INTSORMIL

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

INTSORMIL 2010

2010 Annual Report

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INTSORMIL

USAID
FROM THE AMERICAN PEOPLE

Village children in the Segou Region, Mali where IER, INTSORMIL and Sasakawa Global 2000 collaborate to promote production of the Toroniou millet variety, an important food source.

Photo Courtesy of Elvis Heinrichs, University of Nebraska

Top: Four women in the Douentza Village, Mopti Region, Mali, simultaneously grinding millet to produce flour.

Bottom: Food processors (right and center) and farmer (left) discussing the attributes of the Toroniou millet variety as a source for producing food products during the Producer/Processor Networking Workshop visit to farmers' fields in the Segou Region, Mali, 12 November, 2010

Photo Courtesy of Elvis Heinrichs, University of Nebraska

INTSORMIL
Sorghum, Millet and Other Grains CRSP

2010 ANNUAL REPORT

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Introduction and Program Review

The 2010 INTSORMIL Annual Report presents the progress and notable achievements of the Sorghum/Millet and Other Grains CRSP during the period of September 30, 2009 through September 29, 2010. 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 17 U.S. university scientists and scientists of the National Agricultural Research Systems (NARS), IARCs, PVOs and other CRSPs. INTSORMIL is programmatically organized for efficient and effective operation and captures most of the public research expertise on sorghum and pearl millet in the United States. The INTSORMIL mission is to use collaborative research as a mechanism to develop human and institutional research capabilities to overcome constraints to sorghum and millet production, marketing, 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 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. USAID personnel serve 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 2009-2010, there were 46 students from 20 different countries enrolled in an INTSORMIL advanced degree program and advised by an INTSORMIL principal investigator. Approximately 78% of these students came from countries other than the U.S. The number of students receiving 100% funding by INTSORMIL in 2009-2010 totaled 2. An additional 44 students received partial funding from INTSORMIL. INTSORMIL places high priority on training of women. During the period 2009-2010, 48% 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, 11 host country scientists improved their education as either postdoctoral scientists (3) or visiting scientists (8). Their research activities were in the disciplines of breeding, food science and pathology. These scientists came to the United States as postdoctoral scientists or visiting scientists from Burkina Faso, Croatia, Ecuador, Egypt, India, Mali, Nigeria, Zambia, Zimbabwe and the USA. In addition to non-degree research activities there were 768 participants (400 male and 368 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 CORAF and ASARECA/ECARSAM in Africa and SICNA and the U.S. National Grain Sorghum Producers Association for the purpose of coordinating research activities to avoid duplication of effort and to promote the most effective expenditure of research funds. There also has been efficient collaboration with each of these programs in co-sponsoring workshops and conferences, and for coordination of research and long-term training. INTSORMIL currently cooperates with ICRISAT programs in east, southern and West Africa.

Regional Activities and Benefits

West Africa

The collaborating scientists are using seed multiplication, on-farm testing, and exchange of sorghum and millet varieties 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 are identifying and developing management practices for insects and pathogens attacking grain in storage. Base populations of sorghum and millet cultivars with known adaptation, stability, and acceptability through multi-environment experiments and with resistance/tolerance to pests and drought are being developed. Conventional and/or marker-assisted recurrent selection techniques are used 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 to 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 of Maiduguri 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 3 of the individual projects comprising the Horn of Africa regional program were accomplished during 2009, 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 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. 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

USAID/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 isdesigned 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. Project objectives are:

- Facilitate adoption of production and marketing technologies to improve the incomes of sorghum and millet producers
- Facilitate the development of markets for food use for millet and sorghum and as a poultry feed for sorghum
- Develop stronger farmers' groups and enhance their marketing power
- Extend mechanized food processing technologies to entrepreneurs and processor groups
- Introduce improved agronomic practices into décrue farming systems in northern Mali.

The Cooperative Agreement consists of four components: 1) Management Entity, 2) Production - Marketing activities led by John Sanders, Purdue University Marketing Economist; 3) Food Processing Technology and Training activities, led by Bruce Hamaker, Purdue University Cereal Chemist, 4) 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 5) Academic Training led by Jess Lowenberg -Deboer, Purdue University. Activities are conducted in collaboration with IER. Significant progress was achieved in 2009-2010 through meeting Project objectives as set forth in the workplan.

Management Entity

INTSORMIL was represented at the Partner's meeting by the Management Entity (E. A. Heinrichs), IER Coordinator (M. Diourte), Production-Marketing (B. Ouendeba), Processing (Yara Koreissi), and Décrue Sorghum (A. Wahab Toure). The INTSORMIL project was summarized and presented in the form of an attractive and informative poster produced by M. Diourte and IER staff. The meeting goal was "To support the implementing partners in operating effectively in achieving successful results.

A publicity campaign was initiated with the goal of promoting the project to more rapidly transfer sorghum and millet production, marketing and food processing technologies to farmers and entrepreneurial food processors. The campaign includes signage at project sites, t-shirts and hats with appropriate logos for collaborators, radio TV spots and submission of USAID Success Stories to the Mali Mission.

The Management Entity participated in the Producer/Processor Networking Workshop in Bamako November, 10-12, 2010.

In the past year the Management Entity has established several MOUs (Memorandums of Understanding) with collaborating NGOs and 12 workplans and amendments to the budget have been processed in support of the four project components.

Production-Marketing

There are now four components to the Production-Marketing project:

- Technical support to IICEM for the scaling up process
- Extension of pilot projects
- Resolving implementation and technical problems
- Publishing evaluation, marketing and gender impact studies

Technical Support to IICEM for the Scaling–Up Process

1) In Koutiala the process of bank negotiation between the extension agency, AMEDD, and the bank, BNDA, broke down in the spring of 2010. Rather than the 3,000 ha of bank financed new technology planned there was only 85 ha. However, due to the organization of the farmers' associations implemented by AMEDD and financed by IICEM, there were an estimated 1,335 ha put into the new technology package. Almost all of these farmers obtained the DRA supplied subsidized fertilizer. The bank financing is expected to be more successful in 2011. The Koutiala area goal in 2011 is not yet decided but will probably be around 5,000 ha.

2) In the Segou region 500 new ha was planned and implemented by Global 2000 with 8 new farmers' associations. There we experienced the same problems of poor agronomy, especially the poor handling of inorganic fertilizer, planting in poor soils and little thinning. Also, another bank source for input credit needs to be identified. A feasible area goal is probably around 3,000 ha. Helping IICEM to scale up in the Koutiala and Segou regions is our number one priority in 2011.

3) In the Mopti region we presently have 300 ha in new technologies in six different farmers' associations. Traditional storage of leaving the stalks on the ceilings and roofs is practiced here. Farmers are happy with the new technologies. But we need to move faster with IICEM in constructing storage facilities. More concrete plans for the types of storage facilities, the division of the contributions between IICEM and the farmers' groups and the dates for initiating activities will be a priority in 2011.

Extension of Pilot Projects into New Regions

1) In the Mopti region in 2010 we had 300 ha in new technology. We need a new millet cultivar as Toroniou is an old selection and there has been new breeding work with millet in Mali. Also we will need to improve the agronomy being practiced though the most effective force for improvement is the observation by farmers of other farmers' yields. However, the critical innovation is the rapid construction of storage facilities. This enables farmers to wait for better prices avoiding sales at the price collapse period after harvest The farmers' associations can become "commercantes."They buy small quantities, store, and then systematically look for better prices for both their products and their inputs. We will raise the number of pilot project ha to 500.

2) We began work in the Kayes region in 2008. We are not happy with the old cultivar Seguifa here. We have been pushing IER for a new cultivar that is a Guinea-Caudatum cross, intermediate height and season length. As in Mopti there is a very good, supportive, regional DRA director. So if we can get some new cultivars, we will push to extend the area here by 300 ha and work in the three main production areas with sorghum.

3) Doumbia of IER has been introducing a new conservation technique in Fana with an approximate cost of 5,000 CFA/ha We will investigate putting our technologies and marketing strategies on top of his soils technique. This technique does water retention and slows erosion. Since our combined technologies already cost 40,000 to 50,000 CFA/ha we will stay with farmers already using Doumbia's technique and then investigate the potential to diffuse the combined package.

Resolving Implementation and Technical Problems

1) Resolving the germination problem of Grinkan- This is our number one technical problem as Grinkan is our flagship cultivar because it has been very successful in the Koutiala region.

Germination rates of about 60% were very common in 2010 necessitating replanting.

2) Improve seed quality- Our participant farmers do a good job but have trouble removing the off types and are probably storing with humidity over 11% when there are late rains. We need to improve their performance but also develop a few excellent seed producers and do branding here. We will work with WASA and the seed program of IER on this.

3) Improve and rapidly multiply the storage facilities- We have a collaborative activity with IICEM designed to rapidly increase the number of storage facilities in Mopti.

4) New millet and sorghum cultivars- We need to replace both Toroniou and Seguifa with higher yielding, regionally adapted cultivars in Mopti.

5) Better training for farmers in agronomy especially where we are scaling up- We will put more effort into the agronomy training focusing on fertilizer placement, thinning, selecting good land areas and complementing inorganic with organic fertilizer.

6) Training on dealing with banks- Knowing when they are getting good interest rates and repayment terms is important for both our extension NGOs and farmers' associations. So an important sustainability issue is building up the capacities of the farmers' associations and the main extension partners to deal with the banks.

Publishing, Evaluation, Signage, Marketing and Other Studies

Each year we evaluate the economic results of the previous crop season. We have already done a study of the millet food processors and the price premium for uniform, clean grain and this study needs to be updated now that there are more millet food processors and more farmers' associations selling clean cereal. We also need do a study of the emerging intensive poultry production in Mali and its potential to use sorghum in the feed. We are collaborating with the IER Communication Department in the construction of signs with the appropriate logos of all donors at our field sites. In 2009, women have been integrated in the production-marketing component of the IER-INTSORMIL project in Mali. Jeanne Coulibaly, PhD student at Purdue University, is doing a study on the income and welfare consequences of the new sorghum technologies in the Koutiala region with an emphasis on the effects on women. She will also look at alternative policies and technologies to increase the welfare of women and children. The goal is to help women to benefit from the adoption of new technologies which are likely to impact positively their welfare as well as the whole household's well-being.

Food Processing

Enterprise development accomplishments in the Mopti-Gao Region in the past year include 1) Market survey completed, 2) Seven partners identified, 3) Working with women processors and their associations, 4) Mechanization of entrepreneurial units with contributions made by partners for payback, 5) Building constructed with partner contribution, 6) Dehuller and 2 mills installed and optimized, 7) Two 4-day workshops conducted to train entrepreneurs in technology based improvements i.e. cereal milling and product training in Mopti/Sevare with entrepreneur partners from Sevare, Bandiagara and Gao and 8) A food technologist was recently hired and is now on site in Sevare to work with entrepreneurs and facilitate technology transfer activities.

Linkages with the Production- Marketing component, IICEM (Market evaluation and strategies to finance entrepreneurs) and NGOs (CRS, Afrique Verte and others) have been established and strengthened.

Development of Technology support, optimization and incubation center at IER Sotuba for Bamako area urban processors. Equipment for the center is being purchased and we are developing plans to assist IER in construction of a building to house the incubation center. The purpose of the unit is: 1) development and refinement of processes and products, 2) introduction of new processing technologies, 3) training of entrepreneurs, and 4) providing technological backstopping to entrepreneurs. The unit currently has installed in it the same equipment as is at the Mopti/Gao entrepreneur business sites. Two IER food technologists, Kola Mamadou Tangara and Sidi, have been partially assigned to assist on the project and are currently working on optimizing decorticating and milling processes. Another food technologist has been hired to work full time on incubation center activities. A workshop will be conducted in early 2011 at the incubation center.

A Producer/Processor Networking Workshop will be held in Bamako, November 10-12, 2010 with the objective of building a network between the eight new farmers' organizations producing clean millet in the Segou region and the millet food processors in Bamako. Additional workshops will be held to train entrepreneurs in 2011.

Décrue Sorghum

Research is being conducted to develop a recommended package of practices for each project site. The final package will include a combination of cultivar and crop/nutrient management practices. Cultivar selection- For the first time sorghum cultivars have been extensively tested in the northern décrue region. Thirty three cultivars were tested in farmers' fields and a few cultivars with superior agronomic characteristics (yield etc.) were selected for demonstrations. Cropping practices- Optimum planting density and planting dates have been identified. On farm demonstrations- To reach a wider area and more farmers with technology optimum cropping practices are being transferred to farmers this cropping season via demonstrations conducted with the support of partners DRA, Tombouctou; DRA, Mopti; CONFIGES, Gao and AFRICARE, Goundam.

Institutional Capacity Building

Long Term Training (Academic)- Fatimata Cisse was admitted to Purdue's Food Science Graduate Program in January 2010 and is now conducting her research and taking courses. She is on track to complete her thesis by December 2011. Bandiougou Diawara was admitted to Kansas State's Agronomy Graduate Program in June 2010. He is taking courses this summer and starting his research here in the US. He is a bit behind the proposed schedule, and may need a one semester extension to complete his MS. Sory Diallo was identified as a replacement for a female candidate who withdrew from the program due to the birth of her child. He completed the

English program at the end of the summer and in August 2010 began is MS Agronomy program at Kansas State University. Aly Ahamadou and Mamadou Dembele arrived in June 2009 for the 6-month English language training and then moved to Purdue University in January 2010. In August 2010 they transferred to West Texas A&M University (WTAMU) which has a more applied Ag Economics/Agribusiness program and is a sorghum producing area so it would also be possible for them to do their thesis research locally.

Short Term Training- Abocar Oumar Toure completed in October his short term plant breeding training at Purdue with Dr. Mitch Tuinstra. His training program dates are August 1 to September 30, 2010. Abdoul Wahab Toure is planning to do his short-term training at Kansas State with Drs. Prasad and Staggenborg sometime between July-October 2011.

BMR Sorghum Associate Award

Through the Feed the Future Initiative, the United States Agency for International Development (USAID) is contributing to easing the poverty problem in Central America by working with the University of Nebraska-Lincoln-based Sorghum Millet and Other Grains program. USAID granted a $1.1 million associate award to INTSORMIL in October 2010 for a three year program in six Central American countries—Guatemala, Honduras, Nicaragua, El Salvador, Panama and Costa Rica—and Haiti in the Caribbean. 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 on sorghum (not the grain) that farmers can use for feeding dairy and beef cattle. If the forage is more productive, then dairy and beef cattle produce greater amounts of meat and milk.

Need for Brown Midrib (BMR) Types of Sorghum in Central America and Haiti

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. 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 in Central America is maize intercropped with “maicillos criollos” (photoperiod sensitive, late maturing, "mixed-breed” strains of unknown ancestry) grown on hillsides. The grain is used as human food and as feed grain for livestock, and the stover (leaves and stalks left in the field after harvest) is used for livestock forage. Although maicillos criollos produce low grain yields, they are planted on approximately 67% of the grain sorghum area in Central America. The limited grain yield response and low nutritive values of traditional maicillo criollo varieties in response to management practices is a primary constraint to increased production.

Brown midrib (bmr) sorghums solve the primary constraint of reduced quality forage. A sorghum variety improved for both forage and grain quality enhances the relative value and marketability of the whole crop to both the producer and the end user. The bmr sorghums have a distinctive phenotype (a brown color on the mid vein of the leaf and a brown color on the stalk). Sorghums expressing the bmr phenotype have consistently lower lignin levels which results in significantly higher digestibility and greater palatability than normal sorghums. These traits are consistently associated with improved efficiency in ruminant diets (i.e., increased meat and milk production).

Potential Economic Impact of the BMR Project

Projected yield increase - Research in Central America indicates a 15% increase in grain and forage biomass production. With a total of 502,000 tons of sorghum grain produced in the seven countries a 15% increase in grain production equals a 75,370 ton increase. An increase in forage quantity of 15% at the current 55 ton/ha will result in an 8 ton/ha increase. In addition there will be a significant increase in milk, beef, and poultry production due more nutritive forage.

Projected productivity gains - Based on results of feeding bmr sorghums in the U.S., the gains expected should increase milk and meat production by 15% and 10%, respectively in CA and Haiti.

Projected revenue increase - With an average farm income of $1,750 per year for small-holder farmers and $4,500 for medium holder farmers a 15% income would be an increase of $263 for smallholders and $675 for medium-holder farmers. Based on the number of hectares of sorghum and the extent of the dairy and meat industry in each country the total amount of potential increased revenue ranges annually from $320,850 in Panama to $52,191,600 in El Salvador

Project Timeline

The project duration is planned for three years. In year 1, evaluation and testing of advanced lines will be the primary focus of this project. Seed production of these lines will remain at the foundation seed production level in year 1. After initial large scale evaluation, in year 2, additional testing and small scale seed production will be the primary focus. In addition, demonstrations of the trials will be presented to the small scale producers. Initial lots of certified seed will be produced and distributed through described methods at the end of year 3. Finally, in year 3, varieties will be released; seed will be distributed and demonstration on productivity will be conducted.

Year 1 (2010) Activities

Breeders’ Seed Production - Fifteen bmr sorghum lines of varying pedigree and phenotypic characteristics have already been selected in the CENTA sorghum breeding program (see table below). The 15 bmr accessions selected for further evaluation were selected based on their adaptation, good agronomic characteristics, tolerance to major diseases and pests, high grain yield, and high and nutritious forage production. These selections are uniformly brown midrib and have high yield for both grain and forage. CENTA has increased seed of these lines with intent to produce enough seed for multi-environment testing. Seed of these lines were distributed to cooperators in each country.

Evaluation (Testing of advanced lines from CENTA) - A 20-entry test, composed of the 15 selections, four common (non-bmr) varieties and one local variety (non-bmr) will be planted in two environments (defined by planting date) each in Costa Rica, Guatemala, El Salvador, Haiti, Honduras, Nicaragua, and Panama. One trial was planted in the first planting season (May-June 2010) to identify varieties that produce well in a high rainfall environment (primarily for silage). The second environment in each country was planted in August 2010 to identify the best varieties for the production of grain, forage, and ensilage. Agronomic data (such as but not limited to anthesis, maturity, height and biomass and grain yield, lodging and disease ratings, and composition samples were collected from each location. Evaluations of the quality of the forage and grains was conducted by INTSORMIL PI (Bill Rooney, Texas A&M), who has an equipped NIR (Near-Infrared) spectroscopy analysis laboratory that measures sorghum forage quality parameters such ADF (Acid Detergent Fiber= lignin and thus digestibility values), NDF (Neutral Detergent Fiber= reflects the amount of forage the animal can consume), IVDMD, (In Vitro Dry Matter Digestibility), etc. Based on agronomic and composition data, a subset of varieties will be selected for validation and seed production.

In 2010, four varieties were selected for further testing and seed production in Year 2; CI (Centa/INTSORMIL) 0925, CI0929, CI0947 and CI0973. The information and seed generated in the second year will be used to justify varietal releases and seed distribution in each country respectively in year 3.

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 2010/11 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 31years and the training of sorghum and millet scientists in the United States, Africa and Central America by INTSORMIL now enables these scientists from developing countries and the United States to jointly plan and execute mutually beneficial collaborative research. These collaborative relationships are key components to INTSORMIL's success and will continue as fundamental approaches to meeting the INTSORMIL mission. In the future, INTSORMIL will target NARS collaborative ties that reflect regional needs for sorghum and/or millet production. These ties are in the sorghum and millet agroecological zones of western, eastern, and southern Africa, and Central America. By concentrating collaboration in selected sites, INTSORMIL optimizes its resources, builds an enhanced scientific capability on sorghum and millet, and creates technological and human capital that has a sustainable and global impact.

Sustainable Plant Protection Systems

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 re-lated 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 ma-terials 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. monili-forme*, 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 just this year and is common from West Africa through Egypt and East Africa (Kenya and Uganda). Within region variation suggests that as many as 20 addi-tional 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 some-what cursory manner. *Fusarium pseudonygamai* is the dominant species on pearl millet, while finger millet is host to an amazingly diverse group of *Fusar-*

ium spp. (between 40 and 60 from samples taken in Uganda in 2000). The *Fusarium* species on these crops are not known to be as-sociated 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 child-ren 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 devel-opment 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 subculturing 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 esopha-geal cancer and neural tube defects in humans, their ability to cause a number of diseases in do-mesticated animals, and their effects as trade barriers. Fusaproliferin and beauvericin are not as-sociated 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 mem-branes 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 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. After a series of some 15 backcrosses and sib crosses, mating type testers have been identified for the most frequent of the undescribed species (tentatively named "*F. africana*"). These tester strains have been used to identify a number of strains from across Africa (including Egypt, Ethiopia, Uganda and Mali) that had been previously unidentified but belong to this species, suggesting a pan-African distribution of this species is possible.

"*Fusarium africana*" has been an exceedingly difficult entity to distinguish from its sister species, *F. andiyazi*, which also is an important pathogen of sorghum. The morphology of "*F. africana*" is indistinguishable from *F. andiyazi*, *F. thapsinum* and *F. verticillioides* (Figure 1). Inbred strains of "*F. africana*" that are female fertile of both mating types have been developed and can be used for tester strains. These tester strains cross only with strains identified as "*F. africana*" and not with members of any of the other known mating populations in Fusarium section *Liseola*. Thus, this species represents a new mating population, J, in the *Gibberella fujikuroi* species complex, and sexual crosses are a reliable way to distinguish *F. andiyazi* (which has no known sexual stage) from "F. africana". (Figure 1)

Distinguishing the two species even with DNA sequences is difficult. AFLPs of strains in different species usually share no more than 40% of their bands, while strains in the same species usually share 60% or more of their bands. Strains *F. andiyazi* and "*F. africana*" may share up to 70% of their AFLP bands, suggesting that they should be the same species. However a UPGMA dendrogram (Figure 2) clearly shows that the two species can be separated reliably in spite of their relatively high levels of similarity. This dendrogram also identifies a small group of six strains that are intermediate between the two species and might represent hybrids between them.

Differentiation of *Fusarium* species often can be made by using sequences of either the *tub*-2 or *tef*-1 gene sequences. From 30 strains of *F. andiyazi*, two *Tub*-2 haplotypes were identified – one found in 29 strains and the other found in a single strain. From 24 strains of "*F. africana*," there also were two haplotypes – one

Figure 1. Morphological characters of "*Fusarium africana*". Top row: macroconidia, microconidia, and microconidia in long chains. Middle row: macroconidia, microconidia in long chains, and microconidia in long chains being produce from a monophialides. Bottom row: Perithecia on carrot agar oozing ascospores (two photographs) and eight-spored ascus.

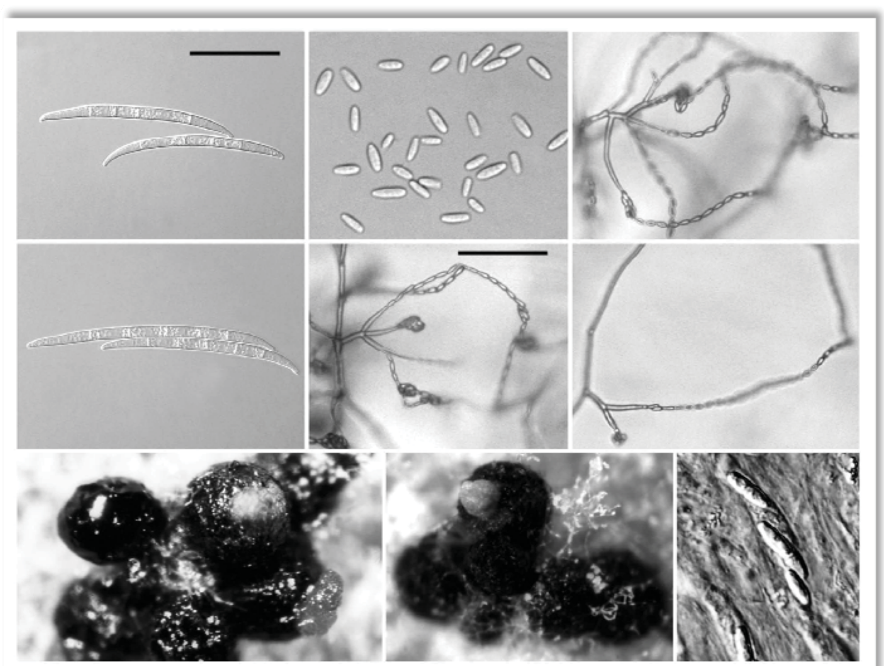
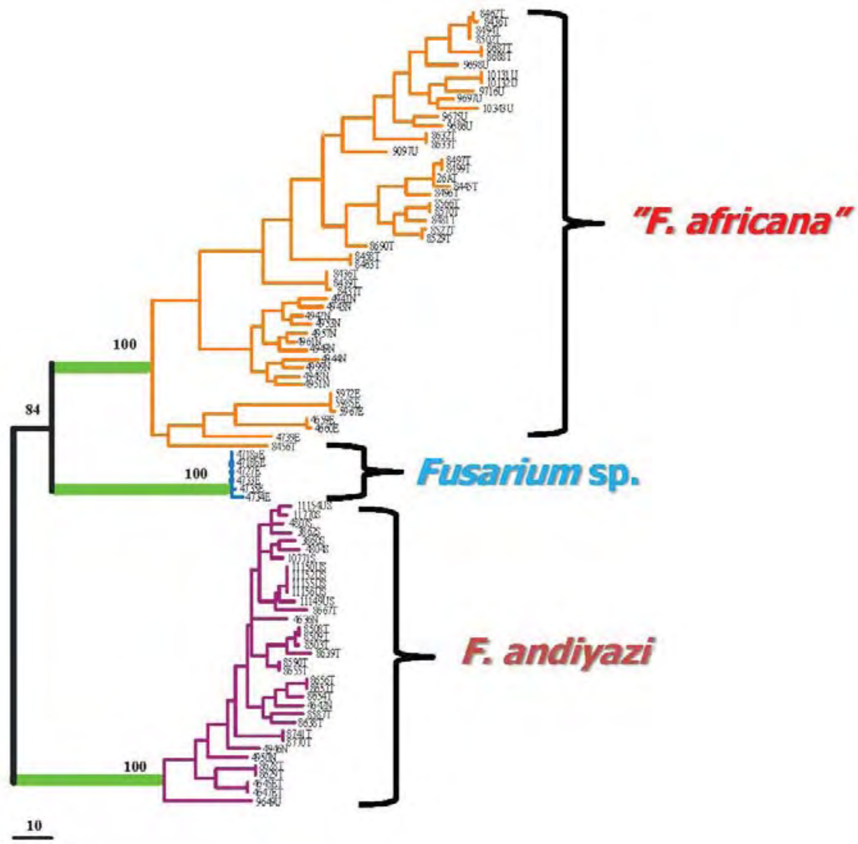


Figure 2. UPGMA tree based on 285 AFLP bands generated by using 3 primer-pairs from 92 *Fusarium* isolates. Bar under the tree shows 10 AFLP bands change. Bootstrap values are indicated above the tree branches.



found in 13 strains and the other found in 11 strains. The putative hybrid, represented by strain 4735, is identical to one of the two species at the nine sites in this gene sequence that can be used to distinguish *F. andiyazi* from "*F. africana*." *Tef*-1 is the most commonly used gene for discriminating species of Fusarium based on DNA sequencing. The 30 strains of *F. andiyazi* were divided into 10 haplotypes based on 12 SNPs. One haplotype contained 16 strains, a second contained four strains and the remaining six contained either one or two strains each. From 20 strains of "*F. africana*," there were six haplotypes based on 14 SNPs. One haplotypes contained eight strains, a second contained five and the remaining 4 contained 1-3 strains each. Surprisingly, the 4735 "hybrid" contains four SNPS found in neither of the species. Of the 26 polymorphic nucleotides in the *Tef*-1 sequence for *F. andiyazi* and "*F. africana*," only one of them can be used to distinguish the two species unequivocally. A search of on-line databases suggests that a number of strains identified as *F. andiyazi* may in fact be "*F. africana*." (Table 1 and Table 2)

Fusarium Ppopulation Characterization – Uganda

Formal description of a new species, *F. intsormilium,* is in progress. 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 identified strains of this species from maize growing in the area from which the finger millet isolates were first recovered, indicating that this species has a host range that goes beyond sorghum and millets. If the species is one that is merely present on sorghum and millet rather than a pathogen of sorghum and millet then it could possibly be used as a biocontrol agent through the displacement of more pathogenic or toxigenic fungi and as a means for insect control, due to its ability to produce the insecticidal beauvericin.

Strengthening Research Capacity

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

Networking Activities

Editorial and Committee Service (2009)

- Editor, Food Additives and Contaminants (2006-2009)
- Editor, Mycological Research (2009-2010)
- International Society for Plant Pathology, Fusarium Committee (2000-2013)
- MycoRed External Advisory Committee (2007-2013)
- Oklahoma Center for the Advancement of Science and Technology Plant Sciences grant re-view panel (2009-2010)

Table 1. Single nucleotide polymorphisms (SNPs) in the *tub-2* gene encoding β-tubulin in *F. andiyazi*, *F. africana* and an unrelated *Fusarium* sp.

SNP	Location	"*F. africana*"	4735	*F. andiyazi*
1	Intron	C T	T	T
2	Intron	G	G	T
3	Intron	G	A	A
4	Exon – 3rd bp	C	T	T
5	Intron	A	A	G
6	Intron	T	T	C
7	Exon – 3rd bp	C	C	T
8	Intron	C	C	C T
9	Intron	T	C	C
10	Exon – 3rd bp	T	C	C
11	Exon – 3rd bp	T	T	C

Table 2. Single nucleotide polymorphisms (SNPs) in the *tef-1* gene encoding Translocation Elongation Factor 1-α in *F. andiyazi*, *F. africana* and an unrelated *Fusarium* sp.

No.	"*F. africana*"	4375	*F. andiyazi*
1*	C	T	C
2	A	G	A
3	A	G	G A
4	A G	G	G
5	T C	C	C
6	A C	C	C
7	C	C	C T
8	G	G	A
9	A	A	A G
10	G A	A	A
11*	T A	A	A
12	T	T	T C
13	A G	G	G
14	A G	G	G
15	A C	C	C
16	T	T	T Δ
17	T Δ	Δ	Δ
18/19	GG	GG	GG AA
20	C T	T	T
21	C	C	C T
22	A C	C	C
23	C	C	C T
24	A	A	A C
25	C	C	C T
26	T	C	T
27	C T	T	T
28	T	T	T C
29	G	A	G
30	C T	T	T

* - Silent exon exchange; all other changes occur in introns.

Research Investigator Exchanges (2009)

- Australia – October 4-11
- Austria – September 6-12
- Brazil – April 1-12
- Italy – October 30 – November 3
- Malawi – November 4-7
- Malaysia – October 12-19
- South Africa – November 11-24
- South Korea – January 11-17; September 28 – October 3
- Zambia – November 8-11

Other Collaborating Scientists (Host country)

- Dr. Sofia Chulze, Department 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 2009 (other than collaborators)

- Peter Cotty, USDA-ARS, University of Arizona, Tucson, Arizona.
- Elettra Berni, Industrial Experiment Station for Food Preservation, Parma, Italy.
- 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.
- Keith Seifert, Agriculture and Agri-Foods Canada, Ottawa, Ontario, Canada.

Publications and Presentations (2009)

Seminar, Workshop & Invited Meeting Presentations (International locations only)

1. KOSEF Center for Fungal Pathogenesis, Opening seminar, Seoul, Korea – 01/09.
2. Korean Society for Microbiology, Korea – 01/09.
3. University of Lavras, Lavras, Brazil – 04/09.
4. University of Recife, Recife, Brazil – 04/09.
5. International Society for Microbiology Inaugural meeting, Tulln, Austria – 08/09.
6. Seoul National University, Department of Agronomy, Seoul, Korea – 09/09.
7. Science University of Malaysia, School of Biological Sciences, Penang, Malaysia – 10/09.
8. University of Malawi, Lilongwe, Malawi – 11/09.
9. Zambian Agricultural Research Institute, Lusaka, Zambia – 11/09.

