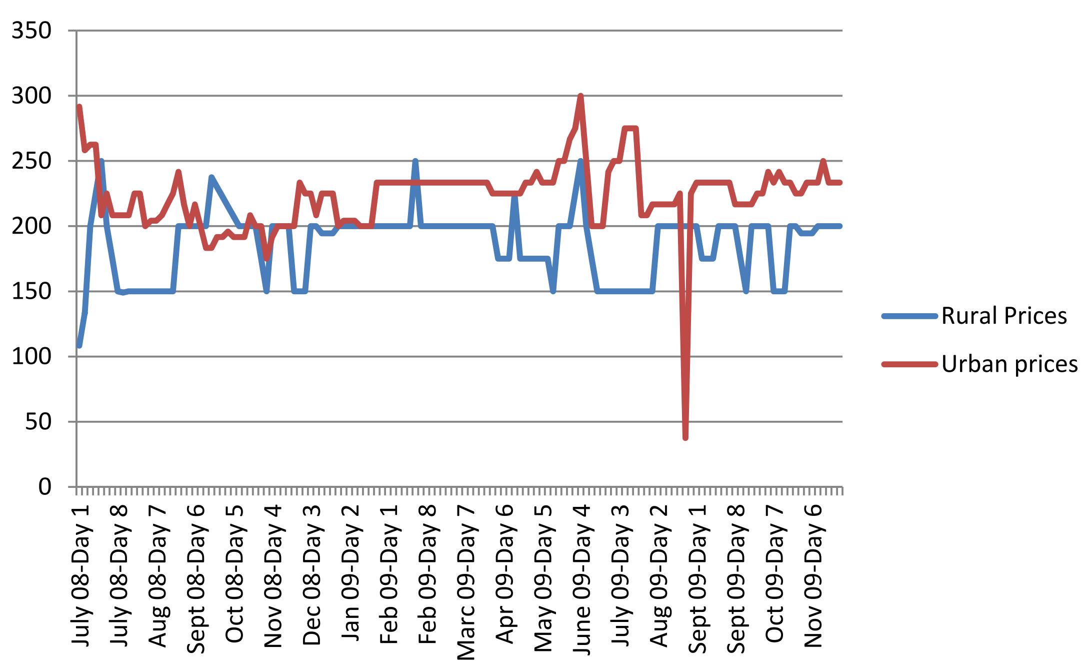
where is the Seasonal Index for time t in month m, Ptm is the

Figure 1. Egg and Milk Production in Tanzania 1999-2009



Source: SUA-OSU: Feed Concentrate study

Figure 2. Sorghum Price in Rural and Urban Markets of Singida, Tanzania (Tsch/kg.)



price observed during the same month and period, and C*MAtm* are the 12 month centered moving average of P*tm*. This index shows the percentage by which data observed during the reference period *(t),* lies above or below the prices of the surrounding 12 months. To determine such percentage the average season index for each month (SI_m) was calculated as:

$$SI_m = \sum_{i=1}^{n} SI_{tm} / n$$

where n is the number of observations in month m. The SI_m shows the average amount by which prices during any given month lie above or below their surrounding prices and is adopted as a measure of seasonality. A graphical representation of these values reflects seasonal patterns that are technically known as the Grand Seasonal Indices (GSIs).

A final step was to calculate the standard deviation of each monthly value in the GSIs (SD*m*). Examination of these standard deviations in conjunction with the GSIs allows one to make inferences about price variation over time. A rule of thumb in interpreting GSI values is to conclude that a fairly robust seasonal high is reached whenever $(SI_m - SD_m) \geq 1$ or when the GSI value is at least one standard deviation above a value of 1.0. This rule suggests that a robust seasonal low is reached whenever $(SI_m + SD_m) \leq 1$ or when the GSI values are at least one standard deviation below a value of 1.0.

Results and Discussion

According to Figure 1 sorghum prices in the rural market of Singida (Mtamaa) are lower than those in the urban central market in Singida. Under normal circumstance one would expect this price difference to exist as the supply of agricultural crops is always high where such crops are produced and they become expensive when transport costs are incurred to move these crops to urban centers.

With respect to price variability results show that sorghum prices in urban areas attain high levels in October-December and January-March. This trend conforms to the expectation that agricultural prices tend to be high during the post-harvest season (after June-July). However it is difficult to detect periods when sorghum prices attain the lowest levels.

Initiate an intervention to improve market linkage between smallholder sorghum farmers and processors

In places where market infrastructure is poorly developed and support services are not available the problem of asymmetric information can affect technology adoption, productivity, and product quality. In the agricultural sector this asymmetry can result in suppliers and buyers being ill-informed about the value chain needs of each other.

There is a need to harness the potential of improved varieties of sorghum for improving productivity, food security and income levels among smallholder farmers in semi-arid areas. This potential can be realized through improved coordination of activities among the major stakeholders, especially between grower groups, processors and consumers. Economic literature suggests that groups organized around people who share common social, economic backgrounds, goals, objectives and interest have been instrumental in enhancing value chain coordination (Mazzacco, 1996).

Thus, this project aims to strengthen market linkages between sorghum farmers and processors.

Project Objectives

- To strengthen coordination/linkages between farmers (associations) and processors in the sorghum value chain;
- Identify and define roles and activities of groups participating in the value chain including researchers from Sokoine University of Agriculture (SUA), extension agents and sorghum farmers and processors and;
- Identity strategies to promote the development and marketing of sorghum-based products.

Project Activities

- Identify sorghum processors using the following criteria: capable of buying sorghum from groups, proximity to farmers, processing capacity, and willingness to contract farmers to supply sorghum;
- Identify farmer groups (associations) capable of meeting quantity and quality requirements from one of the priority regions (Arusha, Dodoma or Singida);
- Implement partners meetings to enhance value chain linkages;
- Provide technical support to farmers and processors;

Selected Project Results

- Many processors in the two regions are small scale processors processing between 50-100 kg of sorghum per week and they mainly sell packaged flour in local markets as blends of sorghum and other grains.
- Processors buy sorghum grain from retailers within regional and nearby markets and occasionally from specific people trusted to supply high quality grain.
- There were no formal contracts between sellers (farmers and traders) and processors.
- Some of the processors operated in groups and were partially supported in terms of machinery and acquisition of processing knowledge. Success stories about these initiatives varied across groups as problems such as failures to get along, mismanagement of resources and shirking/irresponsibility were reported in some groups.
- For the majority, processing was a part-time activity as they were engaged in many other activities as business people other than processing or employees in government and private sectors.
- Many of the farmers operated individually except in Singida where there were about 4 farmers groups that focused on quality improvement and other collective actions.
- Processors indicated that it was difficult for them to get consistent and adequate amounts of sorghum with desired quality from farmers. Although it was possible to get sufficient amount of sorghum in the wholesale and retail markets, the

quality was equally poor or worse.

- Farmers were pessimistic whether buyers, including processors, would be willing to reward quality.

These preliminary findings support the view that buyers and processors are normally suspicious of the abilities and intentions of each other. A meeting involving farmers, processors and other relevant actors was organized on 23rd September, 2011 to facilitate dialogue so that actors can forge a common understanding of the problem and identify means to address it. The findings show that there is limited prospect for medium or large scale processing. Unless there is a substantial increase in sorghum production, it is unlikely that small scale farmers can meet the quantity demands of large scale processors.

Research Results: Zambia

In Zambia, the project activities for September 30, 2010 to September 29, 2011 were to: (1) complete a study of improved seed value chain, (2) complete a study of clear beer value chain, (3) analyze farm household interviews from Luansha, a high potential area, (4) continue the collection of information on monthly price variability, and (5) Bernadette Chimai from Zambia completed M.S. study in agricultural economics at The OSU in June 2011.

Complete study of improved seed value chain. This paper reports the results of the sorghum and millet seed value chain study. Its main objective was to understand the different actors in the chains, and to identify factors that determine the observed low level of technology used. Information from 130 farming households, 57 seed dealers, five seed companies, and two research and development institutions was collected with the view to understand their characteristics, key roles, competitiveness, and constraints with respect to the improved seed value chain. Most seed value chain actors play multiple roles, ranging from varietal development, inspection and certification, seed production, processing, marketing, and provision of extension services. Results of this study were presented in a paper titled "Sorghum and Pearl Millet Seed Value Chains in Zambia: Opportunities and Challenges for Smallholder Farmers" at the Sorghum Food Enterprise and Technology Development workshop in Lusaka, December 6-9, 2010.

This study found that adoption of improved seed and fertilizer is very low among sorghum and millet growers and relatively low for maize growers. Growers are using the same sorghum and millet seed for an average of 13.7 years when the recommended replacement rate by researchers is about three years. Research station yields for sorghum open pollinated varieties (OPVs) range from 3 to 5 tons per hectare in contrast to a mean sorghum yield of 0.3 tons per hectare on farmers' fields. The farm yield is less than 10 percent of the research station yield. The gap between research station yields and farm yields is very large. Public institutions lack documentation of improved production practices by sorghum and millet growers. The responsible institutions should make it a priority to collect data of improved practices along with other data so as to understand current practices so as to make concrete recommendations for improving farm productivity.

There are a number of key actors in the seed value chains for maize, sorghum and millet. They include public sector agencies such as ZARI, SCCI, UNZA, and the Ministry of Agriculture and Cooperatives who play key roles in varietal development, inspection and certification, and in providing extension services. From the private sector, there are five seed companies who mainly deal in maize hybrid seed even though sorghum and millet are also sold by three of the private companies. Most of these companies perform multiple functions which include varietal development, seed production, seed processing and distribution. Farmers' organizations, NGOs and faith based organizations work in close collaboration with the government departments and seed companies in seed distribution and extension services. The most important seed end users are small scale farmers who have a subsistence orientation. Access to organizations that support agricultural development was rated poor by these farmers. They mentioned poor access to agricultural information, modern inputs, including poor quality seed, lack of processing technologies and lack of stable markets.

One huge constraint faced in sorghum and millet production was lack of seed company access to breeder seed/ foundation seed. As mentioned earlier, improved sorghum and millet varieties available on the market were released by the government in collaboration with ICRISAT. Zamseed was given exclusive rights to market the varieties when it was still a parastatal company. Upon privatization, Zamseed was given ownership of breeding material by the government for a limited number of years. Twenty years later, Zamseed still had exclusive rights to breeder material for government developed sorghum and millet varieties. The social cost of the intellectual property rights issue to sorghum and millet growers in terms of lost opportunities to buy more productive varieties has been very high. Today, over 20 years later, seed companies are free to market any new sorghum and millet varieties that are released by public research.

Improved Seed Value Chain Recommendations

That use of improved seed among end users is low represents a major constraint to private sector participation in developing new improved varieties in sorghum and millet. Extension messages are necessary to stress the importance of a higher seed replacement rate compared to the current practice. There is also a need to develop varieties that match farmers' needs. This would contribute to increased demand for improved seed and improve prospects for private sector participation. There is also need to develop an agribusiness extension package for sorghum, including sources of credit. Finally, there is need to teach farmers and traders better business skills; provide feeder roads and marketing infrastructure; build storage facilities and link farmers to finance, out grower schemes, and markets.

When maize subsidies reached their peak in the late 1980s, the area under maize cultivation was about 1 million hectares, accounting for 70 percent of the total area cropped in Zambia. This high percentage of area cropped in maize indicates a near monoculture agriculture that is very dependent on one crop and an agriculture in need of more crop diversity to lower risk of crop failure. Given, sorghum and millet's important role in food security, there is a need to reduce or eliminate direct subsidies to maize production which competes with sorghum and millet production. Alternatively crop subsidy policy should consider providing equal subsidies for maize, sorghum and millet production.

Sorghum-based clear beer supply chain study. Bernadette Chimai and Gelson Tembo presented a paper titled "Sorghum Clear Beer Value Chain" at the Sorghum Food Enterprise and Technology Development in Southern Africa Workshop, Golf view Hotel, Lusaka, Zambia, December 6-9, 2010. Selected results are as follows. Zambian Breweries (ZB) introduced sorghum based Eagle Lager clear beer to the Zambian market in 2005. Eagle lager enjoys 15-17 percent clear beer market share and is reportedly growing at 5-10 percent per annum. The key players in this value added chain are sorghum farmers, traders, brewers, distributors and retailers. ZB started out by contracting 2,500 small scale sorghum farmers in the 2004/2005 agricultural season. Currently, Zambian Breweries (ZB) gets all of its sorghum supplies from a local commodity broker, CHC commodities. CHC purchases sorghum from small scale farmers, small traders and large scale farmers. Prices were K 960,000 to K 1,125,000 per metric ton in 2004/05. The sorghum collection point for CHC Commodities was based in Kabwe District, Central Province. During the 2005/2006 marketing season, the broker purchased 2,900 metric tons of sorghum. Most retail outlets sell at recommended prices of K 2,500 and K 3,000 for the 300mls and 375mls bottle respectively. Eagle beer has provided employment and business opportunities to the distributors and their employees. Retailers are now able to increase the variety of beer products being offered to their customers. Consumers are offered a clear beer at a lower price than that of other clear beers. The introduction of Eagle lager has benefited all the stakeholders involved in the value chain. It has provided sorghum farmers with a ready market for their produce and has ensured a reliable reasonably priced sorghum supply to Zambian Breweries.

Luanshya study of sorghum and millet farmers' efficiency. A survey of sorghum and millet farmers in a high potential area was conducted in two blocks of Luanshya district north of Lusaka. Luanshya was expected to be 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. In the Luanshya survey, 169 households were visited and interviewed. The results show low input use, low output, and little use of recommended management practices in the 2007/08 agricultural season. The area planted to sorghum (0.47ha) is low as well as the sorghum yield (643 kg/ha) and quantity harvested (258 kg) harvested. The percent of households using improved seed was very low (9%) and the use of many recommended management practices was low.

Chimai analyzed the Luansha data set for her M.S. thesis research. Selected results of the determinants of technical efficiency in smallholder sorghum farming are presented here. This study measured technical efficiency and its determinants in sorghum production, technical efficiency in field crop production and the effect of growing sorghum on technical efficiency in field crop production. Technical efficiency in sorghum production is low at only 34 percent, on average. This is a much lower efficiency than for other crops based on studies done for maize (46 percent in Malawi) and cowpeas (87 percent in Nigeria). Most of the Luansha households were less than 50 percent efficient.

The low efficiency means most farmers perform poorly relative to more efficient farmers. The low efficiency presents opportunities for improvements in sorghum production which could result in improved productivity of all resources, higher yields, an increase sorghum produced, and higher incomes. The results suggest that most sorghum producers could nearly double productivity and incomes with improved use of technology and management practices.

Technical efficiency in sorghum production is affected by a number of household and farm characteristics. Access to credit, presence of dependents, scale of field crop production, value of assets and income from livestock activities improve technical efficiency. On the other hand, household size, use of animal draught power, farm size and location in low rain areas reduce efficiency. Some of the factors are outside the farmers' control and cannot be altered to influence efficiency. These include household size, number of dependents and location. However, understanding the way they influence efficiency can be useful in identifying households who are most likely to be technically inefficient in sorghum production due to the interaction of these factors in their environment. Means of cushioning or mitigating the negative effects of these factors can then be identified. If factors that are out of the farmers control have a positive influence on efficiency, these traits can be exploited to improve productivity further. Controllable factors include crop and field management practices like use of animal draught power are easier to manipulate in favor of technical efficiency. Sorghum production efforts directed at increasing accessibility to agricultural loans could have the potential to increase the efficiency of sorghum production, and productivity in the country. This study also revealed differences in household and farm characteristics between sorghum and non sorghum farmers. Generally, sorghum farmers are poorer with lower incomes and assets. Non sorghum farmers have traits identified as having the potential to increase efficiency in sorghum production. If these farmers could be encouraged to grow sorghum, productivity in sorghum production could be increased in the country. This requires an understanding of the factors underlying a farmer's decision to grow sorghum or not. Further research into the farmer's crop choice decision making process would highlight these factors and guide policy and stakeholders in the promotion of sorghum production.

A journal article based on the study is being developed.

Price Variability Study

Data collection has been completed. Monthly historical data was collected 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. Bernadette Chimai, a recent UNZA graduate in agricultural economics, completed her MS Studies at The OSU in June 2011.

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, Gebisa 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).

Presentations

J. Mark Erbaugh, Donald W. Larson, Charles Wortman, Gabriel Elepu, Kaizzi Kayuki (2011) "Expansion of Sorghum Production Technology Transfer in Eastern and Northern Uganda." Paper presented at the INTSORMIL Principal Investigator Meeting in Lincoln, Nebraska, May 11-12.

J. Mark Erbaugh, Salome Maseki, Fredy Kilima and Donald Larson, (2011) "Constraints on the Adoption of Improved Sorghum Seed in Tanzania: A Value Chain Approach." Paper presented at the 27th Annual conference of the Association of International Agriculture and Extension Education (AIAEE), July 5 – 7, Windhoek, Namibia.

J. Mark Erbaugh, Emmanuel R. Mbiha, Fredy T.M. Kilima, Precious Hamukwala , Gelson Tembo , and Donald W. Larson. (2010) "Market Development in Support of Sorghum and Millet Farmers in Tanzania and Zambia" Presented at the Sorghum Food Enterprise and Technology Development in Southern Africa Workshop, Golfview Hotel, Lusaka, Zambia, December 6-9.

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Publications

J. R. Makindara, J. P. Hella, J. M. Erbaugh and D. W. Larson (2011) "Consumer Preferences and Market Potential for Sorghum Based Clear Beer in Tanzania." Journal of Brewing and Distilling. Vol. 2(3) pp. xxx-xxx, October. Available online http://www.academicjournals.org/JBD.

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J. R. Makindara, J. P. Hella, J. M. Erbaugh and D. W. Larson (2011) "Profitability Analysis of Sorghum Farming: The Case of Singida and Simanjiro Districts, Tanzania." Paper accepted by the Journal of Agricultural Economics and Development (JAED). Sokoine University of Agriculture, Morogoro, Tanzania.

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

Project PRF 102

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Introduction and Justification

This project aims to expand markets in West Africa for sorghum and millet through fundamental work on ways to improve grain utilization, identification of health attributes that could be used in market promotion, and dissemination through the mechanism of "Incubation Centers" we have established in Niger and Mali, and strengthened in Senegal. We work primarily through NARS scientists/technologists as well as one university (Nigeria). Much of our focus in West Africa has been towards entrepreneur processors and ways of improving their processing technologies, training, and technical support as they work to make their businesses more competitive. This ongoing effort began in Niger in the late 1990's with establishment of an Incubation Center to introduce mechanized technologies for producing high quality milled products and agglomerated foods, such as couscous. Current activities in Niger include being an advisor to a McKnight Foundation project in processing with PI M. Moussa. In Mali, with funding through the USAID/Mali Production-Marketing project, we have mechanized six entrepreneur processors in the Mopti/Gao region and have recently launched a technology-based Incubation Center at IER-LTA/Sotuba to work with Bamako area entrepreneurs. We also work from the Incubation Center with a USAID implementing NGO, IICEM, to show the local commercial bakers the potential for high-quality sorghum flour composite breads. We continue work with A. N'Doye, Director General at Institut de Technologie Alimentaire in Dakar, to assist in development of a new, more cost efficient mechanized couscous process and market-testing. At University of Maiduguri, Nigeria, this project funds a doctoral student from Mali, M. Diarra, to work with collaborator Prof. I. Nkama. At Purdue, we continue to work on working on high digestibility/high-lysine (HDHL) sorghum, that has uniquely freed proteins from protein body structures, with the aim of making its proteins participate with wheat gluten in dough formation of sorghum:wheat composite flours. This last year we showed proteins in HDHL sorghum to improve dough and bread properties compared to normal sorghum. In Bamako, student F. Cisse showed that traditional sorghum and millet foods (couscous and thick porridges) have significantly slower gastric emptying than non-traditional foods (rice, potato, pasta) that is associated with extended energy release to the body. This health attribute of sorghum and millet foods potentially might be used in promotion of these grains in urban centers.

Objectives and Implementation Sites

The main goal of this project is to expand sorghum and millet markets through improving or developing new sorghum and millet-based products, activities geared to assist entrepreneurs to process and sell market competitive products to urban consumers, and to identify nutritional aspects of products that can be used for their promotion. Collaborations are with Ababacar N'Doye, Director General at ITA, Dakar, Senegal; Yara Kouressi and Mamarou Diourte at IER, Sotuba (Bamako), Mali; Boniface Bougouma at IRSAT, Ouagadougou, Burkina Faso; Moustapha Moussa and Kaka Saley at INRAN, Niamey, Niger; and Prof. Iro Nkama at the University of Maiduguri, Maidurguri, Nigeria.

Specific Objectives

- Work with collaborators to facilitate successful processing enterprises in the West Africa Sahel. Through the Production-Marketing project funded by USAID/Mali, introduce new appropriate technologies and training in the Mopti and Gao region of northern Mali, and in the Bamako region through establishment of an Incubation Center at IER/Sotuba

(Bamako) to bring new technologies and training to urban entrepreneurs in enhancing millet and/or sorghum processing units. In Senegal, to collaborate with ITA to facilitate their new couscous processing technology with packaging and market testing activities. In Niger, expand processing facilities at INRAN and, using our incubation model, to help entrepreneurs gain expertise and funding to start their own enterprises. In Nigeria, to work collaboratively with I. Nkama at University of Maiduguri to facilitate training of women's groups to process millet products.

- Continue investigation to enhance viscoelastic properties of sorghum grain protein for high incorporation of sorghum (high digestibility/high lysine mutant lines) into baked sorghum:wheat composite products (mainly bread).
- Explore "healthy" attributes of sorghum and millet foods that, through studies and documentation, could be used to promote the grains in urban markets. Understand the role of sorghum and millet-based thick porridges in providing extended satiety and energy levels to consumers.
- Support breeding efforts on Purdue's high digestibility/high-lysine sorghum grain to improve grain quality (with G. Ejeta).
- Train two West African 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 (Malian, Fatima Cisse at Purdue).

Research Methodology and Strategy

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 launched in 2008 (team consisting of consultant Mamadou Diouf of ITA/Dakar (retired), Y. Koureissi of IER/Mali, B. Hamaker). Seven entrepreneur units in the Mopti/Gao region have been mechanized with decortication and milling equipment and personnel trained to process a range of primary milled products. Structures were funded and built to specifications by entrepreneurs. In the Bamako area at IER/Sotuba, an Incubator Center has been constructed and formally launched for purposes of technology and processing refinement, training, and use by entrepreneurs for market testing of products. A number of primary and secondary processing equipments and training techniques bring new and appropriate cereal processing technologies to Mali. Surveys and satiety studies are showing potential health value of traditional sorghum and millet foods that might be used in promotion activities to expand markets for the grains. Future activities will further assist entrepreneurs with 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 2012.

Senegal: Collaborative work has recently been on the development and market testing of a new technology developed by ITA to process couscous directly from semolina grits. Our final activities for the current project term is to introduce a new technology for low-cost pregelatinized "instant" thin and thick porridges. Project beginning date – October 2007, ending date – September 2012.

Niger: In the previous project period, we developed an Incubation Center at INRAN/Niamey for local entrepreneurs to be trained and use to test the marketplace and begin to grow consumer sales. The processed product focus was on primary milled and secondary agglomerated products for urban markets. The unit is still active with Niamey entrepreneur processors, as part of a processor association developed at the time of the Center's inception, and has been successful in assisting units to obtain loans for building successful private processing units. This project continues to support and expand this concept and B. Hamaker acts in an advisory role for a complementary project at INRAN funded by the McKnight Foundation. M. Moussa obtained his M.S. from Purdue in May 2007 and returned to Niger to become a scientist at INRAN and implements this project. Project beginning date – October 2007, ending date – September 2012.

Nigeria: Doctoral student, M. Diarra from IER/Mali, is funded through the project and he studies millet processing with collaborator I. Nkama at the University of Maiduguri. M. Diarra conducted a survey and satiety study on Malian thick porridges in 2010 and has trained in rheological techniques to complement the study at Purdue in 2011. Thesis research includes study of thick porridges, processing techniques, and their nutritional role. Project beginning date – October 2007, ending date – September 2012.

Burkina Faso: Collaboration with B. Bougouma focuses primarily on storability and commercialization of millet dolo beer. Millet varietal differences suitable for processes is examined, as well as technology development and training of entrepreneurs. This work is funded through the regional West Africa program. Project beginning date – October 2007, ending date – September 2012.

U.S.: 1) We have investigated ways to make sorghum grain storage proteins viscoelastic so that sorghum (and perhaps millet) flour can be incorporated into composite flours at high levels to increase markets for local grain. The project has partially funded a M.S. student (M. Goodall) at Purdue who will finish in May 2012. This and complementary research funded by a USDA AFRI grant are on improving non-wheat cereal storage protein functionality. Project beginning date – October 2007, ending date – September 2012. 2) Studies on the role of thick porridges of differing consistencies in providing a satiety response and delaying energy release. Graduate student Fatima Cisse from Mali. Project beginning date –August 2010, ending date – September 2012. 3) Continue to work with G. Ejeta toward further improving grain quality of high protein digestibility/high-lysine (and possibly wheat-like property) sorghum. Project beginning date – October 2007, ending date – September 2012.

Research Results

Activities towards expanding markets for sorghum and millet in Mali in Senegal, Burkina Faso, Niger, and Nigeria aimed to increase farmer's incomes

In 2011, the new Incubation Center at IER/Sotuba in Mali became active. In collaboration with A. N'Doye (ITA/Senegal), M. Moussa (INRAN/Niger), and Y. Kouressi (IER/Mali), we have over the last decade developed an "incubation center" concept relevant to the needs of local urban entrepreneurs. The purpose is to facilitate competitive cereal processing enterprises to expand urban markets for sorghum and millet, and with other projects such as J. Sanders Production-Marketing project in Mali to link to farmers. These Centers not only have a training role, but are designed to allow qualified entrepreneurs access to a processing line to produce high quality product and test the market. In Niger, up to 10 entrepreneur processing groups have used the Center at one time, and produce quality milled flours and grits, and pre-cooked agglomerated products such as couscous. Financing has been obtained by a few processors to mechanize their own units and, as they improve their technologies, they are given technical support from the Center to increase their chances of success.

In Mali, through the Mali Mission USAID-funded Production-Marketing project, an incubation facility was expanded in size and potential and began operation in the spring of 2011. As in Niger, its current focus is on high quality primary product processing, flours and grits, and pre-cooked agglomerated products. Agglomerated product processing technology developed at ITA/Senegal was purchased through a fabricator in Senegal and installed at the Center that is comparably low cost for an entrepreneur to use. A project has been initiated with the local USAID implementing group, IICEM, on providing high quality flours for the local baking industry to show that when quality grain is used, and careful decorticating and milling is employed, high quality sorghum flour can be successfully incorporated into baked products without a reduction to their quality. If accepted, then local processors will be trained to supply commercial high quality flours.

In northern Mali, in the Mopti and Gao regions, we continue to work through the Mali Mission USAID-funded Production-Marketing project with seven entrepreneur processors with the goal of mechanizing and increasing their competitiveness. All units have been mechanized and processing and business training completed. Plans are to introduce the next level of processing technologies.

In Senegal, collaborative work with A. N'Doye, Director General of ITA, has focused on assisting them in a new technology they developed for a more economical couscous process. Equipment was fabricated and in 2011 a market test was done showing its high acceptability. A local processor is in discussion to use this technology to produce commercial millet and maize couscous.

Potential Health Aspects of Traditional Sorghum and Millet Foods of Mali

A different strategy to increase markets for sorghum and millet in urban areas is to understand whether there are some inherent qualities of these grains that could make them preferred by consumers over imported cereals and tubers. In this regard, we have over the last 2 years been investigating how the delivery of energy from traditional sorghum and millet foods, such as thin and thick porridges and couscous, compares to typically non-traditional foods consumed in urban centers, such as rice, potatoes, and pasta. "Energy delivery" relates to how fast the stomach empties its contents following consumption of a meal. The human body has an intricate system of detecting macronutrient digestion and changes stomach (or gastric) emptying time to accommodate fast or slow digesting foods. Some foods naturally take a long time to be emptied by the stomach and, therefore, delivery energy over an extended period of time that could be beneficial both for improved post-meal consumption length of activity and satiety. Another impetus for this study are the anecdotal reports rural people consuming certain foods, including thick porridges, for their extended energy and satiating properties.

Last year, we reported survey and satiety questionnaire responses showing that Malian villagers prefer thicker porridges than city dwellers and that these porridges have greater satiety effect at 2 and 4 hours post-consumption. In 2011, Purdue MS student Fatima Cisse compared gastric emptying time and satiety effect of traditional sorghum and millet foods (thin and thick porridges, and millet couscous) and foods that have replaced these in urban centers (rice, potatoes, and pasta). Gastric emptying was determined using a standardized non-invasive and safe 13C-breath test that measures the emptying time the stomach contents after a meal is consumed. All procedures were approved by ethical boards in Mali and at Purdue University. Results showed that the traditional Malian porridges and agglomerated foods (couscous was used in this study) had significantly lower gastric emptying compared to boiled rice, potatoes, and pasta (Figure 1 and 2). Accordingly, the Malian traditional foods studied provide energy over a quite extended length of time, perhaps explaining why rural farmers typically choose to consume thick porridges.

There is a significant diet-related health problem occurring in African cities of obesity and associated metabolic syndrome problems of diabetes and cardiovascular disease. Our study shows that the traditional thin and thick porridges, as well as agglomerated foods like couscous, have an extended energy property that goes along with low glycemic index (and indicator of 2 hours post-prandial blood sugar rise). Additional initial data on satiety millet couscous and the thicker porridges supports a view that these are healthy foods. The data suggests that a promotion campaign could be made to encourage urban dwellers to consume more sorghum or millet traditional foods as good for the health and to provide extended energy and satiety effect. This would significantly increase markets for sorghum and millet in urban areas, and could at the same time have a positive public health benefit. Further studies are probably warranted to examine whether their consumption is inversely correlated to metabolic syndrome diseases.

Sorghum/Wheat Composite Bread

Work continued on trying to make the sorghum grain storage proteins, kafirins, viscoelastic similar to wheat gluten for the purpose of increasing the amount of sorghum flour that can be incorporated into wheat:sorghum composite breads and other baked products. Currently, high quality sorghum flours (fine, near white flours) can be incorporated at around 20% with baked products of similar quality as with 100% wheat. In this project, we work with high digestibility/high-lysine (HDHL) sorghum developed at Purdue University through the INTSORMIL program. The unique feature that this grain has, in respect to the kafirin proteins, a breakdown of the rigid protein body structure so that the kafirins are free to interact with other proteins in a dough system. Last year, we reported that the HDHL sorghum kafirins can be made, in fact, functional in dough to increase viscoelastic properties.

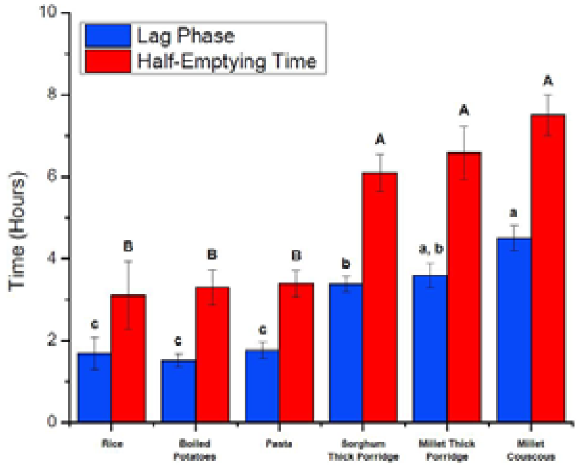

Figure 1. Indicators of gastric emptying time for three traditional sorghum and millet foods (thick porridge and *couscous*) and three non-traditional foods consumed in urban areas (rice, boiled potatoes, pasta). "Half-emptying time" is the measurement in time of release of one-half of the stomach contents into the small intestine. The data shows that traditional sorghum and millet foods provide extended energy release and longer retention of food in the stomach that may be related to satiety.

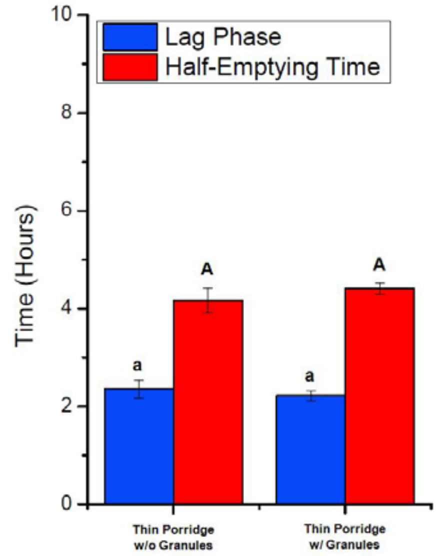

Figure 2. Indicators of gastric emptying time for millet thin porridges with and without the addition of the popular (in Mali) *moni curu* granules. There was no difference between the thin porridge with and without the granules; half-emptying time was in-between the traditional sorghum and millet thick porridges and *couscous*, and the non-traditional rice, boiled potatoes, and pasta as shown in Figure 1.

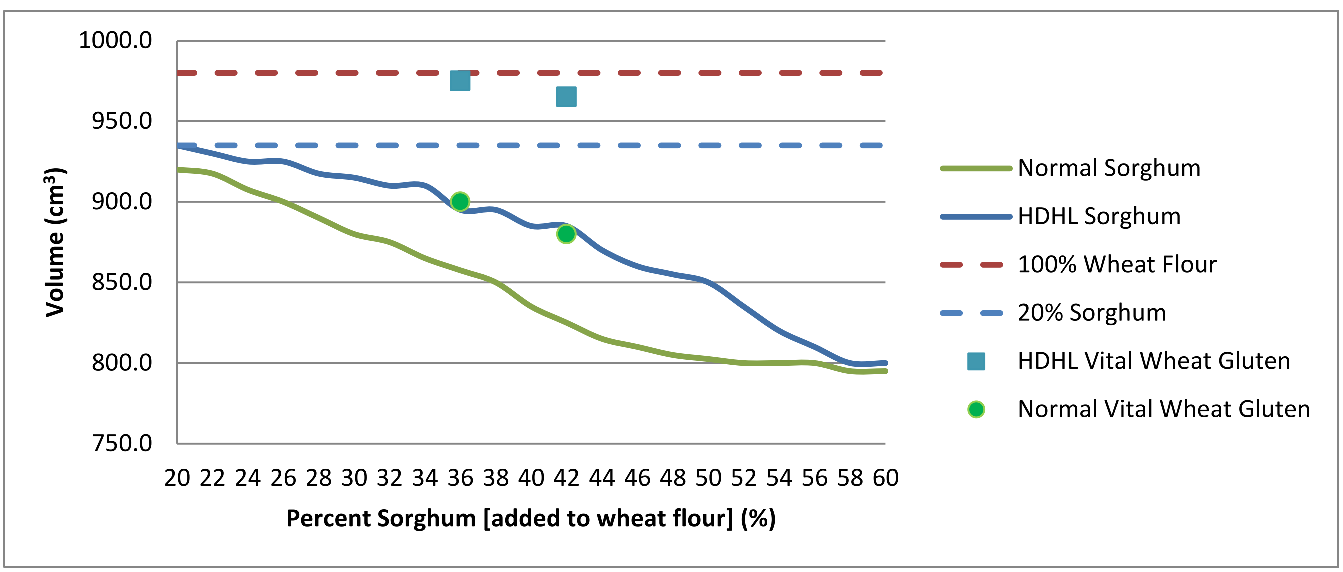

Figure 3. Bread loaf volume with increasing amount of normal and HDHL (with available kafirin proteins) sorghum substitution. The blue square and green circle represent when 10% vital wheat gluten was added at 36 and 42% substitution. Loaf height was essentially the same as 100% wheat bread for the HDHL sorghum:wheat composite breads, while the improvement was much less in the normal sorghum:wheat composite breads.

Although dough properties were shown to improve notably in HDHL sorghum, the increase in bread volume, while significant in the the 30-50% substitution range compared to normal sorghum is still well below that of 100% wheat (Figure 3). That said, we know that, using flour made from high food quality sorghum can be incorporated at 20% and achieve parity in loaf volume with 100% wheat bread. Therefore, there is another factor or factors, such as polyphenolic compounds, that may be causing the lower loaf volume of the 20% sorghum:wheat composite bread. Apparently, the freed sorghum kafirin proteins are not able effectively to capture gas from yeast fermentation. Figure 3 shows that addition of 10% vital wheat gluten to the HDHL sorghum:wheat composite system dramatically improved loaf volume, while showing only a negligible improvement in the normal sorghum:wheat composite. Figure 4 shows loaf volumes of HDHL at 36 and 42% substitution rates as essentially the same as 100% wheat bread. Thus, the freed kafirin proteins of the HDHL sorghum have good ability to improve bread loaf quality. Perhaps the use of stronger wheat with the HDHL trait in an improved grain type would allow for this range of 35-45% incorporation with comparable loaf quality to 100% wheat bread.

Figure 4. From left to right: 100% wheat flour, 36% HDHL sorghum with 10% vital wheat gluten, 42% HDHL sorghum with 10% vital wheat gluten

Sorghum Dietary Fiber

The project provided partial support for a study on sorghum bran dietary fiber and, more specifically, its major fraction the arabinoxylans. We have a broader interest in understanding the action of different dietary fiber structures in the colon related to health benefits. Cereal arabinoxylans have a varied structure (arrangement and complexity of branches on a linear xylose linked backbone) depending on source and environment. Sorghum fiber arabinoxylans interestingly were found not only to have a quite different proposed consensus structure (Figure 5) from the other cereal arabinoxylans tested (corn, rice, and a specific wheat arabinoxylan fraction), but also a very different profile of the fermentation short chain fatty acid (SCFA) products of acetate, proprionate, and butyrate. Sorghum arabinoxylans produced much more butyrate which is viewed as a desirable SCFA related to its anti-inflammatory and other properties. This indicates that it is the food source for a different set of bacteria that product butyrate. Many of the "prebiotics" produce high levels of butyrate and this finding suggests that sorghum bran arabinoxylans may a desirable dietary fiber ingredient with health benefit. (Table 1)

Training

This project funds Mohamed Diarra from IER, Mali to attend the University of Maiduguri, Nigeria for his Ph.D. studies. Mohamed began his graduate program in January 2009 under advisement of Dr. Iro Nkama, INTSORMIL regional PI and B. Hamaker. B. Hamaker made a site visit in December 2009 for thesis research planning including a future training period at Purdue University. Fatima Cisse from IER, Mali is currently a M.S. student at Purdue on the thick porridge satiety study, as is Morgan Goodall who is a M.S. student on the protein functionality study.

Networking Activities

In 2011, B. Hamaker made three trips to West Africa related to work on the Production-Marketing project in Mali.

Publications and Presentations

Journal Articles

Moussa, M., Qin, X., Chen, L.F., Campanella, O.H., and Hamaker, B.R. 2011. High quality instant sorghum porridge flours for the West African market using continuous processor cooking. International Journal of Food Science and Technology. 46:2344-2350.

Kean, E.G., Bordenave, N., Ejeta, G., Hamaker, B.R., and Ferruzzi, M.G. 2011. Carotenoid bioaccessibility from whole grain and decorticated yellow endosperm sorghum porridge. Journal of Cereal Science 54:450-459.

Mejia, C.D., Gonzalez, D.C., Mauer, L.J., Campanella, O.H., Hamaker, B.R. Increasing and stabilizing *B*-sheet structure of maize zein causes improvement in its rheological properties. Journal of Agricultural and Food Chemistry, in press

Goodall, M.A., Campanella, O.H., Ejeta, G., and Hamaker, B.R. Grain of high digestible, high lysine (HDHL) sorghum contains kafirins which enhance the protein network of composite dough and bread. Journal of Cereal Science, In press.

Presentations

Goodall, M., Campanella, O., Ejeta, G., and Hamaker, B.R. 2011. High-digestibility, high-lysine (HDHL) sorghum grain contains kafirins which participate in the protein network of composite dough and bread. American Association of Cereal Chemists International annual meeting, Palm Springs, CA, October.

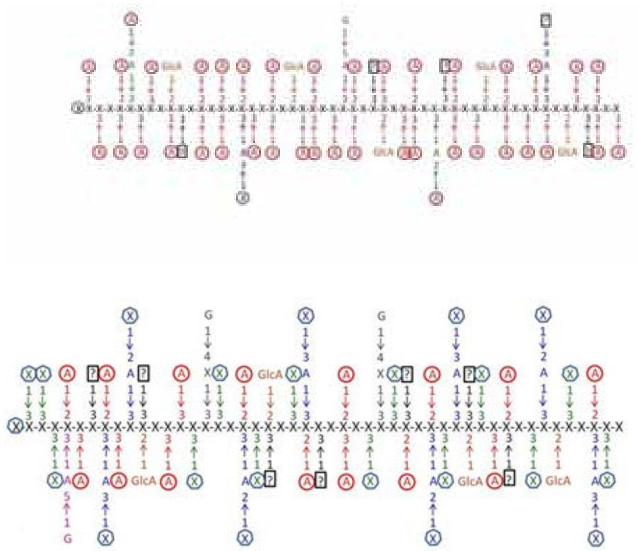

Figure 5. Schematic of the proposed consensus structures of the sugar moieties of alkali-soluble sorghum (top) and corn (bottom) arabinoxylans (bran dietary fiber). Abbreviations: A = arabinofuranose, X = xylopyranose, G = galactopyranose, GlcA = glucuronic acid, and ? = unidentified sugar.

Table 1. Short chain fatty acid production (µmol/100 mg carbohydrate) during *in vitro* fecal fermentation of commercial prebiotic and heteroxylan fractions from corn, wheat, rice, and sorghum bran*

SCFAs Time (h)	FOS**	CAX	CH	WH	RH	SAX
Acetate						
4	408.6^{C} (13.2)	253.7^{D} (38.0)	206.1^{E} (8.1)	125.2^{F} (2.4)	576.7^{A} (1.0)	513.8^{B} (8.1)
8	487.4^{D} (13.0)	561.3^{C} (13.1)	561.8^{C} (24.4)	298.7^{E} (2.6)	762.2^{A} (9.8)	627.6^{B} (11.6)
12	462.1^{D} (48.6)	579.8^{C} (3.7)	626.4^{B} (20.4)	610.2^{BC} (3.0)	769.4^{A} (0.8)	623.6^{B} (12.0)
24	518.4^{E} (4.1)	638.2^{D} (8.4)	665.6^{CD} (20.1)	733.5^{B} (13.9)	781.8^{A} (33.2)	680.0^{C} (8.2)
Propionate						
4	86.9^{A} (5.8)	0.0^{D} (16.3)	0.0^{D} (2.8)	28.6^{C} (3.4)	59.9^{B} (1.6)	38.5^{C} (2.3)
8	196.6^{B} (11.2)	144.2^{E} (7.7)	131.8^{E} (11.4)	162.1^{D} (3.5)	338.0^{A} (3.8)	178.0^{C} (3.5)
12	192.0^{C} (6.3)	374.9^{B} (12.3)	395.9^{B} (20.3)	380.7^{B} (8.7)	474.9^{A} (3.5)	388.5^{B} (6.7)
24	194.8^{B} (2.0)	440.7^{A} (17.5)	430.0^{A} (15.9)	439.6^{A} (5.4)	393.1^{A} (125.5)	416.9^{A} (3.2)
Butyrate						
4	171.7^{A} (4.0)	61.9^{D} (7.1)	55.1^{D} (1.0)	47.1^{E} (2.3)	102.5^{C} (0.3)	121.0^{B} (1.4)
8	167.7^{A} (4.7)	67.6^{D} (0.6)	57.7^{E} (3.7)	33.4^{F} (2.1)	103.1^{C} (1.2)	128.0^{B} (1.5)
12	164.4^{A} (3.3)	73.0^{D} (2.2)	70.3^{D} (2.1)	65.7^{E} (1.2)	104.7^{C} (0.4)	133.9^{B} (2.2)

*Means (standard error) within row with the different capital letter superscripts are significantly different (P<0.05).

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

Project PRF 103
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Introduction and Justification

Jeanne Coulibaly continued her research activities in Mali documenting with a farm model the effects of new sorghum technologies including a new cultivar, Grinkan, moderate fertilization, and a series of improved agronomic recommendations. The improved technology was introduced via farmers' associations. She also evaluated a marketing strategy to improve prices received for sorghum and millet. She demonstrated the profitability of both the new technology and the improved marketing strategy with and without the fertilizer subsidy. The fertilizer subsidy was extended to include sorghum and millet in 2011. Ultimately, the public costs will become too high to continue the fertilizer subsidy.

Our project focus is on West Africa but in 2010 we were asked by INTSORMIL management to do impact studies of the new sorghum cultivars in Central America. In 2011 graduate students Alexis Villacis and Gabriel Garcia spent the summer in El Salvador and Nicaragua interviewing dairy producers using insensitive sorghums for silage and dual purpose. Both have found high returns for these investments in new sorghum cultivars over 40%.

Our work on the Associate award with USAID-Mali. In the 2011 crop season extension was halted in the Koutiala region because of the very low germination of Grinkan, our new cultivar. The late rains leading to mold and insect problems in 2010 were considered to be the primary factor resulting in the low germination. Grinkan is a cross between Guinea and Caudatum and late rains are always a problem with Caudatums. Yields have been outstanding with Grinkan in the 2 to 3.5 ton range as compared with 800 kg to one ton/ha for the traditional sorghum activity in the cotton region.

For seed production in 2012 12 ha of Grinkan in 2011 were planted. Most of this activity is supervised by AMEDD with two local associations of seed producers. We also made arrangements with IER for two stations of IER to produce Grinkan seed for 2012. This will be sufficient seed for our objectives in the Koutiala and surrounding regions (500 to 1,000 ha in Koutiala with another 120 ha in surrounding regions)[1].

In the Mopti region in 2011 we further expanded our area in the new technologies by 340 ha. With the continuation of the previously funded regions which have rotating funds our program now has 760 ha in nine villages with farmers' associations in each village. We also supported the construction of local storage facilities by supplementing the activities of the village. The villages were responsible for the labor and gravel. We provided for the cement, doors, windows, roofs and pallets.

The yields were excellent for millet this year. We need to be concentrating more on the marketing in Mopti. In 2009 only Oualo and Kountogoro received a good price after storage. A principal problem here is collusion between village entrepreneurs and outside buyers. When the farmers' association puts off sales too long and then gets anxious to find a buyer, there is a serious risk for this type of collusion impeding the association from getting a good price. The farmers' association needs to be actively engaged in the price search and bargaining process after the harvest until sales.

Jeanne Coulibaly interviewed farmers in the summer of 2011 for the new bulletin reviewing the progress of the Production-Marketing program in increasing yields, prices and incomes of farmers in the 2010 crop year. Abdoulaye Ibrahim also interviewed farmers

1 The program size in the Koutiala region will be determined by the ability to get a minimum number of people in the village, (> 25 farmers) and the capacity of AMEDD to technically support a larger area. This technical support requires frequent visits and the ability to organize farmers' associations and to train farmers in the agronomic program.

in Burkina Faso and Niger to evaluate the progress of our extension project with new sorghum technologies in these two countries.

Objectives and Implementation Sites

With the increased funding for doing impact work from INTSORMIL we were able to shift focus from our extension activity in Mali to technology and marketing evaluation in Mali and to impact studies of new sorghum cultivars in El Salvador and Nicaragua. Three graduate students were involved in this field work during the summer of 2011. We also had substantial support from many national scientists involved with INTSORMIL including Mamourou Diourte and Niaba Teme in Mali, Rene Clara in El Salvador and Rafael Obando and Nouri Gutierrez in Nicaragua.

In Mali we wanted to estimate the farm level effects of both new sorghum technologies and marketing activities individually and combined. We would also look at the specific changes in 2011 and estimate how the return of cotton prices from their spike in 2010 and the future elimination of the fertilizer subsidies would affect farmers' incomes and adoption of the new sorghum technologies.

In Central America there is a sharp dichotomy between the low diffusion of the new sensitive sorghum cultivars on the hillsides produced by small farmers and the rapid expansion of the insensitive sorghum cultivars produced in the valleys and plains. The most rapid expansion of the insensitive sorghums has been for silage for dairy production in El Salvador and for multi-purpose sorghum including dairy production in Nicaragua. So the fieldwork of 2011 was oriented to estimate the returns to this publicly funded research.

Since both countries are very concerned with the income distribution consequences of their research, we will also be compartmentalizing the benefits from this research comparing consumer benefits with those of farmers of different sizes. For most research consumers are a major beneficiary because the expansion of output reduces the prices that would have prevailed in the market in the absence of the new technology.

On the Associate Award in Mali. Besides producing high quality seed in the Koutiala region the project focused on development in the Mopti region with three goals- improving storage capacity, quality improvement of the millet by reducing impurities (keeping the millet off the ground during harvesting and processing), and improving the contacts and performance in the marketing operation. We had very good years for millet with the new technologies in both 2010 and 2011.

Production-Marketing in Niger and Burkina Faso. The McKnight Foundation is in its second year of supporting our extension of new technologies into these two countries. In 2011 Grinkan, our very successful Malian cultivar, was introduced into the Bobo region of Burkina Faso and the Maradi region in Niger. Farmers really appreciated it and Grinkan was demonstrating its high yield potential on farmers' fields.

The above extension activities are focused on the INTSORMIL targets of increasing yields and quality leading to higher prices and increased revenues for farmers hence more acceptance. We collaborate with a large number of other agencies in the Sahel especially the agricultural research, extension, and NGOs involved in extension type activities.

Research Methodology and Strategy

In the evaluation of new technologies in Mali a household programming model was used with discrete stochastic programming to allow decision making at different periods. This allows us to handle both the production and the marketing decisions in a stochastic framework. With this model we estimated the income effects of the introduction of the new sorghum technologies. We also estimated the effects of the new marketing strategy with and without the new technologies.

There was an international price spike of cotton in 2010. Consequently, the 2011 cotton price was abnormally high. Moreover, fertilizer subsidies had been extended to millet and sorghum in 2011. Besides the evaluation for the 2011 economic conditions we also evaluated the incomes of farmers and the adoption of the new sorghum technologies when prices of cotton return to their average of recent years and when the government of Mali ceases subsidizing the price of fertilizer.

We estimated the rates of return to research for the insensitive sorghums being used in the dairy industry in El Salvador and Nicaragua. The cost savings from these technologies were first obtained by interviewing dairy farmers in the two countries in the summer of 2011.Then with estimates of the demand and supply elasticities and the percentage contributions of the different farm sizes we obtained the total impact of this research and its contribution to consumers and different sizes of farms. Finally, the internal rate of research to this research was calculated. Since dairy technology has been adopted most rapidly by the larger farms the comparison of benefits to consumers with those of large farms is important for the policy dialogue.

For all of this economic research we depend upon interaction with the agricultural scientists and those involved in extension.

For the farm level extension activities in Mali, Burkina Faso, and Niger our performance review of the field programs for 2010 is summarized here. Besides comparing yields, prices, and incomes with farmers not in the program, we also analyzed the performance of the farmers' associations. We were especially interested in repayment rates for the input credits, in the use of storage facilities and in the quantities of sorghum or millet that farmers let the farmers' associations sell for them after repaying their input credits.

Research Results

The impact of the sorghum new cultivar was modeled with the 2011 economic conditions. In this year farm level prices of cotton were increased by 48% after the world price more than doubled in 2010. A further income increase is obtained with the fertilizer subsidy and the introduction of the new sorghum technologies. These changes lead to a substitution of the new sorghum technology in place of the traditional sorghum and increase income by 16%. When the new marketing strategy is also included, another 4% income increase is obtained. In both cases new technology sorghum leads not only to a reduction of the traditional sorghum activity but also decreases in the cotton and maize areas. Credit is constrained and the shadow prices indicate that there would be a high return on further credit availability once the new sorghum technologies become widely available. Another dollar of credit would generate another $ 0.75 and $ 1.30 in profits for the cases of new technology alone and with marketing improvements respectively (Table 1).

The higher prices for cotton in 2011 are expected to be a temporary phenomenon and to decline by 8% at the farm level. Moreover, the fertilizer price subsidy will ultimately become so expensive for the Malian government that it will be eliminated. Restoring cotton prices to their trend level and eliminating the fertilizer subsidies gives some surprising results. There is more area contraction of both cotton and maize in the region. New technology sorghum declines but less than cotton and maize indicating that outside the prime cotton areas sorghum becomes the principal activity. Traditional sorghum production is increased but this activity is not sustainable due to soil fertility depletion. So policy makers need to take into account the increased role in the production system of new sorghum technology as the fertilizer subsidy is eliminated (Table 2).

Two impact studies were undertaken in Central America in the summer of 2011. They address two important questions for these countries and INTSORMIL: Are there high returns on these public investments in sorghum technologies and are the benefits chiefly for the large dairy producers? The technology studied is new insensitive sorghum cultivars introduced for the dairy industry in El Salvador and for dual purpose use (grain sale and use of the forage in dairy) in Nicaragua.

Table 3 compares milk productivities between countries and between farms by size. El Salvador has substantially advanced productivity above that of Nicaragua especially for the large farmers. Large farmer productivity is almost three times that of the large farm sector in Nicaragua. The shift in El Salvador to widespread use of sorghum silage with multiple cuts is the basis for these productivity gains. In Nicaragua the system is still for dual purpose sorghum with the grain being sold and the rest used for forage so there is substantial potential for productivity improvement as Nicaraguan farms move to silage in the future.

To evaluate the returns to sorghum research dairy farmers were interviewed in El Salvador and Nicaragua during the summer of 2011. The principal objective was to estimate the effect of the introduction of insensitive sorghum cultivars on the feed costs of these dairy producers. The gains from new technology on the farm level were estimated by comparing with farmers not employing the technology. The effect on the national production was estimated from the diffusion data of the new sorghum cultivars on the national level. There is a standard economics methodology for estimating the gains to society from this research and then compartmentalizing it into the gains for various groups[2]. Then the estimated costs to the public sector for undertaking this research were estimated. Benefits and costs were utilized to estimate the internal rate of return.

The returns of 43 and 49% for El Salvador and Nicaragua respectively were excellent indicating that there was a high return on these investments and that society would have benefitted from further investments supporting these technologies[3] (Tables 4 and 5). These investments are adaptive research since both countries can take new material from around the world and find cultivars selected for regional adaptation. Their public costs are only the adaptation testing and extension. Nevertheless, this selection process requires good scientists knowing their country's production conditions to do this adaptation testing. Furthermore, good seed production facilities and support to the extension service are necessary.

There has been substantial extension of these new insensitive sorghums provided in El Salvador by a very experienced breeder, by a decade of Israeli technical assistance and in the last five years by the combined program of CENTA (the agricultural research institution), supporting the milk producers' lobby, PROLECHE, with the loan of its scientists for the sorghum extension activities. This extension component was a very important component of the El Salvador success and its costs were included.[4]

There were more benefits for producers (dairy farmers) than for consumers. However, even in El Salvador where dairy technology is increasingly sophisticated and farm level investments substantial, consumer benefits from the reduced prices resulting from technology introduction were greater than the benefits accruing to large farmers. So these are excellent investments from both a growth and an income distribution perspective.

Technology evaluation in the Associate Award of USAID-Mali. With the heavy late rains 2010 was a bad year for sorghum due to flooding on the low land, heavier soil where sorghum is concentrated. The millet on the lighter soils and on the slopes and plateaus did very well. Millet production in both the Mopti and Segou regions was excellent with yield gains of 423 to 912 kg/ha over the traditional millet in farmers' fields. Also the farmers' associations in both regions were able to obtain good sales prices by selling four to five months after the harvest price collapse. The returns on adoption ranged from 51 to 191% (Table 6).

Networking Activities

The fieldwork in El Salvador and Nicaragua was a collaborative activity between Purdue graduate students and the research institutions, CENTA and INTA, in these two countries. In the research process various institutions became involved and both students gave presentations when they finished. Alexis Villacis will be returning to San Salvador to present his results to scientists and policy makers.

2 Parallel supply curves with a price elasticity of demand of -.2 and a price elasticity of supply of 0.1 were assumed.

3 This is a compound interest rate and can be compared with savings accounts or any other investment.

4 We were not able to separate the effect of this large extension input on diffusion but it was included in the research costs. Since these were expensive inputs of experienced researchers and the combined effects were very successful, it would be useful to separate out the impact of these extension components.

Table 1. Adoption of Improved Sorghum Technologies without and with the New Marketing Strategy in the 2011 Malian Agricultural Economy

Traditional Crop	Base Case	Scenario 1	Scenario 2
Technologies	Traditional Technologies No Marketing Strategy 2011 Economy	Improved Sorghum No Marketing Strategy 2011 economy	Improved Sorghum Marketing Strategy 2011 Economy
Cotton Price(F CFA/kg)	231($/kg 0.51)	231($/kg 0.51)	231($/kg 0.51)
Cotton Area (ha)	5.4	4.6	4.4
Percentage change		-16%	-20%
Maize Area (ha)	4.8	3.4	3.6
Percentage change		-28%	-24%
Sorghum Area (ha)	1.8	0.0	0.0
Millet Area (ha)	3	3	3
Percentage change		0%	0%
New Sorghum (ha)	0	4.0	4.0
Total Area (ha)	15	15	15
End Wealth (F CFA)	1,206,482 ($2,666)	1,393,954 ($3,080)	1,444,266 ($3,191)
Percentage change		16%	20%
Marginal value of the improved sorghum credit constraint	-	0.75	1.3
Source: Jeanne Coulibaly, 2011, pp. 63,67.			

Table 2. Crop Area and Income Response to a Reduction in Cotton Price and Removal of the Fertilizer Subsidy in Malian Agriculture (Back to Normal Unsubsidized Prices)

Traditional Crop	Base Case	Scenario 3	Scenario 4
Technologies	Improved Sorghum Marketing Strategy 2011 Economy	Improved Sorghum Marketing Strategy Reduction in Cotton Price	Improved Sorghum Marketing Strategy Reduction in Cotton Price and Removal of Fertilizer Subsidy
Cotton Price (F CFA/kg)	231($/kg 0.51)	212($/kg 0.47)	212 ($/kg 0.47)
Cotton Area (ha)	4.4	2.7	1.8
Percentage change		-39%	-58%
Maize Area (ha)	3.6	3.8	1.6
Percentage change		4%	-56%
Traditional Sorghum Area (ha)	0.0	1.5	5.5
Percentage change			
Millet Area (ha)	3	3	3
New Sorghum (ha)	4.0	4.0	3.0
Percentage change		0%	-25%
Total Area (ha)	15	15	15
End Wealth (F CFA)	1,444,266 ($3,191)	1,370,460 ($3,028)	1,143,398 ($2,526)
Percentage change		-5%	-21%
Marginal value of the improved sorghum credit constraint	1.3	1.4	0.8

Source: Jeanne Coulibaly, 2011, pp. 67, 77.

Table 3. Milk Productivity (liters of Milk per Cow Day) in El Salvador and Nicaragua for Adopters of Insensitive Sorghums

	El Salvador	Nicaragua
Weighted Average[a]	11.6	5.2
Small Herd	6	4.8
Medium Herd	11	5.4
Large Herd	15	5.4

a. Weights for calculating the means in El Salvador are 20%, 50%, and 30% for small medium and large dairy farmers. Weights for Nicaragua are 30%, 30%, and 40% for small, medium, and large dairy farms.

Source: unpublished data from the field research of Alexis Villacis and Gabriel Garcia

Table 4. Returns to Research on Insensitive Sorghum Cultivars for the El Salvador Dairy Industry (Dollars, 1993-2010)

Consumer's Surplus	**$**	**2,097,137**
Producer's Surplus		
Small Farmers	$	106,401
Medium Farmers	$	1,881,258
Large Farmers	$	1,553,466
Total Producers Surplus	**$**	**3,541,124**
Social Gain	**$**	**5,638,261**
Total Research and Extension Costs	**$**	**558,917**
Net Benefits to Society	**$**	**5,079,344**
Internal Rate of Return (IRR)	**49%**	

*Source: Calculated from unpublished data collected in the summer of 2011 by Alexis Villacis.

Table 5. Benefits of Research for Different Groups from Insensitive Sorghum Cultivars in Dairy Production in Nicaragua (Dollars over the period 1990-2010)

Consumer Surplus	3,662,721
Producer Surplus	6,459,826
Small Farmers	5,328,961
Medium Farmers	152,937
Large Farmers	978,124
Social Benefit	10,122,547
Research Cost	865,867
Net Social Benefit	9,256,680
Internal Rate of Return	43%

Source: Calculated from unpublished data collected by Gabriel Garcia in the summer of 2011

Table 6. Income Gains per ha from the New Millet Technologies and from the Marketing Innovations in the Mopti and Segou Regions in the 2010-11 Crop Year

Villages in the Mopti Region	Yield Gain	Gains from Increased Yield [a]	Gains from the Association storage[b]	Gross Revenue Gains[c]	Cost of Technological Package[d]	Net Gains[e]	Return on adoption[f]
	kg/ha	F CFA/ha	F CFA/ha	F CFA/ha	F CFA/ha	F CFA/ha	%
Kani Kombole	537			61,704		24,804	67%
		53,704	8,000		36,900		
Kountogoro	451	45,112	10,500	55,612	36,900	18,712	51%
Oualo	382	53,424	5,000	58,424	30,950	27,474	89%
Villages in the Segou Region							
	kg/ha	F CFA/ha	F CFA/ha	F CFA/ha	F CFA/ha	F CFA/ha	%
Bouadie	619	61,900	12,961	74,861	37,000	37,861	102
Diawarala	423	42,300	14,473	56,765	37,000	19,765	53
Tigui	912	91,200	16,435	107,635	37,000	70,635	191
Tingoni	490	49,000	18,113	67,096	39,500	27,595	70

Source : Calculations from the field interviews of Jeanne Coulibaly from the summer of 2011 in Mali.

[a] Gains from increased yield are obtained by multiplying the yield gain by the harvest price

[b] Gains from storage to the association are per hectare amount of grain stored by the association multiplied by the difference between the harvest price and the association sales price. The gains in price were obtained by the association. We expect them to be divided among the members according to their contribution. Moreover, the association model of getting higher prices is expected over time to be obtained by the individual farmers contributing their grain to be sold by the association. Presently most of this grain sold by the association was the repayment in kind for input credit, which then goes into a revolving fund for the input credit of the next year.

[c] The gross gains are the result of the sum of the gains from increased yield and the gains from the association storage

[e] The net gains are the result of the difference between the gross gains and the cost of the technological package. There would be some additional costs including increased labor from higher plant and weed density resulting from more fertilization. Also more labor would be required by the new operations especially thinning, which farmers do not normally do, and the split application of fertilizers. These additional labor costs were not included here.

[f] The return on adoption is the ratio between net gains and the cost of the technological package. No time discounting was done.

In our fieldwork with farmers in the villages we regularly go over the program components in production, marketing and the development of farmers associations. In November of 2010 we organized and financed a workshop for representatives of the ten new farmers' associations producing millet (Segou region) with our new technologies to meet with the processors of millet products in Bamako. The first day was dedicated to presentations from INTSORMIL scientists. The second day the processors and farmers' organization representatives took over in Bambara and discussed their requirements and concerns. Prices received by the farmers' associations in the Segou region were substantially higher than the prices most farmers were getting. The associations took advantage of the seasonal price recovery and selling a cleaner millet by keeping threshing off the ground in order to demand a premium price for quality.