Journal Articles (2009)

Bentley, A. R., M. G. Milgroom, J. F. Leslie, B. A. Summerell & L. W. Burgess. 2009. Spatial aggregation in Fusarium pseudograminearum populations from the Australian grain belt. Plant Pathology 58: 23-32.

Kabbage, M., J. F. Leslie, S. H. Hulbert & W. W. Bockus. 2009. Comparison of natural populations of Mycosphaerella graminicola from single fields in Kansas and California. Physiological and Molecular Plant Pathology 74: 55-59.

Lee, J., I.-Y. Chang, H. Kim, S.-H. Yun, J. F. Leslie & Y.-W. Lee. 2009. Lineage compo-sition and toxin production of Fusarium graminearum populations from rice in Korea. Ap-plied and Environmental Microbiology 75: 3289-3295.

Leslie, J. F. & S. L. Warren. 2009. The use of a “Vision” seminar in new faculty recruiting. The Department Chair 20: 12-14.

Lima, C. S., J. H. A. Monteiro, N. C. Crespo, S. S. Costa, J. F. Leslie & L. H. Pfenning. 2009. Vegetative compatibility and amplified fragment length polymorphism analyses in Fusarium spp. associated with mango malformation. European Journal of Plant Pathology 123: 17-26.

Lima, C. S., L. H. Pfenning, S. S. Costa, M. A. Campos & J. F. Leslie. 2009. A novel population in the Gibberella fujikuroi species complex associated with mango malformation in Brazil. Plant Pathology 58: 33-42.

Reynoso, M. M., S. N. Chulze, K. A. Zeller, A. M. Torres & J. F. Leslie. 2009. Genetic structure of Gibberella moniliformis populations isolated from maize in Argentina. Euro-pean Journal of Plant Pathology 123: 207-215.

Book Chapters (2009)

Leslie, J. F. & S. L. Warren. 2009. A “Vision” seminar as a part of the new faculty recruiting process. Proceedings of the 26th Annual National Academic Chairpersons Conference (Orlando, Florida), Conference proceedings CD, IDEA Center, Manhattan, Kansas.

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

Project WTAMU 101
Bonnie B. Pendleton
West Texas A&M University

Principal Investigator

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Collaborating Scientists

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Mr. Fernando 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. Gerald J. Michels, Jr. – Entomologist, Texas AgriLife Research, Amarillo, TX 79106
Dr. Michael W. Pendleton – Electron Microscopist, Microscopy and Imaging Center, Texas A&M University, College Station, TX 77843-2257

Introduction and Justification

Entomologists, breeders, pathologists, and extension agents in Mali, Niger, Mozambique, Botswana, and the U.S. are educating students and farmers in IPM and developing, evaluating, and transferring pest management technologies for insects of sorghum and millet. Development and adoption of ecologically-based technologies will decrease loss by insects in the field and storage, reduce pesticide use, conserve soil and water without contamination, and increase yield of food and feed for domestic use and income from marketing. Sorghum and millet are damaged by greenbug, *Schizaphis graminum*, and yellow sugarcane aphid, Sipha flava, in the U.S. and sugarcane aphid, Melanaphis *sacchari*, in Africa that suck juice from leaves and vector viruses. Larvae of sorghum midge, *Stenodiplosis sorghicola*, feed on the ovary and can cause 100% loss of grain. Larvae of millet head miner, *Heliocheilus albipunctella*, tunnel in spikes. Southwestern corn borer, *Diatraea grandiosella*, in the U.S. and maize stalk borer, *Busseola fusca*; and spotted stem borer, *Chilo partellus* in Africa tunnel in stalks, causing susceptibility to disease and lodging. Insects annually destroy 35% of stored grain worldwide. Stored grain pests include maize weevil, *Sitophilus zeamais*.

Objectives and Implementation Sites

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

Specific objectives 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 insect pests and damage they cause; evaluation of potential arthropod pests; agronomic practices to prevent damage by insects and reduce pesticides; cultivars with greater yield and resistance to biotic and abiotic stresses; 3) provide education for students; and 4) develop partnerships with agencies engaged in improvement of sorghum and millet production and betterment of people. By presentations and publications, extension and other agencies will be assisted with transferring pest management information to farmers, scientists, and others in Africa and the U.S.

Research Methodology and Strategy

Evaluating potential pests and understanding the life histories of insect pests and natural enemies. Undergraduate Jody Gilchrest evaluated the effect of photoperiod on greenbug biotypes on sorghum. M.S. student Zachary Eder evaluated fitness and determined the effect of yellow sugarcane aphids on damage and biomass of sorghum. M.S. student Camilo Garzon used pheromones to monitor seasonal abundance 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 Milo Genetics for evaluating sorghum and millet for resistance to millet head miner, sorghum midge, greenbug, sugarcane aphid, stalk borers, and storage beetles. Studying pests of stored grain. Dr. Yaro and the PI prepared posters for hundreds of farmers to manage storage pests in Mali. M.S. student Suhas Vyavhare evaluated resistance of stored sorghum grain to maize weevil. 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 two sorghums to hundreds of farmers in Mozambique and Niger. Field demonstrations, workshops, posters, and training manuals were prepared to teach farmers, extension, and others to recognize pest problems and evaluate and implement IPM options. Undergraduate and graduate students from U.S., Botswana, Mali, and Niger were educated in entomology and IPM.

Research Results

Master's student Zachary Eder graduated in August 2010 after studying fitness of yellow sugarcane aphid in response to temperature and effect on biomass of sorghum. Fifty aphids were used in clip cages on ATx399 x RTx430 sorghum at 13:11 light:dark hours and three temperatures in an incubator. The original aphid in the cage was removed after it produced a nymph that was retained. Offspring were counted and removed each day. At 17:30, 84% of aphids died before reproducing. Aphids at 15:27, 13:24, and 17:30°C spent 25, 21.1, and 7% of their lives reproducing. Each aphid produced only 0.09 nymph per day at 17:30 but 10 times more at 13:24°C. Only 1.9 nymphs were produced per aphid at 17:30 but 8.8 were produced at 13:24°C. Aphids lived 4.4 days at 17:30 and four times longer (16.8 days) at 15:27°C. (Table 1)

Zero, 10, 25, and 40 yellow sugarcane aphids were maintained on each of 10 sorghum plants in three replications for 14 days. Height of each plant was measured from the soil to the tip of the leaves. Data on plant height and leaf stage and damage by (0-6 scale) and number of aphids were recorded daily. After the 14th day, plants were harvested and dried. Height of plants averaged 21.4 cm at infestation. At 14 days, plants with 40 and 25 aphids were 21 and 10% shorter than the check. Emergence of the 4th true leaf was delayed 2.2 days with 40 aphids. Plants with 40 aphids produced 40% less biomass, but with 10 did not differ from the check. (Table 2)

Undergraduate Jody Gilchrest evaluated effect of photoperiod on biotype E and I greenbugs on susceptible ATx399 x RTx430 sorghum at constant daily dark and light temperatures of 10 and 23°C. Photoperiod but not biotype affected greenbugs and should be considered when evaluating for resistance. Only 58.8% of greenbugs at 10:14 light:dark hours survived to produce a nymph. Fecundity of biotypes E and I combined increased 2.5 times, from 24.6 to 61.6 nymphs per aphid, as light increased from 10:14 to 14:10 light:dark hours. Longevity was shortest (38.6 days) at 10:14 but 1.6 times longer (60.9 days) at 12:12 light:dark hours. (Table 3)

The PI evaluated 425 sorghum lines Milo Genetics developed for resistance to greenbug biotype I, with most being more resistant than the check.

In Botswana, David Munthali evaluated pest abundance and natural enemies on 22 Texas sorghum lines and 3 local varieties from the SADC region. Each genotype was planted in a single 7-m row

Table 1.

Temperature night:day (°C)	No. of original 50 producing	Pre-reproductive days	Reproductive days	Nymphs/ aphid/day	Total nymphs/aphid	Longevity (days)
13:24	28	13.5 a	5.3 a	0.87 a	8.8 a	16.0 a
15:27	30	11.3 a	5.7 a	0.81 a	8.3 a	16.8 a
17:30	8	10.6 b	1.5 b	0.09 b	1.9 b	4.4 b

Table 2.

No. aphids maintained per plant	Plant height (cm) 14 days after infestation	Days of visible damage	Days to emergence of 4th leaf	Plant biomass (g)
40	54.4 ± 2.99 a	9.7 ± 0.37 a	8.0 ± 0.54 a	0.55 ± 0.06 a
25	61.7 ± 2.11 b	7.8 ± 0.72 b	6.9 ± 0.39 b	0.66 ± 0.05 ab
10	67.6 ± 1.03 c	6.1 ± 0.75 c	6.2 ± 0.24 bc	0.79 ± 0.04 bc
0	68.7 ± 0.81 c	0.0 d	5.8 ± 0.26 c	0.91 ± 0.09 c

Table 3.

Photoperiod (light:dark hours)	n	Pre-reproductive period (days)	Total fecundity (nymphs/greenbug)	Total longevity (days)
14:10	80	9.5 ± 0.1 a	61.6 ± 1.5 a	52.3 ± 1.4 b
12:12	80	12.6 ± 0.4 b	51.9 ± 2.0 b	60.9 ± 1.9 a
10:14	47	14.0 ± 0.4 c	24.6 ± 2.9 c	38.6 ± 3.3 c

replicated three times in a completely randomized block in net field cages to exclude quelea birds but allow insects. Yield from plants scored 1+2 (0-40% damage) were compared with plants scored 3+4 (41-80%) or 5 (81-100%). Ent62/SADC, TAMA428, Kuyuma, (Macia*TAMM428)-LL9, and (Macia*TAM428)-LL2 were most resistant while (Dorado*Tegemeo)-HW13-CA1-CC2-LGBK-CABK, (5BRON151/(7EO366*GR107B-90M16)*Tegomeo)-HG1-LGBK-CABK-CABK, and Phofu were most susceptible to sugarcane aphids and lost as much as 100% of grain. Ent62/SADC scored 1-2 for damage produced most weight (102.5 g) per panicle. Segaolane, SRN39, and BSH1 sustained much damage without significant yield loss. Grain weight on plants that suffered different amounts of leaf damage declined from 47.2 > 19.0 > 3.1 g/panicle with minimum, moderate, and severe damage. (Table 4)

Fernando Chitio evaluated resistance to sugarcane aphid, stalk borers, and sorghum midge in sorghum from IIAM at Namialo Station in Mozambique. A scale of 1-5 was used to score damage. Variability was great because insects were not uniformly distributed in the field, and sorghums did not differ significantly. But, several sorghums, especially Sima, were less damaged by the three insects, while damage by aphids and stalk borers was 3 on Macia. (Table 5)

M.S. student Camilo Garzon monitored southwestern corn borer moths in pheromone traps in Texas. Numbers of moths varied among locations and with weather. Moths of the 1st generation were trapped from late June - mid-July. Second-generation moths were trapped the 1st week of August until 1st week of September, with a peak on 12 August. A predictive model was created. (Figure 1)

Hame Abdou Kadi Kadi surveyed 60 farmers on knowledge of sorghum insects and control at Tounfafi, Niger. Visits to fields verified their answers. Data were discussed and validated at a village assembly. All farmers said termites attacked sorghum in storage and the grasshopper Oedaleus senegalensis damaged sorghum in morning and afternoon from booting to grain-filling. (Table 6)

Hame Abdou Kadi Kadi, 72 farmers, and a farmer organization of 74 men and 6 women produced seed to introduce sorghum midge-resistant SSD-35 and early maturing Mota Maradi to 238 farmers with 124 ha in 14 villages in Madaoua and Birni N'Konni regions, Niger. A farmer organization, private seed producers, and INRAN Seed Unit are producing SSD-35 to sell to farmers, farmer groups, projects, and institutions. Twenty farmers were surveyed for acceptance of SSD-35. SSD-35 yields 24.4-46.8% more than El Mota. Sorghum yield could be improved to 1,200 kg/ha with SSD-35. At INRAN Konni Station, cost to produce seeds on 1 hectare is 355 000 FRS CFA ($700.00). If 1 kg seed sells for 500 FRS CFA ($1.00), the price for 1,200 kg would be 600 000 FRS CFA ($1,200.00), a benefit of 245 000 FRS CFA ($490.00) per hectare. (Table 7)

M.S. student Suhas Vyavhare finished evaluating 26 genotypes of stored sorghum for resistance to maize weevil and graduated in August 2010. Five newly emerged weevils were put with 5.0 g of grain in each of 10 vials. Each grain in the 10 vials of one kind of sorghum was evaluated for damage on a scale of 1-5, numbers of live and dead weevils were counted, and grain in each vial was weighed once every 3 weeks for 105 days. Nine and 25 weevils

Table 4.

Sorghum variety or line with little damage (1+2) by sugarcane aphid	Grain weight/ panicle (g)
Ent62/SADC	102.5 a
Kuyuma	70.8 ab
(Macia*TAM428)-LL9	70.5 ab
(Macia*TAM428)-LL2	68.8 ab
TAMA428	59.6 bc
SV1*Sima/IS23250)-LG15-CG1-BG2(03)BGBK-LBK-PRBK	54.1 bc
(5BRON151/(7EO366*GR107B-90M16)*Tegomeo)-HG7-CC2-CABK-CABK	51.7 bcd
(6BRON161/7EO366*Tx2783)*CE151)-LG5-CG2(03)BG1-BG2-LBK-PRBK	47.8 bcd
Tegemeo	47.2 bcd
Phofu	41.9 bcd
(Kuyuma*5BRON155)-CA5-CC1-CABK-CABK	40.2 bcd
(5BRON151/(7EO366*GR107B-90M16)*Tegomeo)-HG1-LGBK-CABK-CABK	40.1 bcd
SRN39	38.4 bcd
Lasvida	37.9 bcd
(Dorado*Tegemeo)-HW13-CA1-CC2-LGBK-CABK	37.6 bcd
(Segaolane*WM#322)-LG2-(03)BG1-LG1-LBK-PRBK	37.6 bcd
BSH1	36.8 bcd
Macia	34.4 bcd
(Dorado*Tegemeo)-HW15-CA1-CC2-LG1-CABK	31.7 bcd
(9MLT176/(MR112B-92M2*Tx2880)*A964)-LG8-CABK-LGBK-CABK	27.3 cd
Segaolane	27.0 cd
(9MLT176/(MR112B-92M2*Tx2880)*A964)-CA3-CABK-CCBK-CABK-CABK	26.1 cd
(Dorado*Tegemeo)-HW14-CA1-CC2-CABK-CABK	25.4 cd
(LG35*WM#322)-BE40-LG1-CA1-LGBK-CABK-CABK	23.8 cd
(A964*P850029)-HW6-CA1-CC1-LGBK-CABK	13.2 d

Table 5.

Sorghum	Sugarcane aphid		Stalk borer		Sorghum midge
	Mapupulo	Namialo	Mapupulo	Namialo	Namialo
SPV422	1.3	0.7	1.0 f	0.7	0.3
IESB92008DL	1.3	1.0	2.0 b-d	1.0	0.0
IESB92028DL	1.3	0.7	2.0 b-d	1.3	0.0
IESB92021DL	1.0	1.0	2.7 b	1.0	0.0
ICSV700	1.7	1.0	1.7 c-e	1.0	0.3
IESB92165DL	1.3	1.3	2.3 bc	1.0	0.0
SPV1411	1.7	1.3	2.0 b-d	1.0	0.0
IESB940218DL	1.7	0.3	2.0 b-d	1.3	0.7
Sima (local check)	2.0	0.7	1.7 c-e	1.0	0.7
MR#22*IS 8613/1/2/5-2-1	1.3	1.3	2.0 b-d	1.0	0.7
IESB91104DL	2.0	0.7	2.3 bc	1.3	0.0
NTJ2	1.3	1.3	2.0 b-d	1.7	0.3
104GRD	1.7	1.3	1.3 d-f	1.7	0.7
ICSB654	1.7	2.0	1.7 c-e	1.0	0.3
IESB92001DL	1.7	1.3	2.0 b-d	1.3	1.0
KARI MTAMA-1	2.7	1.3	2.7 b	1.0	0.0
ENT#64DTN	1.3	2.0	1.7 c-e	1.7	1.0
ICSV93046	1.7	0.7	1.7 c-e	1.3	2.3
MR#22*IS 8613/1/2/3-1-3	1.7	1.7	1.7 c-e	2.3	1.7
ICSR93043	2.0	2.0	2.0 b-d	2.0	0.0
IS2331	2.0	2.7	2.3 bc	1.7	0.3
S35	1.3	1.7	1.7 c-e	3.3	1.0
ICSB324	2.3	2.3	1.7 c-e	2.3	1.0
SDSL90167	2.3	1.3	4.0 a	1.7	0.0
E36-1	2.3	2.0	4.0 a	2.3	0.3

Table 6.

Insect pests farmers said attacked sorghum	% respondents	Plant stage	% respondents	Period
Termites	100.0	Storage	100.0	--
Oedaleus senegalensis	100.0	Boot-grain fill	86.6	Morning-afternoon
Poophilus sp.	93.3	Boot	93.3	1200-1400 hours
Schistocerca gregaria	60.0	Boot-grain fill	60.0	Morning-afternoon
Stenodiplosis sorghicola	33.3	Panicle-flower	33.3	Afternoon
Spilostethus sp.	26.7	Grain fill	26.6	1800-0900 hours
Mylabrys	26.6	Flower	26.6	1800-0900 hours
Spodoptera exempta	20.0	Boot	20.0	Afternoon
Spodoptera frugiperda	20.0	Boot	20.0	Afternoon
Heliothis armigera	20.0	Panicle	20.0	Afternoon
Helicoverpa zea	13.3	Panicle	13.3	Afternoon
Ants	13.3	Storage	13.3	--
Amsacta albistriga	6.7	Early development-boot	6.6	Afternoon

Table 7.

Madaoua and Birni N'Konni, Niger, 2008-10	Variety tested	No. farmers	Hectares
Adoption (14 villages)	SSD-35	156	76
	Mota Maradi	82	48
Seed production (10 villages – SSD-35, and	SSD-35	115	98
6 villages – Mota Maradi	Mota Maradi	32	22

Table 8.

Sorghum genotype	Weevils emerged per gram	Final damage score	Final weight (g)
Sureño	8.6 k-m	1.9 l	3.9 a
(5BRON151/ (7EO366*GR107B-90M16)*Tegemeo) -HG7-CC2-CABK-CABK	9.1 k-m	2.1 j-l	3.9 a
(SV1*Sima/TS23250)-LG15-CG1-BG2-(03) BGBK-LBK-PRBK	6.7 m	2.1 kl	3.8 ab
(B35*B9501)- HD9	7.5 lm	2.2 i-l	3.7 a-c
(Dorado*Tegemeo)-HW13-CA1-CC2-LGBK-CABK	11.3 j-m	2.5 g-k	3.5 a-d
(Dorado*Tegemeo)-HW15-CA1-CC2-LG1-CABK	13.1 h-l	2.5 h-l	3.4 a-e
(Macia*TAM428)-LL9	11.7 j-m	2.7 f-k	3.3 a-f
Tegemeo	14.9 f-j	2.5 g-k	3.3 a-f
(Kuyuma*5BRON155)-CA5-CC1-CABK-CABK	15.5 f-j	2.8 f-i	3.3 a-f
Macia	11.6 j-m	2.6 g-k	3.2 b-g
(VG153*(TAM428*SBIII)-23-BE2-EE2-BE1	12.0 i-l	2.6 g-k	3.2 c-g
(9MLT176/(MR112B-92M2*TX2880)*A964)-CA3-CABK-CCBK-CABK-CABK	14.0 g-k	2.8 f-j	3.2 c-g
(Macia*TAM428)-LL2	15.6 e-j	3.1 e-h	3.1 c-g
(Dorado*Tegemeo)-HW14-CA1-CC2-CABK-CABK	15.8 d-j	3.2 c-g	2.9 d-h
(M84-7*VG153)-LBK-PR7-L4-L2-	15.5 f-j	3.2 c-g	2.9 d-h
(850G4300-5*Tx2782)-SM5-CM2-SM2-SM1-CABK-CMBK-CMBK	15.1 f-j	3.0 e-h	2.9 d-h
(5BRON151/ (7EO366*GR107B-90M16)*Tegemeo) -HG1-LGBK-CABK-CABK	21.3 b-e	3.6 b-e	2.8 e-h
(6BRON161/ (7EO366*Tx2783)*CE151) -LG5-CG2- (03)-BG1-BG2-LBK-PR	17.4 c-i	3.1 d-h	2.8 e-h
B409	19.5 c-g	3.3 c-f	2.7 f-h
*Tx2864*PI550607)))))-PR3-SM6	17.9 c-h	3.3 c-f	2.6 g-i
CE151	17.6 c-i	3.3 c-f	2.6 g-i
(Tx2864*PI550607)))))-PR3-SM6	21.4 b-d	3.8 bc	2.4 h-j
(Segaolane*WM#322) LG2-LG2-(03)-BG1-LG1-LGK-PRBK	20.0 b-f	3.8 b-d	2.4 h-j
(9MLT176/(MR112B-92M2*TX2880)*A964)-LG8-CABK-LGBK-LGBK-CABK	22.3 a-c	4.2 ab	2.4 h-j
(A964*P850029)-HW6-CA1-CC1-LGBK-CABK	27.2 a	4.6 a	2.0 ij
B.HF8	25.2 ab	4.5 a	1.8 j
LSD	5.71	0.66	0.651

Table 9.

Improved sorghum variety	Location in Mali	Number of producers	Hectares	Planting date
Tiandougou	Koulikoro	14	9.25	9-20 July
Tiandougou	Yanfolila	5	1.5	5-22 July
Tiandougou	Beleco	4	1.0	10-27 July
Tiandougou	Koutiala	8	6.5	5-22 July
Tiandougou	Kolokani	1	0.5	5-22 July
Tiandougou coura	Yanfolila	4	3.75	9-20 July
Grinkan	Yanfolila	4	3.0	9-20 July

developed per gram and weight loss was 22 and 64% of grain of Sureno and B.HK8 at 105 days. (Table 8)

Michael Pendleton subjected cross sections of sorghum grains to iodine vapor. The iodine molecules were detected using a scanning electron microscope equipped with energy dispersive spectroscopy detector. The iodine and concentration of starch granules were 60 micrometers from the surface of the most resistant genotype but 20 micrometers in the least resistant sorghum.

Fernando Chitio evaluated at Nampula, resistance to maize weevil in grain of 10 sorghums from IIAM Namialo Station, Mozambique. Three female and 2 male weevils were put with 5 g of grain per vial. Tocoli-1 and Ribawe-1 were not damaged, but Noculukuwe-3 and Ribawe-2 were very damaged after 7 months. In general, local sorghum was less damaged.

Hame Abdou Kadi Kadi, 16 extension agents, and 4 interns from Agronomie, Université Abdou Moumouni, Niamey, surveyed 280 men and 40 women farmers on storage insects of millet and sorghum and control. Eighty farmers, 7 interns, and 8 extension agents were trained to identify and control insects of millet and sorghum.

Niamoye Yaro Diarisso and plant pathologist Mamourou Diourté set up an experiment in Mali to secure production and conservation of sorghum seeds to meet requirements of farmers involved in the INTSORMIL regional project. In general, grain of improved sorghums if not stored properly is destroyed by insects before time to sell. When sorghum is harvested this fall, grain will be dried, cleaned, and stored in a plastic barrel for six months to protect against pests such as lesser grain borer, meal moth, and mites. Storage pests will be monitored before the start of 2011 planting. Training including posters on grain conservation following guidelines by INTSORMIL entomologists will continue before planting in 2011. (Table 9)

Networking Activities

Workshops and Meetings. The PI and students presented research at the Great Plains Sorghum Conference and Sorghum Research and Utilization Conference, Mead, NE, 11-12 August; 58th Meeting of the Southwestern Branch of the Entomological Society of America, Cancun, Mexico, 11-14 April; and 57th Annual Meeting of the Entomological Society of America, Indianapolis, IN, 13-16 December. The PI participated in an INTSORMIL West Africa Regional Workshop in Ouagadougou, Burkina Faso, on 19-21 May.

Research Investigator Exchanges

In November 2009, the PI met with scientists involved in the Gates HOPE project and also discussed INTSORMIL research with scientists at IER in Mali. From 8-15 May, the PI traveled to discuss and review research with scientists from IIAM in Mozambique and Botswana College of Agriculture before traveling to Ouagadougou, Burkina Faso to participate in an INTSORMIL West Africa Regional Program Workshop on 19-21 May.

Research Information Exchange

The PI advised extension and National Sorghum Producers on management of sorghum insects. Four hundred twenty-five sorghums developed for resistance to greenbugs were evaluated for Milo Genetics. 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. Three M.S., 60 B.S., and 2 technicians at Botswana College of Agriculture benefited from equipment and research through INTSORMIL. The PI and Dr. Yaro prepared two posters in French to tell hundreds of farmers in Mali how to identify and manage storage pests. During release of SSD-35, Mr. Abdou Kadi Kadi worked with 24 farmers, six extension agents, and two interns from Agronomie, Université Abdou Moumouni de Niamey. Fifty farmers in Niger were informed about sorghum midge through training on identification, biology, damage assessment, and control. Eight extension agents were informed how SSD-35 was developed and trained to identify and control insect pests of millet and sorghum in Niger.

Germplasm Distribution

Seeds of sorghum midge-resistant SSD-35 and early maturing Mota Maradi were produced by 147 farmers on 120 hectares in 16 villages in Madaoua and Birni N'Konni, Niger. In 14 villages in Niger, 238 farmers adopted SSD-35 and Mota Maradi on 126 hectares. A total 1.7 tons of Sima and 1.169 of Macia were produced by Joaquim Mutaliano and Fernando Chitio at IIAM Nampula Station in Mozambique. At Namitil, 1,800 kg of seed of Macia was produced for distribution to farmer associations for multiplication and production.

Publications and Presentations

Journal Article

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Theses

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Vyavhare, S.S. 2010. Resistance to maize weevil (Coleoptera: Curculionidae) of sorghum grain in storage and in the field. M.S. thesis. West Texas A&M University, Canyon, TX.

Miscellaneous

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Yaro Diarisso, N., and B.B. Pendleton. 2009. Les insectes nuisibles du sorgho stocke.

Abdou Kadi Kadi, H., S. Souley, N. Kondo, and I. Salami. 2010. Amélioration de la production du sorgho grâce à la SSD-35-variété résistante à la cécidomyie. Initiative INRAN/PAC II technology identification for users.

Presentations

Pendleton, B., Insect pests of stored sorghum grain; Pendleton, B.B., M.W. Pendleton, E.A. Ellis, G.C. Peterson, F.M. Chitio, and S. Vyavhare, Using scanning electron microscopy to relate the arrangement of starch in sorghum grain with resistance to maize weevil (Coleoptera : Curculionidae); and Vyavhare, S., and B.B. Pendleton, Resistance to maize weevil (Coleoptera: Curculionidae) of sorghum grain in storage and in the field, Great Plains Sorghum Conference and 27th Biennial Sorghum Research and Utilization Conference, 11-12 August 2010, Mead, NE.

Pendleton, B.B. Ecologically-based management of sorghum and millet insect pests in Africa and the U.S. Sorghum, Millet and Other Grains West Africa regional meeting, 19-21 May 2010, Ouagadougou, Burkina Faso.

Eder, Z., and B.B. Pendleton, Development and infestation characteristics of yellow sugarcane aphid (Hemiptera: Aphididae) on sorghum; Gilchrest, J.R., and B.B. Pendleton, Effect of photoperiod on greenbug (Hemiptera: Aphididae) on sorghum; Pendleton, M.W., E.A. Ellis, G.C. Peterson, and B.B. Pendleton, Using scanning electron microscopy and energy dispersive spectroscopy to identify starch in sorghum grain resistant to maize weevil (Coleoptera: Curculionidae); and Vyavhare, S.S., and B.B. Pendleton, Resistance to maize weevil (Coleoptera: Curculionidae) of sorghum grain in the field and in storage, 58th Annual Meeting of the Southwestern Branch of the Entomological Society of America and Society of Southwestern Entomologists, 11-14 April 2010, Cancun, Mexico.

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Sustainable Production Systems

INTSORMIL

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

Project KSU 104
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Introduction and Justification

Increasing population and limited availability of resources (land, water, nutrients and credit) along with lack of human resource and research capacity is constraining agricultural productivity in West Africa. Sorghum and millet based cropping systems are key components of farming practices in West Africa. Due to low productivity of sorghum and millet based cropping systems, the current management practices and cropping systems are not adequate and sustainable. Improved and intensive cropping systems will help transform sorghum and millet from subsistence to cash crop status, generate more income and provide food security. Low and erratic rainfall (water), high temperatures, poor soil fertility (nutrient), soil quality, limited use of fertilizers (both organic and inorganic) and limited availability of high yielding stress tolerant cultivars are key causes for lower productivity. Through our current research we are focusing on testing and integrating 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. Farmers are key players in decision making of technologies to be tested. Farmers' participatory appraisals to understand farmers' perceptions about current management practices, cropping systems and their needs and preferences were completed. Based on survey results we established integrated multi-factor experiments in on-station and on-farm conditions. As a part of training and capacity building, two graduate students (one MS from Ghana and one PhD student from Mali) started graduate degree programs at K-State.

Objectives and Implementation Sites

The main objectives during this year were:

- To identify components of Integrated Cropping Systems Management (ICSM) treatments for evaluation in on-station and on-farm conditions;
- To test and transfer improved crop, soil and water management practices in farmers field;
- To initiate short-term and long-term training opportunities to host country students and scientists; and
- To understand the impact of drought stress on grain sorghum and sweet sorghum germplasm.

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

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; 5. US: Manhattan, 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; (ii) quantify nitrogen fixation by cowpea under different cropping systems; and (iii) 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; (ii) quantify N fixation by cowpea with and without P fertilizer; and (iii) quantify contribution of cowpea to succeeding sorghum crops.

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

Host Country: Niger

Experiment 1: On-Farm Demonstration of Fertilizer Application on Improved Pearl Millet Genotype

Objectives: The main objective of this experiment was to demonstrate the response of improved genotype of pearl millet to micro-dose fertilizer application in on-farm conditions.

Treatments and Experimental Design: This research was conducted in Boboye and Filingue region in 2009. The treatments comprised of two fertilizer levels (farmer practice and micro-dose application in combination with 30 kg N ha^{-1} and 20 kg P ha$^{-1)}$ Experimental design was a randomized complete block design, with ten replications.

Experiment 2: Integrated Millet – Cowpea Cropping System to Improve Productivity

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

Treatments and Experimental Design: This research was conducted at Kollo. The treatments comprised of four cropping systems of cowpea – millet (sole crop rotation, intercropping, strip cropping and continuous cropping) and four technologies (combination of densities and fertilization) - A: low technology (no input), 10,000 plant ha^{-1}, no fertilizer and no insecticide; B: Medium technology-1, 17,000 plant ha^{-1}, rock phosphate 130 kg ha^{-1} and 65 kg Urea ha^{-1}; C: Medium technology-2, 17,000 plant ha^{-1},and micro-dose (6 g NPK) and 65 kg Urea ha^{-1}; and D: High technology, triple super phosphate 30 kg P2O5 ha^{-1} and 108 kg Urea ha^{-1}, and Karate (insecticide) 2.5 l ha^{-1} in three applications. Genotypes were HKP (millet) and TN-5-78 (cowpea). Experimental design was a latin square with cropping systems as rows and technologies as columns, with four 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.