Publications and Presentations

Coulibaly, J., J. Sanders, P. Preckel, T. Baker, "Cotton Price Policy and New Cereal Technology in the Malian Cotton Zone," 2011. Selected paper presented at the annual meeting of the American Agricultural Economics Association in Pittsburgh, Penn, 23 pages.

Coulibaly, J., 2011."Diversification or Cotton Recovery in the Malian Cotton Zone: Effects on Households and Women," unpublished PhD dissertation, Department of Agricultural Economics, Purdue University, West Lafayette, IN.

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. Additional effort was made to measure in vitro and in vivo indices of health contributions by special sorghums. Extensive breeding and analysis of sorghums for flavanoids is ongoing.

Major activities include utilization of El Salvadoran and Nicaraguan sorghum as a substitute for costly wheat flour in a wide array of foods. CENTA has been very effective with excellent progress in dry milling of sorghum into flour and related products. Progress has also occurred in Nicaragua to utilize sorghum in baked products in addition to tortillas.

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 participated in workshops in Central America to provide information to scientists, PVO's and NGO's interested in processing sorghum. We worked with other SMOG CRSP projects in economics, grain marketing and food science to promote healthy foods from sorghum.

Objectives and Implementation Sites

1. Facilitate the growth of rapidly expanding markets for sorghum and millet products by providing information on nutritional properties, processing quality, food manufacturing processes with improved efficiency, and prototype products using sorghum/millet as ingredients.
2. Improve the food and nutritional quality of sorghum to enhance its marketability and image as grains that promote healthy, wholesome convenience foods.
3. Contribute to host-country institutional human capital development by providing short and long-term educational opportunities. Non-degree (short-term) training includes research methodology and conferences or hands-on training workshops; degree training includes MS and PhD programs.
4. Provide practical technical assistance and information on supply chain management, processing technologies and related matters.

We have focused our efforts on improving the utilization of sorghum in Central America and Southern Africa. Key targets are El Salvador, Nicaragua and South Africa. We are working with Ms. Calderon, Texas A&M MS graduate, who leads efforts to utilize sorghum in food systems in El Salvador. Ms. Palacio in Nicaragua (INTA) has developed several workshops on sorghum processing and has presented the technology to small food processors. She is also working with FAO support.

We continue work 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. We participated in a sorghum workshop held in Zambia to promote the use of white food sorghums. University of Pretoria has a strong program in food science and technology with significant numbers of graduate students from African countries. This is a major way of passing information into African processors.

In addition, Dr. L. Rooney, PI, has provided support for value-added supply chain activities in West Africa led by Prof. Sanders at Purdue. He provided information on the utilization of sorghums in composite bread and other products. These projects are making a significant impact on production and use of millets and sorghum by small farmers, processors and entrepreneurs. Excellent progress is continuing because of long term efforts.

Research Methodology and Strategy

The host country scientists in the project are well-educated, experienced and work as colleagues. Information and technology generated flow both directions. The teams have a significant number of experienced scientists who provide leadership and advice to younger scientists.

Research Results

Sorghum for Healthy Foods: Our research on special sorghums has stimulated many major research institutions around the world 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 its image and will 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 bioactives. Work continues to develop sorghum hybrids with higher levels of these phenols and higher grain yields.

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

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

We confirmed that special sorghums containing condensed tannins and high levels of flavanones, flavones and 3-deoxyanthocyanins exist. They are quite high in potential anti- inflammatory compounds that are difficult to find in natural sources. In addition, whole grain high tannin sorghums and their brans significantly reduce the EGI of foods. 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.

The sorghum brans are high in insoluble dietary fiber and antioxidant levels. Those with condensed tannins are more slowly digested because the tannins complex with proteins and possibly starch. Thus, these special sorghum brans or their extracts could play an important role in human health. In addition, the brans provide natural colorants. These studies are continuing and have stimulated significant commercial interest in special sorghums as health foods and sources of unique phytochemicals.

Dr. Awika, a food chemist/ technologist in our lab, has developed a research program on in vitro evaluation of special sorghums' anti-cancer activities using cell cultures. One of his students, Ms. L. Yang, found that the black and tannin types of sorghum clearly had anti-cancer activities against esophageal cancer cells.

Dr. Nancy Turner, Texas A&M human nutritionist, conducted trials demonstrating that black and tannin sorghum brans significantly reduce the development of cancer in rats induced with colon cancer. These studies have been conducted for several years and agree with other findings that special sorghum brans may protect against colon cancer.

Gluten-free Products: White food sorghum flour has been used widely in gluten-free breads and other baked products because of its light color and bland flavor. Standard methods of baking gluten-free breads were compared using different baking procedures with gelatin and/or special starches. A gluten-free sorghum bread that could be sliced and stored was produced using a combination of special starches with sorghum flour. The bread had improved acceptability with excellent flavor and aroma. Sorghum flour and whole grain is more readily available, and production is significantly less expensive than tef, millets, quinoa, amaranth and others. However, it is still difficult to obtain sorghum flour but improved supplies are in the pipeline.

Interest in gluten-free breads and other baked products exists worldwide. The addition of sorghum milled fractions to produce foods containing high levels of antioxidants and other beneficial compounds will increase the value of sorghum in gluten free foods. We still need larger supplies of these sorghums, but the increasing demand may be met in the near future by several companies that have expressed interest in developing new sources of sorghum products.

The use of tannin sorghums in special foods is very promising, especially for Celiacs.

Sorghum Food Utilization in Central America: Ms. V. Calderon and associates at CENTA in El Salvador have made excellent progress in stimulating the use of sorghum flour and other milled products in foods. Their research and development activities on sorghum have created a demand for sorghum flour to extend wheat flour in bread and other baked products. Originally, the demand was created by very high prices for imported wheat flour, but preference for sorghum continued when wheat prices dropped.

We supplied several Omega VI mills designed by Compatible Technology International (CTI) which are used in Africa to grind various grains. The Omega VI mill was modified and a sifting device was constructed in the CENTA Technology Laboratory. This modification has proved more efficient for grinding sorghum than the existing disc grinders available in El Salvador. Several additional Omega VI grinders were sent to El Salvador and Ms. Calderon distributed them to various groups who have used them effectively.

Ms. LeAnn Taylor, from CTI, (Compatible Technology Incorporated) presented seminars on how to build wooden grinders or assemble metal Omega VI grinders locally. They were well attended; subsequently, local groups began producing the grinder locally to reduce costs and increase availability in Salvador and possibly other areas. The grinder has proven effective in a wide array of applications.

Large bakeries as well as small ones are utilizing sorghum composite flours for baked products. Other uses for sorghum include horchata mixes and a wide variety of products that use maize or rice. Substantial savings occur even though prices for wheat flour vary. Once this technology catches on, it will likely be continued even though wheat prices vary.

Interaction with Escuela Agricola Panamericana (EAP) in Honduras continues with short-term training in cereal technology and related activities. Mr. Marlon Ac Pangan, from Guatemala, completed his training this past year.

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. Some farmers produce flour and/or baked products to generate income based on value-added processing.

Networking/Outreach Activities

Rooney conferred with host country colleagues in El Salvador and Nicaragua twice. Ms. Eliana Pinilla, MS student from Texas A&M University, spent a total of 5 weeks in El Salvador conducting research activities with CENTA project leaders. She assisted with workshops and other activities, and collected samples for analysis as part of her MS degree. Winrock International partially supported her travel.

Information was presented at Institute of Food Technologists (IFT) and American Association of Cereal Chemistry International (AACC Int'l) conferences. Several students presented information on health promoting sorghums and sorghum quality for food processing, especially in gluten-free foods for Celiacs. Requests for information on sorghum health foods from Australia, Japan and other countries increased. This led to emerging markets for sorghum in food systems in developed countries. Thus, sorghum is gaining acceptance as a human food with special attributes.

Gluten-free products using sorghum were developed and methods for baking were presented. Celiacs like the white sorghum for baked products because of its bland flavor, light color and low cost. Sorghum brans provide high levels of dietary fiber and antioxidants in gluten-free products.

Sorghum brans added to wheat flour produced excellent, naturally dark-colored flour tortillas with improved nutritional values. Sorghum tannin brans blended with wheat flour made excellent baked products with enhanced levels of antioxidants and dietary fiber. The natural colorants of sorghum are useful in a wide variety of foods.

Sorghum brans were processed into finely ground particles with roasting to produce various colors that can be used to produce extenders for cocoa powder. The different sorghums like lemon yellow, black, red and brown with condensed tannins produce a wide array of different colors.

Training (Degree and Non-Degree)

Three M.S. and one Ph.D. were awarded to students working on sorghum. Dr. L. Rooney collaborates with Professor Taylor, University of Pretoria, South Africa, on two Ph.D. students at the University of Pretoria who are working on sorghum. Ms. C. Chiremba spent time at TAMU and University of Manitoba and is completing her Ph.D. at University of Pretoria.

Ms. Doreen Hikeezi, former INTSORMIL M.S. graduate and lecturer in the Food Science and Technology Dept, University of Zambia, continues 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 Dr. L. Rooney. These "sandwich" degree programs reduce costs enabling education of more students while providing them exposure to U.S. universities and related technologies.

Short Courses: Ms. Pinilla assisted Ms. V. Calderon and Mr. K. Duville, CENTA, El Salvador, in developing several milling technology/short course materials for interaction with a large number of food processors who are using sorghum in baked and other products. Ms. Pinilla completed her MS thesis on analysis and testing of flours produced in El Salvador. She is working in the US food industry, but still collaborates with food industry in Central America.

More than 35 participants enrolled in a one-week short course on practical snack foods processing held at Texas A&M University. 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 intern, Marlon Ac Pangan from Guatemala. He participated in classes, short courses and assisted with research. He graduates from Escuela Agricola Panamericana (EAP), Zamorano, Honduras with BS degree in December 2011.

Sorghum in Central American Foods: 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 of sorghum have real advantages.

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

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Introduction and Justification

Sorghum (Sorghum bicolor) is a staple food of many people in Africa and Asia. The relatively good ability of both sorghum and millet to grow under abiotic stress conditions (poorer soils, low water conditions, etc.) would seem, on the surface, to make them favored crops in semiarid regions. Even with their favorable agronomic properties, however, sorghum production and millet production are greatly overshadowed by maize production. While favored by some for their agronomic efficiency, use of sorghum and millet as food sources for large urban populations are thought to be hampered by several factors. These include limitations on the supply of high quality grains to processors, the lack of small processors, lack of educational resources related to small business development, lack of product development expertise, and lack of knowledge or understanding of the developing body of evidence supporting nutritional claims associated with sorghum and millet consumption.

Sorghum and millet grains are often a substantial source of locally available calories. The overall value of locally-grown grains, however, increases if those grains can be moved through marketing channels into processed products. Unfortunately, when people move from rural areas into urban settings, it is also observed that their dietary intake of maize increases while intake of sorghum and millet decreases. This trend has been linked to numerous factors, including poor availability of sorghum and millet whole grains in urban markets, poor availability of flours and processed products made from sorghum and millets, an economic and sensory perception that maize is "superior," and an inadequate grain marketing channel and infrastructure that make grain aggregation and transportation difficult. Small business development assistance, of the kind necessary to promote industry development, requires direct educational assistance and proactive market development. Specific resources for targeting community-level entrepreneurial groups and/or individuals are limited and essentially unavailable for sorghum and millet-based foods. A comprehensive plan to provide educational materials, educational training, specific business and product development assistance, and targeted market / supply channel management and enhancement is not available. The work proposed will begin to address several of these deficiencies.

Connection of each CRSP Objective over the two-year period with its respective technology for assessment and potential impacts is made in the list that follows.

Objective 1: Supply chain/market development.
Technology: Knowledge transfer on how to incorporate sorghum and millet into food products using existing technologies; knowledge transfer to farmers on the quality traits required by processors.

Potential Impacts: a) Increased use of value-added sorghum and millet in food products, b) Increased sales of sorghum and millet as cash crops, and c) Establishment of farmer-processor relationships: higher and more stable income for farmers.

Objective 7: Partnerships and networking
Technology: Development of University-based partners who can provide marketing and technical support assistance to food processors and food processing entrepreneurs.

Potential Impacts: a) Increased success rate and income of entrepreneurs producing sorghum and/or millet-containing products, b) Increased use of value-added sorghum and millet in food products, and c) Increased sales of sorghum and millet as cash crops.

Objectives and Implementation Sites

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 potential use of sorghum and millet 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.

The two-year work plan of the multinational interdisciplinary team of this project addressed the abovementioned issues by employing multiple strategies. First, the team continued its sorghum-based food business education program that a) educates farmers on grain quality, b) educates entrepreneurs on how to use sorghum to make high quality convenient foods for both urban and rural markets, and c) provides ongoing technical/business support as they develop new sorghum food products and grown their businesses. Second, Drs. Jackson and Weller planned to travel to along with members of the Southern Region of Africa to participate in the INTSORMIL-National Institute for Scientific and Industrial Research, Zambia workshop on Sorghum Food Enterprise and Technology Development in Southern Africa in Lusaka, Zambia. Attendees were anticipated from Zambia, South Africa, Tanzania, Ethiopia, Botswana and the United States. The workshop was to involve presentations by business and food professionals, and sharing of curricular materials designed for both farmers and processors. Third, the team continued to provide a Ph.D. education to one East African university faculty member in the area of sorghum/millet grain quality, product development, and food entrepreneurship, and fostered another collaborator from a national food and nutrition center through to completion of his M.S. degree program. These individuals were selected, in part, based on their employer's willingness to support programs in sorghum quality, sorghum food product development and outreach services.

The project was designed to deliver significant impact by creating increased demand for quality sorghum and millet grain by establishing new outlets and markets for these cereals. The project's long term objectives included the following.

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

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

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

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

These program objectives specifically addressed 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.

Research Methodology and Strategy

Members of the inter-institutional, interdisciplinary team that were to be assembled to achieve the objectives included scientists and staff members from the Departments of Food Science and Technology, and Biological Systems Engineering at the University of Nebraska-Lincoln (UNL), scientists and staff members from the Departments of Food Science and Technology, and Agricultural Economics at the Sokoine University of Agriculture (SUA), scientists from the Tanzania Food and Nutrition Centre (TFNC), and food scientists and economists on staff at the University of Zambia (UNZA).

Extension technical and business assistance for ongoing sorghum/millet food processors was provided one-to-one by SUA and TFNC team members in Tanzania. Introductory workshops on technical and business aspects of sorghum/millet processing were presented periodically throughout the year in various locals. As resources allowed, the UNZA team members provided limited technical and business support to self-identified processors; UNZA has previously received curricular materials from SUA and managed to secure a decorticator and mill for use in training.

Participating processors/entrepreneurs were self-identified and also recruited by growing media publicity, flyers, and interactions/contacts with regional officials throughout Tanzania. Three workshops for new entrepreneurs and small (existing) processors were planned for each year; workshops for farmers were to be held in conjunction with each entrepreneurial workshop to allow for interaction between groups. SUA was to contact the existing network of NGO personnel, Extension personnel, and government officials prior to all workshops to invite them to participate and interact with both clients and presenters.

One Ph.D. student and one M.S. student were to be actively seeking their degrees with programs of study in grain quality/food product development during this work plan's timeframe. It was anticipated that the M.S. student complete his degree requirements on or before May 2011, and the Ph.D. student complete her degree requirements on or before December 2012.

Research Results

In spite of a number of changes in job duties and impeding health issues for some of the collaborators of the project during the second year of the most recent two-year work plan, many of the planned activities were achieved. Continued support to existing processors in Dar es Salaam, Tanzania including identification of two women's groups previously not supported through the INTSORMIL project occurred. One group, known as Glorious, is located in the Mbezi Beach area of Dar es Salaam (Kinondoni District) while the other group, known as the Kitangari Tulinge Women Development Association (KITUWODEA), is from Kitangari village in the Newala District of the Mtwara region (southern part of Tanzania). The Glorious group is a newly-established group whereas the KITUWODEA group is an older group originally established for the purpose of processing cashews. [CRSP Objectives 1, 2 & 7].

The identification of the two groups came about conducting a needs assessment (level of processing knowledge, type of training, registration, processing equipment, etc.). A needs assessment questionnaire was developed and used to gather primary data from the target communities and secondary information from SUA, TFNC, the SUA Government Chemistry Laboratory Agency (GCLA), the Ilonga Agricultural Research Center and the NZASA women's group. The information was used as a base for the development of training materials. The concepts of "from idea to product" and "from product to profit" were used [Project Objective 1; CRSP Objective 2].

Each of the two groups received the first phase the UNL-INTSORMIL training workshop through three days of training using the developed materials (Figure 1). The training was conducted in close collaboration by the NZASA women's group, GCLA and TFNC, which played the role as coordinator. The NZASA group, one of the first women's groups to receive INTSORMIL training, was used in order to share its experience with fellow women/business people. In addition to the training, the KITUWODEA group received simple equipment and utensils [Project Objective 1; CRSP Objective 2].

The NZASA group received support from INTSORMIL to cover costs for developing and printing new packaging materials (Figure 2). With this type of new packaging material, demand for its sorghum flour product increased even though new packages carried a higher price per kilogram of flour than older packages. Also supermarkets and other food stores have started stocking sorghum flour from the NZASA women's group [Project Objective 1; CRSP Objective 1].

A significant number of the new and continuing stakeholders were women. Concerted effort was made to work with women's groups, not only in processing aspects, but also in use of sorghum in consumer and end products. Efforts to show versatility and function of sorghum in a variety of food products were taken to help bolster market demand for sorghum (Figure 3). Linkages and coordinated activities with district-level, national-level, and regional-level (African) professionals were established (e.g., development of a Memorandum of Understanding between INFSORMIL and the TFNC, exhibit at Health Week activities in Dar es Salaam and exhibit at the Sorghum Food Enterprise and Technology Development in Southern Africa Workshop in Lusaka) [Project Objectives 1, 2, 3 and 4; CRSP Objectives 1, 2 and 7].

In December, team colloborators including Dr. Jackson and Dr. Weller, Dr. Ballegu and Jeremia Makindara from SUA, Onesmo Mella from TFNC, and Bernard Moonga and Dr. Shindano from UNZA assisted in hosting the INTSORMIL-National Institute for Scientific and Industrial Research, Zambia workshop on Sorghum Food Enterprise and Technology Development in Southern Africa in Lusaka, Zambia. The workshop involved presentations by business and food professionals (specifically two representatives from the NZASA women's group in Dar es Salaam with sorghum- based food products), and sharing of curricular materials designed for both farmers and processors (Figure 4). Over 40 attendees from the eastern and southern countries of Africa including Zambia, South Africa, Tanzania, Ethiopia, Botswana and Nigeria and the United States including from Texas A&M University and Ohio State University were in attendance at the workshop [Project Objectives 1, 2, 3, 4 and 5; CRSP Objectives 1, 2 and 7].

Educational programs at UNL for 1 M.S. student (Onesmo Mella from TFNC) and 1 Ph.D. student (Nyambe Mkandawire from UNZA) were continued. Onesmo completed the research and thesis portions of his M.S. degree program requirements, and passed his final examination in time for graduation in May 2011. Nyambe successfully completed the comprehensive examination portion of her Ph.D. degree requirements in Spring 2011 with targets of defending her research proposal in December 2011 and completing all requirements for her degree by December 2012 [Project Objective 6; CRSP Objectives 1, 2 and 7].

The recently purchased decorticator and hammermill were used in training of Zambian stakeholders by UNZA faculty and staff members [Project Objectives 1, 2, 3 and 4; CRSP Objectives 1, 2 and 7].

Efforts to rectify inconsistent record keeping needed for monitoring project benchmarks were hampered due to job changes and health of collaborators. Greater diligence in record keeping and reemphasis of need for such data collection is anticipated. Additionally, linkages with other INTSORMIL Eastern Africa projects focused on agricultural economics issues should be strengthened to help collect and evaluate assistance data for value added.

Networking Activities

Dr. David Jackson, Dr. Curtis Weller and Onesmo Mella (M.S. student at UNL from TFNC) traveled in December, along with members of the Southern Regional to participate in the INTSORMIL-National Institute for Scientific and Industrial Research, Zambia workshop on Sorghum Food Enterprise and Technology Development in Southern Africa in Lusaka, Zambia with attendees from Zambia, South Africa, Tanzania, Ethiopia, Botswana, Nigeria and the United States. The workshop involved presentations by business and food professionals, and sharing of curricular materials designed for both farmers and processors.

Publications and Presentations

Several presentations were made at regional meetings in addition to two by Dr. Weller in the Zambia workshop entitled Developing Entrepreneurism:Student Training and Involvement and Measurement of Starch Digestibility in Starch and Flour from Tannin containing Sorghum, one by Onesmo Mella in the Zambia workshop entitled Effects of Malting and Fermentation on the Composition and Functionality of Sorghum Flours, and one by Nyambe Mkandawire at the AACC International Annual Meeting (described below).

Abstract

Mkandawire, N.L., D.J. Rose, C.L. Weller and D.S. Jackson. 2011. Condensed tannin content is not correlated with in vitro starch digestibility of cooked grain sorghum (Sorghum bicolor (L.) Moench) flour. Cereal Foods World 56:A56. AACC International, St. Paul, MN.

Thesis

Mella, O. 2011. Effects of Malting and Fermentation on the Composition and Functionality of Sorghum Flour. M.S. Thesis. Department of Food Science and Technology, University of Nebraska-Lincoln, Lincoln, NE.

Figure 1. Jeremia Makindara of the Sokoine University of Agriculture leading a portion of the "From Idea to Product' workshop for the KITUWODEA women's group.

Figure 2. NZASA women's group's Health Week exhibition in Dar es Salaam displaying examples of sorghum flour in new packaging (upper rows) and old packaging (lower rows) to compare consumer acceptance.

Figure 3. The Glorious women's group showing off products made with sorghum flour at conclusion to training workshop.

Figure 4. Dr. Curt Weller working with attendees at Lusaka workshop to identify top needs for sorghum industry in Africa.

Host Country Program Enhancement

INTSORMIL

Central America (El Salvador, Nicaragua)

William Rooney
Texas A&M University

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Collaborating Scientists

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Dr. Máximo Antonio Hernández, Entomologist, CENTA, San Andres, El Salvador
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Ing. Alfredo Alarcón, Agronomy, CENTA, San Andres, El Salvador
Ing. Edgard Ascencio, Agronomy, CENTA, San Andres, El Salvador
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Dr. John Sanders, Professor, Dept of Ag Economics, Purdue University, West Lafayette, IN.

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. In the current INTSORMIL program, the Central American program has focused its research, development and deployment activities primarily in El Salvador and Nicaragua. However, additional support and activities are allowing the INTSORMIL program to extend throughout Central America.

Institutions

Current INTSORMIL collaboration in Central America are with 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 regional seed companies in Nicaragua and Guatamala which involves testing of INTSORMIL-developed hybrids/varieties. 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. In region coordination is provided by Ing. Rene Clara-Valencia and 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 $100,000 in 2010-2011, which is an increase compared to previous years. In addition, funding for technology transfer funds (see descriptions later) provided other funds to expand research and extension activities in the areas of seed production and utilization. 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.

Sorghum/Millet Constraints Researched

Collaboration

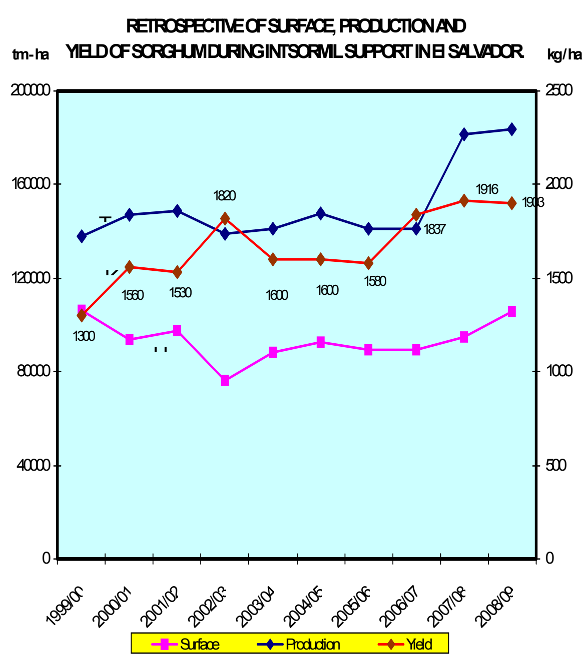
INTSORMIL's Central America program has collaboration with many non-governmental organizations mainly in validation of new sorghum varieties on-farm (see form for complete list), and formal collaboration with national extension services, and it has served as a catalyst for Central American grain sorghum 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. With the funding of technology transfer projects, collaboration with local farmers groups has increased to facilitate seed production in El Salvador, Honduras and Nicaragua. The sorghum utilization technology transfer programs have been possible through interaction with local associations of bakeries in El Salvador and Nicaragua. These groups provide a large and interested audience who wants to know and learn about the use of sorghum in bakery food products.

Sorghum Production/Utilization Constraints

Grain sorghum is the third most important crop in Central America (El Salvador, Guatemala, Honduras, and Nicaragua) after maize and beans. The area devoted to grain sorghum in 2003 was 225,000 ha-1, and produced an average grain yield of 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 (Figure 1) 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 in 2007/2008 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 the expected fluctuations in wheat prices, the interest in utilizing substitute flours, such as sorghum, fluctuate as well. Therefore, it is critical to continue to educate and equip end users so that when the situation warrants, they are in a position to capitalize on the opportunity. Currently, knowledge and the lack of milling equipment for production of grain sorghum flour limits adoption of the use of grain sorghum flour for baked products. Thus, 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

Collaborative research plans of work are planned and organized within both Nicaragua (INTA) and El Salvador (CENTA). Within each research agency, scientists interested in conducting funded research within the mandate of the INTSORMIL program are invited to submit proposals for funding. Projects are reviewed by the regional coordinators and funding is allocated based on mutual agreement on the projects. The areas of emphasis were plant breeding, agronomy, plant pathology, entomology, economics, quality and extension. As the primary cropping year for sorghum begins in August, funding and research are slightly ahead of the INSTORMIL funding year. Activities in this report are associated with the crop year 2010 (May – December 2010).

In addition to the activities of the regional program, the INTSORMIL CSRP was awarded several subcontracts to extend and enhance research activities in the region. First, a USAID Feed the Future subcontract entitled "Identification and release of Brown Midrib (bmr) sorghum varieties to Producers in Central and Haiti". The objective of this project is to develop and release bmr varieties for small farm use in Central America. This project has expanded INTSORMIL funded activity into not only Nicaragua and El Salvador but also Guatamala, Honduras, Costa Rica, Panama and Haiti. Second, an economic impact study was completed to assess the relative value the use of sorghum flour as a substitute for imported wheat flour.

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 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 are now in advanced testing as part of our Feed the Future and/or technology transfer activities.

In hybrid testing, the PCCMCA was coordinated by Rene Clara. A total of eight locations were planted and grown throughout Central America. Data was collected in all eight locations. In El Salvador and Nicaragua, INTSORMIL collaborators conducted these PCCMCA trials. In 2010, the trial had eight entries from private industry. The entry number is reduced from years past; primarily due to industry consolidation and reduced research efforts. This makes INTSORMIL supported breeding activities even more important. The combined results from the El Salvador locations are presented as an example of the research in Table 1.

Testing of bmr Varieties in Central America

Because sorghum is the second major cereal grown in Central America, higher yields and increased nutritional value of sorghumforage and grain also means financial stability for farmers. The cattle, poultry and swine industry of the region rely heavily on grain and forage sorghumand when reliable, high-grade sorghum isn't available for farmers to feed their cattle, poultry and swine, the result can be economic loss.

In the first year of the program, INTSORMIL scientists will focus on evaluating and testing advanced bmr sorghum lines that have already been developed by INTSORMIL in collaboration with the El Salvador national sorghum program, Centro Nacional de Technologia Agropecuaria y Forestal (CENTA). The brown midrib trait, characterized by the presence of a distinctly brown midrib in the leaf, also produces plants with lower lignin content. The reduced lignin content increases the digestibility of the forage. When sorghum is more digestible for livestock it means better meat and milk production.

In 2010-2011, each country completed the analysis of 15 experimental varieties and four standard checks. The combined analysis of data is summarized in Table 2. Based on the results in each country, specific varieties were selected for advanced testing and evaluation. As expected the experimental lines varied in each country (Table 3). By the third year, each country program will provide seed of the two best varieties to small scale farmers through a technology transfer process. Since these are open-pollinated varieties, farmers can save their own seed for the next season's crop. Farmers will be trained in seed production to quickly build up a seed supply which can mean a faster spread of those sorghum varieties to small scale producers throughout the seven countries. (Figure 2)

Grain Utilization – Food Use

The sorghum varieties produced in El Salvador are of sufficient quality to produce flour for human consumption, but the

Table 1. Results of the 2010 PCCMCA sorghum trial, combined across two locations in El Salvador. The trial was also grown in Panama, Nicaragua, El Salvador and Guatamala.

	Hibridos	Flor (dias)	Alt planta (cm)	Rond (t/ha)	Enf (1-5)	Tipo panoja (1-5)	Largo Pan (cm)	Exc (cm)	Color G	Aspt (1-5)	Hum (%)
1	DKS-46	63	165	5.82	1.50	1.9	28.6	17.5	Rojo	1.9	12.6
2	ESH6-3	63	150	5.69	1.13	2.3	31.1	18.0	Blanco	1.5	12.6
3	AMBAR	60	157	5.68	1.50	2.3	27.0	15.2	Rojo	2.0	12.3
4	MS1-560	59	156	5.61	1.63	1.6	33.0	10.0	Rojo	1.9	12.5
5	85P-20	61	143	5.51	1.50	2.6	29.8	9.2	Rojo	2.0	12.4
6	MSH-551	59	175	5.11	1.63	1.8	30.9	17.7	Rojo	2.0	12.5
7	83P17	57	134	4.66	2.13	1.5	33.3	16.2	rojo	2.3	12.1
8	85P-36	61	142	4.44	1.75	1.5	28.7	10.6	Rojo	2.1	12.0
	Promedio	60	153	5.31	1.59	1.9	30.3	14.3	.	2.0	12.4
	$DMS_{0.05}$	1	6	0.56	0.62	0.5	2.3	3.9	.	0.3	0.3
	C.V. (%)	1.8	4.0	10.5	38.8	24.5	7.4	26.9		13.2	2.1

1 = bueno, compacta, 5 = malo, abierta.

Table 2. Mean performance of fifteen brown midrib experimental varieties and four normal and commonly grown sorghum varities in six Central American environments in 2010 and 2011.

Pedigree	Biomass	Pl ht	Lignin	TDN
	kg ha^{-1}	cm	%	%
Centa S-3	12,106	202	6.6	57.6
CI 0916 bmr	11,339	200	5.9	57.0
Centa S-2	11,295	211	7.2	57.8
CI 0947 bmr	10,996	202	5.0	58.6
CI 0932 bmr	10,856	217	5.4	57.4
CI 0910 bmr	10,588	208	6.7	56.6
VG 146	10,482	205	6.9	57.7
Centa-RCV	10,427	189	7.5	57.4
CI 0943 bmr	10,119	196	6.2	57.4
CI 0929 bmr	9,948	203	6.4	56.7
CI 0936 bmr	9,805	201	6.1	57.2
CI 0968 bmr	9,771	200	5.8	57.8
CI 0938 bmr	9,555	200	5.4	58.3
CI 0925 bmr	9,144	190	5.9	57.1
CI 0970 bmr	8,738	182	6.1	57.5
CI 0973 bmr	8,682	198	5.9	57.1
CI 0914 bmr	8,650	184	5.9	57.7
CI 0972 bmr	8,287	180	6.0	57.7
CI 0919 bmr	7,853	179	6.1	57.4
LSD	1,568	14	0.2	0.2

Table 3. Quality parameters for brown midrib experimental lines combined across six environments in Central America.