Experiment 2: Extension of Mechanized Zai, Micro-dose + Compost Application on Sorghum

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

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

Host Country: Mali

Experiment 1: Impact of Reduced Tillage on Millet Yield

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

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

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

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

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

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

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

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

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

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

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

United States of America

Experiment 1: Impact of High Temperature Stress and Selenium (Se) on Grain Sorghum

Objectives: The main objective of this experiment was to study the effects of high temperature stress on grain sorghum and ability of antioxidant Se to protect against damage caused by high temperature stress.

Treatments and Experimental Design: Sorghum hybrid (DK-28E) was grown in controlled environments. Plants were grown at optimum temperature (32/22C) from sowing to 63 d after sowing. Thereafter, plants were exposed to four treatments (a) sprayed with Se and maintained at optimum temperature; (b) sprayed with Se and exposed to high temperature (40/30C); (c) non-sprayed controls maintained at optimum temperature; and (d) non-sprayed control exposed to high temperature. Experimental design was split-plot design with 10 replications for each treatment.

Experiment 2: Response of Sorghum Hybrids to High Temperature Stress

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: Four sorghum hybrids (DK-28E, DKS-29-28, DK-5400, and Pioneer 84G62) were grown in green house from sowing to 10 d prior to start of panicle exsertion. Thereafter, one half of plants of each hybrid were exposed to optimum temperature (32/22C) and the other half to high temperature stress (38/28C) for a period of 10 d. Experimental design was a split plot design with four replications.

Research Results

Host Country: Ghana

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

Results: Cowpea: There was a significant main effect of tillage on cowpea growth and yield in 2009. Biomass, pod and grain yields were significantly lower under no-till than under conventional tillage (Table 1). Lower cowpea growth in 2009 compared to 2008 was due to flooding later in the season. Cowpea relay cropped with sorghum had higher pod and grain yields than cowpea-sorghum intercrop. Fertilizer application significantly influenced cowpea biomass but not pod and grain yield. There was a significant tillage x cropping system interaction effect on cowpea pod and grain yield but not biomass yield (Table 2).

Generally, cowpea pod and grain yields were lower under NT than under CT. Pod and grain yield were significantly lower when cowpea was intercropped with sorghum under NT compared with the other cropping systems under NT or CT. There were no differences between cropping systems in pod and grain yield with CT.

Sorghum: Sorghum stover, panicle and grain yields were significantly higher under CT than under NT (Table 1). Panicle and grain yields were significantly lower with continuous sorghum than sorghum following cowpea or intercropped with cowpea. There was no significant effect of fertilizer on sorghum stover, panicle and grain yield probably because of the wetter conditions in 2009 causing leaching of applied fertilizers. There was a significant tillage x cropping systems interaction on sorghum panicle and grain yields. For all cropping systems, grain yields were significantly lower under NT than under CT.

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

Results: Besides tillage, there was no significant main effect of N fertilizer and variety on stover and grain yields. The interactions were not significant for sorghum stover and grain yields. Averaged across varieties and N fertilizer rates, stover and grain yields were lower under NT than under CT, but significant (Table 3). There were significant differences between varieties in stover and grain yields. Grain yields were significantly lower in local variety, Chere, than improved varieties, Kapaala and Dorado. Grain yield increased with greatest yield at 90 kg N ha-1 (Table 3).

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

Results: Cowpea: For the second season, there were significant effects of cropping system and P fertilizer application on cowpea biomass, pod and grain yield. Similarly for the second season, there was no significant effect of tillage system on cowpea growth and yield.

Table 1. Main effects of tillage, cropping system and fertilizer on cowpea and sorghum 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	2475a	1021a	651a	1926a	1891a	1242a
No Tillage	1501b	629b	384b	1281b	822b	414b
Cropping system						
Continuous SG				1583a	1066b	658b
SG - CP rotation				1643a	14667a	822a
CP - SG intercrop	1916a	717b	447b	1585a	1537a	944a
CP - SG relay	2060a	934a	588a			
Fertilizer rate (kg ha^{-1})						
0	1787bc	799a	503a	1490a	1185b	707b
40 N	1509c	811a	512a	1583a	1238ab	764ab
26 P	2474a	870a	555a	1574a	1470ab	874ab
40 +26 (N+P)	2181ab	822a	499a	1768a	1532a	968a

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

Table 2. Effect of tillage and cropping system on cowpea yield in 2009 at Wa, Ghana.

Tillage	Cropping system	Pod yield (kg ha^{-1})	Grain yield (kg ha^{-1})
CT	CP - SG relay	1030a	647a
	CP / SG intercrop	1013a	654a
NT	CP - SG relay	838a	528a
	CP / SG intercrop	421b	204b

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

Table 3. Main effects of tillage, variety and fertilizer rate on stover and grain yield of sorghum during 2009 at Wa, Ghana.

Treatments	Stover yield ($kg\ ha^{-1}$)	Grain yield ($kg\ ha^{-1}$)
Tillage system		
CT	3797a	1379a
NT	3161a	1641a
Variety		
Kapaala	2218b	1941a
Dorado	2555b	1694a
Local (*Chere*)	5663a	895b
Fertilizer ($kg\ ha^{-1}$)		
0	1973b	912b
30	4112a	1395b
60	3828a	1462b
90	3632a	2276a
120	3848a	1506b

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

Table 4. Effect of tillage and cropping system on cowpea yield in 2009 at Wa, Ghana.

Tillage	Cropping system	Pod yield ($kg\ ha^{-1}$)	Grain yield ($kg\ ha^{-1}$)
CT	CP - SG relay	825ab	517ab
	CP / SG intercrop	887ab	496ab
NT	CP - SG relay	975a	589a
	CP / SG intercrop	725b	406b

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

Table 5. Main effects of tillage, cropping system and P fertilizer on cowpea (CP) and sorghum (SG) 2009 at Wa, Ghana.

Main Effects	Cowpea yield (CP) ($kg\ ha^{-1}$)			Sorghum yield (SG) ($kg\ ha^{-1}$)	
	Biomass	Pod	Grain	Stover	Grain
Tillage system					
Conventional Tillage	1209a	853a	506a	4364a	673a
No Tillage	1171a	850a	497b	4639a	632a
Cropping system					
Continuous SG					
SG - CP rotation				5214a	901b
CP - SG intercrop	1181a	806b	451b	3788a	404b
CP - SG relay	1199a	900a	553a		
P fertilizer ($kg\ P\ ha^{-1}$)					
0	1015b	756b	503a	4380b	621a
26 P	1365a	950a	555a	4622a	683a

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

Cowpea biomass, pod and seed yields were significantly lower when intercropped with sorghum than when relay cropped with sorghum (Table 4). Application of 26 kg P ha-1 increased cowpea biomass, pod and seed yields compared with no P application. There was a significant tillage x cropping system interaction effect on cowpea pod and grain yield. Cowpea relay cropped with sorghum had higher pod and grain yields than cowpea intercropped with sorghum under NT (Table 5). However, there was no significant difference in pod and grain yields when cowpea was relay cropped or intercropped with sorghum under either NT or CT (Table 5).

Sorghum: Generally, sorghum yields were comparatively lower in 2009 than in 2008 season because of frequent and heavy rainfall during flowering stage of sorghum, but the trends were similar. Sorghum following cowpea in rotation had significantly higher stover and grain yields than sorghum intercropped with cowpea (Table 4). There was no significant influence of tillage or

P fertilizer application on sorghum stover and grain yields (Table 4). However there was a significant cropping system x P fertilizer interaction effect on sorghum stover and grain yields being significantly higher following cowpea with application of P fertilizer (data not shown).

Host Country: Niger:

Experiment 1: On-Farm Demonstration of Fertilizer Application on Improved Pearl Millet Genotype

Results: There were significant benefits of improved technology with 20 kg P and 30 kg N ha^{-1} along with microdose fertilizer application of NPK on grain yield (789 kg ha^{-1}) of improved millet genotype when compared to traditional technology of no fertilizer application (211 kg ha^{-1}). On average across the two years (2008 and 2009) the grain yield increase was more 600%.

Experiment 2: Integrated Millet – Cowpea Cropping System to Improve Productivity

Results: There were significant influence of different cropping systems for grain and stover yields of both millet and cowpea (Table 6 and7). Among various systems sole cropping produced significantly greater grain yields of millet or cowpea compared to continuous cropping. These were also greater than other systems. The cowpea yields were very low in 2009 due unfavorable weather conditions. Among various technologies high technology, medium technology-2 with microdose application produced highest yields when compared to low input or with medium technology-1 or the high technology for millet yields. There were no significant differences among various fertilizer treatments for cowpea due to very low yields.

Table 6. Effect of cropping system on yield and yield components of pearl millet and cowpea at on-station trial in 2009 at Kollo, Niger.

Treatment	Millet (kg ha^{-1})		Cowpea (kg ha^{-1})	
	Grain	Stover	Grain	Stover
I. Sole crop rotation	766	1312	84	177
II. Intercropping	338	587	9	32
III. Strip cropping	218	325	44	37
IV. Continuous cropping	429	750	52	73
LSD	211	332	64	63
Significance	***	***	***	***

***, significant at P<0.05.

Table 7. Effect of fertilizer application on yield and yield components of pearl millet and cowpea at on-station trial in 2009 at Kollo, Niger.

Treatment	Millet (kg ha^{-1})		Cowpea (kg ha^{-1})	
	Grain	Stover	Grain	Stover
A. Low technology (no input)	251	475	39	44
B. Medium technology – 1	358	694	66	59
C. Medium technology – 2	740	1116	97	85
D. High technology	492	691	46	68
LSD	211	312	64	93
Significance	***	***	-	-

***, significant at P<0.05.

Table 8. Effect of water conservation techniques on stover and grain yield of two sorghum and two cowpea genotypes at on station trials in 2009 at Saria, Burkina Faso.

Tillage system	Grain Sorghum			Cowpea		
	Genotype	Stover yield (kg ha^{-1})	Grain yield (kg ha^{-1})	Genotype	Stover yield (kg ha^{-1})	Grain yield (kg ha^{-1})
Grass strips	Nongomsoba	1373	695	Local saria	979	560
	Sariaso 14	1298	388	KVX 396-4-4	1662	648
Stone rows	Nongomsoba	1370	608	Local saria	1013	620
	Sariaso 14	1393	520	KVX 396-4-4	1279	646
Control	Nongomsoba	1781	828	Local saria	1448	505
	Sariaso 14	1693	623	KVX 396-4-4	1698	617

Table 9. Effect of various fertilizer treatment on growth and yield of sorghum in farmers fields during 2009 in Northern Burkina Faso.

Treatment	Plant population 21 d after sowing	Stover (kg ha^{-1})	Panicle (kg ha^{-1})	Grain (kg ha^{-1})
A. Control (no input)	27150	252	512	243
B. Micro-dose of NPK	27075	787	1143	583
C. Micro-dose of NPK plus compost	27200	992	1908	1170
D. Recommended NPK	26100	488	1121	601

Host Country: Burkina Faso:

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

Results: The plots were flooded and the yields were very poor and impacted. The improved cultivar Sariaso 14 was more damaged due to flooding. Across all the treatments improved cultivar (Sariaso 14) had lower yields when compared the local landrace (Nongomsoba). There was no impact of various conservation practice due to flooding and water logging conditions across all treatments. Similarly on cowpea yields also there was no significant differences among various water conservations techniques. However, the yield of improved cowpea genotype was greater than the local genotypes across all water conservations techniques.

Experiment 2: Extension of Mechanized Zai, Micro-dose + Compost Application on Sorghum

Results: There were significant differences among various fertilizer treatments on stover, panicle and grain yield of sorghum under farmers fields (Table 8 and 9). Overall, maximum yields were observed in treatments with micro-dose application along with compost, which was followed by micro-dose application alone, and recommended dose of inorganic fertilizer. The lowest yields were obtained in control with no inputs. The recommended fertilizer practice produced lower yield than micro-dose alone or micro-dose plus compost. This could be due to inappropriate method of fertilizer application leading increased losses of fertilizers.

Host Country: Mali

Experiment 1: Impact of Reduced Tillage on Millet Yield

Results: As in previous years, the improved millet genotype, SOxSAT, produced higher yields than the local, Toroniou (Table 10). Despite a significant yield improvement of 42%, SOxSAT is still not as preferred as Toroniou, due to better grain quality. This yield difference was 21% last year. The control (no weeding) produced a yield of 603 kg ha^{-1} of millet, which is within the range of the national millet grain yield of 735 kg ha^{-1}. This year again, one single weeding was the best weeding/tillage option (1211 kg ha^{-1}) of millet grain). This treatment also allows some degree of soil cover by weeds. In fact, weeds growing after the first weeding do not make significant damage to crop, but allow accumulation of biomass. In conclusion, there seems no need for more than one weeding.

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

Results: Yields were significantly increased in 2009 due to early planting. Data confirmed observations that delaying seeding of cereal by 15 days has significantly reduced growth and yield of

Table 10. Impact of genotype and tillage/weeding on millet yield (kg ha^{-1}) in Mali.

Treatments	Grain yield (kg ha^{-1})
Genotypes (G)	
Toroniou – local	769 b*
SOxSAT improved	1089 a
Tillage / Weeding (T)	
Weeding on need	729 c
Weeding ridges on need	801 c
Weeding furrows on need	693 c
Weeding ridges + ridging	1183 b
Weeding ridges + mulching furrows	1011 bc
Control – no weeding	603 cd
Weeding – only once	1211 a
Weeding ridges + mulching ridges	698 c
Interaction GxT	NS

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

Table 11. Influence of millet-cowpea and millet-groundnut intercropping on grain yield of millet genotypes and following yields of cowpea and peanut in Cinzana, Mali.

Treatments	Yield (kg ha^{-1})				
	Millet	Cowpea		Peanut	
	Grain	Pod	Grain	Pod	Hay
1. Toroniou and cowpea – same dates	344 a	709a	472a	-	-
2. Toroniou – 15 days after cowpea	156 c	753a	499a	-	-
3. SO X SAT and cowpea – same dates	281 ab	693a	501a	-	-
4. SO X SAT – 15 days after cowpea	188 c	763a	535a	-	-
5. Toroniou and groundnut – same dates	375 a	-	-	311a	489a
6. Toroniou – 15 days after groundnut	156 c	-	-	297a	498a
7. SO X SAT and groundnut – same dates	385 a	-	-	351a	500a
8. SO X SAT – 15 days after groundnut	271 ab	-		309a	431a

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

both millet genotypes. Millet showed, in both years, the tendency of growing better (Table 11) when intercropped with groundnut, due to higher biomass production from cowpea. Similarly, delaying the seeding of the legume crops has allowed better growth and yield of the cereal crop. The option of delaying the seeding of either intercrop gives an option to the farmer in reducing competition. Again, millet-cowpea or millet-groundnut intercropping had no impact on the growth and yield of none of these legumes (Table 11). In fact, neither delaying the seeding of millet nor using the improved millet genotypes had a significant impact on cowpea (pods and grains) or groundnut (pods and hay). Collaborative farmers stated that millet is not competitive enough to influence the establishment and growth of these legumes. Intercropping is the most common cropping system involving cereals and legumes in these sandy and acid soils of Soudano-sahelian zones of Mali. Thus, intercropping may be improved by delaying the seeding of either crop.

Experiments 3 and 4: Integrated Soil Fertility Management in On-station and On-farm Conditions

Results: Results obtained in 2009 are similar to those of previous years (Table 12). Any ISFM combination involving ACN has shown substantial increases in sorghum growth and yields. Combining both ACN and fertilizers had shown significant increases in yields (69%), both on-station and on-farm. Yield increases have reached up to 79% when crop residues were partially maintained under ACN cultivation and NuMaSS fertilizers. These impacts are due to reduced runoff (by 22%), increased infiltration (deeper wetting front to 2 m), and better fertilizer use efficiency. Any combination involving ACN produced at least 30% yield increase on sorghum. Yield increases have reached 50% of grain sorghum when the combination involved fertilizers. Contour tillage has also improved several soil properties, especially soil organic matter by 22%. Despite significant improvement in yields (34%) and soil carbon (62%), farmers' perceptions are still not favoring crop residues management. The approach in the on-farm sites is to remove and take home most crop residues. These residues are used as either for construction material or fodder (some of which are recycled back to the farm as compost or manure). As for previous years, farmers are not keen about crop residues being left on the field due to 'open' grazing after harvesting. In addition, farmers strongly believe that in case of drought spell, plots with residues are more affected by termites. Further, farmers said that the rate of germination is strongly reduced by crop residues. Furthermore, crop residues left in the field are likely to cause injuries to bare-

Table 12. Impact of ISFM practices on sorghum yield and soil carbon in Fansirakoro, Sotuba, Konobougou, Cinzana and Oumarbougou, Mali.

Technologies	Treatments	Sorghum yield (kg ha^{-1})		C in soil (%)
		2008	2009	2009
ACN	Check	894b	801b	0.22b
	ACN	1212a	1300a	0.36a
Fertilizer	Check	911b	733b	0.25b
	NuMaSS	1347a	1451a	0.41a
Residue Management	Left	1299a	1199a	0.42a
	Removal	929b	898b	0.26b
Tillage	Full tillage	1301a	1400a	0.24b
	Reduced tillage	1224a	1341a	0.25b

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

foot farm workers. These reasons were given as motivation to burn crop residues, thus benefiting from ash improved fertility.

United States: Manhattan, Kansas

Experiment 1: Impact of High Temperature Stress and Selenium (Se) on Grain Sorghum

Results: High temperature stress decreased chlorophyll content, photosynthetic rate and antioxidant enzyme activities and increased oxidant production and membrane damage. Decreased antioxidant defense under HT stress resulted in lower grain yield compared with optimum temperature (OT). Application of Se decreased membrane damage by enhancing antioxidant defense resulting in higher grain yield. Temperature and Se application treatments did not influence plant height (Table 13). The significant effect of HT stress was on yield formation which was reflected in leaf dry weight, total dry matter production, seed size and filled seed weight (Table 13). Foliar spray of Se significantly increased total dry matter production, seed size and filled seed weight. High temperature stress decreased leaf dry weight, total dry matter production, filled seed weight and seed size by about 13, 22, 53 and 51%, respectively, compared with OT. Foliar spray of Se significantly increased filled seed weight and seed size by about 26 and 11%, respectively, over the untreated controls (Table 13).

Experiment 2: Response of Sorghum Hybrids to High Temperature Stress

Results: Short exposure (10 d) to high temperature stress (38/28C) at 10 d prior to flowering decreased pollen viability and seed-set among all sorghum hybrids (Tables 14). However, there were significant differences among hybrids. Pollen germination percentages at optimum temperature (32/22C) were similar and ranged from 72 to 86%, but percentages differed significantly at high temperature stress (38/28C) and ranged from 18 to 42% (Table 14). Percent decrease due to high temperature stress compared to optimum temperature for in-vitro pollen germination was greatest for hybrid DK-28E (79%), followed by DKS-29-28 (67%), Pioneer 84G62 (52%) and DK-5400 (42%). Similar responses were observed for seed-set percentages (Table 14). Hybrids responded differently to short episode (10 d) of high temperature stress. At optimum temperature all hybrids had similar seed-set percentages (between 82 – 92%), whereas at high temperature stress hybrid DK-28E had the lowest percent seed-set (25%), followed by DKS-29-28 (34%), Pioneer 84G62 (55%) and DK-5400 (52%). Percentage decrease in seed-set under high temperature stress compared to optimum temperatures was highest for hybrid DK-28E (73%), followed by DK-29-28 (55%); hybrids DK-5400 and Pioneer 84G62 were similar at about 40% decrease. The pollen grain responses to temperature increases were slightly different for DK-28E (Figure 1a) and DK-5400 (Figure 1b). Both hybrids had similar Tmin close to 16.5 ºC, but Tmax for DK-5400 was around 2 – 3 ºC greater than for DK-28E (40ºC vs. 43ºC). Responses were best described by quadratic equations.

These results suggest presence of genetic variability among sorghum hybrids in response to high temperature stress for percent pollen viability and percent seed-set. These two traits determine one of most important components of yield (seed number per panicle) suggesting scope for genetic improvement. Screening of sorghum germplasm collections and inbred lines for pollen viability, seed-set or other traits for high temperature tolerance are necessary to develop potential high temperature tolerant hybrids. Better understanding of physiological, molecular, and genetic basis of reproductive failure or success and available range of high temperature tolerance in various germplasm collections will help

Table 13: Effect of temperature and Se application at seed-set stage on yield and yield components of grain sorghum grown under controlled environments.

Trait	Temperature			Selenium		
	Optimum	High	LSD	Control	Se sprays	LSD
Plant height (cm)	106.2	103.9	NS	107.0	103.1	NS
Leaf dry weight (g plant^{-1})	13.7	11.8	1.9*	12.1	13.4	NS
Filled seed weight (g plant^{-1})	18.6	8.7	2.7***	12.0	15.2	2.7*
Individual seed weight (mg)	32.0	15.6	1.8***	22.6	25.0	1.8*
Total dry weight (g plant^{-1})	36.2	23.3	5.1**	27.4	32.3	2.8*

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

Table 14. Influence of short episodes (10 d) of high temperature stress starting 10 d prior to flowering on in-vitro pollen germination and seed-set percentage of four commercial sorghum hybrids when grown under controlled environments.

Genotype / Hybrid	Pollen Germination (%)			Seed-set (%)		
	Opt-T 32/22ºC	High-T 38/28ºC	% decrease from OT	Opt-T 32/22ºC	High-T 38/28ºC	% decrease from OT
DK-28-E	86a	18c	79a	92a	25c	73a
DK-29-28	75a	25b	67b	82b	34b	55b
DK-54-00	72a	42a	42c	90a	52a	42c
Pioneer 84G62	80a	38a	52c	92a	55a	40c

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

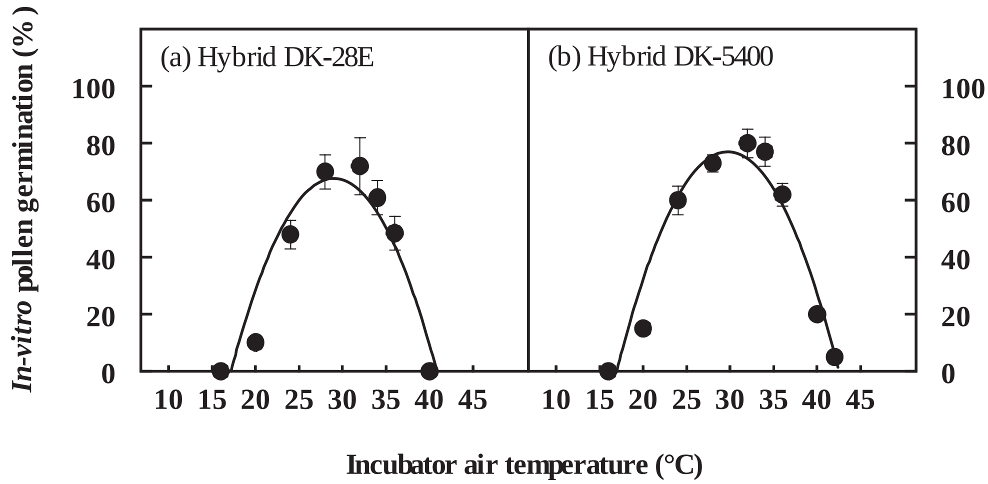

Figure 1. In-vitro pollen germination at various temperatures for hybrids (a) DK-28E and (b) DK5400 to determine cardinal temperatures: Tmin (minimum temperature below which pollen grains did not germinate), Topt (temperature where maximum germination occurred) and Tmax (temperature above which pollen grains did not germinate). Equations: (a) for DK-28E: y = −0.48x2 + 28x –338; r^2 = 0.87; and (b) for DK-5400: y = −0.48x2 + 28x –341; r2 = 0.93.

development of genotypes (or hybrids) with adaptive traits and higher grain yield in semi-arid regions.

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, started his PhD program at Kansas State University (KSU) in Fall 2008 and is going through course work and initiated his research experiments. He is focusing his research 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. Burkina Faso: Mr. Boukare Sawadago, is continuing his MS program at Ouagadougou University.

3. Ghana: Mr. George Mahama Yakuba, started his MS program at KSU in fall 2009. He is working on improving nitrogen use efficiency of sorghum. He is screening sorghum cultivars and hybrids for nitrogen use efficiency; and understanding mechanisms of improved nitrogen use efficiency.

In addition, two students from Kenya (Mr. Raymond Mutava and Ms. Rachel Opole) and one student from India (S. Subramanian) are continuing 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 and developing improved crop management practices for improving productivity of finger millet. Raymond is focusing on screening sorghum germplasm for drought and high temperature tolerance. Satheesh screened sweet sorghum genotypes for abiotic stress (drought or high temperature) tolerance and bioenergy production; and conducted research on understanding impact of drought and high temperature stress on physiology, growth and carbohydrate metabolism in sweet sorghum genotypes under field and controlled environment conditions.

Networking Activities

We have initiated ties with several 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 and Presentations:

Assefa Y, Staggenborg SA and Prasad PVV. 2010. Grain sorghum water requirement and response to drought. Crop Management. doi: 10.1094/CM-2010-1109-01-RV (KAES: 10-296-J).

Djanaguiraman M, Prasad PVV and Seppanen M. 2010. Selenium protects sorghum leaves from oxidative damage under high temperature stress by enhancing antioxidant defense system. Plant Physiology and Biochemistry 48: 999-1007. (KAES: 10-246-J).

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85-90. (KAES: 10-313-J).

Prasad PVV, Kakani VG and Upadhyaya HD. 2010. Growth and production of groundnut. UNESCO – Encyclopedia (KAES: 10-005-B).

Prasad PVV, Vu JCV, Boote KJ and 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. (KAES: 09-183-J).

Mutava RN, Prasad PVV, Roozeboom KL, Yu J, Staggenborg SA and Nippert J. 2010. Evaluating the effects of water stress on growth and development of grain sorghum roots. Annual Meeting of American Society of Agronomy, 31 Oct. – 03 Nov., Long Beach, CA, USA.

Mutava RN, Prasad PVV, Yu J, Kofoid KD and Tuinstra MR. 2010. Characterization of diverse sorghum genotypes for traits related to drought tolerance. Annual Meeting of American Society of Agronomy, 31 Oct. – 03 Nov., Long Beach, CA, USA.

Opole R, Prasad PVV, Kirkham MB. 2010. Effect of high temperature stress on growth, development and yield of finger millet. Annual Meeting of American Society of Agronomy, 31 Oct. – 03 Nov., Long Beach, CA, USA.

Opole R, Prasad PVV, Staggenborg SA and 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.

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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 four countries of eastern and southern Africa and Nebraska supporting the INTSORMIL objective of improving crop and soil 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. A paper was published reporting results of interaction effects of tied ridging and skip-row planting of sorghum research in Ethiopia; the field work for similar research for maize, using buy-in resources, was completed; and research was initiated on planting of a short-season legume in the skip-row area. The second year of research on reduced tillage for teff production was completed in northern Ethiopia with less grain yield for reduced compared with conventional tillage with higher yield with four pre-plant tillage passes compared with one or seven passes. Extension activities continue to promote soil management technology in Ethiopia with financial support from IDRC. In striga-infested eastern Uganda, extension continues in 10 sub-counties with added funding from USAID through diverse partnerships promoting tillage and soil fertility management practices developed, fine-tuned, or verified with INTSORMIL support while the longer term sustainability of these practices is being studied. Complementary funding from AGRA has enabled multi-location fertilizer rate trials for several cereal and pulse crops allowing for benefit:cost analysis comparing profitability of applying different nutrients to different crops. On-farm tillage research was supported in central Tanzania but implementation was poor and discontinued. Collaboration in Mozambique has continued addressing issues of fertilizer nutrient use efficiency in diverse cropping systems through on-farm research. Three students have started higher degree studies with INTSORMIL support. Five journal papers were published.

Objectives

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 U.S. through graduate degree and short-term training, and technical support; 2) Increased productivity of sorghum and teff based cropping systems through better management. Addressed were: the verification and/or promotion in Ethiopia of tied-ridge and skip-row planting, combined with soil fertility management; soil fertility management; teff management in Ethiopia; tillage, soil fertility, and striga management research and extension in Uganda and Tanzania; soil fertility management in Mozambique; and improved responsiveness to climate variability. A third objective “Enhanced demand for sorghum with activities in Uganda and Ethiopia on feeding of livestock and activities in Uganda on grain supply to breweries” was not addressed because of high current and expected future demand globally and in Africa for basic commodities. These objectives support the Sorghum, Millet and Other Grains CRSP vision to improve food security, enhance farm income, and improve economic activity in the major sorghum and pearl millet producing countries in Africa.

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

The implementation sites 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 Cabo Delgado, Nampula, and Manica in Mozambique.

Research Plan

Role of host country scientists. Tewodros Mesfin and Gebreyesus Brhane continued as the main collaborators in Ethiopia; Feyera Liben has started MS studies at Haramaya University. Dr. Kaizzi Kayuki continued to lead collaborative activities in Uganda with a research and extension focus on nutrient supply and tillage for water conservation and promotion of new varieties; Angela Nansamba has started MS studies at Makerere University. Elias Letayo collaborated in on-farm tillage research and *striga* management activities in central Tanzania. Ricardo Maria collaborated in soil fertility research in Mozambique and started PhD study in January 2010. The Nebraska team includes Richard Ferguson and Drew Lyon. 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, and various government and non-government extension partners and community-based organizations.

Research Results

Host Country : Ethiopia

Addressing climate variability in Ethiopia. While earlier work on water conservation and water use efficiency were aimed at a future of increased climate variability, we started to more directly address this topic. Focus group discussions were held with farmers to document farmers' perceptions and traditional decision making processes according to the evolving and anticipated weather conditions in Bosset and Meisso districts in the Central Rift Valley of Ethiopia. The decision process is complex in this area because planting can begin in March and continue to August. Developing weather conditions determine times and amounts of different crops and varieties planted, and affects fertilizer use and other practices. The focus groups addressed farmers' perception of: seasonal rainfall characteristics; climate variability; and their coping mechanism. Indigenous means of predicting on-set of rains were documented. Climate variability implications for soil and water management, tillage and the production of various important crops were discussed including for teff, sorghum, maize, bean and sesame. The results are reported in: **DECISION MAKING STRATEGIES OF FARMERS IN EVOLVING CLIMATE CHANGE**. A need to conduct the focus interviews in other communities was discussed, especially at higher elevation locations. In related activities, visa problems prevented a collaborator from going to Queensland to gain experience with APSIM models and calibrate the skip-row planting routine using Nebraska and Ethiopia data. Instead, he attended short-term training in Nairobi on use of DSSAT models organized by IFDC. A researcher from Melkassa Agricultural Research Center began MS study at Haramaya addressing dry soil planting as a means to cope with increased variability in the on-set of rains; his research will have a field experimentation component and a model use component to assess probability of success with dry soil planting and likely effects on grain yield.

On-farm verification of tie-ridging and fertilizer use for sorghum in Tigray. In on-farm trials conducted over two years in Abergelle of Tigray Region in Ethiopia, tie-ridging resulted in mean yield increases of 27% in grain yield and 46% in stover yield compared with the traditional tillage practice. However, grain and stover yields were 30 and 25% less, respectively, with reduced tillage compared with the traditional practice; reduced tillage consisted of no tillage before planting. Application of 50 kg/ha each of urea and DAP resulted in significant yield increases with 0.23 and 1.40 Mg/ha more grain and stover yield, respectively. With grain and stover farmgate values of 3 and 1 EtB/kg and urea and DAP costs of 3.2 and 3.6 EtB/kg (11 EtB per U.S.$), the benefit:cost ratio of N and P applied was 6.1, but 2 if only the value of the increased grain yield was considered. Planting earlier with a longer season variety resulted in similar yields as planting later with a shorter season variety.

Teff tillage, fertilizer use and weed control. The number of tillage passes before planting affected grain and biomass yield of teff with 4 passes the optimal number compared with one pass for the reduced tillage option and the traditional practice of six to seven passes (Table 1). The fertilizer effect was significant with increased grain and biomass yield with N applied but decreased with N+P applied. With teff grain and straw valued at 11 and 3 EtB/kg and urea and DAP valued at 3.2 and 3.6 EtB/kg, respectively, net returns to N use was 1948 EtB/ha with a benefit to cost ratio of 12.2. The benefit was primarily to increased straw production; the benefit due to increased grain yield alone was 478 EtB/ha with a benefit:cost ratio of 3.0.

Weed control by applying 0.75 kg/ha of 2,4-D controlled weeds as effectively as the farmers' practice of handweeding indicating opportunity for much labor savings at relatively low cost. Weed control practice did not affect grain or biomass yield. The herbicide cost at 0.75 kg/ha was 75 EtB/ha.

Technology dissemination. This has received a boost from an IRDC funded project for technology transfer including promotion of messages resulting from INTSORMIL supported research.

Host country – Mozambique.

Seven on-farm trials were conducted (two failed) to investigate sorghum response to N and P in Cabo Delgado of northern Mozambique. Yields were increased by 75-100% with fertilizer applied. Applying 45 kg/ha N with 20 kg P resulted in increased

Table 1. The effect of tillage passes and fertilizer application on teff grain and straw yield in Tigray, Ethiopia.

Pre-plant tillage passes	Teff yield, Mg/ha Grain	Biomass
1	0.460b	3.20b
4	0.625a	3.97a
6	0.598a	3.67ab
Fertilizer		
0N, 0P	0.573ab	3.63b
23N, 0P	0.631a	4.12a
23N, 10P	0.478c	3.17c
23N, 2.5 Mg/ha manure	0.581ab	3.62b
2.5 Mg/ha manure	0.540bc	3.52bc

Table 2. Benefit:cost ratios for various fertilizer use options in Uganda (preliminary results from 2 to 10 trials conducted in 2009-10). The analysis assumes an opportunity cost of 75% for money invested by smallholder farmers.

Crop/nNutrient	Rate, kg/ha	Benefit:cost
Sorghum		
N	24	2.5
P	4	1.2
Maize		
N	24	3.0
Drybean		
10	10	29.6
P	6	1.5
Groundnut		
P	28	3.9

Phosphorus application was not profitable for maize and soybean. Potassium application was not profitable for any crop.

yield relative to 20 kg P alone in only 2 of the 5 trials emphasizing the importance of P application (Fig. 1).

In a trial conducted in Manica Province, application of 80 kg/ha urea-N was compared with NPK (32-76-32 kg/ha) plus 80 kg urea-N. Application of N alone did not result in increased yield. Yield was increased with application of N, P, and K (Fig. 2). The yield increase was not economical.

Host country – Uganda

Fertilizer use. Trials were conducted at 4 site-years to determine grain sorghum response to N, P, and K with partial support from AGRA. Response to N reached a plateau at less than 50 kg/ha N for most site-years. The economically optimal N rate (EONR) varied with the fertilizer N:grain price ratio (Fig. 3). The respective EONR were 23, 33, and 47 kg/ha N for fertilizer N:grain price ratios of R30, R20, and R10. The N:grain price ratio was 17 following a good harvest in 2010; assuming a opportunity cost of money available to small holder farmers of 75%, the EONR was 24 kg/ha N. Fertilizer P applied to sorghum was most profitable at 4 kg/ha P and K application was not profitable at any rate. Similar trials are underway, with AGRA support, for other crops with 2 to 10 site-years completed per crop. The results show that while N applied to sorghum has a satisfactory benefit:cost ratio, most profitable to smallholder farmers was application of 10 kg/ha N as a starter fertilizer for dry bean, followed by P applied to groundnuts (Table 2).

Sustainability of low input and reduced tillage practices; MSc study. Trials at two locations are in their fifth year. Angela Nansamba has started graduate study at Makerere University and will complete the implementation of this research for her MSc thesis.

Technology transfer. INTSORMIL supported activities are underway in Tororo, Palissa, Kitgum, Kumi, Pader, Soroti, Lira, and Apac districts (Fig. 4). Input stockists from district centers supply 'dealers' in targeted sub-counties with fertilizer for sell to farmers on a pilot basis. Fertilizer prices are high, e.g. $1.40 per kg N in urea, while grain prices following a good harvest in 2010 were low (<$0.10 for sorghum). Still, available data indicates mean returns of >$2 per $1 invested in up to 25 kg/ha fertilizer N applied to sorghum. We held six extension meetings with a total attendance of ~300, mostly women, to discuss fertilizer use issues in August in

Figure 1. Sorghum response to N and P in Cabo Delgado of northern Mozambique.

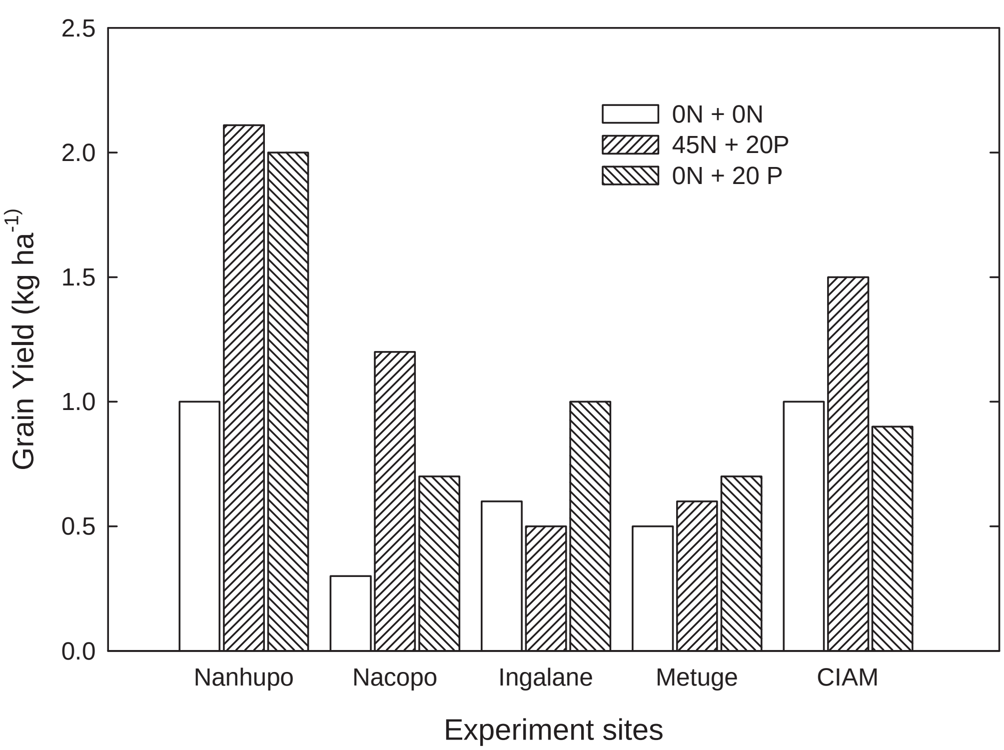


Figure 2. Sorghum response to N, P, and K in Manica of western Mozambique.

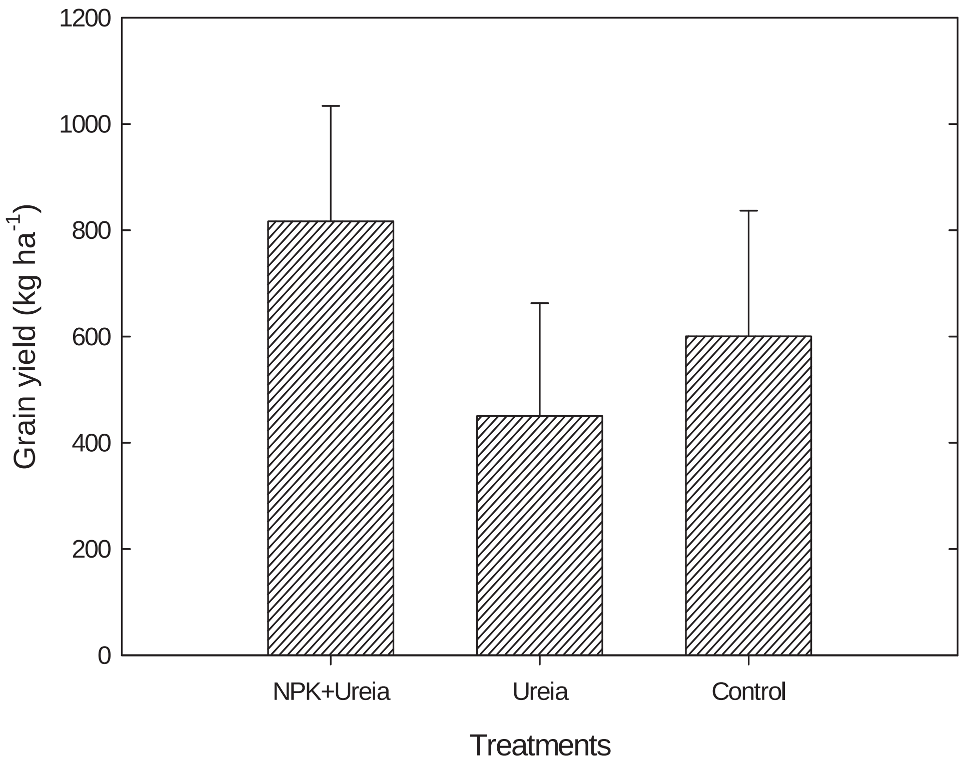


Figure 3. Net returns to fertilizer N applied to grain sorghum in Uganda. R10, R20, R30 are the price ratios of fertilizer N to grain, e.g., at R10 it takes 10 kg grain to buy 1 kg fertilizer N. The economically optimal N rate was 23, 33, and 47 kg/ha N for R130, R20, and R10, respectively.

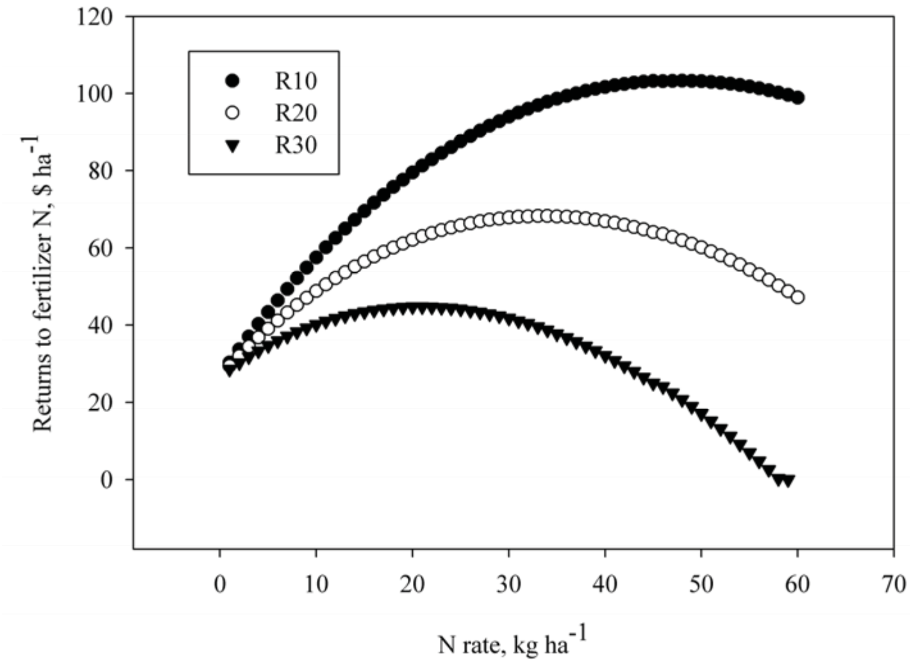
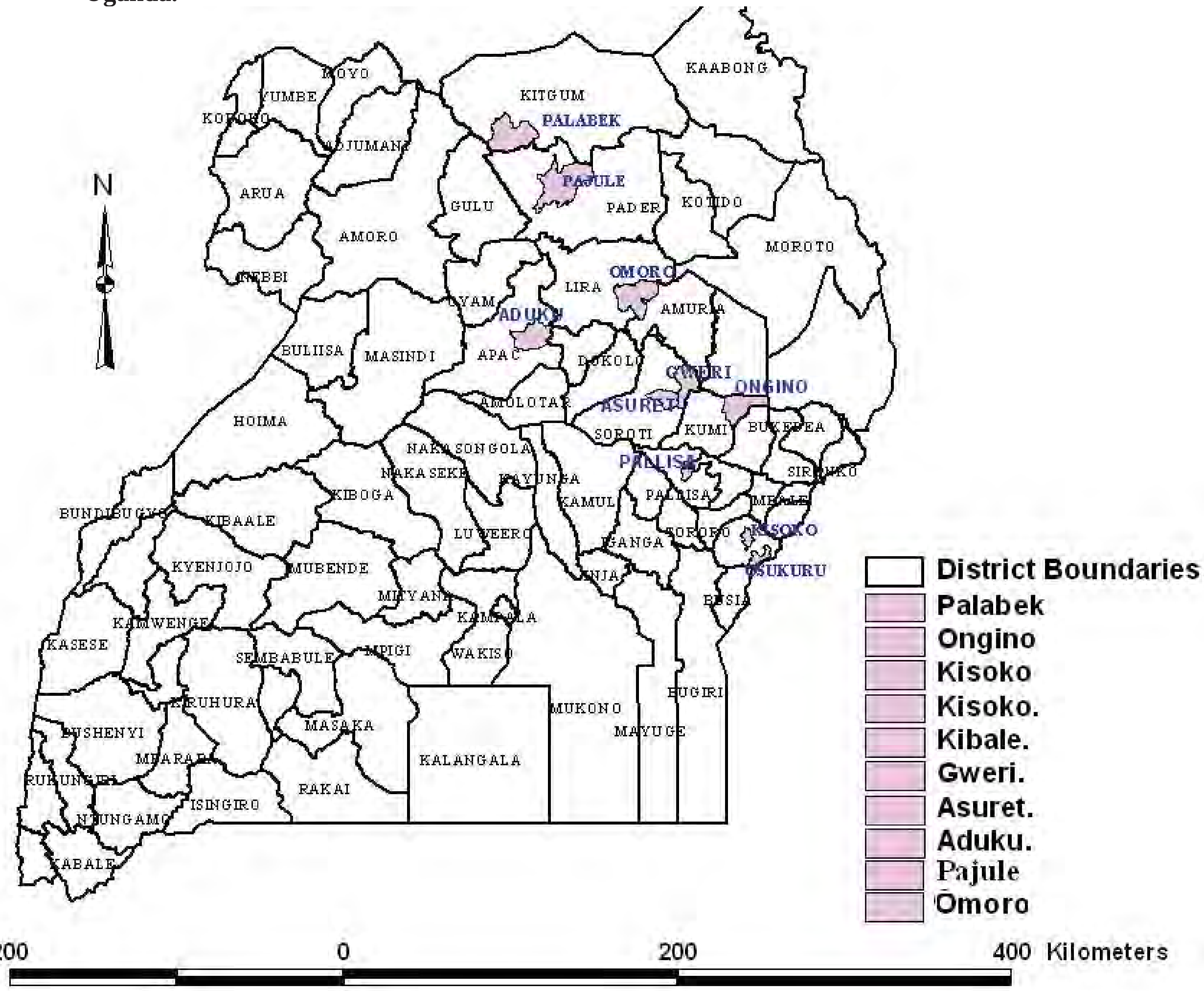


Figure 4. Locations of INTSORMIL-supported technology transfer in eastern and northern Uganda.



addition to field days conducted at demonstration and on-farm trial sites. Discussions were good with farmers recognizing the need to better manage soil fertility and willing 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 sorghum varieties are targeted for release in 2010. These include a Purdue line, Macia obtained through INTSORMIL, and a brown grain line. John Ebiayu, the sorghum breeder, reported arrangements for seed increase on farmers' fields in five districts and on a total land area of ~12 ha with the intent that harvested seed will be sold to farmers in the 2011a season. In the meantime, production of breeders and foundation seed continues at Serere. The seed company, NASECO which markets nationwide and in the Democratic Republic of Congo and is probably the best reputed of >20 local seed companies in Uganda, intends to increase and market seed of the newly released sorghum varieties. They expect to market sorghum seed at about $1.15 /kg with the seed dressed with a systemic insecticide for early shoot fly control and with a fungicide. Interviews have been completed for a baseline and adoption study. A graduate student is planning to conduct her MSc research on factors affecting adoption of soil management practices. (Figures 1, 2, 3 and 4)

Networking Activities

A traveling workshop was conducted in Uganda in January 2010 for Eastern Africa INTSOMIL collaborators. Attending were Gebreyesus Brhane and Tewodros Mesfin, agronomists; Kaizzi Kayuki, soil fertility specialist; Angela Nansamba, agronomist; Johnny Abiayu, sorghum breeder; and Charles Wortmann. Mr. Letayo did not come from Tanzania. Activities included field visits, modes of operation for on-farm research and technology dissemination, an assessment of adoption from INTSORMIL activities in eastern Uganda, and preparation of written extension materials, e.g. leaflets and posters.

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. Accepted.

Mesfin, T., G.B. Tesfahunegn, C.S. Wortmann, M. Mamo, and O. Nikus. 2010. Skip-row planting and tie-ridging for sorghum production in semi-arid areas of Ethiopia. Agron J. 102:745-

750.

Abunyewa, A.A., R.B. Ferguson, C.S. Wortmann, D.J. Lyon, S.C. Mason, and R.N. Klein. 2010. Skip-row configuration and plant population effects on sorghum grain yield and yield stability in the Central Great Plains. Agron J. 102:296-302.

Wortmann, C.S., A.J. Liska, R.B. Ferguson, D.J. Lyon, R.N. Klein, and I. Dweikat. 2010. Dryland performance of sweet sorghum and grain crops for biofuel. Agron J 102:319-326.

Mamo, M. and C. Wortmann, 2009. Phosphorus sorption as affected by soil properties and termite activity in eastern and southern Africa. SSSAJ 73:2170-2176.

Germplasm Enhancement and Conservation

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

Project ARS 101
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Introduction and Justification

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

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

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

Improving Yield and Stability through Resistance to Diseases and Pests

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

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

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

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

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

Improving Marketability through Value-Added and Grain Quality Traits

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

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

Objectives and Implementation Sites

Objectives

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

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

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

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

Implementation Sites

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

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

Improving the Pearl Millet Genetic Map based on AFLP and SSR markers, and QTL analysis of Agronomic Traits

The objectives of this study were to construct a skeleton genetic map of pearl millet using SSR and AFLP markers in a Tift 454 x Tift 99B RIL mapping population, to align the skeleton map with the consensus map and add new markers to the old map, and to detect QTLs for traits of interest

Materials and Methods

For AFLP analysis, DNA (~100 ng) was first digested with EcoRI and MseI, then restriction site-specific adaptors were connected to both sides of the DNA fragments. The following preamplification was carried out using a single selective base primes carrying adaptor-specific sequences. The preamplification product was segregated on 2% agarose gel to check the effect of enzyme digestion and preamplificaton. Then 20 ~ 40-fold dilutions of preamplification products were used for the last two-base-selective amplification with one primer labeled with IRdye 700. The amplification products were separated and visualized using LI-COR. All 64 primer combinations were using to screen the parents to select the best combination to genotype the mapping population. The polymorphic bands were scored manually and fragment lengths were estimated according to molecular ladder.

For SSR analysis, PCRs were carried out on PTC -200 Gradient cycler or MyCyclerTM thermal cycle in a 10 µl reaction mixture containing 10–15 g genomic DNA as template, 50 pmol of each primer, 1 mM MgCl2, 0.1 mM of each dNTP, 1× reaction buffer, and 0.2 U Taq polymerases. PCR cycle began with 94 oC for 5 min, followed by 35 cycles of 94 oC for 30 s, 54 oC for 45 s, 72 oC for 60 s, ended at 72 oC for 10 min, and stored at 4 oC. PCR products were separated on 10% polyacrylamide gel. Electrophoresis instruments, running condition and silver staining methods were as Zhang et al. 2002.

For linkage analysis and map construction, the marker data were scored in dominant or codominant form according to the definition of JoinMap 3. The linkage analysis was conducted with a LOD score of 3.0, recombination frequency of 0.4 to provide evident linkage, and Kosambi map function to convert recombination frequencies to map distances. The chi-square test was performed to all markers to test for segregation distortion. The names of linkage groups and the orientation of the chromosome arms was determined through comparison of the location of SSR markers previously mapped by Qi et al. 2004 and Senthilvel et al. 2008. The graphs of the linkage groups was created using MapChart 2.2.

EST-SSR markers were developed, the mean polymorphism information content (PIC) values calculated, and EST functions predicted. The BC8 ovule transcriptome SSRs data were provided by the Ozias-Akins lab. The SSR finder program written by S.Cartinhour was run against 26,576 contigs derived from ovule RNA amplified by T7-based in vitro transcription, sequenced by 454-technology and assembled using MIRA. The search was restricted to motifs having at least 18 bp long (i.e., di-nucleotide > 9; tri-nucleotide > 6; tetranucleotide > 5). From the SSR containing EST sequences, primer design was conducted with Vector NTI/Contig express 7.0. The expect product lengths for most of primers were around 100-160 bases. The PIC values were calculated using the software PowerMarker 3.25. EST-SSR functions were predicated by executing NCBI BLAST against rice transcripts (CDS+UTR) at the Rice Annotation Project (RAP) database. Only those rice genes that returned an e-value of e-5 or less during the BLAST search were considered putative homologs. BLAST searches were carried out in June 2010.

Phenotype data were collected from the RIL population. RILs were planted in complete randomize design with two replications at Tifton GA during 2006 and 2007. Plots were evaluated for plant heading, height, panicle length and width, and 100 seed weight.

Results

Seven hundred and eighteen SSR primers were used to screen the parents for polymorphism, including 122 genomic SSR primers, 55 RFLP-STS, and the remainder being EST SSR or molecular markers design from EST. The polymorphism rates of genomic SSRs are highest among all the primers we used, with 31.7% and 26.3% for PSMP primers and CTM primers, respectively. The polymorphism rates for conserved intron primers designed from EST from other cereal crops were the lowest, with 4.65% and 5.21% for PCISP and SRSC primers, respectively. The polymorphic rates are in middle for other type primers. Overall, 114 pairs of primers were polymorphic between the two parents, the average polymorphism rate is 14.8%.

All 64 primer combinations were used to screen the two parents, and 37 primer combinations were used in population analysis. The segments between 65 to 650 base pairs were scored. Overall 399 polymorphic DNA segments were scored, 369 of them were finally used for mapping while 361 markers were mapped. An average of 9.7 markers were mapped per primer combination.

Out of 26,576 EST sequences 221 sequences were identified containing SSRs of at least 18-20 nucleotides in length, out of which 14 had more than one SSR. Relative abundance of di- tri- and tetra-nucleotide repeats were 52 (23.5%), 130 (58.8%), and 39 (17.6%), respectively. The tri-nucleotide SSRs were most abundant. The most abundant di-nucloetide was AG/CT (21.1%) motifs. The largest section of tri-nucleotide motifs was GCC/GGC (11.5%), followed by CGC/GCG (10.7%). Out of 221 SSRs, 128 (57.92%) were Type II microsatellites (equal or less than 20 bp). Overall 169 primer pairs were developed from 221 SSR-containing EST sequences. Out of 169 primer pairs, eighteen primers did not give clear amplification products, 80 produced simple products, and 15 produced only fragments longer than the expected length. Thirty two primer pairs showed polymorphism between the parents of the mapping populations. Out of 32 polymorphic primer pairs, 29 pairs were mapped; one primer pair was mapped for 2 loci. Out of 30 mapped loci, 25 were codominant loci, 5 were dominant loci. The EST function blast showed that only 57 ESTs (33.7%) had homologues on the rice genome.

Using JoinMap 3.0, 487 segregating loci (369 AFLP markers and 118 SSR markers), 468 loci (361 AFLP markers and 107 SSR markers) were assigned to nine linkage groups with seven main groups and two two-locus small groups (one of which was LG2 according to previously mapped markers). The total length of the map extended 753 cM and the average length between two loci was 1.61 cM, with some intervals larger than 20 cM in the distal regions in some linkage groups. Of the 66 not previously mapped loci, 52 loci are EST derived markers. Three large EST-SSR marker clusters, containing 6, 6, 9 markers, respectively, were located at the distal region of LG2, LG3 and LG6, respectively. The average marker number of 7 main linkage groups was 69, with the most on LG3 (103 markers) and the least on LG4 (25 markers). The present map is the densest genetic map for pearl millet and contains 468 markers, spanning 753 cM, with an average genetic distance of 1.6 cM between markers.

Both dominant AFLP marker and co-dominant SSR marker presented severe segregation distortions. In this study, 55% of loci showed significant segregation distortion. The distribution of segregation loci in the present map was clustered in certain chromosomal regions and not distributed randomly along the chromosomes. Alignment of the new developed pearl millet genetic map with the consensus map of Qi et al 2004 shows that most anchor markers agree with consensus the map and some inconsistency mainly involved the new mapped marker added to the consensus map. The anchor marker order inconsistencies involved only LG2, LG5 and LG7.

Comparative analysis showed new homologous relation between the pearl millet and rice genomes. EST function showed that locus Xpsms89 and Xicmp3029 on LG2 corresponded to rice chromosome 8 which was not presented on the Devos comparative map (2000). Xugtp 051 on LG4 corresponded to rice chromosome 1. Xcump18 and Xicmp 3078 on LG5 were homologous to rice chromosome 7. Xugtp129.1 is homologous to rice 1 or 5.

QTL analysis of all agronomic traits showed that the LOD value and phenotype variances explained by each QTL were small. The main reason is that this population was designed to evaluate QTLs for root-knot nematode resistance, not for QTL analysis of these specific phenotypic traits, so the differences between the two parents were minimal. Even though these QTLs are only suggestive QTLs, they still provide some useful information for additional research.

In summary, a new genetic map was constructed based on 180 recombinant inbred lines (RILs) derived from intraspecific cross between Tift 99B and Tift 454 using 468 molecular markers (369 AFLP and 118 SSR). The total length of this genetic map, which comprises 7 main groups and two two-locus groups, was 753 cM with average genetic distance between two loci being 1.61 cM. One hundred and sixty nine new pearl millet SSRs were developed using expressed sequence tags (ESTs). One putative quantitative trait locus (QTLs) was detected for each trait, plant height, hundred seed weight, heading date, and panicle length and panicle width. (Figure 1)

Networking Activities

Research Information Exchange.

Served as consultant for Rilington Fields for Southern SARE producer project FS08-228 "Sustainable Production and Niche Marketing of Pearl Millet." The objectives of this project are 1) to develop conservation tillage practices for pearl millet and 2) to develop niche markets with improved profitability.

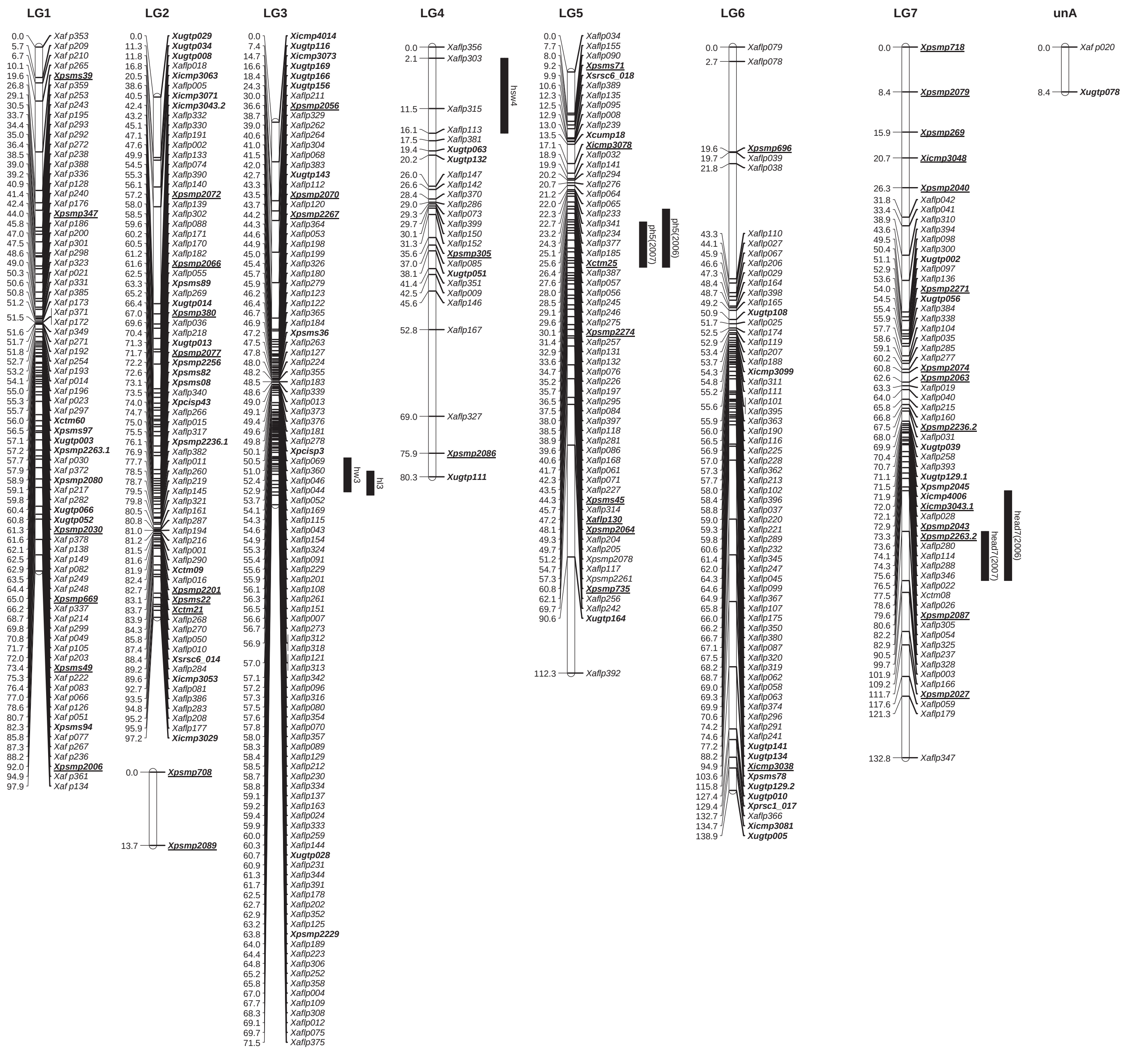

Figure 1. A genetic linkage map of pearl millet [*Pennisetum glaucum* (L.) R. Br.] developed from 180 recombinant inbred lines derived from inbred lines Tift99B and Tift454. Marker distances (cM) are described on the left of the linage groups. Bold markers indicate SSR markers, and underline markers represent previous mapped chromosome anchors. The QTLs for agronomy traits and the bars representing 1-LOD drop intervals are shown on the right side of the linkage group.

Germplasm Conservation and Distribution

33 pearl millet germplasms were provided to the University of Hawaii at Manoa, HI

66 pearl millet germplasms were provided to Metabolix, Cambridge, MA

An RIL pearl millet mapping population developed for mapping the staygreen trait was provided to Ignatius Angarawai, Lake Chad Research Institute, Maiduguri, Nigeria

An RIL pearl millet mapping population developed for mapping striga resistance was provided to Bettina Haussmann, ICRISAT, Niamey, Niger.

Publications and Presentations

Journal Articles

Ni, X., Wilson, J.P., and Buntin, G.D. 2009. Differential responses of forage pearl millet genotypes to chinch bug (Heteroptera: Blissidae) feeding. Journal of Economic Entomology 102: 1960-1969.