Experimental bmr variety	Whole Digestible Nutrients (%)	Protein (%)	RAW FIBRE (%)	ASH (%)	ADF (%)	NDF (%)
CI0970, BMR	56.6	7.46	27.4	7.51	31.83	52.48
CI0943, BMR	55.9	6.78	22.55	6.53	28.38	48.12
CI0947, BMR	58.5	6.96	19.42	5.67	25.91	47.01
CI0973, BMR	55.5	7.78	26.32	6.45	31.56	54.63
CI0916, BMR	56.4	6.58	22.72	6.64	26.49	44.78
CI0919, BMR	55.7	8.37	25.48	6.63	28.86	54.1
CI0929, BMR	56.9	5.98	24.71	6.1	25.66	44.77
CI0932, BMR	58.2	6.31	19.09	5.04	24.21	42.85
CI0936, BMR	55.2	6.87	24.78	5.58	28.39	40.23
CI0968, BMR	56.7	6.01	22.84	5.84	25.9	45.52
CI0910, BMR	55.7	5.63	25.25	6.28	29.88	50.25
CI0938, BMR	59.7	7.06	20.23	6.38	25.42	42.22
Best check	54.6	6.6	23.26	6.11	30.95	48.71

Figure 2. A *bmr* sorghum in a trial in Central America.

milling must be effective to substitute for wheat flour in bakery recipes. The increase in the prices of wheat flour has increased the interest in sorghum flour and sorghum based foods because of the economic and nutritional benefits. To effectively utilize sorghum on a domestic basis, simple milling protocols are needed. The objective of this INTSORMIL funded research was to give technical assistance about the equipment and the methods to produce fine flour from sorghum and to establish the performance of grinders available with regard to capacity, costs and quality of the flour produced.

Various combinations of hammer milling, disc milling and sifting were completed to determine the most effective combination and most important steps required to produce the highest quality flour using at the lowest cost. All milling was completed using small equipment available to cooperative bakeries. Quality varied, depending on the order and combination of steps (Table 5). While all methods produced acceptable flour, the treatment H-D-S as the best with 88 % fine flour. In addition, the disc mill (Omega VI) grinder is capable of producing a fine flour with good separation of the bran in sifting. Furthermore, the hammermill (JF3) does not produce a high percentage of fine flour, but is useful as a first pass previous to improve the production of flour during disc milling.

Technology Transfer

Release of INTA Segovia

In January 2011, the Instituto Nicaraguense de Tecnologia (INTA) officially released the new improved sorghum variety INTA Segovia. This improved variety will benefit the resource-poor farmers that grow sorghum on the hillsides in the dry zones. Dry zones occupy 40% of the land area in Nicaragua. This variety will have a significant economic impact in Nicaragua and in neighboring countries as it produces well in drought prone areas which lack sufficient rainfall for growing maize. INTA Segovia produces higher yields than currently grown sorghum varieties under drought conditions. This drought tolerance is due to the large spreading root system and the fact that leaves roll up during dry periods to reduce transpiration.

INTA Segovia is a photosensitive variety and the small-scale farmers In the Las Segovia prefer to sow photosensitive sorghum varieties called sorgo millón (improved), maicillo or Creole sorghum. Due to the limited availability of seed of the improved sorgo millón varieties farmers grow Creole varieties which are lower yielding, lack seed quality, produce weak plants that are susceptible to insects and diseases and have low drought tolerance. INTA Segovia will solve this problem. The panicle of sorgo millón produces white grain that serve as a base for nutritious human food products and serve as a substitute for expensive imported maize in the form of tortillas, atole (thin porridge), pan (bread), turrón (nougat); and as a feed for domestic animals (beef cattle, pigs and poultry). INTA Segovia reaches more than three meters in height, produces abundant foliage that is utilized as fresh silage and as hay to feed dairy and beef cattle. Research data presented by INTA scientists to farmers at the field day indicate that INTA Segovia is a high yielding drought tolerant grain and forage variety that produced 4,678 kg/ha of grain and 13 tons/ha of forage. In addition, sorghum is commonly grown as an intercrop with maize in this region and studies indicate that planting sorghum in association with maize had little effect on the yield of maize whereas the locally grown variety depressed maize yield when grown in association with maize.

Table 5. Quality of and cost to produce sorghum flour using different combinations of hammer milling (H), disc milling (D) and sifting (S) of sorghum flour in El Salvador.

	Yield (% flour)	% bran	% of fine particles (< 180 micron)	% of fine particles to grain weight	kg of grain per hour	kg de grain per kWh	Operator cost in US $ per 100 kg of grain	Energy cost in US $ per 100 kg of grain	Total cost in US $ per 100 kg of fine flour	Total cost in US $ per 100 kg of grain
							(a $ 1.00 . h⁻¹ y $ 0.19 . kWh⁻¹)			
Dx6	100%	0%	74%	74%	13	7.5	$ 7.61	$ 2.54	$10.15	$13.72
Dx4-S-D-S	92%	8%	81%	74%	9	5.7	$ 10.53	$ 3.32	$13.85	$18.73
H-S-H-S	91%	9%	73%	66%	10	8.7	$ 9.79	$ 2.19	$11.98	$18.12
H-S-D-S	90%	10%	80%	71%	12	9.9	$ 8.24	$ 1.92	$10.15	$14.23
H-H-S	86%	14%	67%	57%	15	9.5	$ 6.45	$ 2.01	$ 8.46	$14.80
H-D-S	94%	6%	88%	82%	15	6.8	$ 6.84	$ 2.78	$ 9.62	$11.70

Through a collaborative agreement between INTA and INTSORMIL, a sorghum nursery of improved cultivars, provided by the INTSORMIL program and managed by Rene Clara, INTSORMIL Central America Regional Coordinator based at the Centro Nacional de Tecnologías Agropecuarias (CENTA) in El Salvador, was evaluated in the sorghum production areas of Nicaragua by INTA Sorghum breeders Rafael Obando and Nury Gutierrez. From this nursery, a variety EIME 119 (International Test of Dwarf Sorghum) that was derived from a sorgo millón variety named "PELOTON," was selected. EIME119 was then evaluated in 40 farmers' fields in the municipalities of Estelí, Madriz and Nueva Segovia, Nicaragua.

Sorghum Utilization

In past years, 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. While prices have dropped in the past year, there remains the likelihood that they will increase again. The substitution of sorghum flour for wheat can reduce cost if bakeries can produce sorghum flour.

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 couple of years, CENTA and INTA food scientists have conducted at least four training sessions and educated approximately 200 participants on the use of sorghum flour as a substitute for wheat flour in baked products. 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.

INTSORMIL funded research on sorghum milling capacity is increasing its use. Between 2008 and 2010, six Omega VI mills were purchased by INTSORMIL and are currently being used in El Salvador to produce sorghum flour. The Omega VI mill has a capacity of 2 pounds per minute. While these mills are in place, their use is dependent on two primary factors; the cost of wheat flour and the cost and availability of sorghum for milling domestically.

As interest in utilization in bakeries is based on prices, the CENTA food quality lab has been supported by CENTA to develop fortified complementary food for babies and pregnant women. There was a consultation of raw materials with staff from various agricultural sectors and sorghum was selected as a primary raw material among others to elaborate this prototype. This program will support production of sorghum nationwide. In addition, the World Food Programme (WFP) will establish purchase and sale agreements with producers to buy the sorghum to be used by small food companies in food production.

Finally, the quality of sorghum produced domestically becomes a more important issue when the grain is sold for commercial use. Samples of commercially produced grain were evaluated for milling quality; some were better than others (Table 6). Quality will continue to be a critical component as grain is moved for commercial food use purposes.

Networking

Several INTSORMIL collaborators attended and made presentations at the 55th annual PCCMCA meetings held in El Salvador in May 2011. INTSORMIL regional fund supported the travel of Vilma Calderon, Salvador Zeledon and Rene Clara to the meeting to make presentations. Regional Coordinators Rene Clara and William Rooney traveled throughout Guatamala, 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. Dr. John Sanders participated in economic impact surveys in both Nicaragua and El Salvador for sorghum flour as a wheat flour substitute and initial surveys to estimate the economic impact of brown midrib sorghum varities. 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; this was

Table 6. Grain quality parameters and milling quality of grain from El Salvador Macio Criollos grown commercially in 2008.

Sorghum Variety	Endosperm Texture	Test Weight (Kg./hl)	100 grain weight (g)	Grain Color	Glume Color	Diám. (mm)	Mill Yield (90 mesh) (%)
Centa-texistep	Soft	65.27	2.33	Cream	Purple	3.6	32.19
Punta de Lanza	Soft	59.95	3.6	Cream	Red	4.0	43.57
Zapa Sonsonate	Soft	62.33	2.46	White	Red	3.3	45.51
Cacho de Chivo	Soft	60.28	3.35	White	Tan	3.2	51.37
Mnzano	Hard	64.68	2.53	Cream	Purple	3.6	48.83
Guacotex	Soft	60.10	2.87	White	Purple	3.7	47.15
Sapo %	Hard	60.95	3.53	White	Purple	4.6	38.95
Nueva Guadalup	Soft	59.71	2.70	Pearly	Red	3.2	41.70

completed in late 2010. Additional agreements with other NGOs are in the discussion phase of development. In sorghum utilization, five Omega mills have been purchased and distributed to bakeries in small regions to promote the use and integration sorghum flour into bakery products in El Salvador. Ing Vilma Calderon has made numerous demonstrations throughout the country regarding the use of sorghum flour as a substitute for wheat flour, including several popular press articles in both print and broadcast media. Eliette Palacio has made numerous demonstrations throughout Nicaragua regarding the use of sorghum flour as a substitute for wheat flour.

Ms. Eliana Pinella, M.S. student and U.S. Citizen bilingual in Spanish will complete her M.S. thesis in Food Science in the fall of 2010. She spent three weeks working with Vilma Calderon and others in the CENTA lab in El Salvador on processing sorghum into flour and producing a wide array of food products from sorghum blends with wheat. Her travel and related expenses were supported by the Winrock Farmer to Farmer Program. She returned to work in the food technology laboratory for two weeks to collect additional information and samples of processed grain and baked products for her MS thesis which will provide information on the composition and quality of the major sorghum varieties grown in El Salvador. Dr. L Rooney traveled to El Salvador (twice) and Nicaragua (once) to interact with Ms. Calderon and colleagues in the CENTA Food Lab and with Ms Elliette Palacious in Nicaragua (INTA). A strong program that has conducted numerous workshops and demonstrations exists in Salvador. The program in Nicaragua has conducted several workshops and is working with the baking industry (with partial support form FAO) to demonstrate the use of sorghum in a wide variety of foods especially bread. Sorghum has a bland flavor and light color which allows its use in composite wheat flours without affecting the taste. Only small amounts of maize can be used because it affects the flavor of the bread.

Mr. Ostilio Portillo joined the sorghum breeding program at Texas A&M University in January 2010 to study for a Ph.D. in Plant Breeding. Ostilio is a Honduran with extensive experience in agriculture within the Central American region. He is working specifically with brown midrib forage sorghum varieties developed out of the CENTA/INTSORMIL program and is coordinating their evaluation throughout the region. He will assist Ing. Clara and W. Rooney in coordinating research projects in the region.

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

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Regional Program Description

The Horn of Africa Regional Program supported activities in Tanzania, Uganda, Kenya and Ethiopia, priority Feed the Future countries. Nine U.S. based principal investigators collaborate with regional scientists in four countries. The disciplines include agronomy and soil & water science, economics, entomology, food science, plant breeding, plant pathology, and rural sociology. The program strives to enhance collaboration among stakeholders for technology development and adoption by sorghum and millet farmers recognizing the importance of marketing efficiency and input supply to investment for increased productivity.

An on-going challenge is to maintain human and institutional capacity for sorghum and millet research and development in the Horn of Africa with some loss of experienced researchers to retirement, other positions, etc. The Regional Program continued to build on past accomplishments, providing mid-career professional development opportunities to scientists through training and technical support, and supporting higher degree training. Financial support is inadequate for sufficient training and national agricultural research services are unable to employ an adequate number of scientists. Resources for technology transfer are enhanced by collaboration with NGOs, Extension, seed companies, and input suppliers.

Sorghum/Millet Constraints

Sorghum and millet are indigenous and important staple crops in the Region but productivity is low. Sorghum, compared with pearl millet, production is more important in the region with >2.5 million hectares excluding production in Sudan. Most sorghum grain is used as cooked food but much also is locally brewed. Stover has diverse uses and accounts for approximately 25% of total crop value on average.

Major production constraints include soil water deficits, stem borers, nitrogen deficiency, Striga, weeds, and quelea quelea. The impact of the constraints can be greatly reduced through integration of improved genetics and management. Limited markets, little available money, and inadequate input supply, however, result in little investment to overcome constraints and boost productivity. Sorghum and pearl millet production is less prevalent than maize production in most countries, except in areas of high concentration of sorghum or millet production, marketing of maize is relatively more efficient with lower aggregation costs. Seed supply for improved sorghum varieties is often inadequate for most farmers with seed companies little motivated to supply because of relatively small market compared with maize seed. Fertilizer use varies across the region with relatively more use in Ethiopia than other areas and with some other more marketed crops commonly having higher priority for fertilizer use compared with sorghum. Sorghum is primarily a food security crop providing good nutrition where many other crops fail and therefore important to the livelihoods of millions of rural families. While about 30% of the sorghum produced in the Region is marketed, its market demand is less than many crops. In many parts of Africa, there is a lack of high-quality grain plus little knowledge regarding potential use of sorghum and millet in a wide variety of both traditional and non-traditional foods. Because of the relatively low marketability and because sorghum is a crop of stressful and risky environments, farmers are less inclined to invest in inputs than for more marketable crops in more productive environments. The INTSORMIL regional project team continues to address the productions constraints through technology development and dissemination to farmers in the region, and marketing constraints through exploring new market outlets for sorghum while enhancing profitability along the supply chain.

Host Country Program Enhancement

Researcher Investigator Exchange

Dr. Gebissa Ejeta (Purdue) has continued to collaborate with breeders in Ethiopia on striga resistance. Seed production is underway for resistant hybrids. Good progress in development of striga resistance through years of INTSORMIL support has led to a BM Gates Foundation funded project for deployment of striga resistance in Africa.

Dr. Wortmann visited Ethiopia and Uganda in September 2010 to: finalize arrangements for Feyere Liben and Angela Nansamba to begin their MS study at Haramaya University and Makerere University, respectively, and to review their research proposals; to evaluate smallholder management decision processes and the implications of climate change; to review on-going collaborative research; and to evaluate the progress of a technology transfer project in Uganda, including arranging for fertilizer supply to village level stockists and seed increase and dissemination for improved sorghum varieties. In visits of August-September 2011, various activities were reviewed including: progress of graduate students, on-going collaborative research; implementation of a newly initiated project with EIAR and the International Water Management Institute to evaluate water use efficiency in sorghum and maize under different water regimes and to calibrate DSSAT and APSIM for Ethiopian varieties; and the technology transfer project in Uganda. In February 2011, he evaluated programs funded by AGRA oriented largely on micro-dose fertilizer use for sorghum and millet production in Mali, Niger, and Burkina Faso.

Dr. Jackson and Dr. Weller continued to enhance entrepreneurial capacity for grain processors with training of two women groups. They met with their Tanzanian collaborators and students at the INTSORMIL co-hosted workshop on Sorghum Food Enterprise and Technology Development in Southern Africa in Lusaka, Zambia. Extension technical and business assistance for ongoing sorghum/millet food processors was provided one-to-one by SUA and TFNC team members in Tanzania. Introductory workshops on technical and business aspects of sorghum/millet processing were presented periodically throughout the year in various locals.

Advisory support was given to 5 publications in international refereed journals involving 12 researchers from the region. Another two papers were published in university supported journals involving four researchers from the region.

Several presentations were made at the INTSORMIL co-hosted workshop on Sorghum Food Enterprise and Technology Development in Southern Africa in Lusaka, Zambia; Dr. Weller presented Developing Entrepreneurism:Student Training and Involvement and Measurement of Starch Digestibility in Starch and Flour from Tannin containing Sorghum. Onesmo Mella presented Effects of Malting and Fermentation on the Composition and Functionality of Sorghum Flours. Mr. Makindara presented Sorghum Clear Beer Value Chain. Mgaya et al. presented Feed Concentrates Market and Prospects for Increased Sorghum and Millet Utilization in Tanzania.

Fertilizer Use in Uganda: Allocating Scarce Monetary Resources for High Returns by Kaizzi et al. was presented at the ASA Annual meeting in San Antonio. Atlas of Sorghum Production in Eastern and Southern Africa, Improving Sorghum Production in Water Deficit Environments of Eastern Africa, and INTSORMIL Supported Sorghum Technolgy Transfer in Uganda were presented at a meeting of CRSP directors in Kampala, Uganda.

Constraints on the Adoption of Improved Sorghum Seed in Tanzania: A Value Chain Approach was presented at the 27th Annual Conference of the Association of International Agriculture and Extension Education (AIAEE), July 5 – 7, 2011 in Windhoek, Namibia.

Building Institutional Capacity

One Ph.D. and 2 M.Sc. degrees in Tanzania, a M.Sc. degree in Uganda, and a M.Sc. degree in Ethiopia received partial financial and advisory support from INTSORMIL. Another Ph.D. for Ethiopia had advisory support only from INTSORMIL. Joseph Mgaya studied the feed concentrate value chain in Tanzania for sorghum and millet. Salome Maseki's MSc thesis addressed factors affecting production technology adoption in Tanzania. Jeremia Makindara addressed the sorghum-based clear beer value chain for his Ph.D. research. J. Mark Erbaugh and Donald Larsen provided advisory and financial support to the studies of the above three students. Angela Nansamba is studying conservation agriculture related treatment effects on crop yield, weed composition, and soil properties following 8 seasons of experimentation. Feyera Liben's M.Sc. thesis addresses various aspects of dry soil planting as a means to resilience against variable on-set of rains and includes four site-years of field study and an analysis of historical weather data. Tewodros Mesfin developed his Ph.D. research proposal to address climate change adaptation strategies for farming systems of the Central Rift Valley. Charles Wortmann provides support to the studies of Nansamba, Liben, and Mesfin. David Jackson and Curtis Weller supported Onesmo Mella who completed a M.Sc. degree at UNL in 2011 addressing Effects of Malting and Fermentation on the Composition and Functionality of Sorghum Flour.

Technology Dissemination.

A technology transfer project in Uganda was expanded from six districts in 2010 to 8 districts in 2011 with non-government organization partners in each. An average of more than 20 demonstrations were conducted in each district; these were complemented with field days. Retail marketing of fertilizer was facilitated in the targeted sub-counties and stockists trained to advise farmers on fertilizer use. The technology transfer project supported the advanced evaluation of sorghum lines from which 3 varieties were released in 2011; two of the varieties meet clear beer brewing preferences and are striga resistant. Twelve farmer groups bulked 1.6 t of seed of these varieties. Additional seed increase was done at the National Agricultural Research Institute. INTSORMIL collaborators in Uganda have linked with the seed company NASECO to increase and market seed of newly released varieties. Over 1000 farmers were enabled to obtain seed of the new varieties. Arrangements were made with the Nile Brewing Company to use grain of new white grain varieties for brewing. Arrangements were made with Kampala bakers to evaluate bread baked from a mixture of wheat and white-grain sorghum flours. (Figure 1)

Collaborators in Ethiopia participated in an IDRC supported project for dissemination of results of INTSORMIL supported research.

Figure 1. Photos of two varieties released in 2011 in Uganda, white grain SRN39 (SESO 1) and and brown grain IS25403 (SESO 3).

David Jackson and Curtis Weller continued to collaborate with SUA to provide training for food enterprise development. Two additional Tanzanian women's groups for food processing received the "From Idea to Product" workshop. A previously trained group acted as resource people in these workshops, sharing their experiences. Some equipment was provided to one group and another received financial assistance for production of packaging material.

Dr. Gabriel Elepu of Makerere University collaborated with Don Larsen and Mark Erbaugh in conducting a baseline and market study in areas targeted for technology transfer. Farmers were found to use few purchased inputs for sorghum production. However, farmers who participated in early work with NARI and INTSORMIL reported 40% higher mean yield than non-participants. Profit was determined to be over twice as high for participants compared with non-participants. Breakeven prices were estimated to be 351/- compared with 410/- per kg for participants and non-participants, respectively.

Research Findings

Development of markets for sorghum and millet farmers in Tanzania, coordinated by J. Mark Erbaugh and Donald W. Larson, Ohio State University.

Marketing studies were completed in Tanzania and Uganda with support from Don Larsen and Mark Erbaugh. In Tanzania, small holders in Singida Rural through sub-contracted traders, and commercial farmers in Kilimanjaro Region were the main suppliers of sorghum grain to Kilimanjaro Brewery in Arusha. In a study of sorghum grain price variability, urban market prices attained high levels in October-December and January-March; price lows were not clearly associated with time of year. In another study, processors were small scale using only 50-100 kg of sorghum per week and selling packaged sorghum-other grain flour blends in local markets; processors buy sorghum grain from retailers within regional and nearby markets and occasionally from specific people trusted to supply high quality grain but with no formal contracts; processors often operated in groups with varied success; processing was generally a part-time activity; grain supply of desired quality was inconsistent; and, farmers supplied sorghum individually except in Singida where there were about 4 farmers groups that focused on quality improvement and other collective actions, although farmers were concerned that processors would not award quality. In Uganda, low prices and transport costs were major constraints to greater market participation, and storage was inadequate to delay sale in anticipation of better prices. Most sorghum was sold at local markets as inadequate transport prevented many farmers from taking grain to a town market in order to by-pass one marketing stage.

Product and market development for sorghum and pearl millet in east Africa, coordinated by David Jackson and Curtis Weller, University of Nebraska-Lincoln.

INTSORMIL aided in the development of successful entrepreneurial businesses and marketing expertise through the nurture of two new women's groups in Tanzania. A M.S. student from the Tanzania Food and Nutrition Centre completed his program at the University of Nebraska-Lincoln addressing Effects of Malting and Fermentation on the Composition and Functionality of Sorghum Flour and returned home.

Crop, soil and water management to optimize grain yield and quality for value-added markets in eastern Africa, coordinated by Charles S. Wortmann, University of Nebraska-Lincoln.

Fertilizer response curves were developed for N, P, K applied to sorghum in Uganda with complementary development of 12 other response curves serving maize, rice, bean, groundnut, and soybean. Mean sorghum grain and stover yield from 11 trials were increased by 200% and 46%, respectively, with the addition of just 30 kg/ha N while boosting the protein content by 4%. Application of 10 kg/ha P, with N applied, resulted in additional increase of 14% in grain yield. Recovery efficiency of applied N was over 120% with 30 kg/ha applied; apparently, the small amount of fertilizer boosted root growth sufficiently that soil N that was otherwise lost to leaching was recovered. The response functions for the 15 crop-nutrient combinations were combined using linear programming in a decision tool that identifies the crop-nutrient-rate combinations that maximize returns on the small investments many small holders are able to make in fertilizer. This optimization of fertilizer increases potential profitability of fertilizer for resource poor farmers. The tool is now being promoted for use by extension in Uganda.

In 215 demonstrations in Uganda, sorghum grain yield was increased by 76% with manure application, 144% with N and P application, and 100% following mucuna as a green manure crop. The sixth cropping season of a trial evaluating several potential components of a conservation agriculture system (reduced tillage, cover crop, rotations, and manure and fertilizer use) for sorghum production was completed. Angela Nansamba will write her MSc thesis reporting results of all seasons with additional observations in seasons 7 and 8 of 2011-12.

In Ethiopia, the first year of research on skip-row planting combined with intercropping with dry bean was completed. As in earlier work, not-planting every third row as a means to conserve water for the grain fill period did not result in increased yield. However, planting common bean in the skip row area greatly increased land productivity, both for sorghum and maize based systems.

The first set of field trials and historical weather data analysis was completed for the thesis study of Feyera Liben. The research is to be completed in 2012. In collaboration with IWMI and EIAR, water use research was initiated for sorghum and maize; the study was intended to have three water regimes including rainfed and irrigation at 40 and 60% available soil water depletion but rainfall was adequate that these depletion levels were not detected. The data from both studies is to be used to improve use of crop growth simulation models.

Networking

The INTSORMIL team consists of scientists from various disciplines that develop research and outreach programs for sorghum, millet, and other grains. The Horn of Africa regional program maintains important linkages to the INTSORMIL programs in other regions, in the U.S. and with the country USAID missions. Numerous outreach partners in host countries include government and non-government agencies and community-based organizations such as for technology transfer in Uganda. U.S. PIs met at the University of Nebraska in Lincoln to coordinate regional activities. Seven journal publications, listed in the individual reports for the HOA region, appeared in Year 5 of this project. Links were established with the Ugandan seed company, NASECO, to market seed of newly released varieties, and with Nile Brewing to purchase grain of the two newly released white grain varieties for clear beer production. Links with grain traders and processors were explored or enhance for more efficient marketing of sorghum.

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(Botswana, Mozambique, South Africa, Zambia)

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Regional Program Description

The Southern Africa regional program is composed of 10 research projects directed by 13 scientists representing 7 agencies in 4 countries. Ten U.S. principal investigators collaborate with the regional scientists. Countries and agencies represented are:

Botswana	Botswana College of Agriculture
Mozambique	National Agrarian Research Institute
South Africa	University of the Free State
	University of Pretoria
	Medical Research Council
Zambia	Zambia Agricultural Research Institute
	University of Zambia

The discipline and scientist representation includes: agronomy (1), breeding (3), socio-economics (3), entomology (2), food science (1), and pathology (3). A problem statement guides program activities: "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". Collaborating scientists bring additional collaborations including Future Harvest Centers, NGOs, and governmental or private organizations as well as other programmatic funds for reciprocal leveraging of resources. Technical backstopping and logistical, material and additional operational support is provided by the U.S. collaborators.

The regional program goal 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 for research in other projects. Projects interact to develop new technology and the interaction will increase as additional opportunities and funding become available. The regional scientists are encouraged to collaborate across country boundaries.

Sorghum/Millet Constraints

Sorghum and pearl millet are major indigenous food crops in the southern Africa region. Both crops form part of the basic staple food security crops for many rural communities in Africa, especially in regions where rainfall is a limiting factor for production of other grain crops. Sorghum is the major cereal in Botswana and parts of Zambia and Mozambique and is used as a livestock feed and to make opaque or clear lager beer. 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, as building material for fences and traditional storage facilities, and sweet sorghum juice as a source of sugar.

Constraints include low grain yield potential, infertile soils, variable moisture availability, numerous insect pests and diseases, poor grain quality, lack of improved seed, problems of seed production and supply, poor distribution and market structures, and lack of established commercial end-use products. Socio-economic constraints including lack of credit for farmers/associations, market structure, and the lack of promotion for end-use food and feed markets hinder development of a diversified sorghum and pearl millet industry. Policy constraints place sorghum and pearl millet at a competitive 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 into value added urban markets, grain quality should be improved as sorghum grain with the required quality traits to meet commercial requirements frequently has inconsistent production and supply, and is frequently cited as a major factor in deciding to use maize as opposed to sorghum. Food companies will use but cannot consistently acquire sufficient quantities of high quality sorghums for processing. 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. A system of identity preservation for production, marketing, and processing is urgently needed. In South Africa, a 14% VAT causes sorghum products to be considerably more expensive than their maize equivalents. In order to grow the market for sorghum, less price-sensitive products are required. A promising area is products that exploit sorghum's health-promoting properties. Additionally, three myths contribute to the slow adoption of new sorghum varieties: sorghum is 1) a crop for the food insecure (poor rural) households, 2) a crop grown only in drought affected or marginal areas, and 3) a crop with anti-quality factors (tannins).

New varieties and hybrids with increased grain yield potential, improved environmental adaptation, increased abiotic (drought tolerance) or biotic (disease and insect) stress resistance, improved end-use traits (for food, feed and forage), and other desirable traits are in development by national programs. Reducing 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. Research to improve disease and insect pest management, and sorghum and pearl millet processing techniques to increase use in value added foods is on-going. Technology developed for new uses includes: health-promoting sorghum cookies for use in school feeding schemes, patented processes to produce a sorghum protein-based material for microencapsulation of health-promoting substances, and assays for selection of sorghum cultivars for milling and porridge making. Strong interaction with the cereals industry, sorghum commercial processing companies and other sorghum stakeholders is taking place in South Africa and across Africa.

Stalk rots, ear rots and grain mold are some of the fungal diseases that have caused economic losses for the production of sorghum. Fusarium is one of the fungal genera that are dominant in causing grain mold of sorghum and millet. The ability of Fusarium spp. to produce mycotoxins that have detrimental health effects for both humans and animals make it very important to evaluate their toxin production in diverse crops that are intended for human consumption. This is even more applicable for Fusarium spp. found occurring in crops such as sorghum and millet without any disease symptoms on the plant hosts. Fusarium species produce a number of mycotoxins, including fumonisins (FUM) and moniliformin (MON) that have been shown to have negative health effects or implications on both humans and animals that consume infected grain. It has been shown that fumonisins and moniloformin occur naturally in maize, sorghum and millet, and that selected potentially toxigenic Fusarium strains isolated from maize, sorghum and millet samples can potentially harbor high fumonisin producing Fusarium species.

Institution Building and Networking

Networking

Workshops and Meetings

A database of sorghum and millet food scientists and technologists in sub-Saharan Africa is posted on the INTSORMIL website.

INTSORMIL, the National Institute for Science and Industrial Research (Zambia) and the University of Pretoria co-sponsored the "Sorghum Food Enterprise and Technology Development in southern Africa" workshop in Lusaka, Zambia December 6-9, 2010. Sixty-four registrants from countries in southern Africa, Nigeria and Ethiopia, were in attendance. The workshop objectives were to provide: 1) information to local entrepreneurs on establishing small scale sorghum food business, 2) information to sorghum end-use processors on sorghum genetics and processing potential, 3) a forum to establish communication for enhanced sorghum value chains management. The intent was to provide general information on a wide-range of topics, and more specific detailed information on aspects of particular importance. The workshop included 25 presentations on various aspects of sorghum and sorghum food processing. An on-site visit was made to National Breweries, Lusaka to observe production of Chibuka beer. The Chibuka is brewed using sorghum and maize. Participants were engaged throughout the workshop, asked many questions, and provided useful suggestions for future workshops. Several indicated that based upon the information presented they would be better able to operate their businesses. Participants from the U.S. included Gary Peterson, Lloyd Rooney, David Jackson, Curt Weller, Don Larson, Joan Frederick and John Yohe. Primary conference organizing and logistical activities were through the Department of Food Science, University of Pretoria. The university was represented by Prof. John Taylor, Dr. Gyebi Duodu and Dr. Janet Taylor.

INTSORMIL was a co-sponsor of the MycoRed AFRICA 2011 Conference in Cape Town. The workshop was held under the auspices of the International Society by Mycotoxicology. Primary crops discussed were maize and peanuts. Generally, the mycotoxins present on sorghum and millet do not have the pathogenic levels of mycotoxins present on maize and peanuts. The program addressed a wide range of issues concerning mycotoxins, including production by mycotoxigenic fungi, natural occurrence, their fate during processing from farm to plate, toxicology and regulatory control. The sorghum presentation was given by INTSORMIL principal investigator Dr. John Leslie (Kansas State University). INSORMIL was also represented at the workshop by Dr. Gary Peterson (Texas A&M University) and Dr. Medson Chisi (Zambia).

Dr. David Munthali presented a paper entitled "Assessment of yield losses caused by the sugarcane aphid, Melanaphis sacchari (Zehntner), on 25 sorghum cultivars under Botswana Conditions" at the 3rd Crop Science Conference held at the CICE, Botswana College of Agriculture, Sebele, Botswana, April 11 – 15, 2011.

Dr. David Munthali hosted a field educational visit to the INTSORMIL Entomology trial as part of the 3rd Crop Science Conference held at the CICE, Botswana College of Agriculture, Sebele, Botswana, April 11 – 15, 2011. The 90 participants included farmers, research scientists as well as extension staff. The participants observed the yield potential of the different sorghum cultivars and their relative resistance to the sugarcane aphids, the sorghum stem borer and the shoot fly.

Dr. Medson Chisi participated in a workshop on the Sorghum Seed Multiplication/HIV project. The workshop was held May 11-14, 2011 in Pretoria, South Africa. The workshop was sponsored by GART-SIDA.

Dr. Medson Chisi participated in a workshop on the DONATA/Technology Transfer project. The meeting was held July 9-15, 2011 in Pretoria, South Africa.

Research Investigator Exchanges

INTSORMIL principal investigators Gary Peterson, Lloyd Rooney, David Jackson, Curt Weller, Don Larson and Management Entity Staff John Yohe (Program Diretor) and Joan Frederick (Administrative Technician) participated in the "Sorghum Food Enterprise and Technology Development in southern Africa" workshop in Lusaka, Zambia December 6-9, 2010

Gary Peterson visited Mozambique, South Africa, Botswana and Zambia, March 26 – April 15, 2010. In Mozambique met with Joaquim Mutaliano (sorghum breeding) and Fernando Chitio (entomology) to discuss status and development of their respective research programs. Met with Dr. Calisto Bias, IIAM Director General, to discuss overall progress and status of the IIAM and INTSORMIL relationship, and possibility of graduate training opportunities for IIAM scientists. In South Africa participated in the MycoRed AFRICA 2011 Conference in Cape Town. Met with Medical Research Council collaborators to discuss research activities. Met with Dr. Neal McLaren, University of the Free State plant pathologist and INTSORMIL collaborator, to discuss research progress and plans for graduate degree programs. In Botswana met with Dr. David Munthali, Botswana College of Agriculture entomologist, to discuss research progress and future opportunities. In Zambia met with Dr. Medson Chisi and F.R. Muuka from the Zambia Agricultural Research Institute (ZARI) Sorghum and Millet Improvement Program, and reviewed status of the regional program. Discussed INTSORMIL status with ZARI staff that have been selected for graduate programs at either University of the Free State or Texas A&M University.

Other INTSORMIL principal investigators visiting collaborators include Dr. John Leslie (KSU) to Zambia and South Africa, Dr. Bonnie Pendleton (WTAMU) to Botswana and Mozambique, and Drs. Mark Erbaugh and Don Larson (OSU) to Zambia.

Visits to the region were made by Dr. John Leslie (Kansas State), Dr. Bonnie Pendleton (West Texas A&M), Dr. Mark Erbaugh (Ohio State), Dr. Don Larson (Ohio State), Dr. David Jackson (Nebraska), and Dr. Curt Weller (Nebraska).

Germplasm Conservation and Distribution

Zambia – Approximately 400-400kg of the improved pearl millet variety 'Dola' was produced for distribution in three to five districts for the 2011-2012 crop season. For sorghum, seed production and distribution activities were continued in collaboration with FARA and FoDis at Nanga in the Southern province. Approximately 6.0 tons of the varieties ZSV-36R (1,350kg), ZSV-15 (1,900kg), Kuyuma (1,900kg) and Sima (850kg) was produced at Nanga. Seed will be distributed to approximately 3,000 small holder farmers in some districts in the Eastern, Southern, Western and Copperbelt provinces.

In collaboration with GART (Golden Valley Agriculture Research Trust) and the University of Zambia School of Agriculture Sciences, the sorghum program is participating in on-farm seed production as a means to transfer seed and improved technologies to farmers. Smallholder farmers are provided with sufficient seed to plant one half hectare. The crop is monitored and supervised by extension officers recruited by an NGO such as Harvest Plus and the Food Crop Diversification project (FoDis). At harvest the farmer pays back in kind the same quantity and retains the rest. The seed from the seed-bank is given to another farmer and the process continues till the fourth year when fresh seed is acquired. This has met with some success with smallholder farmers in the country. A total of 2,350 small scale farmers were beneficiaries of this activity. FARA (Forum for Agriculture Research in Africa) has joined the list of collaborators in technology transfer.

Mozambique – Seed of the improved varieties Macia and Sima was planted at 8 locations (Manica, Namialo, Namapa, Mapupulo, Nacaca, Nampula, Nametil and Sussundenga) for increase. Production at Manica, Namialo and Namapa was poor due to severe drought stress. At the other locations total seed production was 12.2 tons (Macia – 6.85 tons and Sima 5.3 tons). The seed will be sold to technology transfer partners (Lozane farm, Pannar, Semente de Nampula, Agakan and small seed producers) for certified seed production. The grain should plant 1,215ha of certified seed in the 2011-2012 cropping season. Germplasm collection and mass selection for population development was conducted at two sites in Cabo Delagado and Nampula provinces. Twelve landraces collected were segregating for seed color and plant types. Landraces with tan plant and white seed were selected for crossing to improved varieties (Macia, Sima, and introductions). The landrace varieties were characterized and seed increased for storage.

Spreading Research Results

The Zambia pearl millet program conducted 2 varietal demonstrations involving released and elite varieties at three locations. Released varieties included those from Zambia, other SADC countries, West Africa and India. Two field days were conducted. Grain samples were exhibited at three agricultural shows.

The Zambia sorghum program continued technology transfer activities in Sesheke, Siavonga, Rufunsa, Luangwa, Petauke, Masaiti and Mambwe districts. FoDis (Food Crop Diversification Project) and FARA (Forum for Agricultural Research in Africa) participated in the activities. A total of 2,350 smallholder farmers benefited from the seed distribution. Activities were designed to promote sorghum production and consumption. With increased production of sorghum, it is expected that incomes will also increase as well as the profitability of farmers resulting in food security. A host of brewing and feed companies have expressed interest in purchasing sorghum grain if farmers meet the production requirements. Several workshops were conducted in the season that brought together farmers, traders and commercial entities that utilise the grain to strategize on sorghum production. Farmers sought assurances for a market and traders for a fair price. Collaborative activities in technology transfer have now moved to other districts in Sinazongwe, Sesheke, Siavonga, Chongwe, Luangwa, Masaiti and Mambwe. FoDis and FARA are participating in these activities. There are now 14 sites involved in the technology transfer activities – 7 'old' sites where collaborators activities are being monitored and 7 'new' sites where activities are being initiated.

In Mozambique, activities were initiated in four pilot districts the strengthen farmers' sorghum production. The activities involved 45 farmers', 8 extension officers and 2 personal from IIAM headquarters specializing in dissemination and technology transfer.

Human Resource Development Strategy

Constance Chiremba, Zimbabwe/South Africa, Ph.D. Food Science- through INTSORMIL support. Ms Chiremba spent 5 months in the Cereal Quality Lab of Prof Lloyd Rooney at Texas A&M University researching to methods for assessing sorghum and maize grain hardness and the role of grain hardness in food product quality.

Doreen Hikeezi, Zambia, Ph.D. Food Science and Helena Jacobs, South Africa, through INTSORMIL support participated in the INTSORMIL-NISIR Workshop in Zambia in December 2010.

Dr Gyebi Duodu is coordinating a Certificate Course in Opaque Beer Brewing (training course in industrial sorghum beer brewing technology) run by the University of Pretoria. This year 2011 some 30 persons from the industry in southern Africa are taking the course.

Research Accomplishments

Entomology

Mozambique - Agriculture is the major activity for the more than 70% of the Mozambique population that lives in rural areas. Production is constrained by lack of improved production technology, lack of off-farm commercial markets, and poor storage conditions for grains. It has been estimated that pests from the farm to storage damage and destroy 30 to 50% of the countries grain production. Thus economically viable options to increase availability of quality grain from the farm to end-users need to be available to promote sustainable commercial production and marketing of sorghum. While chemical control is effective it will be difficult to efficiently utilize in resource poor Mozambique. Genetic resistance to control pests in either the field or storage adds no production costs and is the most economical mechanism to reduce the level of infestation and grain damage in the field or storage.

Primary research in 2010-2011 was to evaluate a selected set of varieties for resistance to the maize weevil (Sitophilus Zeamais) and to score replicated yield trials for resistance to stem borer (Chilo partellus), sugarcane aphid (Melanphis sacchari), and termites. Twenty-four varieties from year 3 yield trials were evaluated in a laboratory trial for resistance to the maize weevil (Table 1). The experimental entries were selected from introduced germplasm in evaluation trials for grain yield potential and adaptation at the Namialo or Mapupula Research Stations. The entries were introductions from primarily Texas A&M University and the Zambia Agricultural Research Institute. Local varieties Sima and Macia were included as standard checks. Entries were scored four months after infestation on a scale of 1 = no damage to 5 = grain destroyed by the maize weevil. Analysis of data from the trial led to the conclusion that significant differences exist among the experimental entries for resistance to the maize weevil. The checks Sima (2.67) and Macia (2.67) exhibited moderate resistance to maize weevil. Entries 02CS30445, 02CS30932, 03CM15102BK, 03CM15067BK, 02CS30331 and 02CM19225 were less damaged than other entries in the test including the local varieties Sima and Macia. The less damaged entries are from the Texas breeding program and were developed for resistance to sorghum midge, grain weathering/mold, or drought. Nine entries - Elite 16/705 E-7, 04CS523-2-1, ICSV 93010-1/708 E-9, 04CS 798-7-1, 03CM1104BK, 04CS608-6-1, 04CS573-3-1, SDS 1458-1-3-2/724 E-5 and SDS 5006 WSV187/E-4 – were significantly more damaged than the more resistant entries. The resistant entries have the potential to contribute to improved production and utilization with increased grain yield potential and less susceptibility to maize weevil damage.

Table 1. Damage score in storage of 24 varieties evaluated for resistance to maize weevil (*Sitophilus Zeamais* at Nampula, Mozambique.

Entry	Varieties	Damage score†	
12	02CM19225	2.33	d
14	02CS30331	2.33	d
15	03CM15067BK	2.33	d
19	03CM15012BK	2.33	d
23	02CS30932	2.33	d
24	02CS30445	2.33	d
16	04CM452-4-1	2.67	cd
1	25 V 15/709E-1	2.67	cd
6	Sima	2.67	cd
13	Macia	2.67	cd
20	04CS884-5-1	2.67	cd
21	02CS5067	2.67	cd
4	ZSV 15-4/723 E-3	3.00	bcd
5	GVS 17/710 E-2	3.00	bcd
17	03CS GWT115	3.00	bcd
2	SDS 1458-1-3-2/724E-5	3.33	abc
8	SDS 5006 WSV 187/E-4	3.33	abc
11	04CS608-6-1	3.33	abc
22	04CS573-3-1	3.33	abc
9	04CS798-7-1	3.67	ab
18	03CM1104BK	3.67	ab
3	ICSV 93010-1/708 E-9	3.67	abc
7	ELITE 16/705E-7	4.00	a
10	04CS523-2-1	4.00	a
CV%		17.57	

†Scored on a scale of 1 = no damage up to 5 = grain destroyed.

Three sorghum trials were scored for resistance to stem borer, sugarcane aphid and termites. Trial 1 consisted of 12 entries (10 experimental entries and local checks Sima and Macia) grown at Mapupulo. The experimental entries were introductions from Zambia. For stem borer the most resistant entry was Macia. No significant differences between any of the entries were identified. For termites Sima was the most resistant entry. All entries expressed moderate to high resistance to sugarcane aphid. Trial 2 consisted of 15 experimental entries from Texas and the local checks Sima and Macia. Entries sustained little damage to termites. Significant differences for resistance to stem borers and aphids were identified. Entries 02CS30932, 02CS30445, 02CS5067, 04CM884-5-1, 04CS452-2-1 and 02CS30331 were the most resistant entries, and were more resistant than either Sima or Macia. Ratings for sugarcane aphid resistance were similar and although differences were apparent they were not significant. Entries 02CS30932 and 02CS30445 were also most resistant to maize weevil. Trial 3 consisted of 20 entries (19 entries and local check Sima) was evaluated for resistance to stem borer and termite at Namialo. The varieties ICSV 93046 and SDSL 90167 were most resistant to stem borer. Most entries expressed at least a moderate level of stem borer resistance (damage less than 2.1 on a scale of 1 = no damage to 5 = plant death). All lines expressed moderate resistance to termites.

Botswana - Primary research emphasis is to study the effect of leaf damage caused by the sugarcane aphid (Melanaphis sacchari Zehntner) on grain yield of sorghum cultivars under Botswana conditions. Damage caused by the sorghum stem borer (Chilo partellus Swinhoe) and the sorghum shoot fly (Atherigons soccata Rondani) is also evaluated. Field and cage experiments are conducted to assess abundance of sugarcane aphid, sorghum stem borer and sorghum shoot fly on the cultivars and of natural enemies such as coccinellid predators at different plant phenological stages to determine the relationship between crop stage, abundance of pests and their natural enemies. Field and cage experiments are conducted to assess abundance of sugarcane aphid, sorghum stem borer and sorghum shoot fly on the cultivars and of natural enemies such as coccinellid predators at different plant phenological stages to determine the relationship between crop stage, abundance of pests and their natural enemies. Results obtained during the previous seasons showed that abundance and importance of the pest increases with plant age. Farmers in Botswana and other SADC countries mainly grow sorghum for grain. Therefore, it is important when selecting germplasm for use by farmers that the relationship between sugarcane aphid damage and grain yield reduction is understood for each cultivar being evaluated.

The sugarcane aphid test was composed of 35 experimental germplasm entries from Texas A&M University developed for resistance to the sugarcane aphid and five local varieties that are cultivated in the SADC region. The entries were evaluated from the vegetative growth stage through the grain fill and maturation stages to determine relative resistance to the sugarcane aphid. None of the entries were completely resistant to the sugarcane aphid. To determine the effect of sugarcane aphid infestation on grain yield plants were grouped into three damage levels: those displaying minimal (rated as 1 or 2); moderate (rated as 3 or 4) and severe (rated as 5) damage levels, based on the percentage of damaged leaves per plant. Plants that sustained minimal sugarcane aphid damage were assumed to produce grain weight per panicle that was closer to amounts expected from pest free plants. Effect of sugarcane aphid damage on yield was estimated by comparing yield obtained from plants that suffered moderate leaf damage (rated as 3 or 4) or those with severe leaf damage (rated as 5) with the yield produced by plants that had minimal leaf damage (rated as 1 or 2).

The proportion of infested plants per variety showed that sugarcane aphid infestation did not vary significantly among the entries (Table 2). The overall infestation level was low (38.1% per plot). However, the damage scores indicating severity of damage on the plants indicated that five cultivars: WM#177, (SV1*Sima/1523250)-LG15-CG1-BG2(03)BGBK-LBK-PRBK, (Sureno*LG70)-HW5-CA1-CC2-CA1-LG1, (Segaolane*KS115)-HW3-CA3-LD1-CABK-CA2, and (Tx2971/LG70*Ent.62/SADC)-HWBK-CA10-CA2-LE1 had the lowest damage (rating of 1) and were relatively more resistant. Four entries: Segaolane (local check), (LG35*WM#322)-BE40-LG1-CA1-LGBK-CABK-CABK, (Tegemeo*ICSB12)-CA2-CC1-CABK-CA2 and (Doredo*Tegemeo)-HW4-CA1-CA1-CCBK-CABK-CABK-LG1 sustained the greatest sugarcane aphid damage (rating of 4), indicating they were the most susceptible entries. One resistant cultivar, (SV1*Sima/1523250)-LG15-CG1-BG2(03)BGBK-LBK-PRBK was among the cultivars with the least sugarcane damage during the previous (2009 – 2010) cropping season. The other five cultivars with the lowest damage (rating of 1) were in evaluation for the first time. The other cultivars that had minimum sugarcane damage during the 2009-2010 season: Ent.62/SADC;

Table 2. Trial evaluated for resistance to sugarcane aphid and other insdect pests. Sebele, Botswana, 2010-2011.

Pedigree	Sugar cane aphid	Damage score	Number of Coccinelliedae	% Stem borer	% Shoot fly
WM#177	9.1	1	0.0	40.0	11.2
(SVI*Sima/IS23250) –LG15-CG1-BG2(03)BGBK-LBK-PRBK	12.8	1	1.3	30.2	6.6
(Sureno*LG70)-HW5-CA1-CC2-CA1-LG1	17.7	1	1.0	38.6	16.2
(Segaolane*KS115)-HW3-CA3-LD1-CABK-CA2	3.3	1	0.0	24.8	5.4
(Tx2971/LG70*Ent.62/SADC)-HWBK-CA10-CA2-LE1	10.3	1	0.7	13.9	4.9
Tegemeo	35.6	2	6.7	22.3	9.9
Macia	29.6	2	3.3	17.8	8.0
Ent62/SADC	30.0	2	0.0	40.6	12.8
(Dorado*Tegemeo)-HW15-CA1-CC2-LG1-CABK	29.6	2	4.3	30.2	8.8
(9MLT176/(MR112B-92M2*Tx2880)*A964)-LG8-CABK-LGBK-LGBK--CABK	27.7	2	1.0	26.1	15.8
(Segaolane*WM#322)-LG2-LG2-(03)BG1-LG1-LBK-PRBK	39.1	2	0.7	27.7	13.6
(Macia*TAM428)-LL2	31.1	2	2.7	25.7	4.6
(Macia*TAM428)-LL9	34.4	2	0.0	30.1	16.1
(6BRON161/(7EO366*Tx2783)*CE151)-LG5-CC2-(03)BG1-BG2-LBK-PRBK	33.3	2	1.7	31.0	11.8
(Tegemeo*ICSR-939)-CA7-CC1-CABK-CA1	30.0	2	0.0	24.0	10.8
(5BRON139/(6EO361*GR107)*Tegemeo)-HG7-LG1-LG2	31.9	2	1.7	23.9	9.3
(9MLT176/(MR112B-92M2*Tx2880)*Dorado)-CA4-CA1-CC2-CABK-CABK	27.2	2	1.3	22.6	7.0
(9MLT176/(MR112B-92M2*Tx2880)*Dorado)-BE9-CA1-CA2-LGBK-CABK	23.9	2	0.7	19.1	11.2
(Kuyuma*5BRON155)-CA5-CC1-CABK-CA1	33.3	2	0.3	32.8	13.3
(((03BRON171/(6OB124*((Tx2862*(Tx2868*P1550607))-LG53-CG3))-LG3-LG1-CG3-CG2))*Tegemeo)-HWBK-LG7-CA2-LE2	23.6	2	0.3	18.7	3.5
(Tx2971/LG70*Segaolane)-HWBK-CA20-LG1-LE1	22.2	2	0.3	13.1	2.0
(Kuyuma*5BRON155)-CA5-CC1-CABK-CABK	46.2	3	4.0	30.1	11.4
(Dorado*Tegemeo)-HW13-CA1-CC2-LGBK-CABK	51.4	3	1.3	32.6	13.7
(5BRON151/(7EO366*GR107B-90M16)*Tegemeo)-HG7-CC2-CABK-CABK	57.2	3	7.7	19.8	9.8
(CE151*Tx430)-BE3-CA1-LGBK-CABK-CA2-LG1-LE2	52.3	3	0.0	20.7	2.9
(5BRON139/(6EO361*GR107-)*Kuyuma)-HG3-LD2-CABK-CA1-LG2-LEBK	50.0	3	1.7	19.5	6.7
(ZSV-*((Tx430*(Tx430*P1550610))-LG53-CG3-CG3-PR7-LI1-PR2))-CA2-CC1-LGBK-LG1-LG1-LEBK	52.4	3	0.0	19.9	1.0
(Tx2971/LG70*Tegemeo)-HWBK-CA19-LG2-LE1	53.6	3	4.3	18.2	5.3
Segaolame	64.4	4	4.3	41.4	14.3
(LG35*WM#322)-BE40-LG1-CA1-LGBK-CABK-CABK	64.1	4	4.0	27.5	15.3
(9MLT176/(MR112B-92M2*Tx2880)*A964)-CA3-CABK-CCBK-CABK-CABK	64.1	4	4.0	25.8	19.2
(Tegemeo*ICSB12)-CA2-CC1-CABK-CA2	69.5	4	8.0	27.1	11.4
(Dorado*Tegemeo)-HW4-CA1-CA1-CCBK-CABK-CABK-LG1	63.3	4	4.3	21.4	8.0

(Segaolane*WM#322)-LG2-LG2-(03)BG1-LG1-LBK-PRBK; (Macia*TAM428)-LL2; Macia*TAM428)-LL9 and (BRO161/(7EO366*Tx2783)*CE151)-LG5-CG2-(03)BG1-BG2-LBK-PRBK also had relatively low sugarcane aphid damage (rated as 1 or 2) during the 2011 season. These cultivars also had relatively low grain yield loss during the 2009-2010 growing season. Consistent results over two seasons confirm that plant resistance can be effective in reducing damage caused by sugarcane aphid on sorghum. The finding that new sorghum breeding lines being were evaluated for the first time sustained even less damage than the most promising lines that had been evaluated in previous seasons suggests that further breeding for resistance against the sugarcane aphid will result in production of germplasm with greater levels of resistance.

Analysis of data for stem borer and sorghum shoot fly led to the conclusion that for either pest, damage was not significantly different among the entries. For shoot fly, the overall damage was 24.9% (ranging from 31.1 to 41.4%), indicating all entries were equally susceptible to causing minimal to moderate damage. For sorghum shoot fly average damage was 9.4%. Since shoot fly damage causes a "dipteran dead heart" by killing the growing point, damage of 9.4% represents a loss of grain yield.

Food Science

Collaboration between the Department of Food Science and INTSORMIL involves four activities: 1) dissemination of technology know-how between scientists and industrial end-users in Southern Africa; 2) creation and maintenance of a database for scientists and processors on the end-use quality attributes of the major sorghum and millet varieties in Southern Africa; 3) promotion of sorghum in the health food niche market; and 4) improving the viability of sorghum as a lager/stout/non-alcoholic beverage raw material.

There is a reasonable-sized corps of food scientists and technologists in sub-Saharan Africa who are highly knowledgeable about sorghum and millet science and processing technologies. However, their interaction with existing and potential processors of these grains is very sub-optimal. In 2008, a database of sorghum and millet food scientists and technologists in sub-Saharan Africa with their specific areas of expertise was posted on the INTSORMIL website. This database was updated in February 2011 and comprises information on 35 scientists across sub-Saharan Africa. The intention is that it will be updated every two years.

There are three major commercial uses for sorghum in sub-Saharan Africa, each with specific quality requirements: meal and flour for porridge and food manufacture, malt for brewing, and unmalted adjunct for beverages. Existing and potential processors of sorghum in southern Africa are generally confused as to which of the large number of available and potentially available sorghum varieties are most appropriate to their needs. To provide information to address this problem research is on-going in four areas: 1) Development of very simple and rapid end-use quality assessment methods. Current research is concentrated on development of a simple assay to quantitatively measure sorghum grain color. The assay is based on making an alkali extract and measuring the extract color intensity with a colorimeter. 2) Understanding the scientific basis of sorghum quality attributes. Current research concentrated on determining the role of the sorghum kafirin and prolamin proteins in grain hardness. The work provided clear evidence of the role of gamma-kafirin disulphide bonded cross-linking in the corneous endosperm phenotype. 3) Development of a simple system for sorghum end-use quality assessment. Research for this activity is progressing slowly. 4) Creation of a database on end-use quality attributes of sorghum varieties in southern Africa. The database on plant characteristics, grain quality attributes and some end-use quality attributes of most of the improved sorghum varieties and cultivars available in Southern Africa has been created and is available on the INTSORMIL website. Additional data will be added during 2011-2012.

In South Africa, sorghum products are considerably more expensive than their maize equivalents because of a 14% Value Added Tax. In order to grow the market for sorghum, less price-sensitive products are required. A promising area is products that exploit sorghum's health-promoting properties. Development of nutritious sorghum-based foods, particularly cookies, which have high antioxidant activity by being rich in polyphenols and are protein-rich through fortification with soya provide a unique opportunity to move sorghum into new market opportunities. The research on cookies has been extended to encompass the use of naturally fermented whole grain flours and also the use of pearl millet. Fermentation is nutritionally advantageous as the good levels of minerals that are present in the whole grain are made more bioavailable. Excellent technical progress has been made with development of sorghum-based cookies. The concept of sorghum cookies for school feeding in sub-Saharan Africa is being actively marketed. Development of sorghum protein-based microparticles (microspheres) as encapsulating agents for nutraceuticals and other health-promoting agents will provide another new market opportunity to promote the health benefits of sorghum. A patented process (reported in 2010) for producing microparticles from the sorghum kafirin protein has been developed. Scaling-up of the process is being investigated with the use of spent grain, the by-product of sorghum brewing and sorghum bioethanol production, being used an inexpensive raw material. Several health and pharmaceutical applications for the microparticles are being actively pursued.

Commercial sorghum brewing, both lager and stout brewing, traditional opaque beer brewing and non-alcoholic beverage production, is developing rapidly across Africa. There are, however, several sorghum-related technical aspects that require research and development work in order to improve economic viability. Two areas are being investigated: 1) Optimization extract (fermentable sugar yield) from sorghum in lager and non-alcoholic beverage production. Preliminary indications are that red non-tannin sorghums can yield the same level of wort (unfermented beer) as white tan-plant sorghums. The next step is to assess whether the use of red non-tannin sorghums impact product quality. 2) Improving fermentability in sorghum lager brewing. This is a new area of research and has only recently been initiated.

Market Development

A survey of sorghum and millet farmers in a high potential area was conducted in two blocks of Luanshya district north of

Lusaka. Luanshya was expected to be 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. In the Luanshya survey, 170 households were visited, of which 169 were complete interviews. The area planted to sorghum (0.47ha) is low as well as the sorghum yield (643 kg/ha) and quantity harvested (258 kg) harvested. The percent of households using hybrid seed was very low (9%) and the use of many recommended management practices. This study measured technical efficiency and its determinants in sorghum production, technical efficiency in field crop production and the effect of growing sorghum on technical efficiency in field crop production.

Technical efficiency in sorghum production is affected by a number of household and farm characteristics. Access to credit, presence of dependents, scale of field crop production, value of assets and income from livestock activities improve technical efficiency. On the other hand, household size, use of animal draft power, farm size and location in low rain areas reduce efficiency. Some of the factors are outside the farmers control and cannot be altered to influence efficiency. These include household size, number of dependents and location. However, understanding the way they influence efficiency can be useful in identifying households who are most likely to be technically inefficient in sorghum production due to the interaction of these factors in their environment. Means of cushioning or mitigating the negative effects of these factors can then be identified. If the factors that are out of the farmers control have a positive influence on efficiency, these traits can be exploited to improve productivity further. Controllable factors include crop and field management practices like use of animal draught power are easier to manipulate in favor of technical efficiency. Sorghum production efforts directed at increasing accessibility to agricultural loans could have the potential to increase the efficiency of sorghum production, and productivity in the country. This study also revealed differences in household and farm characteristics between sorghum and non-sorghum farmers. Generally, sorghum farmers are poorer with lower incomes and assets. The non-sorghum farmers have traits that have been identified as having the potential to increase efficiency in sorghum production. If these farmers could be encouraged to grow sorghum, productivity in sorghum production could be increased in the country. This requires an understanding of the factors underlying a farmer's decision to grow sorghum or not. Further research into the farmer's crop choice decision making process would highlight these factors and guide policy and stakeholders in the promotion of sorghum production.

In order to measure the effect of growing sorghum on technical efficiency in field crop production, a measure of efficiency in field crop production had to be estimated. Technical efficiency in field crop production was also generally low among the households in the sample with an average of about 35 percent, another indication of potential to increase crop production without changing input levels being used by the farmers. Technical efficiency in field crop production was positively influenced by the access to credit and commodity price information, wealth of the household (as measured by value of household assets), use fertilizer that was paid for by the farmer, hired labor, income from livestock activities and renting land as opposed to owning or borrowing it. The presence of dependents, female headed households, age of the household head and location of farm in low rain areas have a negative influence on efficiency. Farm size had a positive effect for small farms and a negative effect for farms larger than 8.5 hectares. Of interest was the influence of growing sorghum on a household's technical efficiency in field crop production. In this sample, households who grew sorghum had a higher technical efficiency than households who did not grow any sorghum, holding all else constant. This is an indication that adding sorghum to a farmer's cropping basket will improve the efficiency with which the household produces all the field crops given their inputs. Further research into the influence of producing sorghum on efficiency would be useful in understanding the pathways, other than low input requirements, in which sorghum improves efficiency in production of other crops.

A paper has been prepared that shows the results of the sorghum and millet seed value chain study. The main objective has been to understand the different actors in the chains, and to identify the factors that determine the observed low level of technology used. Information from 130 farming households, 57 seed dealers, five seed companies, and two research and development institutions was collected with the view to understand their characteristics, key roles, competitiveness, and constraints with respect to the improved seed value chain. Most seed value chain actors play multiple roles, ranging from varietal development, inspection and certification, seed production, processing, marketing, and provision of extension services.

This study found that adoption of improved seed and fertilizer is very low among sorghum and millet growers and relatively low for maize growers. Growers are using the same sorghum and millet seed for an average of 13.7 years when the recommended replacement rate by researchers is about three years. Research station yields for sorghum open pollinated varieties (OPVs) range from 3 to 5 tons per hectare in contrast to a mean sorghum yield of 0.3 tons per hectare on farmers' fields. The farm yield is less than 10 percent of the research station yield. The gap between research station yields and farm yields is very large. Public institutions lack documentation of improved production practices by sorghum and millet growers. The responsible institutions should make it a priority to collect data of improved practices along with other data so as to understand current practices and to improve farm productivity results.

There are a number of key actors in the seed value chains for maize, sorghum and millet. They include public sector agencies such as ZARI, SCCI, UNZA, and the Ministry of Agriculture and Cooperatives who play key roles in varietal development, inspection and certification, and in providing extension services. From the private sector, there are five seed companies who mainly deal in maize hybrid seed even though sorghum and millet are also sold by three of the private companies. Most of these companies perform multiple functions which include varietal development, seed production, seed processing and distribution. Farmers' organizations, NGOs and faith based organizations work in close collaboration with the government departments and seed companies in seed distribution and extension services. The most important seed end users are small scale, mainly subsistence, farmers. Access to support facilities relevant for agricultural development was rated poor by these farmers. These included poor access to agricultural information, modern inputs, and poor quality of seed, lack of processing technologies and lack of stable markets.

One huge constraint faced in sorghum and millet production was lack of breeder seed/ foundation seed by some seed companies. Improved sorghum and millet varieties available on the market were released by the government in collaboration with ICRISAT. Zamseed was given exclusive rights to market the varieties when it was still a parastatal company. Upon privatization, Zamseed was given ownership of breeding material by the government for a limited number of years. Twenty years later, Zamseed still had exclusive rights to breeder material for government developed sorghum and millet varieties. The social cost of the intellectual property rights issue to sorghum and millet growers in terms of lost opportunities to buy more productive varieties has undoubtedly been very high. Today, over 20 years later, seed companies are free to market any new sorghum and millet varieties that are released by public research.

Breeding

Pearl Millet

Improved seed of the new bristled and bird-tolerant variety Dola was distributed to two districts, Kaoma and Senanga. Sixty-four farmers, with more than 50% female, accessed the seed. Because of logistical problems seed was distributed late which discouraged most farmers from buying the seed citing late delivery. Pearl millet is planted late prior to or at the onset of the rains (October-November). The crop produced good yield with farmers that declined purchase regretting their decision. Monitoring and evaluation of farmers' crop is hampered by inaccessibility of most areas of production due to poor roads, lack of bridges, lack of funds, and floods.