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Books, Book Chapters and Proceedings

Strickland, T., Sullivan, D., Hubbard, R., Truman, C., Wilson, J., Hawkins, G., Lee, D., Tubbs, S., Beasley, J., and Phatak, S. Conservation tillage and cover cropping: effects on soil carbon, nitrogetn, and crop water use in the coastal plain of Georgia. p. 122-135 in: The Dahlia Greidinger International Symposium - 2009 Crop Production in the 21st Century: Global Climate Change, Environmental Risks and Water Scarcity. March 2-5, 2009 Technion-IIT, Haifa, Israel

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 though out crop management or agronomic practices, seeking market opportunities for those adopting the recommended packages of technologies, and resulting with increased income and well being of poor farmers.

We have two areas of focus for domestic agriculture. The first is in the area of cold tolerance in sorghum with the idea of improving conventional sorghum lines and hybrids, via genetic introgression of genes from exotic sorghum landraces from areas of the world where sorghum has evolved in the temperate zone, such as China. The additional trait of cold tolerance may render sorghum more adaptable to the northern states and offer greater opportunity than other crops, particularly if these areas also have greater challenges with limitations of water for irrigation.

The second area is in the area of biofuels. This year's report will cover our work in this area. Recent use of sorghum as an alternate biomass energy source makes it one of the most efficient crop for biofuel production. However, the conversion efficiency of any biomass source to liquid fuels such as ethanol is strongly influenced by cell wall composition, especially the lignin content of the cell wall. As the lignin slows down the biomass conversion by interacting with the cellulolytic enzyme, pretreatment of biomass is necessary to separate lignin from cellulose. Further genetic improvement of sorghum for efficient conversion of lignocellulosic biomass to ethanol is a promising way to enhance processing efficiency and reduce costs related to pretreatment of biomass to eliminate the lignin. The bmr phenotype, which is characterized by brown colored leaf midrib, is one of the most economically important traits related to biofuel production using sorghum as a biomass. The bmr phenotype in sorghum has been found to be associated with mutations in several genes encoding monolignol synthesizing enzymes such as caffeic acid O-methyl transferase (COMT) and cinnamyl alcohol dehydrogenase (CAD) and the effects of these mutations are mainly low lignin composition in the cell wall. Thus, bmr mutants are the most important sources of low cost biofuel producing biomass sources. However, in sorghum there are no studies establishing allelic associations of the all available bmr mutant groups.

The enzyme, cinnamyl aldehyde dehydrogenase (CAD), which has been found to be a key enzyme involved in lignin biosynthesis in many crop plants, reduces cinnamyl aldehyde precursors in the last step of monolignol biosynthesis. Generally, the CAD enzyme is encoded by a multi gene family in most of the crop plants (for example EgCAD2, EgCAD1, AtCAD4, AtCAD5, ZmcCAD2, OsCAD2). In maize and rice the brown midrib phenotype has been found to be associated with reduced CAD enzyme activity which is encoded mainly by CAD2 gene. In sorghum, at least, four independent loci have been identified to be associated with the brown midrib phenotypes. However, there are no molecular clues available so far for these phenotypes.

Objectives

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

1. Determine allelic association, chemical characterization and saccharification properties of brown midrib mutants of sorghum
2. Conduct a genome-wide analysis of the cinnamyl alcohol dehydrogenase family in sorghum to identify the brown midrib6 gene

These objectives were addressed as part of the doctoral research of Ana Saballos, a Ph.D. student of Gebisa Ejeta at Purdue University.

Research Methods

Allelic Association, Chemical Characterization and Saccharification Properties of Brown Midrib Mutants of Sorghum

The objective of the study was to establish allelic relationships among the bmr mutants and characterize the changes resulting from each mutation on lignin composition and their effect on the yield of fermentable sugars obtained after enzymatic saccharification of the stover. This study also aimed to develop molecular markers specific to *bmr7* and *bmr27*, which are two novel alleles of the gene encoding COMT.

The allelism test was conducted over a period of 3 years (2004-2006) using *bmr* groups *bmr6*, *bmr18*, *bmr19*. F1 progeny was produced from crosses of female (male-sterile) plants of bmr6, 18 and 19 with all available unclassified *bmr* lines and evaluated for complementation of the mutation. The F1 progeny from each cross was selfed and bmr phenotype was recorded in segregating F2 population. The leaf mid rib samples were collected from wild type and *bmr* lines and processed for histochemical staining and mass spectrometry. Stalks from five random plants per line were harvested and the stover was used for lignin concentration and thermochemical pretreatment and enzymatic saccharification studies.

Genome-Wide Analysis of the Cinnamyl Alcohol Dehydrogenase Family in Sorghum to Identify the Brown Midrib6 Gene

This study was attempted to identify the multi *CAD* gene family in sorghum and its relationship with the gene families from other species using the published genome sequence and the identification of the key gene for the *bmr6*. The available *cinnamyl alcohol dehydrogenase (CAD)* gene sequences from other species (*OsCAD2* from rice, *AtCAD4* & 5 from *Arabidopsis* and *AmCAD2* from maize) were used as queries in the BLAST search and the corresponding orthologs were identified and a complete relationship with other species was established using a phylogenetic analysis. The brown midrib mutants *bmr6-ref, bmr6-3, bmr6-27,* belonging to the *bmr6* group and their normal isolines were used for complete molecular analysis and a RIL population (*bmr* × non *bmr*) for the validation of the hypothesis. Total RNA from these genetic material was extracted using tissues collected at different stages and first strand cDNA was synthesized with the I script cDNA synthesis kit. As the *CAD2* gene is the key gene responsible for the brown midrib phenotypes in other plants, this gene was cloned and structurally modeled in all of the above *bmr* and their isolines using the maize *ZmCAD2* gene as a reference sequence. Additionally, expression studies were conducted to know the association of sorghum *CAD* genes with the different bmr sub groups.

Research Results

Genetic and Chemical Characterization of the Sorghum BMR Mutants

The allelism test revealed that *bmr2*, *5* and *14* were not allelic to any of the tester lines and based on the results bmr mutants included in the test classified in four allelic groups, with the fourth group including the above three. In this study, we used genetic and chemical approaches to establish that there are mutations at least four independent bmr loci, represented by *bmr2, bmr6, bmr12* and *bmr19* groups. Each allelic group is clearly differentiated based on the intensity of histochemical staining. Furthermore, all four allelic groups were distinctly different in their cell wall composition in terms of lignin residues. Moreover, enzymatic saccharification of bmr stover prepared from *bmr* mutants representing the four allelic groups revealed significant differences for most of the *bmr-N* pairs. Overall, lignin changes among the *bmr* allelic groups found to be associated with up to 25% increase in glucose yield compared to wild type isolines. Molecular analysis of *bmr7* and *bmr25* alleles revealed mutations in the *COMT* gene, which are responsible for the complete loss of S residues in the lignin. The *COMT* sequence of bmr25 revealed a point mutation causing a premature stop codon. The mutations created unique restriction sites in both the alleles, which we converted into CAPs markers for identifying these alleles. Based on our allelism test and overall results of our study, we provided a new nomenclature for all *bmr* lines or groups.

Sbcad2 is the Brown Midrib6 Gene

In-silico analysis of CAD genes from other species revealed a total of 14 *CAD*-like genes in sorghum genome. Of these, ten genes were expressed. Among these *CAD* genes, *sbCAD2* corresponded well with the conserved motifs from the bonafide *CAD* genes, indicating that it might be a probable candidate gene for the bmr6 phenotype. The phylogenetic analysis based on sequence comparisons resulted in five groups (I to V) and *sbCAD2* gene was associated with group I where other bonafide *CAD* genes were also present. Sequencing of the *sbCAD2* bmr6-ref mutant allele revealed C-T transition, creating a premature stop codon and truncated non-functional protein which lacks nucleotide binding site and most of the residues that form substrate binding site. Sequencing of the *bmr6-3* allele revealed a G-A transition, resulting in amino acid substitution and altering the cofactor binding site. Finally, the sequence analysis of *bmr6-27* allele revealed nucleotide insertion and formation of truncated protein. We identified novel restriction site alterations resulting from mutations in all these groups and converted them into CAPs markers. These CAPs markers are validated in the RIL population and complete linkage was identified between mutated *sbCAD2* gene and the bmr phenotypes, thus clearly indicated the mutation in the *sbCAD2* gene is the cause for *bmr6* phenotype. Further supporting this hypothesis, *sbCAD2* gene was the predominately expressed gene in sorghum involved in lignin synthesis. Furthermore, RT-PCR analysis of *CAD* gene family in normal and *bmr* sorghum revealed down regulation of *sbCAD2* gene. Structural modeling of *sbCAD2* enzyme and its mutant versions with *AtCAD5* enzyme from *Arabidopsis* revealed that even though *sbCAD2* contains large residue changes, it retains similar overall structure, with secondary structure preserved throughout. Interestingly, the overall expression analysis of *CAD* gene family revealed *SbCAD8* gene as the most highly expressed gene in the aerial part of the plant and is hypothesized to be involved in the production of S and G residues observed in the bmr6 mutants. Finally, the results of this study greatly facilitate the use of *bmr* allele specific molecular markers in genetic studies and breeding programs and also form a basis for further enhancing the sorghum *bmr* lines for biofuel production.

Training (Degree and Non-Degree)

Ana Saballos, a Ph.D. student from Nicaragua working on bmr mutants in sorghum, completed her education and now works as a post-doctoral research assistant at the University of Florida, Gainsville, FL.

Networking Activities

Dr. Gebisa Ejeta spent a great deal of time on travel this past year as the 2009 World Food Prize Laureate on speaking engagement globally. He traveled in all continents except Australia speaking at universities, scientific conferences, government and international organizations concerned with global food security issues. He has tried to advance the cause of science that benefits humanity particularly in areas of the world where hunger prevails.

Publications and Presentations

Saballos, A., W. Vermerris, L. Rivera and G. Ejeta. 2008. Allelic association, chemical characterization and saccharification properties of brown midrib mutants of sorghum (Sorghum bicolor (L.) Moench). BioEnergy Research 1(3): 193-204.

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

Project PRF 1015Gebisa Ejeta Purdue University

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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. We have been funded by the United States Agency for International Development (through INTSORMIL) and the Rockefeller Foundation under two separate grants supporting our *Striga* research. The Purdue University Department of Agronomy provided additional funds for the renovation of laboratory space dedicated to the special measures required for safe containment of parasitic plants. The Purdue College of Agriculture has provided bridge funding to guarantee the salary of the containment officer. We are currently seeking funding from the Bill and Melinda Gates Foundation and from the National Science Foundation to support *Striga* research in separate projects for which the Facility is vital.

Objectives

Much of our *Striga* research is conducted in our containment facility supported by this project making possible the 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, the following research objectives were addressed:

1. Develop an improved screening method for post-germination *Striga* resistance characters.
2. Compare *Striga* seed collected from different areas and host crops in terms of their germination responsiveness in laboratory assays to various crop species and varieties.
3. These objectives were addressed as part of the doctoral research of Idris Amusan, a Ph.D. student of Gebisa Ejeta at Purdue University.

Research Methods

An Improved Post-Germination Laboratory Observation System for Monitoring Striga Growth on Sorghum and Maize

Examining the early underground stages of *Striga* development on host roots is necessary to determine the morphological or physiological properties and the underlying genetics that might confer resistance to these parasitic weeds. Knowledge of the specific genetic events is vital to deliberate breeding for broad-based resistance in host crops. Root examinations are inherently difficult. Excavation of field or pot-grown *Striga* infested plants does not yield useful results since young parasites are delicate and start at less than a millimeter in size. Even if soil is successfully removed leaving attached parasites intact, these same attachments will not survive another observation.

Sorghum may have any of several resistance reactions to *Striga* infection. While any resistance character may not singularly have lasting effect, combining several incomplete resistance characters should offer a more complete and durable crop protection. Breeding for *Striga* resistance would be greatly assisted by in vitro methods that allow inspection of pre-attachment and early post-attachment phases of *Striga's* interaction with host root systems. Such observations would suggest underlying resistance mechanisms in source germplasm and allow selection for specific resistance traits, alone or in combination, in breeding populations.

We have developed and used in vitro growth systems of various designs. An agar based system has been quite useful in identifying sorghum seedlings with resistance based on low *Striga* germination stimulant production. With slight modifications, the "agar gel assay" has been extended to compare sorghum accessions for their ability to trigger formation of the parasitic attachment organ (haustorium) in *S. asiatica* and to observe early post-attachment reactions on sorghum expressing an apparent hypersensitive response to *Striga* (Mohamed et al., 2010). Host growth is restricted in the confines of a Petri dish so monitoring success of individual parasitic attachments is limited to about a week. Also, perhaps owing to the wet agar medium, attachment frequency is low, even on susceptible sorghum varieties. Co-culture of *Striga* on sorghum on moistened paper towels (paper roll assay) allows observations of parasitic associations over several weeks, but we have had found that attachment frequency in this system is also low if the growth medium is too wet. A fundamental problem with previous methods is that newly attached *Striga* are so small (millimeters or less) that a microscope capable of at least 10× magnification is required to view newly attached parasites. This means that the entire apparatus has to be put under a dissecting scope and viewed field by field along whatever part of the host root system is infected. Since several infested root systems need to be examined periodically over the course of the experiment, the number of experimental subjects is limited to how many root systems a person or persons can examine under the microscope in a day. Furthermore, the focused intense light required for microscopic observation can harm tender parasites by overexposure to heat and light during the growth period.

We developed a sand based rhizotron for monitoring *Striga* parasitism with the aid of a scanner during the critical attachment and early post-attachment phases. This apparatus, called the sand-packed titer plate assay (SPTPA), was used to describe some *Striga* resistance characters in maize (Amusan et al., 2008). We have found this as an improvement over other described methods for studying early post-attachment interactions between *S. hermonthica* and maize and sorghum hosts because the growth medium was well suited to both host and parasite and complete root systems could be captured in high resolution digital images in relatively quick scans. We used the SPTPA to examine *Striga* susceptible and resistant maize and sorghum, previously identified in field trials, to pinpoint where specific resistance characters counter Striga parasitism.

The *Striga* resistant sorghum used to test the system was SRN39. Originally derived from an African landrace, this tan plant caudatum type has shown stable resistance to *S. hermonthica* across several geographical areas in both east and west SSA, perhaps owing to multiple resistance traits against the parasitic weed. It has been successfully used as a donor parent for developing *Striga* resistant varieties. It is reported to be a low germination stimulant producer for *S. asiatica*. This contrasts markedly from the susceptible sorghum chosen for this study, Shanqui Red, a red plant Kaoliang type originating from China. Shanqui Red is a high Striga germination stimulant producer and extremely susceptible to Striga, often leading to complete yield loss under field infestation.

The SPTPA basically consists of a sandbag sandwiched between the top and bottom of a clear plastic titer plate modified to accommodate a growing maize or sorghum seedling (cut top for shoot growth, drainage holes to shed excess moisture) when stood on edge. The cover of the plate can be removed first to infect the root system with pre-germinated *Striga* seed (to overcome cultivar differences in germination stimulant activity) and then to observe progress of infection over a few weeks with minimal intrusion. Observations are made on high resolution scans taken of roots exposed only for the few seconds necessary to acquire a digital image.

Stages of development of attached Striga on host roots were captured at 3, 9 15 and 21 days after inoculation (DAI) using a HP 4670 see-through flatbed scanner. The "cover" of the titer plate was removed and the scanner was placed directly on the surface of the Striga infested host roots on the sandbag. Infected roots were scanned at 1200 dpi resolution and saved for later viewing. Stages of development of attached Striga on host roots were defined as S1, attached Striga with seed coat intact; S2, emergence of cotyledons; S3, Striga shoots having one to two leaf pairs; S4, Striga shoots having three to five leaf pairs; S5, attached Striga having 6 or more leaf pairs or Dead, attached Striga turned brown or purple on host root.

Differential Germination Response of Striga Seed Sources to Potential Host Crop Species

There are reports of both intracrop specific (react differently to cultivars of a single host crop species) and intercrop specific (reacting differently to different host crop species) strains of *S. hermonthica*. We have seen this in our own work and we have evidence that at least some of this can be explained by differences between *Striga* populations in germination responsiveness to host root exudates. We measure germination stimulant activity of sorghum accessions in our facility by the agar gel assay. This is a relatively quick and sensitive measure of germination stimulants exuded by host seedling roots. The active germination stimulants in the exudates of sorghum and other *Striga* hosts are believed to be the strigolactones (SLs), a group of related compounds for which at least 15 structures have been reported. Sorghum produces at least six different SLs. In collaboration with Dr. Harro Bouwmeester at Wageningen University in the Netherlands, we have analyzed the strigolactone (SL) content of root exudates of several of our sorghum accessions and found they differ markedly both in terms of the kind and amount of SLs they exude.

It is vital to the lasting success of resistance breeding to predict and monitor virulence in Striga populations. At each point in sorghum/*Striga* association where resistance characters may act, there are corresponding avirulence characters in the parasite that either trigger the resistance reaction (e.g., cause an HR) or simply fail to respond to host signals in manners that lead ultimately to parasitism (e.g., do not germinate in response to certain SLs in the host root exudate). Virulence, on the other hand leads to parasitic establishment and success. *Striga* that does, for instance, germinate in response to a certain SL in the sorghum root exudate is virulent, in that it has taken the first step toward a parasitic association. A sorghum line that exuded the germination stimulant for this virulent *Striga* is, at least at this stage, susceptible. Even though, as breeders, we only directly manipulate the genetic combinations in the host plant, we cannot fully protect crops from *Striga*, even with a battery of resistance traits, if we do not understand the indirect selective pressure we may be exerting on the weed for virulence. Consider, for example a field in West Africa, with depleted fertility where *Striga* has become a pest on sorghum. If the farmer cannot afford to improve the soil through inputs, she may switch to growing millet which can produce a crop on poorer soils and, at least initially, is *Striga* free. Perhaps cultivation of millet can continue for a few seasons, but eventually, *Striga* infestations increase until millet cannot produce a crop. She tries switching back to sorghum, but it continues to experience heavy infestations. So she switches to fonio, that produces for a few more seasons, initially *Striga* free, but eventually also overtaken by the parasite, until the only option is to abandon that field. In this case, the original *Striga* population consisted of a intercrop specific strain, capable of infecting sorghum, but not millet or fonio. The switch from sorghum, though initially successful, put pressure on the weed population, allowing only the growth of individuals able to complete their life cycle on millet. Virulence toward millet built up because those few individuals passed on the virulence to the next generation. Whatever resistance the millet or fonio had toward this strain was eventually overcome. She cannot go back to former crops, because seed from those foes are still in the soil. The same scenario is likely to play out when resistant cultivars replace susceptible varieties of the same crop species because of intracrop specific individuals within a *Striga* population. This can be avoided through integrated management (e.g., crop rotation, pulling any emerged parasites before they set seed, adding fertilizer and conserving moisture) and further ensured if resistance traits are stacked in the improved cultivars such that multiple mutations would have to occur in the parasite population, that is, the accumulation of virulence genes to overcome resistance genes in the host.

We have defined differentials in the sorghum host in terms of their germination stimulant activity towards *Striga* in the agar gel assay and by the SLs present in their root exudates. Those like Shanqui Red which have high germination stimulant activity in our agar assay and, if the SL in the root exudates are analyzed by mass spectrometry, have a relatively high abundance of a SL called 5-deoxystrigol. Others, like SRN39, show very low or no germination stimulant activity toward Striga and, instead of 5-deoxystrigol, which they do not exude, have a different SL, orobanchol.

We used these sorghum lines (SRN39, resistant and Shanqui Red, susceptible) with contrasting SL profiles to test in the agar gel assay for their germination stimulant activity towards five different Striga seed sources collected from different hosts in different countries: *S. hermonthica* collected in Nigeria from a maize host; S. hermonthica collected in Niger from a millet host; *S. hermonthica* collected in Mali from a sorghum host; *S. hermonthica* collected in Sudan from a sorghum host; and S. asiatica collected in the USA (North Carolina) from a maize host;. We also tested two *Striga* susceptible pearl millets (brm06 and ICMV16) and both *Striga* susceptible (5057) and resistant (ZD05) inbred maize lines. GR24, a synthetic SL with high *Striga* germination stimulant activity, was used as a positive control, testing the same *Striga* seed sources in the agar assay for germinability. *Striga* seed was preconditioned by surface sterilizing and incubating in moist conditions at 29°C for 11 days. Conditioned *Striga* seed was embedded in 0.7% agar into which a newly germinated cereal seedling (millet, maize or sorghum) was planted, or for controls, sprayed with a solution of GR24 to a final concentration in agar of 10-8M.

Plates (three of each host variety) were incubated in the dark for three days at 29°C. Germination rate was determined under a dissecting microscope by counting Striga seed (germinated / total) within 3mm of the host root. The experiment was repeated three times for a total of nine plates per entry.

Research Results

The SPTPA reveals an incompatible response to *Striga* in resistant sorghum line SRN39

The SPTPA was well suited to progressive monitoring of the parasitic association between *Striga* and sorghum. Like the difference between resistant and susceptible maize reported in Amusan et al., 2008, post-attachment differences in *Striga* growth on roots of susceptible Shanqui Red (Figure 1, left) and resistant SRN39 (Figure 1, right) were obvious within a few weeks of co-culture. Attachment of *S. hermonthica* to the roots of sorghum was first observed at 3 DAI, irrespective of resistance classifications of host plants. A significant number of parasites on roots of resistant sorghum (SRN39) had arrested growth after initial emergence of one to two leaf pairs (S2). Although a few of the attached *Striga* on resistant sorghum roots developed to S4 and S5, their shoots were diminutive with poorly emerged leaf pairs. Although no measures of sorghum growth were taken, it should be noted that shoots of all hosts remained green and increased in size during their time in co-culture. Likewise their roots remained succulent and continued to grow during the observation period.

Growth stages attained by parasites at 9 DAI ranged from Striga with unbroken seed coats (S1) to shoots having between 7 – 9 leaf pairs (S4). However, there are differences in percentages of attached *Striga* at different stages of development on resistant and susceptible sorghum. Shanqui Red had significantly higher percentages of Striga that attached to their roots developing 3 to 6 leaf pairs (S3) relative to the resistant cultivars SRN39 by 9 DAI. Higher percentages of attached *Striga* on SRN39 remained at S1. Shanqui Red had twice the number of *Striga* attached to their roots relative to SRN39, suggesting some pre-attachment resistance. Of those Striga that did attach, by 21 DAI (Figure 1), susceptible Shanqui Red supported significantly higher percentages of attached *Striga* with 7-9 leaf pairs (S4) and more than 9 leaf pairs (S5) on their roots compared to resistant SRN39. In the same period, 47% of parasites on SRN39 and did not grow beyond S3 and many parasites on resistant roots were clearly dead by 21 DAI.

SRN39 appears to have, in addition to low germination stimulant activity, an incompatible response to infection, i.e., attached parasites are slow to develop on its roots and many die either before or shortly after making vascular connections. The SPTPA is being used to examine segregating RIL populations between SRN39 and Shanqui Red and others. We hope to use this phenotyping to map the gene(s) responsible for the incompatible response in sorghum and find molecular markers which will allow more rapid screening for this and other post-germination Striga resistance traits.

Differential germination responses of Striga seed sources

We found in our agar assay that the *Striga* seed sources tested vary in their germination response to different seedling host roots co-cultured in the agar gel assay (Figure 2). Maize inbreds 5057 (*Striga* susceptible) and ZD05 (Striga resistant) only caused germination of the Carolina *S. asiatica* and *S. hermonthica* from Sudan in the agar assay. This was not reflective of field studies conducted in West Africa where maize is plagued by *Striga* (note that even *Striga* collected from a maize host in Nigeria did not germinate). Resistance of ZD05 is not due to low germination stimulant activity (Amusan et al., 2008). Perhaps in agar, maize does not exude the strigolactones used by the West African *Striga* strains as germination cues. The agar gel assay as we use it for sorghum may not be useful for screening maize for low germination stimulant activity since even susceptible inbreds on maize adapted Striga appear to be low germination stimulant lines.

Sorghum Shanqui Red (Striga susceptible and a high 5-deoxystrigol exuder) stimulated the germination of all *Striga* sources tested, except those collected in Niger from a millet host. Germination stimulant activity of Shanqui Red on the West African sources tested (from maize and sorghum hosts) was about 20% lower than the stimulant activity on the Sudanese source and on *S. asiatica*. Sorghum SRN39 (Striga resistant, low 5-deoxystrigol, high orobanchol exuder) showed very low or no germination stimulant to any of the *Striga* sources tested. These results reflect their performance in *Striga* infested field plots.

The pearl millets tested (both *Striga* susceptible) only showed germination stimulant activity toward *S. hermonthica* collected from a millet host in Niger and from a sorghum host in Mali. They were not highly stimulatory toward *S. asiatica* seed germination either. It will be interesting to see what SLs millets and maize exude under laboratory conditions and whether these differ from sorghum. The differences we observed in laboratory tests of germination stimulant activity may explain at least some of the differences in virulence observed between *Striga* populations between regions and crops across SSA. We will continue to investigate this phenomenon and relate the germination stimulant activity to SL profile.

Training (Degree and Non-Degree)

Idris Amusan, a Ph.D. student from Nigeria working on Striga resistance in maize, completed his education and accepted a maize breeding position at Ag Reliant based in Aimes, Iowa.

Networking Activities

Dr. Gebisa Ejeta spent a great deal of time on travel this past year as the 2009 World Food Prize Laureate on speaking engagement globally. He traveled in all continents except Australia speaking at universities, scientific conferences, government and international organizations concerned with global food security issues. He has tried to advance the cause of science that benefits humanity particularly in areas of the world where hunger prevails.

Publications and Presentations

Amusan, I. O., Rich, P. J., Menkir, A., Housley, T., and Ejeta, G. 2008. Resistance to Striga hermonthica in a maize inbred line derived from Zea diploperennis. New Phytologist 178: 157-166.

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

Projects PRF 104
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Introduction and Justification

Sorghum is poised to play a key role in agricultural development and food security in developed and developing countries around the world. The role of sorghum in agricultural development is expanding as genetic, genomic, and agricultural technologies that have been developed for the crop are transferred to targeted regions throughout the world. The 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. Other more basic research efforts focus on the development and use of emerging genetic and genomic technologies to develop new traits for sorghum and more efficiently use the natural genetic variation in sorghum to improve the crop.

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.

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:

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:

Soumana Soumana, INRAN, NIGER
Daniel Aba, IAR, NIGERIA

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 and John Beitler, DuPont Crop Protection, USA
Olumide Ibikunle, CPP Development Specialist, DuPont Crop Protection, USA
Kay Porter, Pioneer Hi-Bred International, USA

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

This project and approach will directly contribute to the vision of the INTSORMIL CRSP for 2007-2011. The 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 region. The populations are advanced and selected in summer and winter nurseries and then transferred to the target region for evaluation in conference with collaborating 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 provide in-country testing and 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 on 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 diverse. 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 combined with DNA sequencing capacity are being used to search for genes involved in complex traits 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 characterizing the AM panel for grain quality and plant performance traits to identify genes and sources of alleles that can be used to enhance the crop.

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 also 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. Grain molds and weathering in the field can have a major effect on sorghum grain quality and value. Seed quality is diminished not only for nutritive value, but the flour produced from molded grain generally has poor color quality and reduced aesthetic value.

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.

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 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, Purdue began collaborative research trials with scientists from Nigeria, Niger, Burkina Faso, and Mali, DuPont Crop Protection, and Pioneer Hi-Bred. The objective of this collaboration was to demonstrate the efficacy of a technology package that combines hybrids and seed treatments to improve yield potential and *Striga* resistance of sorghum in West Africa (Figure 1). An array of trials were initiated in four West African countries to test ALS herbicide resistant hybrids developed at Purdue combined with herbicide seed treatments developed at DuPont. Preliminary results appear very promising. 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 in 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.

Strategies for gene and allele discovery are being evaluated in a study of genes that control 'height mutants' in sorghum. The dwarf phenotype (dw1:Dw2:dw3:dw4) of sorghum has been exploited since the 1940s (Quinby 1974, 1975). The dw3 allele commonly used in commercial production is a 7765 base pair gene that contains a 880 base pair tandem duplication in exon 5 (positions 5650-6531) that disrupts the protein function (Multani et al., 2003). Karper (1932) noted that this dw3 mutation produced a useful dwarf phenotype but was unstable and reverted to Dw3 or tall at a frequency of approximately 1 in 600 plants depending on the genetic background. These tall plants are generally termed 'height mutants' (Figure 2). 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" and, in some cases, seed lots must be destroyed if the frequency of off-types is too high

Analyses of DNA sequences of dw3 plants demonstrated that the instability of this allele was the result of unequal crossing-over that produced one wild-type allele and another allele with 3 tandem repeats (Multani et al., 2003). The goal of this research project was to identify and characterize a stable dw3 allele in sorghum and initiate efforts to incorporate this trait into elite sorghum germplasm. A high throughput extraction protocol was used to extract DNA from a large collection of sorghum genotypes and PCR was used to screen these samples for changes in the target sequence. A new dw3 allele that did not contain the 882-bp insertion was identified. DNA sequencing experiments showed that a small deletion in the coding sequence of this allele resulted in non-functional protein product. Field studies demonstrated that this allele had a stable dwarf phenotype that did not produce any height mutants (Figure 3). This new allele was termed dw3s for dw3-stable and it will provide an opportunity to fix the dw3 instability in current sorghum germplasm. Genetic markers and a high-throughput introgression strategy has been developed to rapidly introduce this trait into elite germplasm.

Networking Activities

Workshops and Meetings

Health, Research, and Entrepreneurship: Sorghum Food for Celiac Patients, Naples, Italy, October 15-21, 2009

Certified Crop Adviser Conference, Indianapolis, IN, Dec 16, 2009

Global Food Security Summit, Purdue University, West Lafayette, IN, Feb. 8, 2010

Fourth Annual Plant Breeding Conference, Plant Breeding Coordinating Committee, Johnston, IA, August 15-17, 2010

Research Information Exchange

West Africa research trial evaluation with DuPont Crop Protection and Pioneer Hi-Bred in research plot tours at IER and ICRISAT in Mali, INERA in Burkina Faso, INRAN in Niger, and the Alliance for a Green Revolution October 1-12, 2009

D.A. Aba from IAR-Nigeria was hosted at Purdue University for short-term training and research exchange from November 2-21, 2009

Figure 1. Collaborative research trials evaluating the efficacy of herbicide seed treatments on herbicide resistant hybrid sorghum varieties for reducing Striga infestations and increasing grain yields in Zaria, Nigeria.

Figure 2. Tall *dw*$_3$ revertants commonly referred to as "height mutants" in a commercial sorghum production field.

Figure 3. Growout plot of a genotype homozygous for a new *dw₃*-stable allele. No mutants were found in more than 50,000 plants evaluated.

West Africa Research Coordination Meeting, DuPont Crop Protection, Wilmington, DE, Feb. 18-19, 2009

Abocar Toure from IER-Mali was hosted at Purdue University for short-term training and research exchange from Aug 1-Sept 30, 2010

Advanta Sorghum Field Tour, Purdue University, West Lafayette, IN, September 8, 2010

DuPont Crop Protection and Pioneer Hi-Bred Sorghum Field Tour, Purdue University, West Lafayette, IN, September 16-17, 2010

Germplasm Conservation and Distribution

Distributed replicated experiments to evaluate efficacy of herbicide seed treatments and host-plant resistance to Striga to NARs collaborators in Niger, Burkina Faso, Nigeria, and Mali

Publications and Presentations

Journal Articles

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

Projects 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 (ie, 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:

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.

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.

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.

IDENTIFY AND MAP GENES RELATED TO GRAIN QUALITY SUCH PROTEIN DIGESTABILITY, NUTRACEUTICAL POTENTIAL AND GRAIN QUALITY PARAMETERS PER SE. Variants that possess unique grain traits such as increased protein digestibility and enhanced antioxidant characters have been identified and characterized in our program. The purpose of this project is to assess the feasibility of producing cultivars that possess these characteristics. In collaboration with the

TAMU grain quality program (L. Rooney, D. Hays), we are assessing the feasibility of combining both grain mold resistance and enhanced digestibility.