The grain quality of 27 released, elite, indigenous or exotic pearl millet varieties along with one sorghum, one cowpea and one cassava variety was evaluated. The evaluation was conducted by the University of Zambia's Food Science Department. Traits evaluated were protein, fat, moisture, calcium, fiber, energy, carbohydrates and phosphorous. Values comparable to those reported in literature were obtained. A detailed report of the study is in preparation.

Five genetically and morphologically dissimilar parental composites are at various stages of improvement by recurrent selection, and new varieties formed from the cycles when opportunity allows. During 2010-2011, three new varieties were formed from the new late, new local and new late back-up composites. Severe bird damage impaired formation of new varieties from the new early and new early back-up composites. More than 200 experimental cytoplasmic male-sterile (CMS) based top-cross hybrids were formed from the 19 CMS A-lines of A1, A4 and A5 cytoplasm types. The A-lines were obtained from ICRISAT and used as seed parents with 12 experimental (11 Zambian and 1 University of Nebraska) top-cross pollinators. In addition, 45 protogyny population hybrids were formed from 16 released, elite and exotic open-pollinated varieties.

To create new breeding populations and to diversify the germplasm base, selfing of 35 cream and white seeded lines continued. The progenies will be used to create varieties, hybrids, composites and breeding lines and maintained as unique germplasm for future use. Nineteen A-/B-line pairs were maintained and seed to 12 R-lines increased in isolation plots.

Seven replicated grain yield trials involving open-pollinated varieties, composites and experimental hybrids and hybrid parents involving 28 to 182 entries were conducted at three locations. Significant differences were obtained among genotypes in all trials. From the advanced trials, 11 early and 7 late maturing open-pollinated varieties were identified for future testing. The varieties exhibit excellent grain yield with some varieties producing in excess of 3,000 $kgha^{-1}$.

Sorghum

Zambia

The National Agriculture Policy of 2005 and the Sixth National Development Plan (SNDP) 2011 – 2015 emphasizes crop diversification where maize does not dominate the agriculture landscape as a means to increase food security at the household level and assist market development. Sorghum is an important traditional cereal crop, particularly in drier environments and for smallholder farmers, with a major role in achieving this goal. Local sorghum varieties have good quality traits e.g., food and brewing but yield is low. New improved varieties of sorghum that are high yielding and resistant to pests and diseases have been released. However, poor grain quality, lack of improved seed and end-use markets have been cited as the main reasons for low sorghum grain production and lack of commercialization. Additionally, improved varieties have not been evaluated under low pH and their performance under these conditions is poor. Improving the quality of the grain for food, feed and other industrial end–uses is critical in increasing market access. Varieties with the quality traits desired by end-use processors will lead to a measurable increase in the use of sorghum grain, thus increasing commercialization and food security at the household level. The challenge is to develop stable sorghum varieties for all the agro-ecological zones in Zambia that meet grain quality production standards for end-use.

A number of trials were designed to identify suitable varieties and hybrids from the breeding nursery and crossing block with suitable traits for food, forage, and brewing purposes. The trials were conducted at Mansa, Golden Valley Research Station and Lusitu in the 2010 and 2011 season. Slightly above normal rains were recorded at all stations. GART recorded the highest trial means and low CVs while Mansa Research Station had low mean yields with high CVs. There were no significant differences among entries in most trials at the station but agronomic scores were taken. The site for research trials at Mansa had leached soils with low organic matter with a pH of 3.5 and management was poor.

In general, the season provided an opportunity for the program to identify sorghum lines that have potential for various end-uses.

New varieties ICSV 930101, [ICSV112*SDS3136]1-13-1 and [SDS5006*WSV187]23-2-1 yielded 20 – 30% more than the variety check Kuyuma in region I and II. In the Sorghum Advanced Variety Trial at GART, new varieties ZSV-36R, [Framida*SDS3845] F6-5, and ELT3-11 produced more than 5 tons/A, between 9 – 20% more grain than Kuyuma (Table 3). New hybrids (ZSH-205, ZSH-222 and ZSH-225) in the preliminary trials performed well (had more than 4500 kg/ha) and will be evaluated widely in the coming season. Entries in the Sweet Sorghum Trial at Mansa performed poorly but at GART varieties Madhura and Wray had a Brix reading of 17.7 and 18.5% respectively while Sima the check had a reading of 10.2%. Among the forage sorghum hybrids, FSH-207 had a high fresh weight of 29 tons per hectare, significantly more than the dual purpose sorghum variety Sima had a mean of 20 tons per hectare (Table 4). Additionally, the experimental hybrids MMSH-1040 (24 t/A), FSH-201 (24 t/A), MMSH-1296 (23 t/A) and FSH-106 (23 t/A) all expressed a higher fresh weight than Sima. In advanced testing at grain varieties and forage hybrids with adaptation to specific environments that will produce significantly more grain or forage than local varieties or checks. When released and adopted by farmers the new technology can increase the supply of grain for improved food security and enhanced end-use markets.

Both open pollinated varieties and hybrids were developed for target end-uses. Some of the varieties and hybrids were sent to the Department of Food Science at the University of Zambia (UNZA) and the University of Pretoria for quality analysis. The National Institute for Science and Industrial Research (NISIR) is evaluating some of the varieties for their suitability in brewing. Entries selected for grain quality evaluation are from the advanced trials and have been evaluated at both on-station and on-farm and are generally two or more seasons before release. Traits associated with improved quality such as tan plant, thin white pericarp, and hard endosperm are routinely used to identify sorghum lines for use in food quality.

The line designated ZSV-36R, a brown seeded open pollinated variety with moderate levels of tannins in the sub-coat has been selected for pre-release. The variety has outperformed local varieties by 600% and can withstand bird pressure better than white grain types.

Mozambique

Sorghum is a major cereal grain and is considered a food security crop in most provinces in Mozambique, especially in provinces where rainfall is a limiting factor for maize and rice production. The adoption of previously released varieties Macia (1999) and Chokwe (2003) has been minimal and unknown because of inadequacies of the seed system. A major constraint to increasing sorghum production and food security is the use photosensitive, late-maturing landrace varieties.

Table 3. Sorghum Advanced Variety Yield Trial at Golden Valley Research Station in 2010/2011

PEDIGREE	ENTRY	DAYS TO 50% FLOWER	PLANT HEIGHT [cm]	HARVESTABLE ROWS	FRESH HEAD WEIGHT [KGS]	GRAIN WEIGHT [kgs/Ha]
ZSV-36R	1	81	204	61	4.5	5944
[Framida x SDS3845]F6-5	4	78	208	69	4.7	5567
ELT3-11	3	76	187	63	4.0	5392
[ICSV112 x WSV187]15-1-1-1	10	71	190	58	3.8	5158
[ICSV112 X WSV387]19-3-1	9	74	208	55	3.6	4975
KUYUMA	11	78	203	54	3.5	4958
SDS 3047	6	71	188	55	3.7	4889
ZSV-15	12	77	211	62	3.8	4886
CZADIN 1237-1	5	75	189	63	3.7	4656
ELT2-16	17	76	178	65	3.6	4542
ZSV-15-4	7	69	177	55	3.7	4519
ELT2-14	15	86	195	65	3.5	4506
ELT2-22	16	74	177	62	3.3	4344
ELT1-19	18	77	203	62	3.3	4300
[ICSV112 x SDSA3136]1-13-1	2	83	174	54	3.1	4147
ELT1-11	19	76	162	61	3.1	3897
ELT2-23	20	76	217	69	4.1	3630
ICSV930101-1	8	86	222	58	2.5	3517
ELT3-11	13	71	207	66	3.7	2816
SD DEVIATION		5	16	5	0.5	741
MEAN		76	194	61	3.6	4581
LSD		9	45	21	1.4	1353
CV [%]		6.3	8.3	8.2	13.3	16.2
F CALCULATED		2.3	1.0	0.5	1.0	0.9
F REQUIRED [5%]		2.1	2.1	2.1	2.1	2.1
t 0.05 = 2.021						

Table 4. Forage Sorghum Hybrid Trial at GART 2011

PEDIGREE/CROSS	ENTRY	DAYS TO 50% FLOWER	PLANT HEIGHT [m]	STAND COUNT [COUNT]	FRESH WEIGHT [Kgs/Ha]	DRY WEIGHT [kgs/Ha]
ZSH-207	4	75	2.9	47	30972	14037
MMSH-1040	6	82	2.5	42	24222	6243
FSH-201	1	79	2.3	34	24074	6699
MMSH-1296	9	80	2.6	48	22704	6550
FSH-106	2	81	2.3	36	22694	6484
SIMA	10	81	1.7	48	20556	7366
MMSH-1388	8	76	2.8	38	20296	10759
FSH-100	3	75	2.4	33	15333	6482
MMSH-1257	7	73	2.4	30	14222	5108
MMSH-1038	5	80	2.2	28	13806	5358
Mean		82	2	42	20889	7509
LSD		59	161	35	5451	1071
CV%		5	11	24	29	37

Table 5. Grain yield and other performance traits of varieties grown at Namialo and Mapupulo during the 2010/2011 cropping season.

Variety name	Plant height cm	Days to 50% Anthesis	Stem borer damage rating	Sorghum midge damage rating	Sugarcane aphid damage rating	Yield_ton/ha Namialo	Yield_ton/ha Mapupulo
GV SIMA 710E-2	156.7	78	1	1	2	7.020	8.260
ICSV-93010-1/708 E-9	138.3	73	2	1	2	6.320	6.120
ELITE-17/707 E-6	138.3	75	2	2	1	5.990	6.100
ZSV-15/709E-1	161.7	75	2	1	2	5.640	4.940
(SDS-5006*USV-187)E-4	139.7	73	1	1	2	5.450	6.020
ZSV-15-4/723 E-3	121.7	75	2	1	1	4.920	5.520
SDS-1958-1-3-2/724 E-5	154.7	75	1	1	1	4.680	4.910
SDS-3047/722 E-8	141.0	75	2	1	2	4.620	7.380
KUYUMA/708 E-10	135.0	73	2	1	2	4.150	7.140
Macia	131.7	71	2	1	1	3.820	10.380
Sima	198.7	78	1	1	1	3.670	6.520
ELITE-16/705 E-7	148.3	78	1	1	2	2.480	6.580
Grand mean	147.1	75	2	1	2	4.900	6.660
l.s.d. (5% level)	4.535	*	0.8802	0.5034	0.7467	2.801	4.70
CV (%)	1	0	3.1	4.3	8.2	23.60	10.00

The sorghum breeding program uses pedigree breeding and mass selection for population development to develop lines for advanced testing. Based on research results, crosses and backcrosses are made to create new populations for subsequent selection and evaluation for yield, adaptation, and pest (disease and/or insect) resistance. The program utilizes the expertise of farmers in the selection program. Introductions from SMIP (Zambia), IER (Mali), ICRISAT and INTSORMIL (Texas A&M University) provide an array of germplasm in which to select. Collections of local landrace varieties preserve the indigenous genetic diversity and provide additional populations for selection.

Several performance trials were conducted to evaluate the adaptation and grain yield potential of elite introduced genotypes. Entries in the National Performance Trials included 12 early and intermediate maturing varieties, of which 8 promising genotypes were selected and submitted for variety release. Seventeen varieties research to local diseases and pests were selected and evaluated at four sites (Namialo, Namapa, Sussundenga and Mapupulo research stations). Twenty-five sweet sorghum varieties were evaluated with the best five varieties selected for evaluation in specific environments in the next (2011-2012) cropping system. This represents the third year in evaluation for entries in these two tests and next year entries will be selected for release as varieties. The entries are being grown for seed increase. A 12 entry (10 introductions from Zambia and two local checks) was grown at Namialo and Mapupulo. Test cv was high (23.6) and Namialo but exceptional at Mapupulo (10.0) (Table 5). At Namialo, 9 experimental entries produced more grain than the check Macia. At Mapupulo, Macia produced the most grain but 7 experimental entries were not significantly different from Macia. Across locations the average grain yield performance was 5.7 t/ha, which represents a grain yield increase of 42.9% when compared with the lowest yielding variety.

The sorghum breeding program is beginning to develop germplasm specifically adapted to Mozambique. Introductions each year are crossed to local landraces and improved varieties Macia, Kuyuma, and Sima to produce segregating populations. Additionally, two experimental hybrids were produced for evaluation. Eighteen lines were selected in F6:7 populations for seed increase. A total of 70 introductions of improved varieties and 34 (A-/B- and R-) were crossed for seed increase, and 14 inbred lines selected for regional trial testing. Seventy-two inbred lines were sent to Kwazulu Natal University (South Africa) to convert the inbred lines into A-/B- and R-lines for use as hybrid parents.

Agronomy research to evaluate the use of mulch in poor soils for water conservation was conducted. The results led to the conclusion that yield increased from 0.6 t/ha to an average of 3.8 t/ha. This represents an increase in grain yield performance of 15% over farmer's normal agronomic practices without mulch and biocharcoal.

Plant Pathology

Sorghum was planted at Cedara and Greytown (KwaZulu Natal Province) for disease evaluation, determination of changes in host physiology in relation to epidemiological processes and yield loss evaluation. Highly significant differences in root rot severity were recorded between genotypes which ranged from 32 to 57 %. Comparisons of root rot severity in fungicide drenched and undrenched plots provided limited variation against which to quantify root rot x yield loss relationships. Regression analyses yielded low a R^2 value but suggested a 0.68% loss in yield for each 1 % increase in root rot severity which translates into yield losses in the range of 22-39 %. A line evaluation trial consisting of 223 entries yielded one line with less than 10% and 16 lines with less than 20% root rot severity suggesting that root rot resistance is scarce. Root samples collected for physiological studies i.e. phenol and/or anti-fungal protein levels are still being analysed and will be related to host disease responses. Currently, root rot evaluation requires destructive sampling and a significant relationship with these anti-fungal components could provide a marker for non-destructive disease resistance selection.

Evaluations also included responses to leaf pathogens (anthracnose, sooty stripe, leaf blight) and grain molds. Conditions did not favour ergot evaluation. Results indicated good sources of resistance to the major foliar diseases. However, grain mold resistance in adapted white grain germplasm remains limited (Table 5). Although not statistical, many of the better adapted, higher yielding white lines were susceptible to root rot and lodging. Analyses of multi-seasonal data from line and cultivar trials were used to determine the stability of genotype response to diseases over changing environments. These trials have also been used to source material for extended physiological analyses in an attempt to relate susceptibility to host physiology.

A 22 entry Sorghum Genetics of Pericarp Nursery (Table 6) from Texas A&M University was planted on two planting dates at Cedara. Variations in germplasm include the presence or absence of a testa, high and low phenol contents, red, tan and purple plant/glume colour and white, red and brown grain colour. The goal of the study is to determine physiological markers that may be used as a selection criterion for grain mold resistance since field ratings, mycotoxin levels and actual colonization are poorly correlated. Mycotoxin levels in the samples are still being analysed with emphasis on zearalenone, DON and NIV, toxins known to occur at significant levels on sorghum grain and a growing concern to food safety in Africa. In addition, florets and soft dough grain were collected during the season and have been frozen for analyses including phenols/flavanoids, and anti-fungal proteins. Initial physiological results suggest that seed and glume proanthocyanodin content($r=0.62$** and $r=0.87$** respectively) and to a lesser extent seed flavanol content ($r=0.52$*) are related to suppression of grain molds. Ergosterol (as a measure of active fungal colonisations) and chitin (a measure of total fungal colonization) contents are being analysed to compare visual field ratings with actual colonization.

Etiology of root rot and grain mold was also evaluated. One hundred and sixty-two fungal isolated from sorghum roots have been evaluated for root rot causal potential and differential host colonization. Accurate identification of the isolates and intra-species variation has been completed using gene sequencing (Elongation factor; ITS) and data analysis and summarization is in progress. *Fusarium oxysporum* was commonly isolated from roots and host response to 97 isolates ranged from stimulated

Table 6. Mean field rating and grain characteristics in the genetics of pericarp nursery.

Entry	Field rating	Plant col.	Pericarp	Mesocarp	Testa	Spreader	Plant color	Seed color
SC630-11EII (9)	2.0	PPQQ	RRYYII	ZZ	b1b1B2B2	SS	purple	dark red, pearly
SC719-11E (15)	2.0	PPQQ	RRYYii	zz	B1B1B2B2	ss	purple	red, chalky,
R.TAM2566 (19)	2.0	PPQQ	RRYYII	ZZ	B1B1B2B2	ss	purple	dark brown-red, pearly
TX2911 (20)	2.0	PPQQ	RRYYII	ZZ	b1b1B2B2		purple	red, pearly
R.Tx2917 (8)	3.0	ppQQ	RRYY				Tan	red
SC630-11 Eii (10)	3.0	PPQQ	RRYYii	ZZ	b1b1B2B2	SS	purple	light red, pearly
SC748-5 (11)	3.0	PPQQ	rrYYIl	ZZ	b1b1B2B2	ss	purple	lemon yellow, pearly
SC103-12E (16)	3.0	PPQQ	RRYYII	Zz	B1B1B2B2	SS	purple	dark brown-red, chalky
SCAY13 (21)	3.0	ppQQ	rrYY	ZZ			tan	lemon-yellow
SCAY21 (23)	3.0	ppQQ	rrYY	ZZ			tan	red
B.Tx635 (6)	3.5	ppQQ	RRyyii	ZZ			tan	white pearly food grade sorghum
Dobbs (17)	3.5	PPQQ	RRyyii	Zz	B1B1B2B2	SS	purple	brown, chalky
SCAY16 (22)	3.5	ppQQ	RRYY	ZZ			tan	red
B.TX378 (1)	4.0	PPQQ	RRyyii	Zz	b1b1B2B2	SS	purple	red, chalky
B.TX3197 (2)	4.0	PPQQ	RRyyii	Zz	b1b1B2B2	SS	purple	white, chalky
R.TX430 (3)	4.0	PPQQ	RRyyll	ZZ	b1b1b2b2	SS	purple	white, pearly, yellow endosperm
R.TX436 (5)	4.0	ppQQ	RRyyii	ZZ	B1B1b2b2		tan	white
B.TXARG-1 (7)	4.0	ppQQ	RRyyii	ZZ			tan	waxy endosperm
SC109-14E (14)	4.0	PPQQ	RRyy--	Zz	B1B1B2B2	ss	purple	white pearly, purple testa
SCAY14 (24)	4.0	ppQQ	rrYY	ZZ			tan	lemon-yellow
LSD 0.05	**0.6**							

growth to severe inhibition. Other notable genera isolated from roots including *Acremonium*, *Periconia*, *Curvularia* and *Fusarium* spp. *Trichoderma* spp. were evaluated for biocontrol potential but with limited commercial potential. Grain mold etiology was determined from grain samples collected over 3 seasons and a range of localities. Grain colonization was quantified using RT-PCR. Species within the *Fusarium graminearum* species complex are capable of producing mycotoxins, especially trichothecene derivatives including deoxynivalenol and nivalenol. PCR was used to determine species identity and trichothecenes in 76 members of the FGSC (including some isolates from maize). Analysis of the sequence data generated from the TEF-1α gene confirmed that F. boothii was the predominant lineage in maize. At least three lineages were found in sorghum, namely *F. meridionale*, *F. acaciae-mearnsii* and *F. cortaderiae* (the latter only one isolate). Although the 3-ADON chemotype was not detected, the DON chemotype, producing both DON and 15-ADON was the only chemotype detected in maize FGSC isolates. The NIV chemotype was detected in only one sorghum isolate. This explains the absence of DON recorded in previous analyses of sorghum despite its high presence in maize. NIV has not previously been quantified in sorghum. Many samples exceeded the EU recommended level of 0.7 ppm. Trichothecenes such as NIV and DON are known protein synthesis inhibitors and consumption of grain contaminated with these mycotoxins can cause anemia and immunosuppression, haemorrhage, diarrhoea and emesis. The results indicate the importance of resistance to grain molds.

Grains were similarly evaluated for colonization by the mycotoxigenic fungi *Aspergillus flavus*, *A. parasiticus*, *Fusarium verticillioides* and *F. proliferatum* which can lead to reductions in yield and the production of aflatoxins and fumonisins that are harmful to humans and animals. Based on quantitative (q) real-time-PCR to determine the presence and biomass of aflatoxin-producing *Aspergillus* spp. and fumonisin-producing *Fusarium* spp. and aflatoxin and fumonisin quantification using HPLC it was concluded that only minute amounts of these mycotoxins occur on sorghum. The soft grain genotype NS5511 was more prone to aflatoxin contamination than the other cultivars. Results indicate that *Aspergillus* and *Fusarium* spp. and their mycotoxins do not pose a threat to sorghum production in South Africa.

A study is being conducted on the role of weather on infection of sorghum by grain mold fungi and the effect on grain quality. Variation in fungal colonization of grain as detected by RT-PCR and mycotoxin levels associated with the various season/locality/cultivar interactions are being analysed with the aim of developing a mycotoxin risk prediction model taking these factors into consideration. Provisional analyses using stepwise multiple regression analysis, after transformation of data to ensure linearity, suggest that maximum temperature and minimum humidity are primary driving variables in the colonization of sorghum by *Fusarium* spp. Re-analysis with these selected variables using 3-dimentional regression analysis will be done subject to the final analysis of grains for mycotoxins.

MRC

Sorghum and pearl millet are indigenous African crops and form part of the basic staple foods for many rural communities. The growth and production of these grains can be negatively affected by plant diseases caused by diverse fungal genera. Stalk rots, ear rots and grain mold are some of the fungal diseases that have caused great economic losses on the production of for example, sorghum. *Fusarium* Link is one of the fungal genera that are dominant in causing grain mold of sorghum and millet. The ability of *Fusarium* spp. to produce mycotoxins that have detrimental health effects for both humans and animals make it very important to evaluate their toxin production in diverse crops that are intended for human consumption. This is even more applicable for those *Fusarium* spp. that are found occurring in crops such as sorghum and millet without any disease symptoms on the plant hosts. *Fusarium* species produce a number of mycotoxins, including fumonisins (FUM) and moniliformin (MON) that have been shown to have negative health effects or implications on both humans and animals that consume agricultural crops that are infected by them.

Previously it has been shown that both FUM and MON occur naturally in maize, sorghum and millet, and that selected potentially toxigenic *Fusarium* strains isolated from maize, sorghum and millet samples from Nigeria, can potentially harbor high fumonisin producing *Fusarium* species. As part of the research plan to confirm that the fungi isolated from maize, sorghum and millet, do have the potential to produce mycotoxins in in vitro cultures, chemoprofiling and molecular analyses were done. Millet patty cultures were developed, optimized and the results compared to those of the same fungi grown in maize and sorghum patties. FUM and MON profiles of 19 *Fusarium* strains and two control strains were determined by HPLC analyses. Results indicated that there are variations in the potential or ability of *F. proliferatum* isolates to produce either FUM or MON, and that these fungi can use grains as a source for toxin production irrespective of their original hosts, and that some strains have the ability to produce large quantities of either FUM and/or MON under conducive conditions.

This year the research was focused on repeating chemical analyses of high FUM and MON producers and confirming previous results obtained, and to molecularly characterize or confirm the identity of *Fusarium* isolates originally isolated from sorghum and millet. Molecular analyses confirmed 17/18 isolates as *F. proliferatum* (MRC 8737 to MRC 8746 and MRC 8726 to MRC 8732), while the other isolate was identified as *F. andiyazi* (MRC 8725). The unidentified *Fusarium* isolate from millet, turned out to be *F. pseudonygamai* (MRC 8723), while MRC 8724, originally from sorghum, is a new *Fusarium* species of rather little mycotoxigenic consequence. The high producing MON control, provisionally identified as *F. andiyazi*-like (MRC 8279), was molecularly identified as *F. napiforme*, a species known to produce MON. It was confirmed that it produced extremely high levels of MON, ranging between 23020-33430 mg/kg, in grain cultures.

The outcome of these determinations gives better insight into the potential and ability of *Fusarium* species, isolated from sorghum and millet, to produce mycotoxins on several grain sources, which may have a marked influence on food safety and security of sorghum and millet as both these crops are basic staple foods for many rural communities in Africa, and to establish the potential risk that unidentified mycotoxigenic fungi may have on grain commodities consumed by humans and animals.

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

Bruce Hamaker and Bonnie Pendleton
Purdue University and West Texas A&M University

Regional Coordinators

Bonnie Pendleton (West Texas A&M University) and Bruce Hamaker (Purdue University)

West Africa Coordinators

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Mamourou Diourté – Production sub-project coordinator, Plant Pathologist, IER, Mali
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Scientists

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Souley Soumana – Sorghum Breeder, INRAN, Niger
S. Jean B. Taonda – Agronomist, INERA, Burkina Faso
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Abdoul Wahab Touré – Agronomist, IER, Sotuba, Mali
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Regional Program Description

Multi-agency, multi-disciplinary teams of agronomists, entomologists, food scientists, plant breeders, pathologists, poultry scientists, extension educators, and others are developing, evaluating, and transferring technologies to improve production and marketing of sorghum and millet and manage Striga in West Africa. The regional program with collaboration among scientists at IER in Mali, INRAN in Niger, INERA and IRSAT in Burkina Faso, Institut Sénégalais de Recherches Agricoles and ITA in Senegal, University of Maiduguri in Nigeria, universities in the U.S., 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 resource management; develop and disseminate information on stresses to increase yield and quality; enhance stability and yield through genetic technologies; and better lives of people dependent on sorghum and millet.

Mamourou Diourté from Mali coordinated the production component of the "Increasing farmers' and processors' incomes via improvement in sorghum, pearl millet, and other grain production, processing, and marketing systems" project. The production sub-project involves agronomists S. Jean B. Taonda in Burkina Faso, Seyni Sirifi in Niger, and Abdoul Wahab Toure in Mali; entomologists Hame Abdou Kadi Kadi in Niger and Niamoye Yaro Diarisso in Mali; pathologists Mamourou Diourté in Mali and Adama Neya in Burkina Faso; and plant breeders Ignatius Angarawai in Nigeria, N'Diaga Cisse in Senegal, Souley Soumana in Niger, and Abocar O. Touré and Niaba Témé in Mali. The scientists are using seed multiplication, on-farm testing, and exchange of varieties of sorghum and millet to disseminate the best cultivars in combination with fertilizer and other crop management options such as crop rotations and protection. They are educating farmers how to manage storage disease and insects through grain harvesting and storage practices. They are developing and distributing adapted cultivars of sorghum and millet with stability and acceptability through multi-environment experiments and resistance to pests and drought. They are generating dual-purpose and open-pollinated varieties, and lines for hybrids.

Ababacar N'Doye from Senegal coordinates the processing and marketing systems component of the project "Increasing farmers' and processors' incomes via improvement in sorghum, pearl millet, and other grain production, processing, and marketing systems." The sub-project involves food scientists Boniface Bougouma from Burkina Faso, Moussa Moustapha from Niger, and Iro Nkama from Nigeria, and poultry scientist Salissou Issa from Niger. The project focuses on processed food and animal-feed markets and expansion through development of quality, competitive millet- and sorghum-processed products and greater use of sorghum in poultry feed. The goal is to enhance urban markets for improved sorghum and millet cultivars for farmers to sell surplus grain with emphasis on development and transfer of food technologies to farmers, NGOs, food processing and marketing entrepreneurs, and consumers. Activities were focused on processed products that contribute to development of markets for sorghum and millet by development and transfer of technologies to entrepreneurs. Technologies for production of sorghum and millet breads and other products were transferred; local processing groups were assisted to initiate businesses; and sorghum and millet are being characterized as "functional foods" for health. Competitive composite flour and other products are being marketed. For animal feed, use of sorghum for poultry in West Africa was validated and education provided on availability of low-tannin varieties, with the goal to increase use of sorghum. Projects funded through the Mali Mission and directed by John Sanders and Bruce Hamaker provided collaborative assistance with marketing aspects of the West Africa regional program.

Hamidou Traoré from Burkina Faso coordinated the "Integrated Striga and nutrient management for sorghum and pearl millet" project. Involved are Mountaga Kayentao from Mali, Nouri Maman and Souley Soumana from Niger, and Moctar Wade from Senegal. Goals were to identify and characterize Striga-resistant sorghum and millet; characterize and implement integrated Striga management systems for millet that incorporate fertilizer, rotation or intercropping; 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 technology packages to increase yield of sorghum and millet and incomes of farmers throughout West Africa.

Sorghum/Millet Constraints Researched: Teams of scientists, extension educators, and farmers in Burkina Faso, Mali, Niger, Nigeria, and Senegal are evaluating and transferring technologies to manage Striga and improve production and marketing of sorghum and millet. Sorghum and millet, staple foods of Sub-Saharan Africa, suffer yield loss because of poor soil, scarce and erratic rainfall, warm temperature, and insect, disease, and weed pests such as Striga. Other pests of sorghum and millet in fields in West Africa include anthracnose, millet head miner, sorghum midge, and stalk borers. Colletotrichum, Curvularia, Aspergillus, and Fusarium that cause human cancers, lymphatic diseases, and gastritis, and insects such as beetles and moths cause loss of grain quality and weight within a few months in storage. Resistant cultivars and packages of improved crop, soil, water, and pest management technologies can reduce pesticide use, conserve natural resources of soil and water, more efficiently use fertilizer, and increase stability and yield of food and feed for domestic use and income from marketing. Adapted cultivars of sorghum and millet with resistance to drought and pests in multiple environments are being developed and transferred. Agronomic and pest management technologies that include use of resistant cultivars, crop rotation, fertilizer, and herbicides are being developed to manage pests in the field. Pests are being identified and controls developed and transferred to manage grain harvesting and storage. Development and adoption of high-yielding, quality sorghum and millet with increased nutritional value are improving human health. Enhanced urban markets are being developed for farmers to sell surplus grain of improved sorghum and millet. Processed products such as competitive composite flour are contributing to development of markets for sorghum and millet through transfer of technologies to entrepreneurs to initiate businesses. Use of sorghum in poultry feed was validated. Partnerships among host-country scientists, NGOs, international agencies, extension, and farmers are transferring technologies for improved agricultural production and marketing. Greater, more stable yields and enhanced markets will better the livelihood of people dependent on sorghum and millet and help end hunger in West Africa by increasing farm incomes and agricultural development.

Institution Building

A couscousier for steaming couscous (Figure 1) and a gas dryer from Burkina Faso were provided to complete the incubation unit at INRAN for sorghum- and millet-processing entrepreneurs in Niger. Seyni Sirifi in Niger was provided a camera and computer.

Figure 1.

Mme Dembélé Yara Koréissi from Mali was partially supported from INTSORMIL to attend the African Nutrition Leadership Program in South Africa in March, which built capacity in leadership, communication, and advocacy skills in food and nutrition science.

Adama Sanou, a student at the Rural Development Institute of the University of Bobo-Dioulasso in Burkina Faso, learned to evaluate 15 sorghum varieties in the laboratory, greenhouse, and field at Kouaré. Hame Abdou Kadi Kadi, entomologist in Niger, collaborated with Dr. Kadri Aboubacar, Agronomie, Université Abdou Moumouni de Niamey, Niger, to supervise two students as pest management interns.

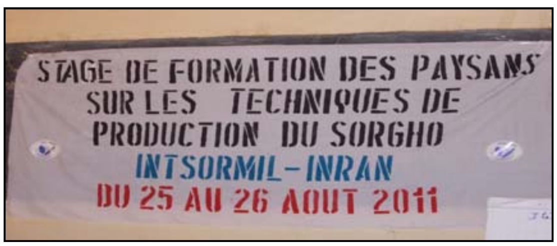
Ignatius Angarawai, millet breeder in Nigeria, participated in an international training course on pearl millet and seed production in India in April. He was a visiting scientist at ICRISAT in Niamey, Niger. He was Principal Investigator for Diversity Trust International grants "Germplasm collection of unexploited stay-green (Maiwa millet) pearl millet in Nigeria and collecting of accession in geographical gaps. He also was Project Manager for an Alliance for Green Revolution in Africa (AGRA) grant "Enhancing resource poor farmers' productivity with pearl millet hybrid in Nigeria."

Networking

Workshops and Meetings

One hundred women and 80 men from different areas of Niger attended training on 25-26 August. INRAN scientists also promoted INTSORMIL to the policymakers, extension workers, NGOs, farmer associations, and private seed producers assembled. (Figure 2)

Figure 2.



Funds provided to Seyni Sirifi from Vara Prasad helped organize a farmer field day in Tillabery region, Niger, to promote tied-ridge technology. Two U.S. PIs participated in the field day. A movie made of the field day is available at INRAN. Seyni Sirifi's tied-ridge technology was selected at a workshop on transferable technologies for a Niger technology transfer program funded by World Bank project PAC II. NGOs, farmer organizations, private industries, and regional programs and institutions like INTSORMIL, ICRISAT, IRD, AGRYMET will spread the research results through meetings, workshops, field days, and other communications.

Abdou Wahab Toure, Mamourou Diourte, Niamoye Yaro Diarisso, and Bonnie Pendleton put on a workshop for 26 trainers of decru sorghum farmers from Mopti, Gao, and Tombouctou on 29-30 June at Sotuba, Mali. At Sanankoroba, Marako, and Dialokoroba, Mali, field demonstrations were visited by a farmer's organization, Minister of Agriculture, APCAM, and OHVN. The national media ORTM and local media helped inform more than 300 farmers.

In Niger, participatory exchanges/training/"platform" meetings were organized among stakeholders (farmers, processors, scientists, nutritionists, private companies, NGOs, extension, international agencies, and government) for contracting partnerships and adopting processing technologies for sorghum and millet grain. Entrepreneurs and women processor associations of 15-30 members making sorghum- and millet-processed foods continued to increase from two to more than 15 in Niamey (10), Maradi,

Figure 3.

and Tillabery regions of Niger. (Figure 3) The processors were trained in food sanitation and packaging and business management in June in Niamey. INRAN under technical guidance from Bruce Hamaker continued networking and partnering with the McKnight Foundation, CORAF, Afrique Verte, Alliance for Green Revolution in Africa (AGRA), Sasakawa Global 2000/IMS, Gates Foundation HOPE project, ICRISAT/INRAN/ PROMISO 2/European Union, and Synergy/Niger Loan institution to develop and promote technology transfer of sorghum- and millet-processed products in Niger and West Africa. Networking reinforced capacity building of local processors in equipment procurement and technology appropriation at the regional level in Burkina Faso, Mali, and Niger. The INRAN/INTSORMIL processor incubation centre was publicized on radio and television channels or satellites.

INTSORMIL held a workshop 21-23 June in Mali to demonstrate to IICEM processor partners new technologies using high through-out technologies developed at Institut de Technologie Alimentaire (ITA) in Dakar for processing market-competitive millet- and sorghum-based agglomerated products (couscous of different particle sizes, degue, and moni curu) with increased quality and value. Seven beneficiaries of INTSORMIL from Gao, Mopti, and Bandiagara, two beneficiaries from the local processor association AMTCL/Bamako, and four partners from IICEM millet and sorghum processors participated.

Research Investigator Exchanges

Sorghum and millet scientists who worked in West Africa during the year included food scientist Bruce Hamaker, animal scientist Joe Hancock, entomologist Bonnie Pendleton, agronomists Vara Prasad and Scott Staggenborg, economist John Sanders, plant breeder Mitch Tuinstra, and Short Heinrichs.

Research Information Exchange

Publication

Moussa, M., B.R. Hamaker, et al. Sept. 2011. High-quality instant sorghum porridge flours for the West African market using continuous processor cooking. International Journal of Food Science and Technology.

Presentation

Abdou Kadi Kadi, H., B.B. Pendleton, S. Souley, and I. Salami, La SSD-35-une variété de sorgho résistante à la cécidomyie

Figure 4.

pour améliorer la production et générer des revenus, Journee d'Information de l'INRAN, 16 October, Niamey, Niger. (Figure 4)

Germplasm Distribution

Souley Soumana with INRAN released more than 50 hybrids to help fight food insecurity and famine in Niger. With the support of the INTSORMIL technology transfer project, farmers of Tillabery produced and sold seed of improved IRAT 204.

Research Accomplishments

"Increasing Farmers' and Processors' Incomes via Improvement in Sorghum, Pearl Millet, and Other Grain Production, Processing, and Marketing Systems" Project – Production

Souley Soumana, sorghum breeder in Niger, used the pedigree method to advance into F5, 42 F4 populations from crosses between MDK (locally adapted landrace with quality grain and drought tolerance) and Sureño (quality grain and tolerant to grain mold). From the F4, he released a line with quality grain and medium maturity. In the hybrid observation nursery, the line had good aptitude for combination and produced a good hybrid from the male sterile lines NE223A and ATX623 used in the hybrid program. In the hybrid observation nursery, of 255 testcross hybrids, he identified and chose with farmers and private seed producers more than 50 good hybrids to produce and use in adaptation experiments in many ecological zones of Niger. (Figure 5)

Figure 5.

Niaba Teme, sorghum breeder in Mali, developed 10 sorghum populations for stay green, grain quality, and resistance to Striga. The transfer of stay green trait and grain quality was through backcross, marker-assisted selection, and field evaluation. Donor parents for stay green were B35 and Tiandougou while the donors for grain quality were CSM63E, Floulatieba, and a Sikasso local cultivar. Striga resistance donor to CSM219E was Seguetana CZ. The populations were at BC1F3 levels in 2011 for stay green introgression and F3 for resistance to Striga. All 96 lines from the crosses were grown in natural conditions at Sotuba and Cinzana in 2011.

Abocar Oumar Touré and Abdoulaye Gaoussou Diallo, sorghum breeders in Mali, made crosses to improve breeding stock. Eighty-two F2, 82 F3, and 66 F4 were planted at three locations. From the evaluation, 82 F2 families were retained, and single-plant selections were advanced by the pedigree method. From F2 to F3, 308 panicles were selected, 82 F3 generations were planted, and 67 panicles were selected to F4. One hundred twenty panicles were selected from 66 F4.

On farms at Bancoumana, lines 08-FA-F5T-6-2 (2,710 kg/ha), 08-FA-F5T-6-1 (2,440kg/ha), and 08-FA-F5T-34 (2,330 kg/ha) were significantly superior to the local check. (Table 1)

Five hybrids were compared to the local check by five farmers on farms in Ouelessebougou, Bancoumana, Kita, and Cinzana regions. Each genotype was planted in five-row plots 5 m long, with 0.75 m between rows and 0.5 m between hills. In collaboration with the companies Fasso Kaba, Nagoshi, and Comptoir 2000, seeds of five hybrids (Sewa, Sigui-kumbe, Fadda 150A*Grinkan, and 02-SB-F4DT-12A*02-SB-F4DT-298) were planted in isolation on farms. The seeds and protocol were provided by IER.

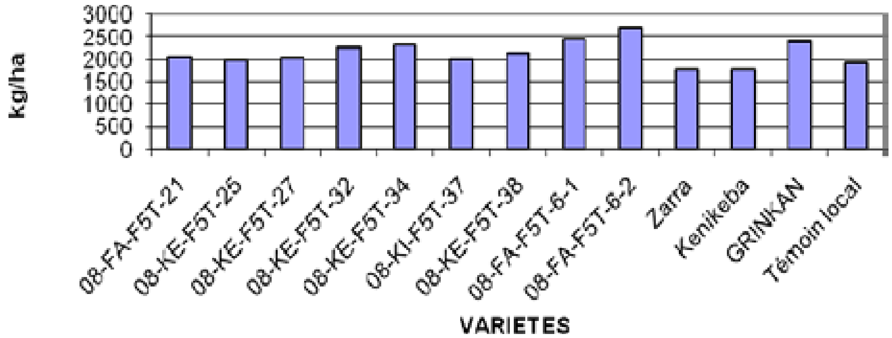
At Kolombada and Sotuba, new hybrids 02-SB-F4DT-12A*04-SB-F5DT-249 and 97-SB-F5DT-150A*06 SB-F'DT-15 were planted to control nicking of the flowering date of the two parents. Four females per two males were used. The female parent 02-SB-F5DT-12A/B was planted in isolation at Kolombada station.

Crossing was done manually during the off season at Sotuba to produce seed of new hybrid F1 sorghum for cytoplasm reaction and agronomic evaluation. The A/B pair BC5 (F5 F5DT-16) and BC2 (03-SB-F5DT-134) were crossed to sterilize the two lines to produce enough seed for regional testing. The different parents were grown on about 1 hectare. (Table 2)

On farms at Sikasso, Kita, and Kebila, grain yields of sorghum hybrids Fadda and Sewa were superior by 70-25% over the local check.

Ignatius Angarawai, millet breeder at Lake Chad Research Institute in Nigeria, identified new sources of pearl millet male sterile A/B pairs (LCICM-2, LCICM-9, and LCICM-90) with A4 cytoplasm resistant to downy mildew that can be used to develop new hybrid parental lines. Dissemination of three new pearl millet varieties involving PEO5532 (SUPERSOSAT) gained 90% acceptance through farmer selection in 80 villages each with an average of 200 families. Alh Kamisu of Dazigau Nangere Local Government Yobe state of Nigeria was identified as a farmer entrepreneur

Table 1.



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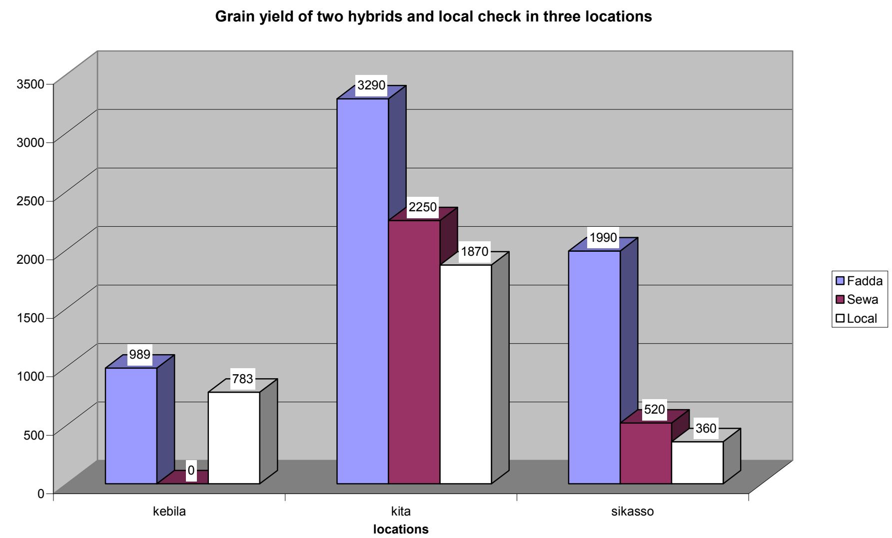


to grow improved varieties. During the rainy season, he cultivated SOSAT-C88 for seed on 11 hectares certified by the Nigerian Seed Agency. A storage facility is being built near the road for easy access to transportation and marketing of the grain produced.

Despite crop failure caused by drought throughout Niger, agronomist Seyni Sirifi did sorghum and pearl millet demonstrations and on-station experiments on pearl millet and cowpea cropping systems. For sorghum demonstrations, he used a package of tied-ridge technology (Figure 6) manure (5 tons/hectare), urea (50 kg/ha), three plants per hill, and 31,250 hills per hectare developed during four years of on-station experiments on seedbed preparation in agroecological zones with low (200-300 mm/year), medium (300-500 mm/year), and high (>500 mm/year) rainfall. (Figure 7) The tied-ridge technology improved sorghum productivity in low rainfall areas because of good water-holding capacity and conservation that are problems in heavy soils with low filtration, much runoff, and bad aeration. Sorghum production with the traditional cropping method (no till) was poor because of bad germination and stand loss from water stress. (Figure 8) Farmers obtained yield increases of 10 fold by tied-ridge technology. The farmers realized poor production of sorghum was caused by lack of soil management, but said adoption of the tied-ridge technique required animal traction instead of making ridges by hand. (Figure 9)

Figure 6. Tied ridge made by hand in Niger

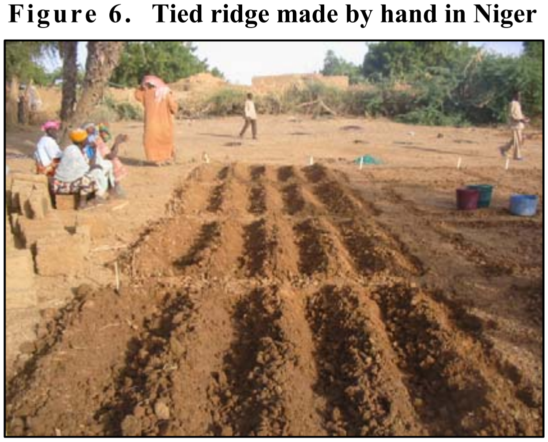


Figure 7.

Figure 8. Sorghum plot with traditional cultural practices (left). Sorghum plot with tied-ridge technology (right).

Figure 9. Panicles from 1 m² with tied-ridge (left) and traditional technology (right). PIs holding panicles from the m² plot.

Seyni Sirifi demonstrated improved fertilization of millet by a combination of a micro-dose Coca Cola bottle cap of NPK (6 g per hill), 20 units per hectare of phosphorus, 30 units per hectare of nitrogen, two plants per hill, and 15,000 hills per hectare. During the last two growing seasons, demonstrations during the growing and harvest seasons in several regions with poor sandy soil showed large yield differences in grain and stover between improved and traditional technologies. Many farmers used the new fertilizer technology to improve their poor sandy soils.

Abdoul Wahab Touré, agronomist in Mali, evaluated cultural practices (plant population, fertilizer rates, and planting dates) to increase grain yield of new tan sorghum varieties CSM388, Tiandougou, Niatichama, and Séguifa at Sotuba. A split-split plot design was used with four blocks. Sub-plots were populations of 50,000 (0.75 x 0.50 m, two plants per hill), 80,000 (0.75 x 0.25 m, two plants per hill), and 100,000 plants per hectare (0.75 x 0.25 m, three plants per hill). (Table 3)

No interactions involving fertilizer, plant population, and varieties were significant for grain, stover, and biomass yields. Grain yield compared to that of the check increased 245, 699, 533, and 531 kg/ha for 41-46-0, 51-61-15-4, 71-76-30-8, and 71-76-30-8-36-16 fertilizers, respectively. Most yield was obtained by using 51-61-15-4, but cost of fertilizer, price of grain, and labor for application should be determined. Use of 41-46-0 and 56-61-15-4 fertilizer resulted in 37% increase in stover. Both 41-46-0 and 56-61-15-4 yielded more biomass. (Table 4)

The expected number of sorghum hills and plants per hectare were achieved. Grain, stover, and biomass yields increased between 50,000 to 80,000 plants per hectare, but increasing to 100,000 plants did not significantly increase yields. (Table 5)

The number of hills was almost the same for the four varieties of sorghum. CSM 388 had the greatest plant population and yielded most. CSM 388 was followed by Tiandougou, then Séguifa and Niatichama. Early-maturing Seguifa was attacked by birds, while conditions were not conducive for grain filling of late-maturing Niatichama. (Table 6)

Mamourou Diourté, plant pathologist in Mali, prepared pure cultures of Colletotrichum graminicola for evaluation of leaf anthracnose of newly developed sorghum varieties. Infested grain stored at Sotuba in October 2010 was sampled in March 2011. Ten sorghum seeds with symptoms of mold “caminièkin” characteristics of attack by C. graminicola were disinfected with 2% sodium hypochlorite for 15 minutes and rinsed in sterile distilled water. The seeds were spread on PDA and cultures were incubated at a photoperiod of 12 hours at 25°C. After 72 hours, the mono-emerged colonies were re-isolated on new PDA. Two kilograms of

Table 3.

Characteristics of sorghum varieties tested in Mali

Local name	Breeding number	Year of release	Plant height (m)	Cycle (days)	Sensitivity to photoperiod	Grain yield (kg/ha)	1000-grain weight (g)
Niatichama	97-SB-F5-DT-150	1997	1.75	110-120	LS	2000	23
Tiandougou	98-SB-F2-78	1998	1.75	120	NS	3000	21
Séguifa	MLS-92-1	1992	2	100	NS	3000	30
JIGISEME	CSM 388	1984	3.7	120-125	S	2500	25

Fertilization: 100 kg/ha of di-ammoniac phosphate were applied at planting and 50 kg/ha of urea at 30-40 days after planting

Table 4.

Effect of fertilizer application using a ladder approach on grain, stover, and biomass yields

		Formula	Grain yield	Diff/ F0	Stover yield	Diff/F0	Biomass yield	Diff/F0
F0	No fertilizer	0-0-0	1407	0	5857	0	6822	0
F1	100 kg/ha DAP + 50 kg/ha urea	41-46-0	1642	245	6575	688	8982	1060
F2	F1 + 100 kg/ha 15-15-15-4	56-61-15-4	2106	699	8066	2179	11066	3144
F3	F1 + 200 kg/ha 15-15-15-4	71-76-30-8	1940	533	7715	1828	10472	2550
F4	F3 + 100 kg/ha lime	71-76-30-8-36-16	1938	531	7441	1554	10236	2314

Table 5.

Effect of sorghum plant population and variety on grain, stover, and biomass yields					
Plant population	**Hills/hectare**	**Plants/hectare**	**Grain yield**	**Stover yield**	**Biomass yield**
50,000, 0.75x0.50m, 2/hill	25,438.8 b	48,333 a	1,642 b	6,345.4 b	8,717.5 b
80,000, 0.75x0.25m, 2/hill	48,464.9 a	84,518 b	1,907 a	7,531.0 a	10,272.2 a
100,000, 0.75x0.25m, 3/hill	49,210.5 a	105,088 c	1,940 a	7,717.1 a	10,503.1 a

Table 6.

Grain, stover, and biomass yields of sorghum varieties					
Sorghum	**Hills/hectare**	**Plants/hectare**	**Grain yield**	**Stover yield**	**Biomass yield**
CSM 388	41,462.0 a	84,737 a	2,186.4 a	10,390.4 a	13,615.0 a
Niatichama	40,526.4 a	73,743 b	1,483.2 d	6,586.3 c	8,925.5 c
Séguifa	41,520.5 a	78,947 ab	1,718.7 c	4,254.7 d	6,472.4 d
Tiandougou	40,643.3 a	79,825 ab	1,930.8 b	7,559.9 b	10,310.8 b

healthy sorghum grain was washed with distilled water and dried in the open air in a laboratory, and the seeds were sterilized for 20 minutes at 120°C. Grains after cooling were inoculated with 100 ml of 105 spores/ml from a pure colony of C. graminicola. After 4 weeks of incubation, maximum inoculum was obtained to inoculate at least 40 advanced breeding lines. Twelve tall and 25 short varieties of sorghum were evaluated for resistance to the disease. After germination, young plants (3-5 leaves stage) were inoculated with C. graminicola. All varieties were relatively sensitive to the disease; this could be explained by alternation of wet and dry periods during the rainy season that favored development of anthracnose. The short varieties were more resistant than the tall ones, but only short varieties 09-KO-F5DT-54 and 09-SB-F5DT-191 were resistant. More than 60 sorghum advanced-breeding lines were artificially evaluated for resistance to Colletotrichum graminicola at Sotuba. (Table 7)

Entomologist Niamoye Yaro Diarisso assessed at Sotuba, Mali, germination of Grinkan, Niachitiama, Seguifa, Tiandougou, and Tiandougou coura sorghum after storage in polyethylene or triple bags. Once each month from February through August 2011, whole kernels and those damaged by Rhyzopertha dominica or other storage insects were counted and weighed. Seguifa, which seemed resistant to storage insects, had more than 90% germination and was less than 6% damaged after storage in triple or polyethylene bags (Figure 10).

But, in general, the sorghum grain was much less infested and germination was greater after storage in a triple than a polyethylene bag. Germination of Grinkan was greatest in May (80%). Damage to Grinkan in August was less than 10% in a triple bag but three times greater in a polyethylene bag. Most germination of Tiandougou occurred in April after storage in a triple bag (65%) while most germination after storage in a polyethylene bag was 60% in May. Greatest germination of Niachitiama was 50% in June in a triple bag and 45% in May in a polyethylene bag. Infestation of Niachitiama or Tiandougou in triple bags was only 5% in June, July, and August but 12-15% in June and increased to 35% in August in polyethylene bags. Percentage of germination of Tiandougou coura stored in a triple bag was greatest in May (85%) and decreased to 65% in August; germination after storage in a polyethylene bag was greatest in April (75%) but decreased to 38% in July (Figure 11). Tiandougou coura was not infested by insects in a triple bag but was 75% infested in August in a polyethylene bag (Figure 12).

Entomologist Hamé Abdou Kadi Kadi assisted Dr. Kadri Aboubacar of Faculté d'Agronomie, Université Abdou Moumouni de Niamey, Niger, with field training of internship students. An intern at Kollo assessed resistance of 10 pearl millet varieties to damage by millet head miner. An intern at Konni surveyed knowledge of sorghum insect pests and control methods by 80 farmers in four villages. An identification handbook was used to identify the insects. Visits to fields verified the farmers' answers. Data were discussed and validated at a village assembly. At Dibissou, Konni, 100, 55, 50, and 45% of farmers used cultural, chemical, traditional, and physical controls, respectively, against sorghum insect pests in the field. Only 30% used resistant sorghum. All farmers used traditional methods of repairing and cleaning granaries before storing sorghum panicles or grain. Chemicals, ash, and salt were used by 70, 40, and 15%. Azadirachta indica, Boscia senegalensis, Annona senegalensis, and Balanites eagyptiaca leaves were used by 25, 15, 10, and 10% of the farmers, respectively. (Table 8)

"Increasing Farmers' and Processors' Incomes via Improvement in Sorghum, Pearl Millet, and Other Grain Production, Processing, and Marketing Systems" Project – Marketing

Fifteen local food processor groups (from Dosso, Niamey, Maradi, and Tillabery, Niger) with 15-30 members were incubated at the newly completed INRAN sorghum- and millet-processing pilot unit. (Figure 13) Moustapha Moussa, food scientist, helped contract partnerships between the processors and 10 farmer entrepreneurs (three at Ouallam, two at Tera [Tillabery], one at Dantchandou, one at Falwel [Dosso], and three at Safo [Maradi]) to grow 50 tons of quality sorghum (Sepon 82, IRAT 204, F1-223) and millet (HKP and Sosat) grain for making agglomerated products, fortified foods for making porridges and composite bread. About 12 tons of mechanically threshed clean grain of sorghum and millet were being tested and processed into quality (flour and agglomerated) products at local processor units linked to INRAN cereal-processing incubation unit. Moustapha helped develop networks to diffuse sorghum and millet technologies (e.g., couscous, grits-like couscous, instant flour, and composite bread) generated through INTSORMIL collaboration to markets in Niger and other West African countries. (Figure 14)

Processed products were promoted and marketed by processors to more than 30 stores and open markets in Niamey and other parts of Niger. The processor incubation approach implemented in Niger is being reproduced in Burkina Faso, Mali, and Nigeria. Two couscous agglomerators were reproduced in Niger for the INTSORMIL Mali project. Potential for making sorghum and millet composite bread in Ouallam and Tera-Tillabery was explored by linking two bakeries with one well-established bakery making sorghum and millet bread in Niamey, Niger.

Yara Koreissi Dembele, food scientist in Mali, reported six mechanized units for processing millet and sorghum products were functional for entrepreneur processors in Mopti/Gao region who prefer to obtain quality grain from farmers' groups organized at Koutiala, Douentza, and N'Garasso by J. Sanders and O. Botorou. From 24-30 July, workers at Gao, Mopti, Sevare, and Bandiagara were trained to operate and maintain machines and document production. Processors in Mopti/Gao region are processing milled products sold in the market. Several of the wormen processors were in difficult situations, and being part of the project was a significant opportunity for them.

At Bamako at IER/LTA in Sotuba, an Incubation Centre was completed with new cereal agglomeration equipment to be an interactive facility where local small- and medium-scale food processor entrepreneurs are trained in new cereal-processing technologies, use equipment to produce products on a limited scale, test the marketplace, bring feedback to the Centre for process improvement, and access investment funds for mechanized operations. Markets are being expanded by using quality raw commodities bought (with premiums) from local farmers to process quality products. INTSORMIL held a workshop 21-23 June to demonstrate to IICEM processor partners new technologies using high through-out technologies developed at Institut de Technologie Alimentaire (ITA) in Dakar for processing market-competitive millet- and sorghum-based agglomerated products (couscous of different particle sizes, degue, and moni curu) with increased quality and value. Seven beneficiaries of INTSORMIL from Gao, Mopti, and Bandiagar, two beneficiaries from the local processor association AMTCL/Bamako, and four partners from IICEM millet and sorghum processors met to schedule the supply of grain, promotion plans, and sign contracts of retrocession (payback contracts) for the mechanized units. Meetings were held at IICEM to discuss collaboration with the LTA team and SAODEF (school of bakers) for larger industrical processing of sorghum- and millet-containing foods.

Table 7.

Anthracnose severity index of sorghum varieties at three growth stages, Sotuba, 2011

Sorghum variety	Disease severity index			Plant reaction
	Seedling	Stem elongation	Flowering	
Tall varieties				
08-KO-F5DT-32	2	4	6	ms
09-SB-F5DT-40	2	4	5	sw
09-SB-F5DT-43	2	4	5	sw
08-KO-F5DT-45	2	5	5	sw
08-KO-F5DT-47	2	5	5	sw
08-KO-F5DT-55	3	5	7	ms
08-KO-F5DT-61	2	5	5	sw
09-SB-F5DT-68	2	4	5	sw
08-KO-F5DT-107	2	5	7	ms
09-SB-F5DT-133	2	4	5	sw
09-KO-F5DT-114-2	2	5	6	ms
09-KO-F5DT-20	2	5	5	sw
Sureno (resistant check)	2	3	4	sw
IS18442 (susceptible check)	4	10	12	vs
Short varieties				
09-KO-F5DT-54	1	4	3	sw
09-SB-F5DT-191	1	3	3	sw
09-KO-F5DT-4	2	4	4	sw
09-KO-F5DT-12	2	4	5	sw
08-KO-F5DT-35	2	6	7	ms
09-SB-F5DT-37	2	3	4	sw
09-KO-F5DT-51	2	4	4	sw
09-KO-F5DT-59	2	4	4	sw
09-SB-F5DT-69	2	3	4	sw
09-KO-F5DT-70	2	5	4	sw
08-KO-F5DT-92	2	5	4	sw
09-KO-F5DT-99-1	2	5	6	ms
09-SB-F5DT-111	2	3	4	sw
09-KO-F5DT-132	2	4	4	sw
09-SB-F5DT-141	2	5	5	sw
09-KO-F5DT-148	2	6	5	sw
09-KO-F5DT-153	2	4	5	sw
09-KO-F5DT-163	2	5	4	sw
09-SB-F5DT-164	2	4	5	sw
09-KO-F5DT-168	2	3	4	sw
09-SB-F5DT-188	2	4	4	sw
09-KO-F5DT-194	2	5	5	sw
09-KO-F5DT-197	2	4	5	sw
09-KO-F5DT-198	2	5	5	sw
02-SB-F4DT-298	2	5	5	sw
Sureno (resistant check)	2	3	4	sw
IS18442 (susceptible check)	4	10	12	vs

ns = not susceptible (0-1), sw = weak susceptibility (2-6), ms = moderate susceptibility (6-9), vs = very susceptible (9-18)

Table 8.

Application	Control method	Percentage of respondents
Field	Cultural	100
	Chemical	55
	Traditional	50
	Physical	45
	Resistant varieties	30
Storage	Granary repair and cleaning	100
	Chemical	70
	Ash	40
	Salt	15
	Leaves of *Azadirachta indica*	25
	Leaves of *Boscia senegalensis*	15
	Leaves of *Annona senegalensis*	10
	Ground leaves of *Balanites eagyptiaca*	10

Figure 10.

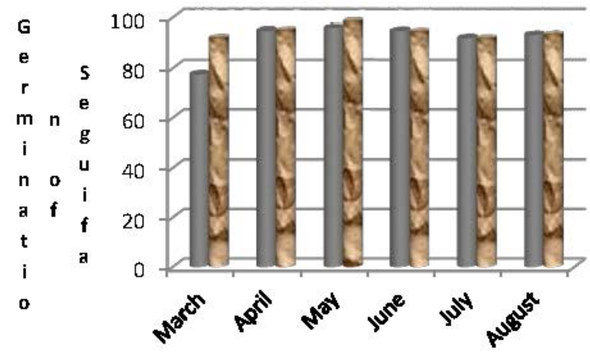


Figure 11.

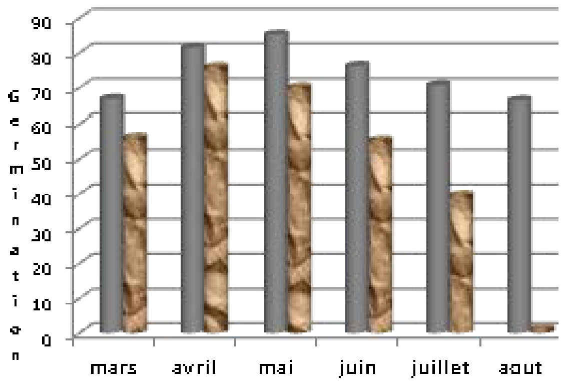


Figure 12.

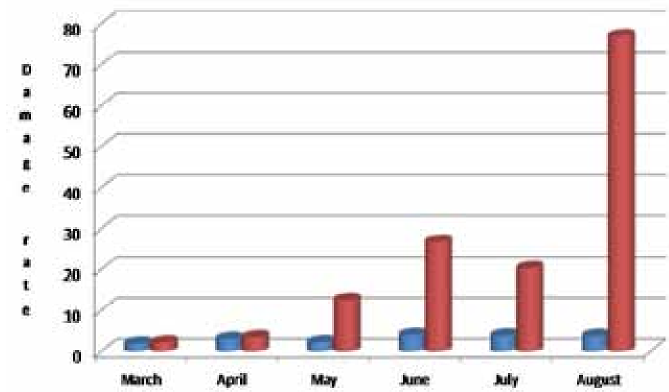


Figure 13.

Figure 14.

Special Projects
Technology Transfer

INTSORMIL

Transfer of Technologies for Production and Marketing and Striga-Management of Sorghum and Pearl Millet in West Africa Mali, Niger, Senegal, Burkina Faso, and Nigeria

Technology Transfer Specialist

Dr. Mamourou Diourte

U.S. Coordinators

Dr. Bruce Hamaker and Dr. Bonnie Pendleton

Expected Outcomes

Farmer entrepreneurs are expected to properly grow, store grain, and sell quality improved varieties of sorghum and millet resistant to Striga and other pests to food and feed processors for local and regional markets in West Africa.

Farmers are being educated to identify and manage insect and disease pests so quality grain can be stored longer to obtain a price premium when sold.

Hundreds of farmers, including women, are receiving training for producing and using improved varieties of sorghum and millet for seed and grain for food and feed.

Production Activities

Beginning in June 2010, dynamic farmers were selected throughout the different countries to produce quality seeds of improved sorghum or millet. Farmers and extension agents were taught to manage production and disease and insect pests. Farmers built clay walls and INTSORMIL paid for metal roofs for new seed-storage facilities in various countries.