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

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.

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.

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

Anthracnose Resistance Mapping

In Central America as well as the southern U.S., anthracnose (caused by Colletotrichum graminicola) can be a significant disease of sorghum. The disease can infect all above-ground portions of the plant, although infection in the leaves and stalks is usually the most economically damaging. Due to this, the disease can be very destructive to forage production because even if it does not reduce yield it will reduce forage quality. Over the past ten years, our program has identified new and unique sources of anthracnose resistance and this was highlighted in by Mehta et al. (2005) who described four sources of resistance controlled by different genes and determined that each was highly heritable. Our program has collaborated with molecular geneticists to identify at least one anthracnose resistance locus from SC748-5 to the end of linkage group 5 (Perumal et al., 2008).

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).

Table 1. List of brown midrib selections created for testing in the Central American region.

No.	Designation	Pedigree
1	CI 0968 bmr	(RCV * B03290) S-11-7
2	CI 0972 bmr	(RCV * B03290) S-13-9
3	CI 0970 bmr	(RCV * B03290) S-13-1
4	CI 0973 bmr	(RCV * B02043) S-19-1
5	CI 0916 bmr	(VG-146 * B02043) S-2-2
6	CI 0919 bmr	(VG-146 * B02043) S-26-1
7	CI 0914 bmr	(VG-146 * B03289) S-5-4
8	CI 0095 bmr	(S-2 * BO2043) S-17-6
9	CI 0925 bmr	(S-3 * B03289) S-21-4
10	CI 0929 bmr	(S-3 * B03288) S-30-12
11	CI 0932 bmr	(S-3 * B03288) S-95-9
12	CI 0936 bmr	(Tortillero * B03292) S-2-5
13	CI 0938 bmr	(Tortillero * B02043) S-5-2
14	CI 0943 bmr	(Tortillero * B03292) S-12-4
15	CI 0947 bmr	(Tortillero * B03292) S-64-13

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.

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 produced 30 experimental hybrids that have been planted in replicated yield trials in four locations (Weslaco, Corpus Christi, College Station, and Halfway, Texas) to evaluate their relative agronomic potential, their antioxidant content and the effect of environment and genotype x environment interaction on those traits. These trials have been harvested and analysis is currently underway. 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 compounds.

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

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

Impact

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

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

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

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 major food and feed grain in the semi-arid tropics. It is ideally suited to marginal semi-arid environments due to its efficient water use, tolerance to high temperatures, multitude of uses (grain, forage, biomass), ability to produce harvestable grain yield in diverse cropping systems, and performance in rotation systems. 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, lower value and quality of grain and forage, and government policy. Primarily a feed-grain in the U.S., demand for sorghum for ethanol production and as a food grain or nutraceutical should increase. The overall project objective is to develop new 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 at developing germplasm and parental lines suitable for use as hybrid seed parents. Lines, either R- (pollinators or males) or A-/B- pairs (female seed parent and maintainer) are selected for disease resistance, improved weathering resistance, and wide-adaptation. Replicated observation and grain yield trails are used to identify those parental lines with the combining ability to produce more grain than standard check hybrids. The superior lines then undergo additional evaluations in subsequent years to confirm the results.

In Mozambique several 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

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

Segregating populations are developed in Texas and evaluated/selected for adaptation and resistance to specific diseases or insects, drought tolerance, and grain mold/weathering resistance. Appropriate germplasm is provided to host country collaborators to evaluate the populations 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. A 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 (Sebele), and South Africa (Cedara), insect resistance screening in glasshouse and field facilities at the Botswana College of Agriculture (Sebele), 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 multilocation testing to identify the best genetic combinations for the trait(s) of interest. Selection in diverse environments should identify widely adapted genotypes with resistance to multiple stresses.

For southern Africa primary biotic stress resistance traits are for adaptation to indigenous cropping systems, seedling and adult plant stage resistance to sugarcane aphid, 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 resistance, and drought resistance. 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. Sugarcane aphid (Melanaphis sacchari (Zehntner)) trials were provided to collaborators at the University of the Free State (a 45 entry x three replication preliminary trial and a 24 entry advanced trial and the Botswana College of Agriculture (a 24-entry advanced 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.

Growing the sugarcane aphid yield trial at two locations (Sebele, Botswana and Cedara, South Africa) provides the opportunity to evaluate in two distinctly environments (Table 1). For grain yield, measured as grain mass per panicle, the standard check Ent62/SADC produced the most grain per panicle. Relative rank of the entries varied by location. The sib entries (Macia*TAM428)-LL9 and (Macia*TAM428)-LL2 performed well at both locations, especially at Sebele. Other entries that produced excellent grain yield include (Dorado*Tegemeo)-HW15-CA1-CC2-LG1-CABK and (Kuyuma*5BRON155)-CA5-CC1-CABK-CABK. To confirm yield results from prior years the trials should be grown in replicated on-farm tests. Grain mold is a major problem in growing white grain sorghum in certain environments in southern Africa, and Cedara provides an excellent environment to evaluate germplasm for resistance. Most entries in the yield trial expressed more susceptibility to grain molds with only three entries - (Kuyuma*5BRON155)-CA5-CC1-CABK-CABK, (Dorado*Tegemeo)-HW13-CA1-CC2-LGBK-CABK and (9MLT176/ (MR112B-92M2*Tx2880)*A964)-CA3-CABK-CCBK-CABK-CABK – score as moderately resistant (scored at 2.7 on a 1 resistant to 5 susceptible scale). There is the need to develop cultivars and parental lines with improved levels of grain mold resistance.

The 45-entry preliminary sugarcane test was grown to provide an initial evaluation of the relative performance on new germplasm. The test was composed of 36 experimental entries and 9 standard checks (Table 2). For grain mass per head, a relative measure of grain yield, the top two entries and 8 of the top ten were experimental entries. Additionally, the level of grain mold resistance is improving. All of the top entries for grain mass exhibited at least moderate (scored at 3.0) grain mold resistance. Three entries – (Sureno*LG70)-HF5-CA1-CC2-CA1-LG1, (Tegemeo*ICSB12)-CA2-CC1-CABK-CA2, and (Tegemeo*ICSR-939)-CA7-CC1-CABK-CA1 – expressed good grain mold resistance with ratings of 2.3, 2.0 and 2.5, respectively. Additional evaluations will be conducted in the next 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 sugarcane aphid resistance has been incorporated into elite cultivars with excellent grain yield.

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.

Table 1. Evaluation of the sugarcane aphid resistance yield nursery for grain mold and adaptability at Cedara, South Africa and Sebele, Botswana, 2009-10.

Entry	Pedigree	Grain mold†	Grain mass per panicle Cedara	Rank	Grain mass per panicle Gaborone	Rank	Lodging	Flag Leaf height	Head height	Uniformity ‡
			g		g		%	m	m	
6	Ent62/SADC	4.0	72.9	1	102.5	1	0.0	1.4	1.6	1.3
12	(Dorado*Tegemeo)-HW15-CA1-CC2-LG1-CABK	3.0	69.3	2	31.7	16	4.6	1.3	1.7	1.0
8	(9MLT176/(MR112B-92M2*Tx2880)*A964)-LG8-CABK-LGBK-LGBK-CABK	3.0	66.2	3	27.3	17	3.6	1.5	1.7	1.3
2	Segaolane	3.0	61.0	4	27.0	18	0.0	1.4	0.8	1.3
14	(Kuyuma*5BRON155)-CA5-CC1-CABK-CABK	2.7	60.9	5	40.2	10	3.3	1.3	1.8	1.0
3	Kuyuma	4.3	57.7	6	70.8	2	11.7	0.8	1.3	1.0
9	(LG35*WM#322)-BE40-LG1-CA1-LGBK-CABK-CABK	3.0	57.2	7	23.8	21	11.3	1.1	1.5	1.3
7	(9MLT176/(MR112B-92M2*Tx2880)*A964)-CA3-CABK-CCBK-CABK-CABK	2.7	56.9	8	26.1	19	0.0	0.8	1.6	1.0
10	(Dorado*Tegemeo)-HW13-CA1-CC2-LGBK-CABK	2.7	55.4	9	37.6	13	4.3	1.1	1.5	1.0
17	Tegemeo	4.0	54.1	10	47.2	9	7.3	1.4	0.8	1.0
20	(Segaolane*WM#322)-LG2-LG2-(03)BG1-LG1-LBK-PRBK	3.0	52.6	11	37.6	14	0.0	1.4	0.8	1.0
4	Macia	3.7	50.7	12	34.4	15	1.3	1.4	0.8	1.3
22	(Macia*TAM428)-LL2	4.0	50.1	13	68.8	4	0.0	1.0	0.8	1.0
11	(Dorado*Tegemeo)-HW14-CA1-CC2-CABK-CABKK	3.0	49.9	14	25.4	20	2.6	1.1	1.4	1.0
16	(5BRON151/(7EO366*GR107B-90M16)*Tegemeo)-HG7-CC2-CABK-CABK	3.7	48.8	15	51.7	7	34.0	1.3	1.7	1.0
13	(A964*P850029)-HW6-CA1-CC1-LGBK-CABK	3.3	46.7	16	13.2	22	0.0	1.0	1.3	1.3
1	TAM428	3.3	46.2	17	59.6	5	0.0	0.6	1.1	1.3
19	(SV1*Sima/IS23250)-LG15-CG1-BG2-(03)BGBK-LBK-PRBK	3.0	45.5	18	54.1	6	2.0	1.4	0.8	1.6
5	SRN39	3.0	41.6	19	38.4	12	6.6	1.1	1.4	1.3
18	(Macia*TAM428)-LL9	3.7	33.8	20	70.5	3	10.6	1.3	1.1	1.0
15	(5BRON151/(7EO366*GR107B-90M16)*Tegemeo)-HG1-LGBK-CABK-CABK	3.3	29.4	21	40.1	11	6.0	0.8	1.5	1.0
21	(6BRON161/(7EO366*Tx2783)*CE151)-LG5-CG2-(03)BG1-BG2-LBK-PRBK	3.7	28.3	22	47.8	8	0.0	1.1	0.8	1.0
LSD P>0.05)		1.3	14.4				8.6	0.5	0.6	-

†Rated on a scale of 1=no grain mold to 5=kernel covered and some grain deterioration.
‡Rated on a scale of 1=very uniform to 5=very uneven.

Table 2. Evaluation of the sugarcane aphid resistance nursery for grain mold and adaptability at Cedara, South Africa, 2009-10.

Pedigree	Plant/grain color†	Grain mass per panicle	Grain mold‡	Lodging (%)	Flag Leaf height	Head height	Uniformity§
		g		%	m	m	
(Sureno*LG70)-HW5-CA1-CC2-CA1-LG1	T/W	70.9	2.3	9.0	1.1	1.8	2.0
(Dorado*Tegemeo)-HW13-CA1-CC2-LGBK-CABK	T/W	69.4	3.0	0.0	0.8	1.1	1.5
(Tegemeo*ICSB12)-CA2-CC1-CABK-CA2	T/W	65.9	2.0	0.0	1.3	1.0	1.0
(Dorado*Tegemeo)-HW15-CA1-CC2-LG1-LGBK	T/W	61.2	3.7	0.0	1.1	1.3	1.0
Ent62/SADC	T/W	58.4	4.3	0.0	1.0	1.1	2.0
(Tegemeo*ICSR-939)-CA7-CC1-CABK-CA1	T/W	58.4	2.5	3.7	1.4	1.7	2.0
(5BRON139/(6EO361*GR107-)*Tegemeo)-HG7-CA1-LG1	T/W	57.8	3.0	8.3	1.1	1.2	1.5
(5BRON139/(6EO361*GR107-)*Tegemeo)-HG7-LG1-LG2	T/W	57.6	3.0	1.3	1.1	1.7	1.0
(9MLT176/(MR112B-92M2*Tx2880)*Dorado)-CA4-CA1-CC2-CABK-LGBK	T/W	56.3	3.0	0.0	1.2	1.5	1.0
Segaolane	R/W	54.7	3.0	3.0	1.0	1.0	2.5
WM#177	R/W	53.2	3.0	1.6	0.8	1.3	1.7
(5BRON154/(87BH8606-4*GR127-90M46)-HG10-LG1-LG3-CGBK*Macia)-HG10-CA1-LG1	T/W	52.8	3.0	23.3	1.1	1.5	3.0
(9MLT176/(MR112B-92M2*Tx2880)*Dorado)-BE9-CA1-CA2-LGBK-CABK	T/W	51.6	2.3	0.0	0.7	1.1	1.5
(Segaolane*KS115)-HW3-CA3-LD1-CABK-CA2	T/W	50.9	2.5	2.3	0.8	1.1	1.5
(Kuyuma*5BRON155)-CA5-CC1-CABK-CA1	T/W	50.8	2.7	11.3	1.3	1.7	2.0
(Kuyuma*5BRON155)-CA5-CC1-CABK-CABK	T/W	50.6	2.0	33.6	0.6	0.9	1.0
(5BRON139/(6EO361*GR107-)*Kuyuma)-H17-CG2-LDBK-CA1	T/W	50.1	3.7	7.3	1.0	1.3	2.5
(9MLT176/(MR112B-92M2*Tx2880)*A964)-CA3-CABK-CCBK-CABK-CA2	T/W	49.7	3.0	0.0	0.9	1.2	1.2
(5BRON154/(87BH8606-4*GR127-90M46)-HG10-LG1-LG3-CGBK*Macia)-HG3-CA1-LG2	T/W	49.2	3.3	0.0	0.7	1.2	2.5
TAM428	P/R	49.0	4.0	2.0	1.1	1.3	2.0
Tegemeo	T/W	48.2	4.0	15.3	0.9	1.3	1.0
Macia	T/W	47.6	3.3	13.3	1.2	1.5	1.0
(Tegemeo*ICSB12)-CA12-CC1-LG1-LG1	T/W	47.4	2.3	4.6	1.4	1.6	1.0
(Tegemeo*WM#322)-CA2-CC2-CABK-CA2	R/W	46.6	3.3	11.7	1.0	1.3	3.0
(Dorado*Tegemeo)-HW13-CA1-CC2-LGBK-CABK	T/W	45.7	3.3	0.0	0.9	1.4	1.0
(5BRON139/(6EO361*GR107-)*Kuyuma)-HG3-LD2-CABK-CA1	T/W	45.5	3.3	1.6	1.3	1.3	1.5
(9MLT176/(MR112B-92M2*Tx2880)*Dorado)-CA4-CA1-CC2-CABK-CABK	T/W	45.3	2.7	0.0	1.3	1.2	2.0
Kuyuma	T/W	44.5	4.0	14.0	0.8	1.3	1.5
(CE151*Tx430)-BE3-CA1-LGBK-CABK	T/W	44.5	3.7	11.3	1.1	1.1	1.5
(R.88B928*Tegemeo)-HW1-CA1-LGBK-CABK-CABK	T/W	42.7	2.7	2.6	1.2	1.7	2.5
(Tegemeo*WM#322)-CA1-CC1-CABK-CA2	R/W	41.8	2.3	0.0	1.3	1.5	1.0
CE151	T/W	41.3	4.0	5.0	0.9	1.3	1.2
(A964*P850029)-HW6-CA1-CC1-LGBK-CABK	T/W	41.2	2.3	3.6	0.7	0.9	2.0
(5BRON151/(7EO366*GR107B-90M16)*Tegemeo)-HG7-CC2-CABK-CABK	T/W	40.5	3.3	39.0	0.9	1.1	3.0
(5BRON151/(7EO366*GR107B-90M16)*Tegemeo)-HG7-CC2-CABK-LG1	T/W	40.0	2.7	13.3	1.2	1.5	1.2

Table 2. – cont'd Evaluation of the sugarcane aphid resistance nursery for grain mold and adaptability at Cedara, South Africa, 2009-10.

Pedigree	Plant/grain color†	Grain mass per panicle	Grain mold‡	Lodging (%)	Flag Leaf height	Head height	Uniformity§
(Kuyuma*LG35)-CA10-LGBK-CABK-LG1	T/W	39.8	2.3	17.6	1.5	1.2	2.5
(CE151*Tx430)-HW2-CA1-CG1-LDBK-CA1	T/W	39.5	4.0	1.6	0.8	1.3	1.0
(5BRON151/(7EO366*GR107B-90M16)*Tegemeo)-HG1-LGBK-CABK-CABK	T/W	38.0	3.7	7.0	1.1	1.6	1.0
SRN39	T/W	35.9	2.3	5.6	1.0	1.3	1.5
(Kuyuma*LG35)-CA6-CC2-CABK-LGBK	T/W	35.5	3.0	37.6	1.2	1.3	1.0
(9MLT176/(MR112B-92M2*Tx2880)*Dorado)-BE1-CA1-CA2-CC2-LGBK-CA1	T/W	35.1	3.0	0.0	0.7	0.9	1.0
(9MLT176/(MR112B-92M2*Tx2880)*Segaolane)-CG1-LG1-CA1-CG2-CC2-CA2	T/W	33.4	3.0	0.0	0.8	1.1	1.0
(Malisor84-7*(6OB172/88CC445*Tx2862))-LG19-CG1-CA1-CABK-CC1-CABK-CA1	R/W	32.7	3.0	0.0	0.9	1.1	1.2
(99GWO92*ZSV15)F3-H55-HW1-HW1-LG1	T/W	30.4	2.7	49.0	1.3	1.4	1.0
(R.88B928*Tegemeo)-HW1-CA1-LGBK-CABK-CA1	T/W	28.3	3.0	3.3	0.8	1.2	1.5
LSD.05		17.3	1.9	17.6	0.4	0.3	1.2

†P=purple, R=red, T=tan, W=white.
‡Rated on a scale of 1=no grain mold to 5=grain covered with mold and some deterioration.
§Rated on a scale of 1=very uniform to 5=very uniform.

Designation/pedigree of the eight lines from the Lubbock program are:

- 03CM15067 (((((Tx2880*(Tx2880*(Tx2864*(Tx436*(Tx2864*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
- Sureño
- 02CS30445 (99CA3019 - (VG153*(TAM428*SBIII))-23-B32-BE2-BE1)
- B409 (B1*(B7904*(SC748*SC630)))-HF17B
- 02CS5067 (B1*BTx635)-HF8
- 01CS19225 (B35*B9501)-HD9

Preliminary data analysis indicated that several of the lines express grain yield equal to or better than the local check Macia (2.79 t/ha at Sussundenga). The national sorghum program anticipates proposing lines for release following an additional year of testing in 2010-2011.

To evaluate hybrid combining ability and grain yield potential of new germplasm releases and advanced experimental lines three replicated yield trials were conducted at the Texas AgriLife Research Center, Lubbock, during 2009. All trials had three replications with a plant population of approximately 52,000 plants per acre. The experimental site received one pre-plant and two post-plant irrigations.

Yield trial 1 was developed to evaluate the grain yield of recently released pollinator lines on standard A-Lines and proprietary A-lines from a seed company. The purpose of the test was to generate data on proprietary A-lines for comparison with commonly used public A-lines. The test mean was 6230 kg/ha. Standard checks were ATx2752*Tx2783 (6968 kg/ha), ATx399*RTx430 (6338 kg/ha), and ATx399*Tx2737 (5805 kg/ha). Twenty-two hybrids produced more grain with yield ranging from 6241 to 7619 kg/ha. The pollinators of the two best hybrids, 01BRON184 and 04BRON262, are both tan plant white grain lines with excellent adaptation and foliar disease resistance. Test weight of the experimental hybrids was as good as the standard checks. Flowering, ranging from 62 to 69 days after planting, was later than normal and all of the hybrids would be classified as medium to medium-late.

Yield trial 2 (28 entries) tested the combining ability of elite pollinators on standard A-lines. Grain yield of the check ATx642*RTx430, ATx399*Tx2737, ATx2752*Tx2737, ATx2752*Tx2783 and ATx399*RTx430 was 7809, 7708, 6517, 6178 and 6142 kg/ha, respectively. Fourteen hybrids with grain yield ranging from 6546 to 8081 produced more grain than the test mean of 6532 kg/ha and test weight mean was similar to that of the checks. All of pollinators are tan plant with either red or white grain. Most of the experimental hybrids were taller than the standard checks. Additional research and evaluation is needed to ensure the hybrids are not too tall for use in the U.S.

Yield trial 3 (53 entries) tested the combining ability of elite pollinators as tan plant hybrid parents on ATx631 (Table 3). ATx631 is a common public A-line. Grain yield of the checks ATx399*RTx430, ATx399*Tx2737, ATx631*Tx2783, ATx631*Tx2952 and ATx631*Tx2737 was 7962, 7465, 7216, 6969, and 6858 kg/ha. Test mean was 6505 kg/ha. Although an experimental hybrid was not the top yielding hybrid, nineteen hybrids with grain yield ranging from 6567 to 7605 produced more grain than the test mean. Test weight was similar to that of the checks. The pollinators were also used in yield trial #2 and several produced hybrids with excellent grain yield indicating excellent combining ability. The experimental hybrids were generally taller and later than the check. This results from selecting lines slightly taller and later than commonly used lines. Additional research is needed to ensure the hybrids are not too tall for use in the U.S.

Research continued to develop sweet sorghums with improved adaptation to semi-arid production systems. Selections were made in the F3 and F4 generations. Based on previous research crosses were made to produce segregating populations with better adaptation. Selections were made to incorporate the brown midrib trait into both sweet sorghum and three dwarf grain lines.

Research with the TAMU Cereal Quality Laboratory continued to study the flavonones eriodictyol and naringenin in lemon yellow grain. The compounds have potential benefit as nutracueticals in sorghum. Selections with the pedigree of B.HF14*B8PR1011 are potential A-lines for hybrid production and are entered in the sterilization nursery. Selections were made in new additional segregating populations to for lemon yellow grain color and better agronomic traits. Experiments were initiated to study the accumulation of the flavonones.

Interest in using sorghum for brewing and malting is increasing. The southern Africa cultivar ‘Barnard Red’ was crossed to elite adapted cultivars (Macia and Kuyuma) to develop populations to select for enhanced levels of brewing and malting quality in elite adapted cultivars. The populations will also be used for potential graduate student research. Two additional cultivars, ICSV400 and ICSV111, were obtained and sent to the Puerto Rico winter nursery to develop populations for selection and research.

Lloyd Mbulwe with the Zambia sorghum and millet improvement program completed a 6 week training program at Texas A&M University. Mr. Mbulwe participated in sorghum breeding activities at College Station, Corpus Christi and Lubbock. Activities in the field and laboratory were included in the program. The expectation is that Mr. Mbulwe will return to Texas A&M University for a PhD program if INTSORMIL is renewed for 5-years.

A Puerto Rico winter sorghum nursery contributed to research progress. The nursery was 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.

Achievement of Activities Proposed in Work Plan

Activities proposed in the Work Plan were 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,

Table 3. Grain yield and other agronomic characteristics of tan plant hybrids grown at Lubbock, TX 2009.

HYBRID	Plant color†	Grain color‡	Grain yield	Test weight	Days to 50% anthesis	Plant height	Panicle exsertion	Uniformity§	Leaf and plant death	Desirability¶
			kg/ha			cm	cm		%	
ATx399*RTx430	P	R,YE	7962	58.8	68	127	15	1	30	2.3
ATx631*04BRON262	T	W	7605	60.8	65	150	13	1	43	2.0
ATx631*06BRON289	T	W	7514	61.6	63	147	18	2	30	2.0
ATx399*Tx2737	P	R,YE	7465	60.4	69	114	10	1	30	2.2
ATx631*03BRON172	T	R	7343	61.6	65	163	18	1	40	2.2
ATx631*06BRON294	T	W	7254	61.6	66	142	10	1	33	2.3
ATx631*Tx2783	P	R	7216	62.3	69	163	8	1	40	2.0
ATx631*05BRON289	T	W	7147	61.9	66	147	13	1	47	2.1
ATx631*04BRON273	T	W	6982	59.3	69	155	13	1	33	2.1
ATx631*Tx2952	T	R	6959	63.6	69	155	13	1	47	2.1
ATx631*04BRON271	T	R	6939	61.7	68	142	20	1	37	2.3
ATx631*Tx2951	T	W	6910	62.2	69	147	5	1	37	2.1
ATx631*Tx2737	RP	W,YE	6858	60.8	69	152	8	1	37	2.2
ATx631*04BRON254	T	R	6839	61.9	66	147	8	1	37	2.1
ATx631*06BRON297	T	W	6828	61.7	68	163	10	1	47	2.1
ATx631*02BRON166	T	W	6812	61.9	66	140	13	1	30	2.1
ATx631*04BRON267	T	R	6795	60.8	66	160	10	1	30	2.2
ATx631*04BRON291	T	R	6759	62.0	69	142	13	2	43	1.9
ATx631*Tx2957	T	W	6745	60.9	69	140	10	1	50	2.1
ATx631*R88B928	T	W	6612	58.2	68	122	8	1	40	2.3
ATx631*07BRON285	T	DR	6608	55.1	69	155	5	1	33	2.0
ATx631*05BRON296	T	W	6604	62.6	67	157	10	3	40	2.5
ATx631*06BRON277	T	R	6587	63.4	69	193	5	3	47	2.0
ATx631*05BRON298	T	W	6567	60.8	63	163	13	2	23	2.1
ATx631*06BRON287	T	R	6478	61.7	68	145	15	1	53	2.2
ATx631*Tx2947	T	W	6477	61.9	68	137	5	1	40	2.2
ATx631*04BRON259	T	R	6426	61.6	69	150	15	1	27	2.0
ATx631*Tx2946	T	R	6392	61.5	69	140	10	1	40	2.2
ATx631*05BRON299	T	W	6373	61.8	69	152	13	1	47	2.2
ATx2752*Tx2783	P	R	6362	63.4	69	142	5	1	67	2.6
ATx631*02BRON173	T	W	6348	60.9	69	132	13	1	50	2.3
ATx631*05BRON285	T	W	6339	61.4	68	150	13	1	40	2.1
ATx631*07BRON267	T	R	6310	62.6	68	160	15	2	40	2.3
ATx631*Tx2948	T	R	6307	61.6	69	147	13	1	33	2.2

Table 3. – cont'd Grain yield and other agronomic characteristics of tan plant hybrids grown at Lubbock, TX 2009.

HYBRID	Plant color†	Grain color‡	Grain yield	Test weight	Days to 50% anthesis	Plant height	Panicle exsertion	Uniformity§	Leaf and plant death	Desirability¶
			kg/ha			cm	cm		%	
ATx631*07BRON257	T	W	6251	61.9	68	157	13	2	40	2.1
ATx631*04BRON275	T	R	6243	62.9	68	163	15	1	53	2.2
ATx631*Tx2954	T	R	6202	62.5	68	145	10	2	30	2.1
ATx631*07BRON264	T	W	6176	63.3	69	190	15	2	40	2.0
ATx631*06BRON274	T	W	6071	61.7	68	142	10	1	43	2.2
A.DLO357*BE2668	P	DR	6003	62.3	69	124	8	1	33	2.1
ATx631*06BRON293	T	R	5984	61.7	64	140	18	1	37	2.3
ATx631*Tx2956	T	W	5938	61.6	69	132	10	1	33	2.3
ATx631*04BRON258	T	R	5935	61.2	65	147	15	1	27	2.4
ATx631*05BRON279	T	R	5893	60.9	68	130	10	1	50	2.3
ATx631*05BRON290	T	R	5850	61.6	66	142	10	1	43	2.1
ATx631*07BRON266	T	R	5833	62.6	69	175	8	3	57	2.0
ATx631*05BRON300	T	R	5768	62.1	63	160	13	2	43	2.2
A8PR1059*LG35	T	R	5710	61.5	69	130	5	1	33	2.2
A8PR1059*6OB143	T	R	5592	60.8	69	122	3	1	37	2.2
ATx631*05BRON280	T	W	5457	60.8	66	145	13	2	37	2.3
ATx631*06BRON279	T	W	5158	62.0	65	180	13	2	53	2.1
MEAN			6505							
LSD.05			1271							
CV			14.4							

†P=purple, T=tan.
‡R=red, DR=dark red, W=white, YE=yellow endosperm.
§Rated on a scale of 1=uniformity to 5=no uniformity.
¶Rated on a scale of 1=most desirable to 5=not desirable.

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; evaluate forage and sweet sorghum populations for adaptation to a semi-aired production system; provide seed of lemon yellow grain lines for analysis.

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; participate in graduate training for regional breeders as appropriate.

Networking Activities

Participated in the Sorghum/Millet Germplasm Committee meeting, ATSA Corn and Sorghum Research Conference, December 10, 2009, Chicago, IL.

Participated in the Texas Seed Trade Association Production and Research Conference, February 8-9, 2010, Dallas, TX

Participated in the INTSORMIL Technical Advisory Committee meeting, July 26-27, 2010, Lincoln, NE.

Participated in the SICNA/Great Plains Sorghum Conference August 11-12, 2009, Mead, NE.

Zambia and South Africa, November 7-21, 2009. In Zambia met with host country regional collaborator to discuss status of the regional program and interview potential short-term and graduate student candidates. In South Africa, met with University of the Free State collaborator to discuss status of research, plan future research, and interview a potential graduate student. In Johannesburg, met with representatives of SABMiller Brewing Company to discuss possible collaboration in developing sorghums for improved brewing and malting quality. In Pretoria, outlined a potential program to develop sorghums for improved brewing and malting quality. In Cape Town, met with Medical Research Council collaborators to discuss status of research and plan future collaborative research activity.

Botswana, Mozambique, South Africa and Zambia, February 27 – March 14, 2010. In Botswana, met with Botswana College of Agriculture entomology collaborator to review status of the research activity. In Mozambique met with breeding collaborator to evaluate development of his research program and evaluation of germplasm selected from Texas developed populations. In South Africa, met with University of the Free State collaborator to discuss graduate training and evaluate sugarcane aphid resistant germplasm for disease resistance at Cedara. In Zambia met with collaborators from the Zambia Agricultural Research Institute and reviewed status of the regional program.

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

Publications and Presentations

Wu, X., B. Jampala, A. Robbins, D. Hays, S. Yan, F. Xu, W. Rooney, G. Peterson, Y. Shi and D. Wang. 2010. Ethanol fermentation performance of grain sorghums (Sorghum bicolor) with modified endosperm matrices. J. Agric. and Food Chemistry: 58:9556-9562.

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 (in review).

Pendleton, M.W., B.B. Pendleton, E.A. Ellis, G.C. Peterson, F.M. Chitio and S. Vyahare. 2010. Using scanning electron microscopy to relate the arrangement of starch in sorghum grain with resistance to maize weevil (Coleoptera:Curculionidae). In Proc. Of the 2010 Great Plains Sorghum Conference & 27th Biennial Sorghum Research and Utilization Conference. Meade, NE. Aug. 11-12, 2010.

Crop Utilization and Marketing

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

Projects KSU 102
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Introduction and Justification

Throughout human history, as economies have grown and people have experienced greater wealth, consumption of animal products has increased. Poultry production is particularly well suited to a rapidly growing demand for animal products because of relatively low expenditures for facilities, equipment, and land area to enter into the industry. Additionally, the short production cycle (less than two months of age at slaughter for a broiler vs six months for a pig vs 18 months for a feedlot steer) and extreme efficiency of growth (feed to gain ratios of 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 West Africa.

Our overall strategy for this project has been to assemble a team of U.S. and host country collaborators to focus on educational and promotional programs to ensure expanded use of sorghum as animal feed. Research activities to ensure improvements in sorghum grain quality 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/production. Specifically for the 2009-2010 fiscal year, we coordinated a Poultry Road Show to disseminate data from a truly regional project involving a common protocol replicated in Senegal, Mali, Burkina Faso, Niger, and Nigeria. The objective of this project was to compare maize to locally produced sorghum grain that had been properly milled and, of equal importance, to develop a network of collaborating poultry scientists in this part of the world. Salissou Issa (former Ph.D. student at Kansas State and now Animal Production Specialist with INRAN) spent the spring of 2010 in West Africa organizing our Road Show. We originally had planned that this activity be only a Poultry Field Day to be held in Niger. However, we expanded the project to include bringing all of our collaborators to Ouagadougou, having a day-long seminar there and then transferring all of our collaborators to Niamey for a second day-long seminar. We had 40 to 50 key poultry producers at each of these seminars. This project, served as the core activities for the successfully completed Ph.D. program of Salissou Issa (of Niger). Additional accomplishments for this INTSORMIL project during the 2009-2010 fiscal year included numerous presentations by three students at professional meetings in West Africa, Iowa and Denver and lectures by Dr. Hancock in West Africa, Mexico, Chicago, Houston, and Kansas.

Objectives and Implementation Sites

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

1. We were able to work with plant breeders (e.g., Clara, Vargas, 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 conducted in Kansas and possibly Central America during the next fiscal year.
2. The input of cereal chemists (e.g., Ndoye, Nkama, Rooney, and Bean) in West Africa, Texas, and USDA/Kansas were used to identify seed characteristics (endosperm type/texture/chemistry, tannin type and concentration, and molds/mycotoxins) deemed of value for the sorghums fed to broiler chicks in West Africa, Central America, and Kansas during the next fiscal year.
3. The expertise of economists (e.g., Ouendeba and Sanders) in West Africa and Indiana was solicited to facilitate discussion of economic constraints on the poultry industry in West Africa.
4. Collaboration with grain scientists (e.g., McKinney and Behnke) in the Feed Science Program at Kansas State University was used to establish best manufacturing practices for diets used in our experiments in West Africa, Nicaragua, and Kansas during the next fiscal year.
5. Interaction with animal nutritionists (e.g., Issa, Traore, Hien, Sangare, Missohou, Rios, and Campabadahl) in West Africa, Central America, and Kansas was essential to diet formulation strategies and conduct of our chick-feeding experiments. Additionally, Issa, Traore, Hien, Sangare, Missohou, and Nkama served as experts in animal agriculture for their respective countries in a Poultry Road Show held in Burkina Faso and Niger.

Specific sites utilized for our 2009-2010 activities included EISMV in Senegal, CRRA in Mali, INERA and CIRDES is Burkina Faso, INRAN in Niger, Univ. of Maiduguri in Nigeria, UNA in Nicaragua, and of course, continuation of our research activities on campus at Kansas State University.

Research Methodology and Strategy

Active participation of host country scientists was a core component of our project during the 2009-2010 fiscal year. Collaborators form Senegal, Mali, Burkina Faso, Niger, and Nigeria finalized the common experiment used to address a region-wide concern among poultry producers as it relates to the use of sorghum grain. These same collaborator shared their experiences and expertise in our Poultry Road Show in May of 2010. At these same meetings each of these collaborators shared thoughts about plans for the "next step" for joint activities. As for the Americas, planning with Vargus (of AMPROSOR, the National Sorghum Producers Association of Nicaragua) and Rios (at UNA) was expanded to include a key scientist from Honduras in regard to our demonstration projects in Central America. Finally, at Kansas State, Scott Williams completed his M.S. degree and Chad Paulk continued in his research efforts as related to his graduate training.

Research Results

Specifically for the 2009-2010 fiscal year, Issa completed and published his dissertation most of which was the direct result of INTSORMIL activities in West Africa. These same data were shared, station-by-station with local poultry producers, by 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). This project involved some 2,000 birds at the 5 sites with a control diet that was corn-based with fishmeal, peanut meal, cotton seed meal, and soy bean meal as the primary protein supplements. Sorghum was used to replace the corn on a wt/wt basis so that treatments were corn- vs sorghum-based diets with the cereals ground through a 6.4 mm vs 2 mm screen. The birds were allowed to consume feed and water on an ad-libitum basis for 42 days with weights taken on day 0, 21, and 42. At the end of the experiment, 12 birds/pen were killed for carcass evaluation. Carcass measurements included weights of the live bird, carcass, gizzard, liver, mesenteric fat, and full/empty intestines. Additionally, gizzards were scored for lesions on a scale of 0 to 5. Results indicated that sorghum grain was an excellent feedstuff for growing birds and should be used to completely replace corn when economically feasible. This project served as the rationale for our Poultry Road Show during the summer of 2010. A key end-result of our Road Show was not only to assist key poultry producers in the use of sorghum, but also to "keep alive" the collaboration of activities among the team of West African poultry scientists that we have assembled.

As for Central America activities, the projects with our collaborators in Nicaragua (Rios and Vargas) were completed. This initiated additional planning and inclusion of yet another key scientist (Able Gernat) from this region of the Americas.

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. Our next steps will be to continue such research activities and emphasize transfer of our findings to livestock producers and feed manufacturers that will use the sorghum grain produced by crop farmers.

Networking Activities

Our networking activities continued to be extensive during the 2009-2010 fiscal year. The on-site supervision (by Issa) of our Poultry Road Show in West Africa resulted in the solidification of a core research team set to meet the need for information among West African poultry farmers. Additionally, our feeding experiments in Nicaragua resulted in the initial steps of forming an equal team of scientists, industry personnel, and sorghum farmers in El Salvador, Nicaragua, and Honduras. Hancock also was active in promoting sorghum with presentations and seminars given around the globe (e.g., West Africa, China, the U.S., and Canada).

Publications and Presentations

Hancock, J.D. 2010. Feed processing and ingredient selection to improve profitability in livestock production. Proc. USGC Southeast Asia Road Show, Jakarta, Ho Chi Minh City, and Hanoi.

Hancock, J.D. 2010. Sorghum grain as a feedstuff for livestock. Proc. USGC Export Exchange Conference, Chicago, IL.

Hancock, J.D. 2010. Sorghum grain as a feedstuff for livestock. USGC Southeast Asia Sorghum Team Seminar, Houston, TX.

Hancock, J.D. 2010. Feed processing and ingredient selection to improve profitability in livestock production. Proc. Bochoco Technical Seminar, Celaya, Mexico.

Hancock, J.D. 2010. Facts and myths about sorghum as an animal feed. Proc. INTSORMIL Poultry Project Road Show, Ouagadougou, Niamey, and Maiduguri.

Hancock, J.D. 2010. Feed processing factors that affect production: 1) Grinding and mixing of ingredients to produce quality feeds for pigs; 2) Thermal processing technologies to produce quality feeds for pigs; 3) The role of feed and feed processing in development of gastric ulcers. Proc. Manitoba Swine Seminar, Sharing Ideas and Information for Efficient Pork Production, Winnipeg, Manitoba.

Williams, S.M., J.D. Hancock, S. Issa, and T.L. Gugle. 2010. Effects of excess dietary protein from soybean meal and dried distillers grains with soluble in nursery pigs. J. Anim. Sci. 88 (E-Suppl. 3):93.

Williams, S.M., J.D. Hancock, S. Issa, C.B. Paulk, and T.L. Gugle. 2010. Effects of extruding DDGS at high and low temperatures on nutritional value of diets for nursery pigs. J. Anim. Sci. 88 (E-Suppl. 2):553.

Williams, S.M., C.B. Paulk, J.D. Hancock, S. Issa, and T.L. Gugle. 2010. Effects of feeding excess dietary crude protein from soybean meal and dried distillers grains with solubles on nursery pig performance. p 54. Kansas Agric. Exp. Sta. Rep. of Prog. No. 1038.

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

Project OSU 101
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Introduction and Justification

Improving the income and food security of small-scale sorghum and millet farmers in Zambia and Tanzania through the identification of new market opportunities and related constraints in the 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.

The major achievements in the past year were completion of the project activities as specified in the work plans for 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) completing a study and beginning a study of the improved seed value chain in Zambia and Tanzania, respectively; (4) continuing studies of food processing chain in Tanzania and beginning the same study in Zambia; (5) continuing the collection of monthly retail, wholesale and farm price information; (6) Joseph Mgaya from Tanzania completed his research on the feed concentrate industry and his M.S. degree at The OSU in June 2010; (7) Bernadette Chimai from Zambia completed her M.S. coursework at The OSU in 2009/10 and has returned to Zambia for her research analyzing the Luanshya farm household data; (8) Rebecca Lubinda from Zambia did not begin her PhD study in agricultural economics at the Regional Universities Forum for Capacity Building in Agriculture (RUFORUM) at Bunda College in Malawi. She was unable to begin in 2010 because of delays in the start of the program. We decided to no longer support this activity because we are in the last year of the current project. The funds will be re-allocated to support other project activities. The project supported two M.S. students in agricultural economics at SUA and two senior research projects at UNZA.

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 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 and linkages to new markets. (Picture 1)

Picture 1. Don Larson, Joseph Mgaya (M.S. degree recipient), and Mark Erbaugh

Objectives and Implementation Sites

The INTSORMIL overall approach is to increase food security and promote market development of sorghum and pearl millet. This is to 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 a means of increasing 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 Journal of Agricultural Economics and Development (JAED). We are awaiting word of acceptance from the editor of the University of Swaziland journal: UNISWA Research Journal (UREJ) for the Zambian adoption paper. Household surveys are currently being analyzed in high potential sorghum production areas in both countries. A conference paper proposal has also been submitted recently to the Association of International Agricultural and Extension Education, titled: Constraints on the Adoption of Improved Sorghum Seed in Tanzania: A Value Chain Approach.

Sorghum-based clear beer studies: In both countries we are examining the entire value chain for sorghum-based clear beer 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 assure 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. These studies are in progress.

Improved seed value chain studies: An improved seed value chain study has been completed in Zambia and a similar study will be completed in Tanzania early next year.

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.

Seasonal price variability studies: Many times farmers are 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. Data collection of the monthly price changes, costs of storage and household seasonal cash flows continued in 2010. Price analyses have begun to identify ways farmers can sell at higher prices in the post-harvest season.

Description of Interdisciplinary Team

This project is part of an INTSORMIL team of scientists from various disciplines that develop research and outreach program for sorghum, millet, and other grains. We maintain contact with several INTSORMIL researchers to identify opportunities for collaboration. The scientists include John Sanders (economist) at Purdue University, Gary Peterson, (plant breeding and Regional Program Coordinator for Southern Africa) at Texas A& M University, Charles Wortmann (soil scientist) and David Jackson (food scientist) at University of Nebraska, Gbisa Ejeta (plant breeding and Regional Program Coordinator for the Horn of Africa) at Purdue University, Medson Chisi (sorghum breeder) at the Golden Valley Research Station in Zambia; the sorghum research team at Ilonga Agricultural Research Institute, Kilosa, Tanzania; and the Entrepreneurship and Product Development Group at the University of Nebraska and Sokoine University of Agriculture, Tanzania. (Picture 2)

Picture 2. Tanzania Research Team: Fredy Kilima, Don Larson, Joseph Mgaya, Emmanuel Mbiha

Research Results: Tanzania

In Tanzania, the project activities for September 30, 2009 to September 29, 2010 were to: (1) To initiate a study of improved seed value chain, (2) To complete a study of the feed concentrate value chain, (3) To continue a study of fortified food value chain, (4) To continue with price data collection, which are needed to analyze seasonal variability of sorghum and millet in the project areas, and (5) complete study of sorghum based clear beer value chain.

Study of Improved Seed Value Chain

Ms. Salome Maseki, who is pursuing her M.Sc. in Agricultural Economics at Sokoine University of Agriculture, Department of Agricultural Economics and Agribusiness, is conducting this research. The title of her thesis is "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 is to identify value chain factors that affect the use of improved sorghum and millet seed in Singida region. She completed a survey with 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. Data collection was completed in 2010. She expects to complete her study in 2011.

Study on Feed Concentrate Value Chain

Mr. Joseph Mgaya, who is sponsored by the project, completed his M.Sc. in Agricultural Economics at The OSU in June 2010. He has completed a feed concentrate value chain study and selected results are presented here.

Maize production in semi arid regions is accompanied by the high risk of a poor harvest. The government has put forward initiatives to promote and improve production of drought tolerant crops such as sorghum and millet in these regions. Unfortunately, these efforts have shown poor results due to lack of developed commercial markets for these crops. The main objective of this research is 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.

One potential new market for sorghum and millet growers that is expected to grow rapidly in the future is the animal feed industry. The current size of the animal feed market in Tanzania is nearly 802,000 tons annually. There are more than 60 feed manufacturers in the country located mostly in Dar es Salaam, Arusha, Mwanza, Morogoro and Pwani regions. Most of these manufacturers under utilize their production capacity (about 50 % of capacity) due to low demand for animal feeds. Results show that 61% of surveyed feed manufacturers are medium scale producers (1001 to 10,000 tons per year), 21.7% are small scale feed manufacturers (up to 1,000 tons), and 17.4% are large scale feed manufacturers (10,001 to 40,000 tons).

As population and incomes grow, the demand for livestock products (such as meat, milk and eggs) will grow. Poultry producers are the largest user of animal feed followed by dairy producers. 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 7-10 percent or more in the future.

Feed industry stakeholders reported a willingness to use sorghum and millet in animal feed. The main constraints which hinder utilization of these crops in the industry are the tendency of animal feed stakeholders to prefer maize due to past experience, greater availability of maize, and maize price advantages in some regions. Feed industry stakeholders' level of knowledge of utilizing sorghum and millet in feed was indicated to be a major constraint. They have no proven formulations for these crops in animal feeds. To overcome these problems, stakeholders should be educated and encouraged to use these crops as substitutes.

Data from the Bank of Tanzania monthly economic report indicated that the national average wholesale price for maize in 2009 was 26.9% lower than the sorghum price. Dodoma, a major sorghum growing area, has monthly average prices of maize higher than sorghum prices except in January. The average price of maize in Dar es Salaam is observed to be 30.3% lower than the price of sorghum. Thus, increasing sorghum supply, productivity, educating feed manufacturers on proper rations, and more competitive prices are fundamental to expanding sorghum utilization in animal feeds.

Study of Fortified Food Value Chain

Freddy Kilima and Emmanuel Mbiha, SUA faculty and INTSORMIL collaborators, led the fortified food value chain study. The main objective of this study was to examine new market opportunities and supply chain constraints for sorghum and millet actors in the fortified food industry. The thrust is to increase food security and income among the actors through promoting fortification of sorghum and millet composite foods. The specific objectives were to: (i) identify actors in fortified food value chain; (ii) identify constraints to increased utilization of sorghum and millet in fortified foods; (iii) estimate prospect for increased utilization of sorghum and millet in fortified foods and; (iv) examine strategies to increase returns and reduce risks for farmers in the sorghum and millet value chain. To achieve these objectives, a survey was conducted in Arusha and Dar es Salaam which are major markets for sorghum and millet in Tanzania. In total, 11 sorghum and millet fortified food processors were interviewed. These processors were purposefully selected to accommodate variation in scales of operations. These interviews were conducted by field assistants and the project collaborators between June and early August, 2010. Preliminary results are presented below.

The concept of fortifying cereal flour has received overwhelming global support because it allows consumers in low income communities to derive important nutrients (vitamins and minerals) from locally available and inexpensive sources of carbohydrates such as sorghum and millet.

Despite many efforts, sorghum and millet yields and production remain stagnant and the utilization of these products in the industrial sector is very small. Poor utilization is an outcome attributable partially to past sorghum research efforts that have tended to focus mainly on agronomic and breeding aspects, while ignoring research on marketing and utilization. This research bias has contributed to the slow growth in demand for sorghum and millet products and maize continues to be the preferred staple for many Tanzanians, whereas sorghum and millet continue to be perceived as a "poor man's crop".

Strategies to reduce food insecurity and poverty among sorghum and millet farmers should go beyond improving production and address critical constraints related to new product development, marketing and utilization. The future prospects of farmers in drought prone areas of Tanzania will depend on improving the marketing of sorghum and millet. Thus, there is a need to promote the acceptance of these products in commercial channels, especially in urban areas where sorghum and millet meals compete with more popular foods such as maize, rice and wheat. This will require improving both the agronomic performance and other qualities of sorghum and millet products that affect market demand such as color, palatability, and nutritional content. Other value adding processes along the value chain such as fortified foods for specific groups such as people living with HIV/AIDS and weaning foods might also help to increase market demand.

The processing of sorghum and millet in Tanzania is divided into two groups: home-based processing and agro-industrial processing. Home based processing can be done by individuals or groups of individuals and it provides employment and generates income for many people, especially women. In Tanzania it is common to find women selling sorghum or millet porridge, local beer, non-alcoholic drinks from fermented products (e.g. "togwa") and other formulations of these products such as different blends of weaning foods. Actors belonging to this group are neither regulated nor taxed but they often succumb to marketing problems because they lack management and marketing skills. Consequently their market share is small and their products lack broad market appeal.

Agro-industries convert commodities into processed products which are more marketable than raw sorghum and millet grains. Processors are increasingly being monitored to ensure compliance with business laws and by-laws such as licensing, labor and tax requirements as well as food safety and environmental regulations. Many of these operations are capital intensive and use more skill and advanced technologies than do home-based processors.

Most commercial millers or food processing firms indicated an interest in producing fortified foods but they were uncertain of the fortification process, the nutrients that needed to be added and they lacked appropriate equipment and experience.

Assessment of in country capacity for food fortification revealed that there were many small hammer and plate mills in sorghum growing areas and major consumption centers. Processor's believed the market for fortified sorghum and millet products were good if appropriate technologies (e.g. batch mixing of fortificants) were identified and promoted. However, the focus should be on small to medium scale operations so as make full use of capacity and reduce the risk of a highly variable supply of grain.

A key to the development of the sorghum milling industry depends on the consistency of sorghum grain supply for commercial processing. The predominantly small scale production of sorghum and millet cannot guarantee adequate supply of high quality grain needed for commercial milling.

In principle grain quality encompasses aspects of seed productivity (genetic potential), production practices (agronomy) and post-harvest operations. Therefore efforts to promote fortification of sorghum and millet should identify a set of interrelated interventions to accelerate the adoption of improved seed that has improved vigor, are well adapted to semi-arid regions and have desirable tastes and milling qualities. Thus, interventions to alleviate nutrient deficiencies in sorghum and millet products, enhance product marketability and boost earnings for all actors along the value chain should embrace: Crop varieties with potential to increase nutrient content and availability in primary products; processes that enhance human nutrient intake through interventions in food processing, preparation and product diversification; agronomical interventions, which increase the content of nutrients in plants; and capacity building to support services and development of appropriate technologies.

Examine the Value Chain for Sorghum-Based Clear Beer

Jeremia Makindara, a faculty member and PhD candidate at SUA is 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 and are being tabulated. He expects to complete his PhD dissertation on this study by the end of this year.

The estimated size of the commercial sorghum market in Tanzania is shown in Table 1. The table shows that clear beer has become a major market for sorghum in relatively a short period of time, and likely will continue to grow rapidly.

The sorghum value chain in Tanzania starts with production carried out by smallholder farmers in semi arid regions such as Dodoma, Singida, Tabora, Morogoro, Shinyanga, Lindi and Mbeya. After production, sorghum is normally purchased by agents called brokers (alias Madalalis) at the village level or at village markets (Figure 1). The brokers bulk the produce until a reasonable amount is acquired for transport to urban markets or to the main traders who are located in urban or regional markets. From the regional markets, bulking continues and when a sufficient amount has been collected, it is then transported to major sorghum users such as Dar Brew in Dar es Salaam or other regional markets for sale to the final consumers as shown in Figure 1.

Increased opportunities for sorghum in the brewing industry is possible if more clear beer products have sorghum content, new products are developed, or sorghum beer producers adjust their marketing strategy. The long term sustainability of the value chain depends upon a number of factors including: potential demand of the buyers, consistent and high quality supplies from producers, adequate transportation and storage infrastructure, profitability for all chain members, trust and contract enforcement mechanisms.

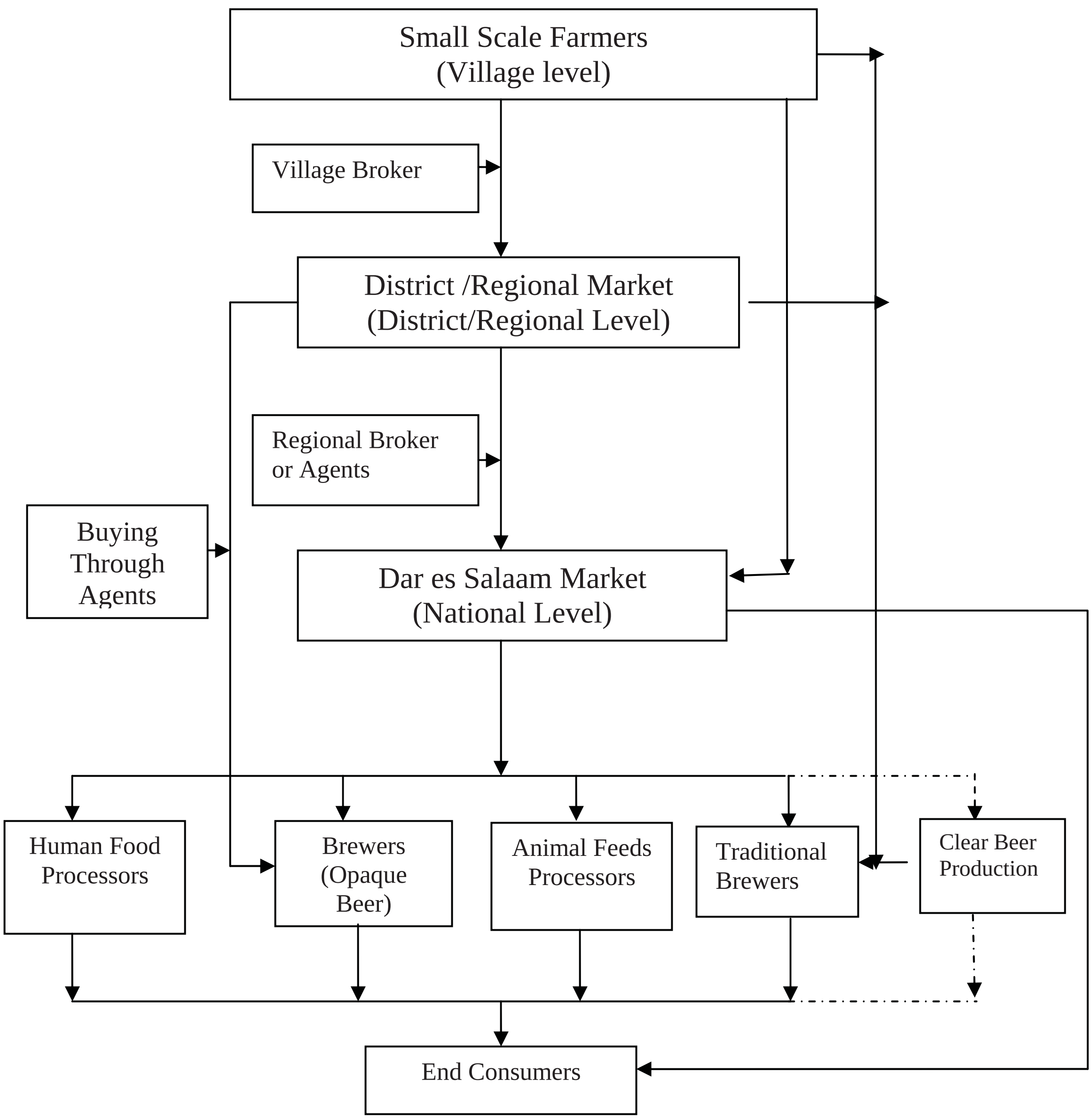
Table 1. Estimated Sorghum Demand by Major Buyers in Tanzania, 2008

Institution (Buyers)	Estimated Sorghum demand (tons) per year
DarBrew (Opaque beer)	800
Tanzania Breweries Ltd. (TBL) (clear beer)	1,040
Processed Foods (Power Foods)	600
Processed Foods (Nyirefamily Ltd.)	300
Fidahussein (Export)	<1,000
Animal Feeds	300
Strategic Grain Reserve (up to October 2006)	1,900
Small scale sorghum based weaning foods producers	
Estimated total demand	< 0.25
	5,940.25

Sources: Mbwaga, Riches, and Gebissa, 2006: Survey data, 2008.

Figure 1. Sorghum Value Chain in Tanzania

(The dotted lines show a potential sorghum value chain in clear beer brewing)



Continue the Collection of Information on Monthly Price Variability

The project is collecting monthly price data to assess seasonal variability of sorghum and millet prices over a four year period (2008-2011). This process has entailed Tanzanian collaborators at SUA developing a protocol to collect the following data: (a) Collect wholesale and retail prices for sorghum and millet in Dodoma and Singida (central Markets) and; (b) Collect farm gate prices in the main sorghum and millet producing regions.

The persons from the Department of Agricultural Economics and Agribusiness (DAEA) are contracted to:

- Collect data from the respective regions, twice every week, and to enter data in a standard form translated into Swahili
- Instructions for data collection are in user-friendly form and the lead consultants from DAEA provide instructions on how to fill the form
- Collect all forms by the end of the year.
- Select a student from Tanzania for M.S. study at The OSU

The project supported M.S. degree study at The OSU in agricultural economics for Joseph Mgaya, from Tanzania. He completed his graduate study in June of 2010. The OSU provided a cost share tuition award for this student.

Research Results: Zambia

In Zambia, the project activities for September 30, 2009 to September 29, 2010 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) select a student from Zambia for M.S. study at The OSU to beginning Autumn term 2009 and (6) select a student (Rebecca Lubinda) for the PhD program in agricultural economics located at Bunda College, Malawi. (Picture 3)

Picture 3. Zambia Research Team: Medson Chisi, Priscilla Hamukwala, Gelson Tembo, Mark Erbaugh

Complete Study of Improved Seed Value Chain

Priscilla Hamukwala, a UNZA faculty member and INTSORMIL collaborator, studied the improved seed value chain for sorghum, millet and maize in Zambia. The value chain has three interlinked components: (1) value chain actors, (2) enabling environment (policies and institutions and that shape the market environment), and (3) service providers (business services that support the value chain's operations). Both primary and secondary data were used in the study. Selected results of the sorghum and millet seed value chain study are reported here.

The main objective was to understand the characteristics, key roles, competitiveness, and constraints of key actors in the improved seed value chain and to identify factors that constrain the use of this technology. Information was collected from 130 farming households, 57 seed dealers, five seed companies, and two research and development institutions. Most seed value chain actors play multiple roles, ranging from varietal development, inspection and certification, seed production, processing, marketing, and provision of extension services.

The study found that farm yields of sorghum and millet are low (about 0.5 ton/ha) and have been stagnant for over 20 years. Maize yields are higher but more variable from year to year which increases the food security risk among smallholder households. Government of Zambia subsidies for fertilizer, seed (60 percent of the price to farmers) and price supports for maize growers have expanded the area planted to maize even in drought prone regions of the country where sorghum and millet are better suited.

The study found that adoption of improved seed and fertilizer was 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 every three years. Farmers reported using 'improved seed' varieties (for sorghum Kuyuma and Sima and for millet Lubasi) that were released in 1989 and 1993, respectively. No new varieties have been released since 1999. Farmers are not adopting the more recently developed improved seed varieties. Research station yields for sorghum 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 which is less than 10 percent of the research station yield. The gap between research station yields and farm yields is very large; there is 10 times more yield on the research station plots.

Farmer adoption of improved seed, fertilizer/manure, plus improved agronomic practices would increase yields and income two to three times more than present yields and incomes. This is a conservative estimate. The economic impact of adoption could be even higher depending upon the "gap' between research station yields and farm yields in various agro-ecological zones.

A critical constraint in the production of sorghum and millet seed is lack of breeder seed/ foundation seed by some seed companies. Originally, 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 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. The fact that the use of improved seed among the end users is very low represents a major constraint to private sector participation in the investment of developing new improved varieties in sorghum and millet.

Limited access to input markets, extension services, lack of desired varieties and processing technologies were some of the challenges that farming households reported as constraints. Despite new markets for sorghum in the brewing industry, and emerging markets in food processing and feed concentrates, farmers still view marketing as a challenge.

The study recommends initiatives to link farmers to markets through value chains that build and strengthen linkages between farmers and processors. Farmers can then be assured of reliable markets that want high quality grain, adequate quantities, and regular quantities at a reasonable price. Contracting, farmer associations, and out-grower schemes can build and strengthen these linkages. Stronger linkages between farmers and markets can create powerful incentives for farmers to adopt new technology that can increase productivity and incomes.

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 financing; to teach farmers and traders better business skills; provide feeder roads and marketing infrastructure; build storage facilities and link farmers to markets, finance and out-grower schemes.

Sorghum-Based Clear Beer Supply Chain Study

Bernadette Chimai and Gelson Tembo are revising and updating this report. The main activity that remains to be done is the estimation of future demand for Eagle lager. They intend to estimate the future demand based on sales/production forecasts based on trends in sales and production of the beer since its introduction in 2005. Sales data from Zambian Breweries in Lusaka has been difficult to obtain. They continue efforts to obtain better information.

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

A survey of sorghum and millet farmers in a high potential area was conducted in two blocks of Luanshya district north of Lusaka. Luanshya 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. Luanshya was selected after the researchers visited the Mumbwa area (the original high potential area selected) in June only to discover that very little sorghum was being grown there now. Maize is the major crop now grown in the Mumbwa area. The change to maize was due in part to large government subsidies (60%) for maize seed and fertilizers. In the Luanshya survey, 170 households were visited, and 169 interviews completed. Data entry and cleaning has been completed. A draft report titled "Sorghum and Millet Technologies in Luanshya District of Zambia" has been prepared. Table 2 shows grower cropping patterns, yields, and input use in the 2007/08 agricultural season. The percent of households using improved varieties, manure, and/or fertilizer was very low for sorghum and millet households. These data indicate the magnitude of the challenge to increase productivity among small holders. Chimai will continue analysis of this data set for her thesis research titled: "Determinants of Technical Efficiency in Smallholder Sorghum Farmers in Zambia."

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.

Table 2. Cropping pattern, land productivity and use of productivity-enhancing inputs, 2007/08 agricultural season, Luanshya, Zambia.

			% of households using…		
Land use or crop	**Mean area (ha)**	**Mean yield (kg/ha)**	**Improved varieties**	**Manure**	**Fertilizer**
	(1)	(2)	(4)	(5)	(6)
Maize	0.79	1,709	49.1	8.0	83.4
Sorghum	0.24	827	2.6	3.4	5.2
Millet	0.12	1,012	1.2	1.2	4.8
Groundnuts	0.12	2,144	2.5	2.5	3.8
Other field crops	0.23	-	1.0	1.0	2.9
Garden	0.05	-	75.8	51.5	84.8
Fallow or virgin	3.25	-	-	-	-

Source: Luanshya survey.

A final-year student in the Department of Agricultural Economics and Extension Education, University of Zambia, has been spearheading this study and is using it as her thesis project.

Select a Student from Zambia for M.S. Study at the OSU and for Ph.D. at Bunda College (Ruforum)

Bernadette Chimai, a recent UNZA graduate in agricultural economics, completed her MS coursework at The OSU 2009/10. Rebecca Lubinda, a faculty member in the Department of Agricultural Economics and Extension Education at UNZA, did not begin PhD studies at Bunda College due to program startup delays. Project support for her studies has been cancelled.

Networking Activities

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

Publications and Presentations

J. Mark Erbaugh, Donald W. Larson, Emmanuel R. Mbiha, Fredy T.M. Kilima, Gelson Tembo, and Priscilla Hamukwala. 2010. “Market Development in Support of Sorghum and Millet Farmers in Tanzania and Zambia.” INTSORMIL Annual Report 2009. INTSORMIL publication 09-01. USAID/INTSORMIL Grant. University of Nebraska. Lincoln, Nebraska. Pp. 77-86.