At INRAN, a sorghum line with medium maturity and quality grain was released and 50 hybrids selected with farmers and private seed producers will be evaluated in many ecological zones. One hundred women and 80 men attended a workshop on 25-26 August to learn techniques to boost sorghum productivity and protect against recurrent food insecurity. At the training, INRAN scientists introduced INTSORMIL to policymakers, extension, NGOs, farmer associations, and private seed producers. (Table 1)

Marketing Activities

Entrepreneur processors signed contracts with farmers who produced quality millet and sorghum grain. Partnerships were contracted between 16 processors and 10 farmer entrepreneurs in three regions of Niger to grow 50 tons of quality sorghum and millet grain. An optimized mechanical thresher was used to produce clean grain. A couscous-steaming machine and gas dryer were purchased to complete the processing incubation unit at INRAN. The unit was used by 15 processor groups of 15-30 members to produce competitive sorghum and millet agglomerated products (couscous and grits-like couscous and instant flour and composite bread) marketed in 30 stores and open markets in Niger. The processors were trained in food packaging and sanitation and business/management. The INRAN/INTSORMIL Incubation Centre was publicized at local and regional meetings and on radio and television. A 12-minute film was produced on sorghum and millet processing in Niger.

Farmers in Senegal supplied raw millet for ITA, and 'Early Thaï' maize (hard with good production of cornmeal) was obtained from collaboration with Société des Fibres Textiles. ITA used their semi-industrial pilot plant to produce flour. Since March 2011, ITA produced couscous from flour produced in the same place to satisfy ITA workers and women's groups of Gueule Tapée-Fass-Colobane District in Senegal. Economical millet and maize couscous was tested in two dishes in the District of Gueule-Tapée-Fass-Colobane. Four hundred gram bags of couscous valued at 225 F.CFA each were supplied to groups of women who earned 25 F.CFA per bag sold. Couscous from millet was preferred over maize. Three young people helped with market development. The project hosted two students from universities in France. (Table 2)

Table 1. Amount of Improved Sorghum Seed Disseminated from 2009-2011 to Farmers in Niger

Quantity of seed disseminated	Tillabery Région	Area covered	Tahoua Region	Area covered	Maradi Region	Area covered
Sepon-82	2T	200ha	3T	300ha	2T	200ha
IRAT 204	6T	600ha				
SSD-35			3T	300ha	2T	200ha
Mota Maradi					4T	400ha
Total	**8T**	**600ha**	**6T**	**600ha**	**8T**	**800ha**

Table 2.

Delivery date	Destination	Quantity (400-g bags) Millet	Maize
24 March 2011	ITA technical store	30	27
2 June 2011	ITA technical store	90	
1 July 2011	ITA technical store	11	
	District of Gueule Tapée-Fass-Colobane	39	50
7 July 2011	ITA technical store	50	50
13 July 2011	ITA technical store	50	
19 July 2011	ITA technical store	50	50

Striga Management Activities

On 4 July at Kamboinsé Research Station in Burkina Faso, six farmers were trained in sorghum seed production and Striga control. Fertilizer and 10 kg of seed of Framida sorghum resistant to Striga were given to each farmer to plant 1 hectare. On 17-18 November, 26 farmers including two women and four extension agents visited the plots. The tour was covered by national television. Seeds were purchased from each farmer. Seed (2,500 kg) will be transferred to IRSAT for processing dolo, and 700 kg will be distributed as certified seed to more farmers. (Table 3)

Advertisement

Signs with logos of INTSORMIL, host-country programs, and U.S.-AID were posted beside sorghum fields and put onto grain and food products in stores. Baseball caps with the logos were produced and given to farmers, processors, and extension agents throughout the host countries.

A film on INTSORMIL was produced and broadcast on national television in Mali. Participants were interviewed for a video on INTSORMIL present and past collaborative research and educational activities.

Table 3. Production of Sorghum Seed by Farmers in Western Burkina Faso, 2011

Village	Farmer name	Area (ha)	Yield (kg)	Quantity of seeds bought
Kwakwalé	Sanou Siaka	2	1,767	1,500
Toussiana	Ouattara Gabriel	3	5,923	2,000
Toussiana	Ouattara Moussa	3	3,399	1,000
Sokoroni	Traoré Mourlaye	1	980	980
Sokoroni	Traoré Ousmane	1	335	335
Sokoroni	Traoré Amidou	1	260	260
Sokoroni	Diallo Adama	0.25	47	47
Sokoroni	Dembélé Fati	2	933	933
Sokoroni	Ouattara Diakalia	1	178	178
Sokoroni	Sanogo Adama	1	135	135
Sokoroni	Koné Abdramane	0.5	130	130
Total	**11**	**15.75**	**14,087**	**7,498**

Progress Report on Expansion of Sorghum Production Technologies in Eastern and Northern Uganda [Tot Project] and Related Sorghum Projects

Co-Principal Investigators

Kaizzi C. Kayuki, Charles Wortmann, Mark Erbaugh, Don Larson

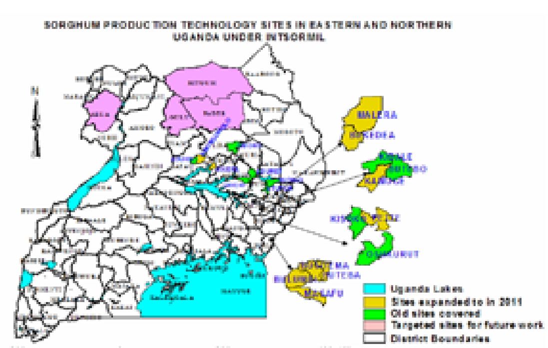
Partners

Makerere University, District extension staff, NGO and CBO, NaSARRI - Serere

Activities Implemented

On-farm demonstrations (373) of Integrated Soil Fertility Management (ISFM) technologies were conducted in 2011 in Kisoko, Osukuru and Petta sub-counties [Tororo district], Opwatetta, Kibale, Kapwayi, Kanyum, Butebo and Nasuretta [Pallissa district], Asuret, Omulala, Gweri and Telemut [Soroti district], Aduku [Apac district] and Omoro [Lira district]. Activities are implemented by farmer groups and Farmer Field Schools with great participation of women. Project activities were expanded in 2012 to Buhuni, Ejapet, Masafu and Osia sub-counties [Busia district]; Petta SC [Tororo district]; Kapunyansi and Kamuge SC [Pallissa District], Bukedea and Malera SC [Bukedea district]; Abongomola and Aduku Sc [Apac district]; and Kwera SC [Dokolo district]. This totals 27 sub-coutnites across 8 districts. (Figure 1)

Figure 1.



Activities were enabled and monitored by community based facilitators who previously attended our Training of Trainers (TOT) course on ISFM. The facilitators link our TOT team with the farmers. As many of these facilitators are likely to continue living in the vicinity beyond the life of this project, long term benefit to local communities is expected because of knowledge, skills, contacts, and experiences gained from working in these facilitator roles. Results from 373 on-farm demonstrations conducted in 2011 are presented in Tables 1-3 (see below).

Agro-input dealers in the communities were supported to improve input supply. Non-availability of inorganic fertilizers is a frequent complaint of farmers. The project encouraged shop owners in the community to stock fertilizers which were initially bought by the project from a nearby major town. Farmers were informed on the availability of fertilizers in their locality during end of season and beginning of season planning meetings, and through radio announcements on local stations. The quantity of fertilizers sold and the crops on which they are used is presented in the Table 4. The quantities are small but significant as there is no tradition of fertilizer use in these areas.

A baseline and adoption study was done by Dr. Gabriel Alepo of Makerere University. Adoption, yields and income were significantly greater among farmers who participated in NARO-INTSORMIL supported activities compared to farmers who had not participated.

Stakeholder Training Workshops on ISFM

These were organized at all project sites (8 during 2011A and 12 during 2011B seasons) and attended by NGO, extension agents and political leaders in the area [local councils 1 – 3]. Topics covered include the use of compost, kraal manure, green manure in rotation with cereals, inorganic fertilizers, a combination of inorganic and organic fertilizers, making compost, crop rotation, reduced tillage, soil and water management. Common attendance was 100 - 120 farmers per site. Farmers participating in the project reported to other participants their observations of the performance of the alternative technologies.

Trained 80 trainers in ISFM, including extension agents, agro-input dealers and farmers.

Researcher managed trials investigating the effect of reduced tillage/conservation agriculture practices on system sustainability are implemented at Pallissa DATIC and Bulegeni ADC. Ms. Angela Nansamba is enrolled at Makerere University, Kampala and is conducting her M.Sc. research on these trials.

Leaflets and posters were prepared, printed and distributed in project areas on (i) Fertilizer use to increase sorghum production and (ii) Increase sorghum yield using manure. These were printed in English, Luo, Iteso and Luganda [2000 copies of leaflets in each language].

The project supported multiple locations and included on-farm and farmer evaluation, of advanced lines. Based on these results, three sorghum lines i.e., SRN39 (SESO1), M91057 (SESO2), and IS25403 (SESO 3)] were released in May 2011 and were accompanied by rapid seed increase. SRN39 (SESO1 – INTSORMIL) and M 91057 (SESO2 INTSORMIL) are white seeded, high food quality, and preferred for clear beer production. A brown grain cultivar (SESO3 – INTSORMIL) is preferred for local consumption, local brewing, and good storage. (Figure 2)

Seed increase for SESO1, SESO2 and SESO3 included 4 t produced on station at NARL, a larger farmer increase with farmer-to-farmer dissemination. The private seed company NASECO is increasing and marketing the seed but we do not have their numbers. (Figure 3)

Figure 2.

Figure 3. Breeder's seed increase.

Researcher managed trials to evaluate (SESO3 – INTSORMIL) and SESO2 response to N, P and K fertilizers are being carried out on-farm in Apac and Dokolo districts.

Use of white sorghum flour in bread making is being explored with Hot Loaf Bakery, Nyange Bakery and Kyengera Bakery.

Project Impact

On-farm demos used for technology dissemination stimulate a great deal of farmer-to-farmer transfer.

Mrs. Osinde Faith in the Tororo district testified that before her farm was not productive but she now has much improved production and receives over 100 visitors on her farm.

Mr. Etyang testified that because of the use of ISFM practices, crop performance improved and he has received 30 or more visitors.

Alupo Jane had very degraded soil and the sorghum crop could only grow to 3 ft tall. She received funding to purchase cattle manure which she applied to her fields. She is now a model farmer and continues to use manure on her crops. Today many people seek advice from her including visitors from other districts who come to learn her farming techniques.

Improved Livelihood

Mr. Omagolo Justine, a farmer in Opwatetta Sub county, Pallissa district, selected manure which he applied on ½ acre of sorghum. He grew 800 kg as opposed to 150 kg without manure. He sold his crop for 550CFA per kg which he used for food and school fees. He urges his fellow farmers to use the technologies to improve their livelihood. (Figure 4)

Figure 4.

Ms. Atima Margaret, a farmer in Osukuru Sub county, Tororo district, selected manure from the mother-baby demos. She applied it too ½ acre of sorghum and was able to harvest 500 kg, which she used for home consumption. "I am now food secure, thanks to NARO - INTSORMIL teaching me the value of manure" she related to her fellow farmers and strongly encouraged them to apply the technologies too.

Farmers have taken up the growing of SESO 3 because it is sweet, unfortunately SESO 2 is heavily damaged by birds.

There is increased awareness by farmers of ISFM technologies in addressing poor soil fertility which is a major constraint to agricultural production in the project area.

Table 1. Sorghum grain yield (t/ha) across the on-farm demonstrations in three districts during the 2011A season with cv "SESO 3"

Treatment	Pallissa district		Tororo district			Soroti district		
	Kanyum	Kapway	Kisoko	Osukuru	Petta	Adacar Amina	Omulala	Telemut
No. of demos	17	32	15	15	8	30	6	10
Control	0.6^{e}	0.5^{d}	1.0^{c}	1.0^{d}	0.9^{e}	1.3^{d}	1.1^{d}	1.1^{e}
2.5 t/ha FYM	1.1^{d}	1.0^{c}	1.8^{b}	1.7^{c}	1.4^{d}	2.0^{c}	1.7^{c}	1.5^{d}
(15 kg N + 7.5 kg P + 2.5 t FYM) ha^{-1}	1.5^{b}	1.3^{b}	2.2^{a}	2.0^{b}	1.9^{c}	2.1^{c}	3.0^{b}	2.0^{c}
(30 kg N + 15 kg P) ha^{-1}	1.4^{c}	1.3^{b}	2.3^{a}	2.3^{a}	2.3^{b}	2.8^{b}	2.8^{b}	2.5^{b}
(30 kg N + 15 kg P + 30 kg K) ha^{-1}	1.9^{a}	1.7^{a}	2.5^{a}	2.4^{a}	2.7^{a}	3.2^{a}	3.7^{a}	2.8^{a}
Mucuna						2.3^{c}		
	***	***	***	***	***	***	***	***

Table 2. Sorghum grain yield (t/ha) across on-farm demonstrations in four districts during the 2011B season with cv "SESO 3"

Treatment	Pallissa district			Tororo district				Soroti district			Busia district			
	Sidanyi	**Kapuyansi**	**Kadesok**	**Kisoko**	**Osukuru**	**Petta**	**Kwapa**	**Adacar Amina**	**Omulala**	**Telemut**	**Bulumbi**	**Ejapat**	**Masafu**	**Osia**
No. of demos	8	10	15	10	15	8	6	25	11	15	11	7	5	10
Control	0.6^{d}	0.5^{d}	0.8^{c}	1.0^{c}	0.8^{e}	1.0^{e}	1.1^{e}	1.0^{d}	1.0^{e}	1.0^{d}	0.8e	0.8^{e}	0.8^{e}	0.8^{e}
2.5 t/ha FYM	1.3^{c}	1.0^{c}	1.6^{b}	1.8^{b}	2.1^{d}	1.5^{e}	1.4^{d}	2.1^{c}	1.6^{d}	1.6^{c}	1.4d	1.5^{d}	1.3^{d}	1.2^{d}
(15 kg N + 7.5 kg P + 2.5 t FYM) ha^{-1}	1.6^{b}	1.4^{b}	1.7^{b}	2.2^{a}	2.4^{c}	1.8^{c}	1.8^{c}	2.2^{c}	2.1^{c}	2.6^{b}	1.7c	1.7^{c}	1.7^{c}	1.6^{c}
(30 kg N + 15 kg P) ha^{-1}	1.6^{b}	1.4^{b}	2.1^{a}	2.3^{a}	2.7^{b}	2.0^{b}	2.0^{b}	2.7^{a}	3.0^{b}	2.7^{b}	1.9b	2.0^{b}	2.0^{b}	1.8^{b}
(30 kg N + 15 kg P + 30 kg K) ha^{-1}	2.1^{a}	1.9^{a}	2.1^{a}	2.4^{a}	3.0^{a}	2.3^{a}	2.6^{a}	3.2^{a}	3.8^{a}	3.0^{a}	2.4a	2.5^{a}	2.5^{a}	2.3^{a}
Mucuna								2.5^{b}						
	***	***	***	***	***	***	***	***	***	***	***	***	***	***

Table 3. Sorghum grain yield (t/ha) across additional on-farm demonstrations in three districts during the 2011B season.

Treatments	Bukedea district	Apac district				Dokolo district			
	Malera and Bukedea	Aduku				Kwera			
	(SESO 3)	Sekedo	SESO2	SES03	Mean	Sekedo	SESO2	SESO3	Mean
No. of demos	25	10	10	10		10	10	10	
Control	0.8^{c}	0.9^{b}	0.8^{d}	1.1^{d}	0.8^{d}	0.9^{b}	0.9^{b}	1.3^{a}	1.1^{b}
2.5 t/ha FYM	1.5^{b}	1.2^{c}	1.0^{c}	1.4^{c}	1.2^{c}	1.7^{a}	1.6^{a}	1.9^{a}	1.8^{a}
(15 kg N + 7.5 kg P + 2.5 t FYM) ha^{-1}	1.6^{b}	1.4^{bc}	1.2^{b}	1.7^{b}	1.4^{b}	1.9^{a}	2.0^{a}	2.0^{a}	2.0^{a}
(30 kg N + 15 kg P) ha^{-1}	1.7^{b}	1.6^{ab}	1.3^{b}	1.8^{b}	1.5^{b}	1.8^{a}	1.6^{a}	1.8^{a}	1.6^{a}
(30 kg N + 15 kg P + 30 kg K) ha^{-1}	2.0^{a}	1.8^{a}	1.5^{a}	2.1^{a}	1.8^{a}	1.6^{a}	1.9^{a}	1.9^{a}	1.9^{a}
	***	***	***	***	***	***	***	***	***

Table 4. Locations of agro-dealers supported and fertilizer sales information.

Fertilizer	Fertilizer and amount sold	Crops used
Opwatetta	50 TSP and 100 kg urea	Sorghum
	60 kg TSP	Groundnuts
	100 kg urea	Maize
Kibale and Butebo	250 kg urea and 100 TSP	Maize
	100 kg urea and 50 kg TSP	Sorghum
	120kg urea	Vegetables
Kisoko	50 kg TSP	Maize
	120 kg urea	Maize and vegetables
	100 kg TSP	Groundnuts
Osukuru	50 kg TSP and 100 kg urea	Maize, sorghum and groundnuts
Aduku	800 kg urea and 200 kg TSP	Maize, sorghum and vegetables

Educational Activities

Educational Activities

INTSORMIL gives high priority to training host country scientists who will have major responsibilities for sorghum and millet research in their home countries. Training is also provided for young U.S. scientists who plan for careers in international development work.

The most frequently used mode of training is graduate study for advanced degrees, with the students' research forming an integral part of an INTSORMIL project. During the years covered by this report, 46 students were enrolled in an INTSORMIL advanced degree program. Approximately 83% of these students come from countries other than the U.S. which shows the emphasis placed on host country institutional development (Figure 1).

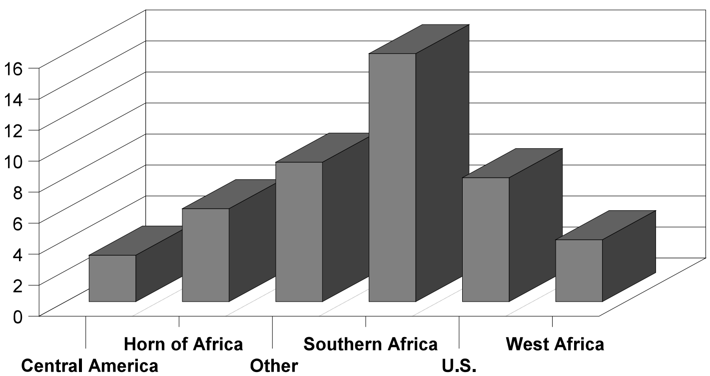


Figure 1. Degree Participants by Region

INTSORMIL also places a high priority on training women which is reflected in Figure 2. From 2010-2011, 50% of all INTSORMIL graduate participants were female. Thirty-three of the 46 students received partial INTSORMIL funding and 13 received full INTSORMIL scholarships.

All 46 students worked directly with INTSORMIL principal investigators on INTSORMIL projects. These students are enrolled in graduate programs in six disciplinary areas, agronomy, breeding, economics, entomology, food science, and pathology.

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 2010-2011 there were 16.

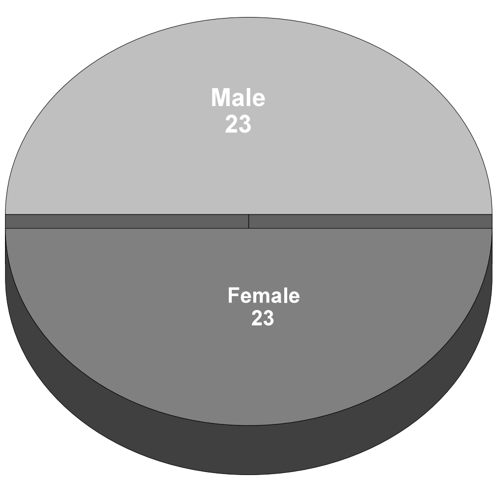


Figure 2. Degree Participants by Gender

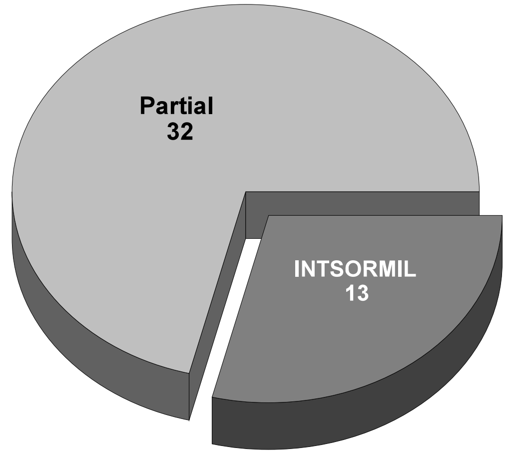


Figure 3. Degree Participants Funding

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. Five postdoctoral scientists and 5 visiting host country scientists were provided the opportunity to upgrade their skills in this fashion from 2010-2011.

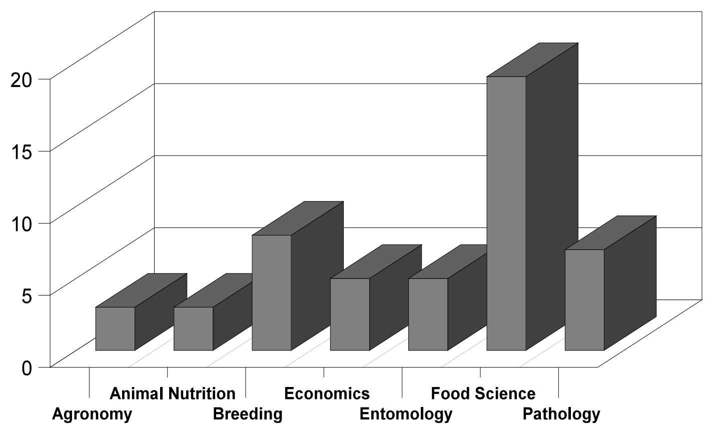


Figure 4. Degree Participants by Discipline

Year 5 INTSORMIL Degree
Training Participants
September 30, 2010 – September 29, 2011

Name	Country	Univ.	Discipline	Advisor	Degree	Gender	Funding
Kasosi, Angelia	Uganda	UNL	Agronomy	Charles Wortmann	M.S.	F	I
Liben, Feyera	Ethiopia	UNL	Agronomy	Charles Wortmann	M.S.	M	I
Maria, Ricardo	Mozambique	UNL	Agronomy	Charles Wortmann	Ph.D.	M	I
Bergsma, Benjamin	USA	KSU	Breeding	Mitch Tuinstra	M.S.	M	P
Burns, J. Kyle	USA	TAMU	Breeding	W. Rooney	M.S.	M	P
Kasoma, Chapwa	Zambia	UNZA	Breeding	Medson Chisi	M.S.	M	P
Chikot, Patrick	Zambia	KwaZulu	Breeding		Ph.D.	M	P
Gill, John	USA	TAMU	Breeding	W. Rooney	Ph.D.	M	P
Muuka, Ferdinand	Zambia	UNZA	Breeding	Medson Chisi	Ph.D.	M	I
Portillo, Ostillo	Honduras	TAMU	Breeding	W. Rooney	Ph.D.	M	I
Chimai, Bernadette	Zambia	OSU	Economics	Erbaugh/Larson	M.S.	F	I
Garcia, Gabriel	Bolivia	PRF	Economics	John Sanders	M.S.	M	P
Maseki, Salome	Tanzania	Sokoine U	Economics	Don Larson	M.S.	F	P
Villacis, Alexis	Ecuador	PRF	Economics	John Sanders	M.S.	M	I
Makindara, Jeremia	Tanzania	Sokoine U	Economics	Don Larson	Ph.D.	M	P
Gilchrest, Jody	USA	WTAMU	Entomology	Bonnie Pendleton	B.S.	F	P
Diarra, Drissa	Mali	WTAMU	Entomology	Bonnie Pendleton	M.S.	M	P
Garzon, Camilo	Colombia	WTAMU	Entomology	Bonnie Pendleton	M.S.	F	P
Boswell, Sara	USA	TAMU	Food Science	L. Rooney	M.S.	F	P
Cisse, Fatima	Mali	PRF	Food Science	B. Hamaker	M.S.	F	I
Goodall, Morgan	USA	PRF	Food Science	B. Hamaker	M.S.	F	I
Lindsay, John	USA	TAMU	Food Science	L. Rooney	M.S.	M	P
Mella, Onesmo	Tanzania	UNL	Food Science	David Jackson	M.S.	M	I
Muronzwa, Juliet	South Africa	U of Pretoria	Food Science	John Taylor	M.S.	F	P
Pinilla, Luz	Colombia	TAMU	Food Science	L. Rooney	M.S.	F	P
Yang, Liyi	China	TAMU	Food Science	L. Rooney	M.S.	F	P
Adetunji, Adeoluwa	Nigeria	UNL	Food Science	John Taylor	Ph.D.	M	P
Anyango, Joseph	Kenya	U of Pretoria	Food Science	John Taylor	Ph.D.	M	P
Asif, Muhammad	Pakistan	TAMU	Food Science	L. Rooney	Ph.D.	M	P
Barros, Fred	Brazil	TAMU	Food Science	L. Rooney	Ph.D.	M	P
Chiremba, Constance	South Africa	U of Pretoria	Food Science	John Taylor	Ph.D.	F	P
da Silva, Laura	South Africa	U of Pretoria	Food Science	John Taylor	Ph.D.	F	P
Dlamini, Bheki	South Africa	U of Pretoria	Food Science	John Taylor	Ph.D.	M	P
Diarra, Mohamed	Mali	PRF	Food Science	B. Hamaker	Ph.D.	M	I
Hikeeze, Doreen	Zambia	U of Pretoria	Food Science	John Taylor	Ph.D.	F	P
Kruger, Johanita	South Africa	U of Pretoria	Food Science	John Taylor	Ph.D.	F	P
Mkandawire, Nyambe	Zambia	UNL	Food Science	David Jackson	Ph.D.	F	I
Taleon, Victor	Guatemala	TAMU	Food Science	L. Rooney	Ph.D.	M	I
Yang, Liyi	China	TAMU	Food Science	L. Rooney	Ph.D.	F	P
Xu, Haidi	China	PRF	Food Science	B. Hamaker	Ph.D.	F	P
Fuentes-Bueno, Irazeuma	USA	KSU	Plant Pathology	John Leslie	M.S.	F	P
Mavhunga, Mudzuli	South Africa	U of Free State	Plant Pathology	Neal McLaren	M.S.	F	P
van Rooyen, Danelle	South Africa	U of Free State	Plant Pathology	Neal McLaren	M.S.	F	P
Bushula, Vuyiswa	South Africa	KSU	Plant Pathology	John Leslie	Ph.D.	F	P
Nor, Nik	Malaysia	KSU	Plant Pathology	John Leslie	Ph.D.	M	P

Year 5 INTSORMIL Non-Degree
Training Participants
September 30, 2010 – September 29, 2011

Name	Country	Univ.	Discipline	Advisor	Activity	Gender	Funding
Kayuki, Kaizzi	Uganda	UNL	Agronomy	Wortmann	VS	M	I
Kumsa, Assefa	Ethiopia	UNL	Agronomy	Wortmann	VS	M	P
Tesfaye, Kindie	Ethiopia	UNL	Agronomy	Wortmann	VS	M	P
Ibikunie, Olumide	Nigeria	PRF	Breeding	Tuinstra	VS	M	P
Adebewola, Abdul-Rasaq	Nigeria	UPretoria	Breeding	Peterson, G.	PD	M	P
Edema, Mojisola O.	Nigeria	UPretoria	Breeding	Peterson, G.	PD	M	P
Fasasi, Olufunmilayo	Nigeria	UPretoria	Breeding	Peterson, G.	PD	M	P
Stefaniak, Thomas	U.S.	TAMU	Breeding	Rooney, W.	PD	M	P
Ac Pangan, Marlon	Guatemala	TAMU	Food Science	Rooney, L.	VS	M	P
Saleh, Amgad	Egypt	KSU	Pathology	Leslie, J.	PD	M	P

VS = Visiting Scientist   PD = Post Doctoral

Year 5 INTSORMIL
Conference/Workshop Activities
September 30, 2010 – September 29, 2011

			Participants		
Name	**Location**	**Date**	**Male**	**Female**	**Total**
Portillo, Ostillo	El Salvador	May, 2010	1	0	1
Eder, Zachary	Texas	November, 2010	1	0	1
Vyavhare, Suhas	Texas	November, 2010	1	0	1
Gilchrest, Jody	California	December, 2010	0	1	1
Vyavhare, Suhas	Texas	December, 2010	0	1	1
Amador-Diaz, Mildred	Nicaragua	August, 2011	0	1	1
Cardoza-Gomez, Edith	Nicaragua	August, 2011	0	1	1
Cudro-Castillo, Sergio	Nicaragua	August, 2011	1	0	1
Martinez-Mendoza, Carlos	Nicaragua	August, 2011	1	0	1
Navarete-Blanco, Angel	Nicaragua	August, 2011	1	0	1
Rivera-Gutierrez, Eunices	Nicaragua	August, 2011	0	1	1
Vargas-Rocha, Sheila	Nicaragua	August, 2011	0	1	1
N'Doye, Ababacar	Indiana	September 3-13, 2011	1	0	1
Mycotoxin Workshop	Italy	October, 2010	10	10	20
Scientific Writing Workshop	Zambia	October, 2010	38	22	60
Scientific Writing Workshop	Korea	November, 2010	17	27	44
Scientific Writing Workshop	Japan	November, 2010	35	42	77
Scientific Writing Workshop	Malaysia	November, 2010	49	88	137

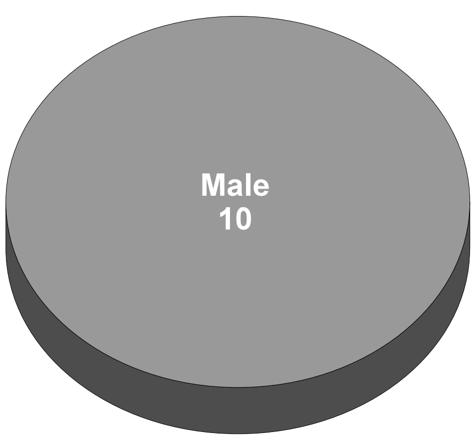


Figure 5. Total Non-Degree Participants by Gender

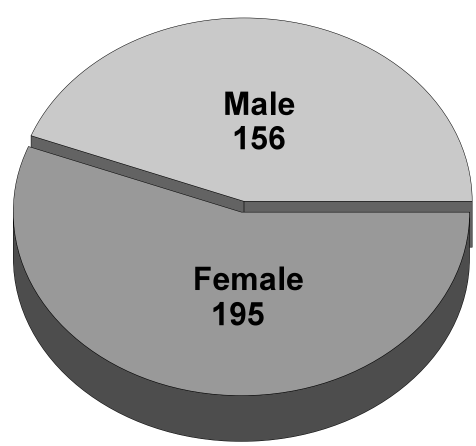


Figure 6. Total Conference/Workshop Participants by Gender

Appendices

INTSORMIL Sponsored and Co-Sponsored Workshops 2006-2011

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
INTSORMIL West Africa Regional Planning Meeting	Bamako, Mali	August 28-29, 2009
Sorghum Food Enterprise and Technology Development in Southern Africa Workshop.	Lusaka, Zambia	December 6-9, 2010

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
CIRDES	Centre International de Recherche-Developpement Sur l'Elevage en Zone Subhumide
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
IRSAT	Institut de Recherche en Sciences Appliquées et Technologies
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