Gelson Tembo, Priscilla Hamukwala, Donald W. Larson, J. Mark Erbaugh, and Thomson H. Kalinda 2010. “Adoption of Improved Technologies by Smallholder Cereal Producers in Siavonga District of Zambia.” Revised paper prepared for USAID/INTSORMIL, University of Nebraska and The Ohio State University project. Columbus, Ohio. Revised and re-submitted to the University of Swaziland journal: UNISWA Research Journal (UREJ).

Fredy T. M. Kilima, Emanuel R. Mbiha, J. Mark Erbaugh and Donald W. Larson. 2010. “Adoption of Improved Agricultural Technologies by Smallholder Maize and Sorghum Farmers in Central Tanzania.” Revised paper prepared for USAID/INTSORMIL, University of Nebraska and The Ohio State University project. Columbus, Ohio. Forthcoming in the Journal of Agricultural Economics and Development (JAED). Sokoine University of Agriculture, Morogoro, Tanzania.

Priscilla Hamukwala, Gelson Tembo, Donald W. Larson, and J. Mark Erbaugh. 2010. “Sorghum and Pearl Millet Improved Seed Value Chains in Zambia: Challenges and Opportunities for Smallholder Farmers.” INTSORMIL Scientific publication. Posted at INTSORMIL.ORG.

J.M. Erbaugh, S. Maseki, F. Kilima and D. Larson. 2010. “Constraints on the Adoption of Improved Sorghum Seed in Tanzania: A Value Chain Approach.” Abstract submitted to the Association of International Agricultural Education and Extension.

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

Project PRF 102
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Lloyd Rooney, Professor, Texas A&M University, College Station, TX

Introduction and Justification

The overall goal of this project is to facilitate the development of markets for locally grown sorghum and millet, particularly in the urban areas of the Sahelian region of West Africa (Senegal, Mali, Burkina Faso, Niger and northern Nigeria). Our main focus is to conduct research on technologies for processing of high quality sorghum and millet products with extension to NARS food technology laboratories and models of transfer to entrepreneurs for product commercialization. Related to this, activities also focus on improvement of grain and flour properties (nutritionally-enhanced sorghum and method to make seed proteins functional in leavened bread systems) for improved utilization and competitiveness. We also work on other health-related aspects of these cereal grains that could be used in promotion campaigns for increasing consumption of local grains. These activities address a need in Africa to find other avenues for farmers to sell their grain and to receive premiums associated with industrial uses.

In the past year, the project has been active in four areas: 1) focused involvement in the USAID Mali mission-funded project "Transfer of Sorghum, Millet Production, Processing and Marketing Technologies in Mali", and activities with collaborators in Senegal, Burkina Faso, Niger, and Nigeria aimed to increase farmer's incomes through expanded markets, 2) incorporation of the high digestibility/high-lysine mutant sorghum in composite bread, 3) health aspects of West African thick porridges, and 4) investigating the role of sorghum phenolic compounds on promoting protein interactions that influence nutritional quality. During this period, the PI traveled four times to West Africa for a training workshop with entrepreneur partners in Mali with team members Y. Koreissi (IER scientist) and M. Diouf (consultant), to co-coordinate the West Africa all-PI regional meeting held in Burkina Faso, to a processing workshop coordinated by J. Sanders in Mali and meeting with A. N'Doye in Senegal, and a site visit to for the Mali Production-Marketing project.

In Mali, we have two activities associated with the "Transfer of Sorghum, Millet Production, Processing and Marketing Technologies in Mali" project funded through the USAID Mali Mission. In the Mopti/Gao area in the north, the project team works with seven entrepreneur partners (4 in Mopti/Sevarè, 1 in Bandiagara, 2 in Gao). For each processing unit, a grain decorticator and two mills have been installed in structures built to the specifications of the project. Partners have contributed the buildings and the project the equipment on a partial payback scheme. Workshops have been given to train technicians on cereal processing to produce quality products, equipment maintenance, and this last year on business management and markets. In the second part of the processing project, a training center is now constructed and is being outfitted to do applied research, training, and entrepreneur engagement with markets involving new processing techniques for secondary cereal products. The first workshop for Bamako area processors and our Mopti/Gao partners will be held in April 2011.

Work is continuing on the possibility of functionalizing sorghum grain proteins, kafirin, to contribute to dough strength and baked product quality. The objective of this study is to try to increase the amount of sorghum flour that can be used in composite flour products. With the rise in price of wheat over the last year, it would be of benefit if sorghum flour amount could be increased from the about 20% current maximum level to a higher level. This is based on previous work showing that isolated maize and sorghum storage proteins (zein and kafirin) can be made to participate in dough structures and bread making. In the last year, a rheological test was identified that shows that sorghum kafirin proteins in our high digestibility/high-lysine mutant sorghum flour clearly are participating in dough formation and its strength when mixed with wheat flour at 30 and 60% levels. This easy rheological test is now being used as a tool to optimize functioning of the protein. Our goal is to increase sorghum flour content while retaining good product quality, perhaps to the 35-40% level.

In the last year, a new project was initiated on healthy aspects of the African thick porridges. While it is somewhat intuitive and anecdotal evidence exists that the thick porridges are satiating and provide extended energy particularly for those living in villages and farming, this is not documented in the literature and could be used in promotion activities to increase consumption of sorghum and millet. M. Diarra, as a part of his doctoral studies under Prof. I. Nkama at University of Maiduguri, Nigeria, studied the Malian thick porridge tô using a survey questionnaire and a satiety scoring. Malian villagers, as expected, consume thick porridges more frequently than city dwellers and prefer thicker consistency thick porridges. When subjects were asked to consume to fullness very thick to, thick to, medium thick to, and a control rice porridge, the two thick porridges were clearly and significantly more satiating at 2 and 4 hour after consumption.

Finally, a M.S. thesis was completed at Purdue by J. Cholewinski, who was partially supported by the project, on factors in sorghum grain that promote protein polymerization during the cooking process. This goes back to studies in the 1980's and 1990's showing that sorghum protein digestibility is low due to disulfide-mediated polymerization that creates a difficult-to-digest polymer matrix that surround protein bodies, thus lowering overall protein digestibility. Later studies suggested that similar polymerization effect during cooking creates web-like structures that contain in part gelatinizing starch granules that may lower their digestion rate. High digestibility is desirable for nutritionally vulnerable populations who need full nutrition for the staples they consume, though low or slow starch digestibility may be desirable for some in Western countries. In this study, phenolic compounds were shown to be unique in sorghum flour that promote such polymerization, presumably through an oxidation-reduction mechanism. This could lead to a way through genetic approaches to manipulate macronutrient digestibility.

Objectives and Implementation Sites

Collaboration sites in West Africa are associated with exploring ways to expand sorghum and millet markets mainly through improving or developing new sorghum and millet-based products, and activities geared to assist entrepreneurs to process and sell market competitive products to urban consumers. 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 the Incubation Center at IER/Sotuba (Bamako) to bring new technologies and training to urban entrepreneurs in establishing 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 wheat-like properties of sorghum grain protein for high incorporation of sorghum (high digestibility/high lysine mutant lines) into baked products (mainly bread).

Explore "healthy" attributes of sorghum and millet foods that, through studies and documentation, can be used to promote their market expansion. Understand the role of sorghum and millet-based thick porridges in providing extended satiety and energy levels to consumers.

Understand the fundamental basis for the poor digestibility property of some sorghum foods for its manipulation.

Train two West African young scientists, one to the Ph.D. level (Malian, Mohamed Diarra at University of Maiduguri under advisement of Prof. Iro Nkama and B. Hamaker) and the other to the M.S. level (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, 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 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 can be used in promotion activities to expand markets for locally produced 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 recently has focused on development and market testing of a new technology developed by ITA to process couscous directly as grits. The product picture can be seen in the West Africa Regional program write-up in this report. Project beginning date – October 2007, ending date – September 2011.

Niger: Our long-term strategy has been to develop 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 has been on primary milled and secondary agglomerated products for urban markets. The unit is active in working with Niamey entrepreneurs and has been successful in assisting units to obtain loans for building successful private processing units. The technical training and support to entrepreneurs has been essential in this effort. Moustapha 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 2010.

Nigeria: Studies are funded through PRF-102 for a doctoral student, M. Diarra from Mali, with collaborator I. Nkama at the University of Maiduguri on millet processing. M. Diarra conducted a survey and satiety study on Malian thick porridges in Mali in 2010 and has a training scheduled 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 2011.

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 2011.

U.S.: 1) Investigations to find 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 expand markets for local grain production. Research funded by both INTSORMIL and a USDA grant focus on on improving non-wheat cereal storage protein functionality. Project beginning date – October 2007, ending date – September 2011. 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 – December 2011. 3) Continue to work with G. Ejeta toward further improving grain quality of high protein digestibility (and possibly wheat-like property) sorghum. Project beginning date – October 2007, ending date – September 2011.

Research Results

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

Processing

The project is using the "incubation center" concept in Niger and Mali to work with local entrepreneurs to facilitate competitive cereal processing enterprises to expand urban markets for sorghum and millet. In Niger, over time a processing center at INRAN/Niamey has been established and now, through the work of M. Moussa, works with many processor groups. The success of this project is seen in processors being trained in improved mechanized ways to process high quality sorghum and millet foods (milled and agglomerated products), their testing of products in the marketplace, and most importantly the beginning of the more successful units obtaining funds to mechanize their own units. The INRAN unit provides continual technical support which assists the entrepreneurs in their enterprises. A strong NARS processor association has made this technology transfer scheme function well. In Mali, through the Production-Marketing project funded through the USAID mission, the same incubator concept is being used to bring in new appropriate cereal processing technologies to Malian processors, and through training and technical support activities to strengthen the competitiveness of local entrepreneurs. Most notable, a new grit-based couscous processing technology, developed by collaborator A. N'Doye, Director General at ITA, is being transferred to Malian processors.

Satiety of Thick Porridges

A study was recently conducted to examine thick sorghum/millet consumption related to preference and satiation in the Sikasso, Segou and Mopti regions of Mali. This is part of a larger study to understand the effect of thick porridges, and delayed glucose delivery to the body, on satiety and overall food consumption.

The conclusions from the following data are that thick sorghum and millet porridges (tô) are generally eaten more frequently in the villages and are consumed in a thicker consistency (Figure 1), and are very satiating (thicker porridges correlated with lower hunger scores at 2 and 4 hours post-consumption) (Figure 2). Moreover, subjects, who were told to consume the porridges until they felt full, consumed more dry matter (flour) in the case of the thickest tô.

This data supports the concept that traditional thick porridges made from sorghum and millet are satiating and provide extended energy. Thus, a promotion campaign seems appropriate to state that sorghum and millet to is healthy food and should be consumed more in urban areas. Another study will be conducted in 2011 to more thoroughly compare sorghum and millet traditional foods to non-traditional foods prepared in urban areas from imported staples.

The satiety study was designed so that participants consumed as much tô as they wanted until they felt "full". Participants were asked at 2 and 4 hours after consumption to judge their feeling of hunger (0=full, 1=slightly hungry, 2=hungry, 3=very hungry). VTT=very thick tô, TT=thick tô, MTT=medium thick tô, CRP=control rice porridge. (Figure 3)

Sorghum/Wheat Composite Bread

We continue to work on the concept of functionalizing sorghum grain proteins, or kafirins, to make them viscoelastic and contribute to composite flour dough strength and baked product quality. Our goal is to substantially increase the amount of sorghum flour that can be used in composite flour products, thus leading to greater markets for sorghum farmers. Previously we showed that isolated maize and sorghum storage proteins (zein and kafirin) can be made to participate in dough structures and bread making, and last year found that sorghum kafirin proteins in high digestibility/high-lysine (HDHL) mutant sorghum flour, developed at Purdue, clearly participates in dough formation and improves its strength when mixed with wheat flour at 30 and 60% levels (Figure 4). This easy rheological test is now being used as a tool to optimize functioning of the protein. Our goal is to increase sorghum flour content while retaining good product quality, perhaps to the 35-40% level.

Sorghum Phenolics and Protein Digestibility

Previous studies showed that sorghum protein, as well as starch, digestibility of sorghum foods is generally lower than in other cereals. In our laboratory, we conducted many studies showing that proteins undergo sulfhydryl-disulfide interchange to make protein polymers that are hard to digest and further restrict access of proteases to the bulk of the kafirin storage proteins. Yet, it has not been clear why sorghum proteins behave this way. In this study, which was part of the M.S. thesis research of J. Cholewinski at Purdue, we showed that sorghum contains phenolic substances that promote the oxidation-driven disulfide bonded polymer formation (not shown) and that overall sorghum phenolics are more potent oxidants than the comparison grain, maize (Figure 5). This indicates that a specific sorghum phenolic compound or compounds is responsible for the process that creates the low protein, and related starch, digestibility problem. Further identification of this compound(s) will allow for a genetic approach to improve nu-

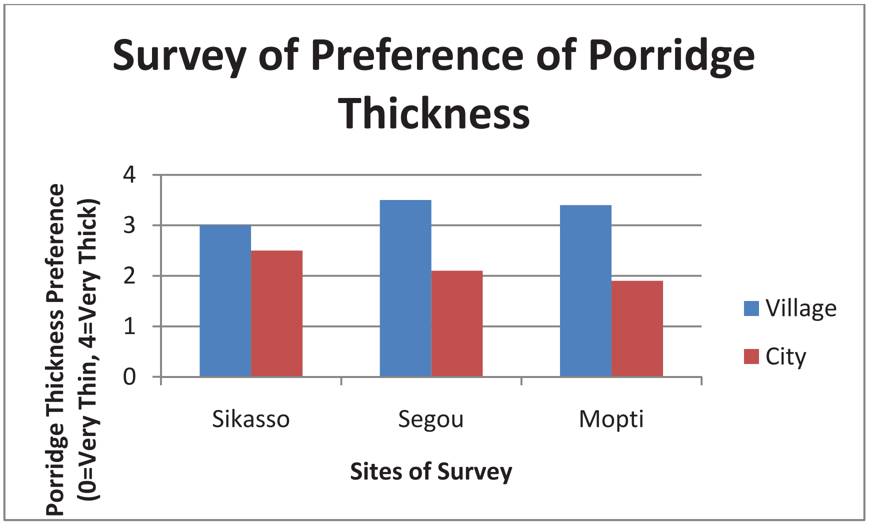

Figure 1. Villagers eat thicker tô than city dwellers, perhaps related to its satiating effect and extended energy property.

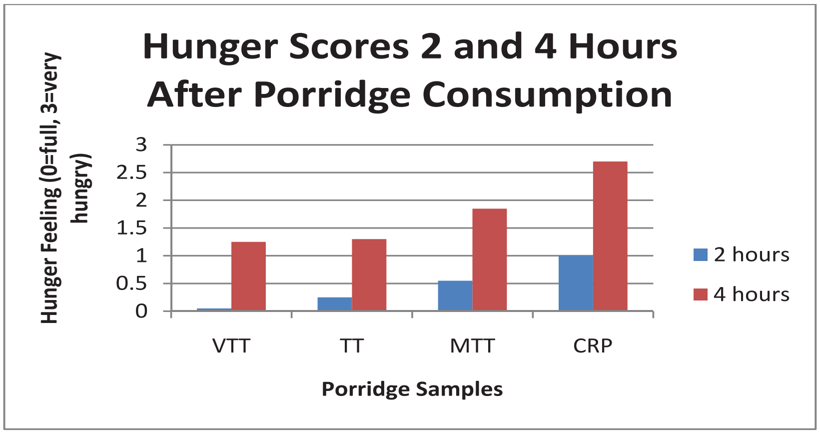

Figure 2. Satiety study participants revealed large differences in hunger feeling 2 and 4 hours after consumption of sorghum porridges of different thicknesses. Notably, participants still felt full 2 hours after eating very thick and thick tô, and after 4 hours only felt slightly hungry. After consuming the control rice porridge, at 4 hours participants felt very hungry.

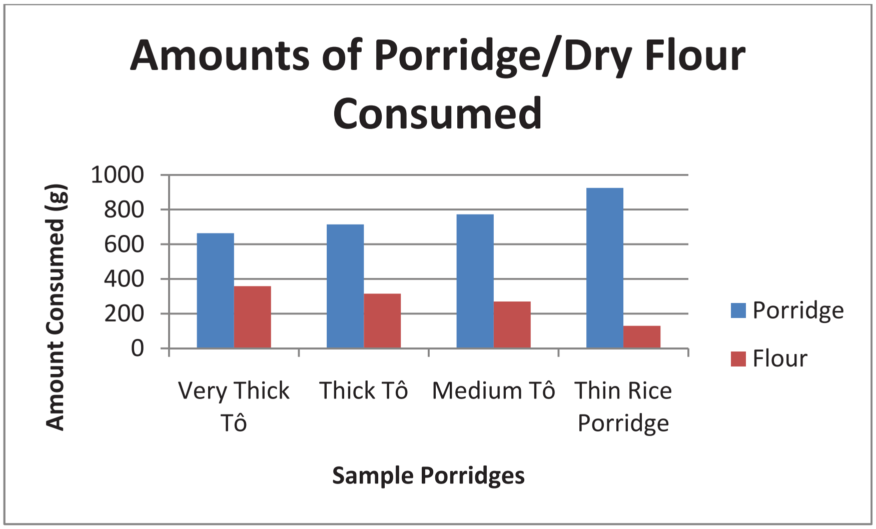

Figure 3. **Shows that while less volume of very thick porridge was required for participants to feel full (at time of consumption), they consumed more sorghum/millet flour.**

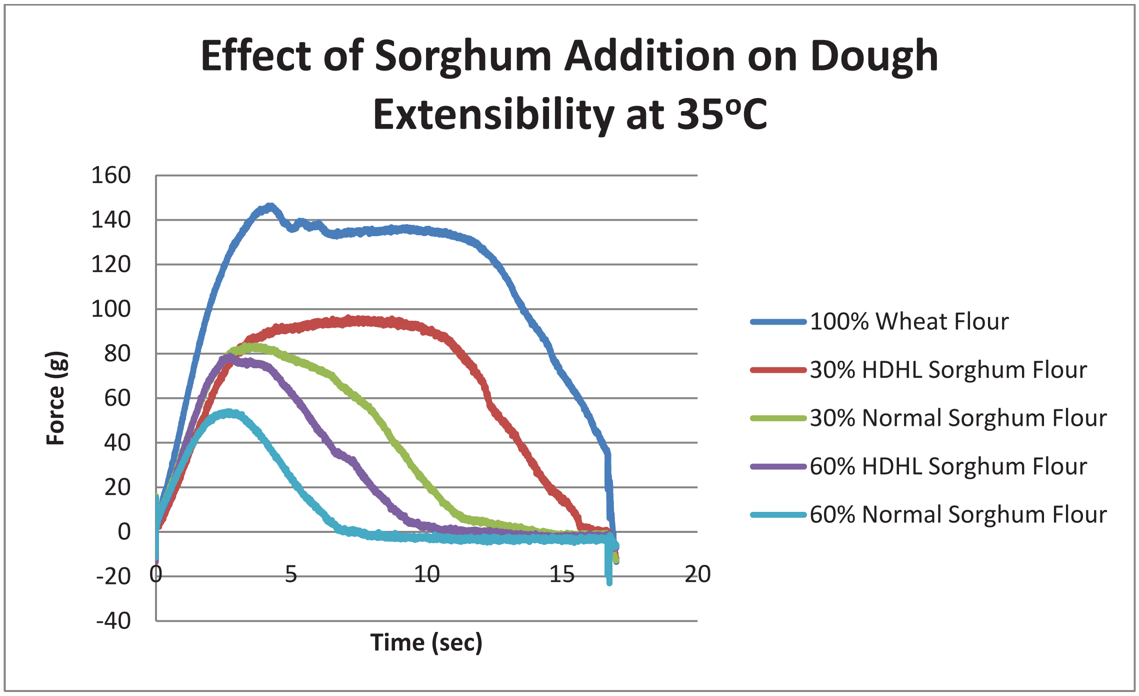

Figure 4. **Dough extensibility data of sorghum/wheat composite flours showing that proteins from the high digestibility/high-lysine (HDHL) sorghum mutant flour do participate in viscoelastic dough formation.**

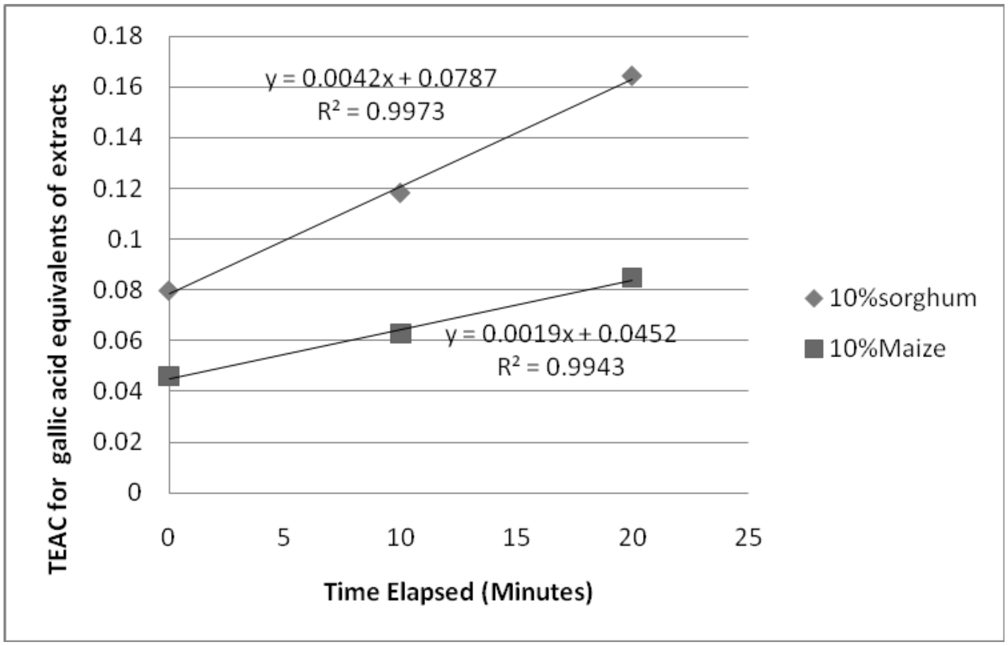

Figure 5. Oxidizing power of sorghum phenolics are shown here to be significantly higher compared to the same amount found in maize.

tritive properties of sorghum foods, and may give insight how to manipulated digestibility in other grains.

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

B. Hamaker made four trips to West Africa and one to South Africa in 2010: 1) two trips to Mali solely for Production-Marketing project work, 2) one additional trip to Mali to participate in a Bamako workshop organized by J. Sanders, 3) to organize with B. Pendleton and participate in the biennial West Africa Regional program workshop held in Ougadougou, Burkina Faso, and 4) to participate in the International Union of Food Scientists and Technologists biennial meeting held in Cape Town, South Africa.

Publications and Presentations

Journal Articles

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

Presentations

Moussa, M., Aboubacar, A., Saley, K., N'Doye, A., Hamaker, B.R. 2010. Use of an incubation concept to transfer cereal processing technologies to entrepreneurs in Niger. IUFoST biennial meeting, Cape Town, South Africa, August.

Hamaker, B.R. 2010. Technology transfer through incubation centers. Production-Marketing

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

Project PRF 103

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Introduction and Justification

In the 2010 crop year the major activity was the scaling up process in Mali for USAID-Mali. With the high yields for Grinkan (sorghum in Koutiala region) and the high prices for Toroniou (millet in the Segou region) in 2009, USAID-Mali asked IICEM (an activity of Abt consulting company) to become more directly involved in getting new sorghum and millet technologies out onto the farms. In 2010 IICEM, AMEDD and Global 2000 pushed for area expansion of the sorghum and millet technology package in the Koutiala and Segou regions. The goal was to increase the area in new technologies to 10,000 ha. Approximately 3,700 ha were put into new technologies with 1,800 ha in the greater Koutiala region.

The Production-Marketing project was asked to provide technical support to IICEM and their collaborative agencies involved in implementation, extension and monitoring. We worked with AMEDD (a regional NGO0 and the BNDA-national development bank) contacts and were intensively involved in training through our collaborator, Niabe Teme, from IER. We also continue to interact with IICEM on the strategies, supplies and back up for the scaling up. Since we have good working relationships with the implementers of the technology (AMEDD and Global 2000) this was a very satisfying activity to facilitate technology expansion without being directly responsible.

In lessons learned were developing relations with the BNDA for getting input credit for the farmers' associations, with which we were working, and some of the requirements for more effective training in project implementation. The big problem in moving from a pilot project to large scale expansion is the decreased management input that we can make as we move to larger scale. To the extent that training can be improved and systematized the difficulties in scaling up will be reduced.

We also continued our expansion of pilot project activity with Toroniou in the Mopti region.Besides the technical orientation we finance the pilot project activity. In 2009 we had 120 ha in the Mopti region. We expanded 300 ha in 2010 with four new sites and a doubling of area in Wollo. This expansion brings the total Mopti area in 2010 to 430 ha. Since the rainfall was very good here as in the rest of Mali farmers were happy and we had good yield results.

We tried to also extend our pilot project activity into the Kayes region but with our other activities were not able to do so. Kolokani on the edge of the Kayes region was continued. IICEM did attempt to expand activities in Kayes but the fertilizer could not be arranged. We will try to implement four new pilot project sites in Kayes in 2011.

Jeanne Coulibaly took over the evaluation of the 2008 project results, which are now being published. Felix Baquedano got major results from his thesis on the impacts of cotton and sorghum technologies on farmers' incomes in the cotton zone published.

Objectives and Implementation Sites

We had dual objectives in 2010. First we wanted to help IICEM extend as rapidly as possible the new sorghum and millet technologies into southern and central Mali, Koutiala and Segou regions. We had good pilot project results there and USAID-Mali was pushing for a scaling up of these activities. In Mopti, Segou and Kayes we also continued our pilot project activities.

Our objective with IICEM was to reach the maximum area and farmer participation possible. Two requirements were considered critical. First our pilot project would no longer be supplying the input credits so we had to get the banks involved. Negotiation with the banks was begun in each region. In Koutiala the BNDA wanted to make contracts directly with the farmers' association and to provide certificates with which farmers could then buy fertilizer from the fertilizer distributors. These certificates would then be cashed in at the bank. As this process was begun in the Koutiala area large quantities of subsidized fertilizer became available. There was a substantial price difference, CFA 13,500/sack as compared with CFA 15,000/sack for Urea and CFA 19,000/sack for DAP. All the farmers' organization except one then withdrew from the BNDA credit program and self financed their own fertilizer or got credit from the CMDT or the DRA, the two organizations providing the subsidized fertilizer.

There is discussion for 2011 of also making the subsidized fertilizer directly available to sorghum and millet producers. As long as the input credit is principally for inorganic fertilizers the availability of the subsidized fertilizer is going to be an important determinant of the demand for this credit. Once this question is resolved and farmers know how much they will need to pay for fertilizer, then more regular relationships with the banks can be established.

The second fundamental component of scaling up is organizing the training to substitute for the intensive management input during the pilot project stage. Substantial effort was put into this training in 2010 but there was not enough manpower in our and IICEM's program. So this input was very insufficient. As a result the farmers often planted on poor soils, did not do weeding, the fertilization was broadcast rather than side dressed and often the weeding was late. Much more effort needs to go into training in 2011.

On the pilot project there was a serious germination problem with Grinkan. This apparently resulted from the late season rains causing molds. Mold is always going to be a risk with the higher yield potential but more susceptible to late rains characteristics of caudatums[1]. Farmers indicated germination of around 60% and the necessity for substantial replanting and thinning. We need to do more germination testing and at least anticipate this problem. With the late rains even the Guineas suffered from the mold and consequent germination problem in 2010.

Farmers reported that the seed quality of Toroniou (millet for the Segou and the Mopti regions) was good. The rainfall was also excellent in 2010. So the seed quality problem was not an issue with Toroniou in 2010 as it had been in 2009. Millet yields were excellent in the Mopti region.

Research Methodology and Strategy

This project has become primarily an extension program to move technologies from the station onto farmers' fields. Accompanying these technologies are the introduction of marketing strategies to obtain higher prices for the farmers and to thereby insure that the technologies are profitable enough to support the increased input purchases and increased risks. Moreover, an essential project component is the development of farmers' cooperatives to implement the marketing strategies and to give the farmers' bargaining power in product sale and input purchases.

Once a high yielding cultivar with associated practices, that are highly profitable to the farmer, is identified the pilot project needs to scale up. To do this we identify other collaborative agencies to provide manpower, financing and bank contacts. In 2010 with the coordination of USAID-Mali IICEM took over the lead in pushing the technologies out. They developed contracts with extension oriented NGOs, AMEDD and Global 2000, and with the federal extension service, DRA. There were a series of efforts to get banks involved. Our role was to become a technical adviser.

1 Grinkan is a cross with 75% Caudatum and 25% Guinea.

Two research functions then become important. First, what does it take to shift from a pilot project to a rapid scaling up especially in establishing the ties to the credit institution? Input credit and then later inventory credit are very important for driving the program. Also expanded training needs to replace the intensive management input of the pilot project.

Secondly, as productivity and outputs are increased, the natural market evolution especially for feed and processed food products needs to be facilitated. In the last two years during the process of rapidly expanding the size of the pilot project, the market studies have been neglected.

Besides these two activities to facilitate scaling up we have our traditional research activities First there is an annual report on project performance with respect to farmers' yields, prices and incomes as compared with farmers outside of the project. There is a one year delay in this reporting as a fundamental component of the marketing strategy is for the farmers' association and the farmers to wait until the price recovers from its post harvest price collapse and then document the price advantages of being in the project.

The second component is the field research done on research questions as they become important in the field. In 2010 we had a serious seed germination problem. So we will need to pay more attention to the economics of seed production. We have been attempting to develop an incentive payment system for seed producers[2]. Another problem is developing better threshing systems. Both the threshing on canvas and the threshing machines introduced have had problems. Clean cereals are critical to getting a quality premium for farmers and for facilitating the more rapid expansion of the food processing industry. We need to facilitate this process by systematically keeping the grain off the ground and ascertaining why the threshing machines have been breaking down so often.

Research Results

Decline of cotton and the rise of the cereals in the south of Mali

In the last decade with the declining cotton prices, the increasing population pressure, and soil exhaustion cotton production has collapsed from almost 35,000 tons to below 10,000. Meanwhile both the maize and the millet areas have doubled. The increase of millet production is indicative of the increasing soil problems as millet is the least demanding of the three cereals for soil fertility and can go into the sandier, more marginal soils. In the last five years Koutiala farmers have been fertilizing the cereals more and the yield effects are clear. This is also consistent with the recent successes of Grinkan in the Koutiala region. Farmers are ready to use sufficient inputs on their cereals and they are paying more

2 For seed quality rouging of off- types is critical. Farmers have difficulty with this because it reduces yields and they have to uproot the taller plants they would normally select for seed. So price incentives for quality seed are essential.

attention to the agronomic recommendations. So in the scaling up process for sorghum in Koutiala we need to continue to assist the expansion of new markets. From the Malian perspective it is important to get back into international competition by introducing Bt cotton and obtaining the cost reductions made possible by the reduction in the number of sprayings. (Figure 1)

Evaluation of Production-MarketingProject of 2008-09[3]

In 2008 with good weather we had the first big success of Grinkan in Garasso (Koutiala region). For the 50 ha (approximately that many farmers) mean yields were 1.64 tons/ha (1.96 tons/ha by crop cut measurement). This was an estimated 488 kg/ha increase over traditional cultivars. With fertilizer prices high this was an increase of costs per ha of 61,200 CFA/ha[4]. Prices received were also increased from the harvest price of 85 CFA/kg to 115 CFA/kg. Besides the repayment to the farmers' association for the input credits farmers delegated all of the rest of the harvest to the association to sell for them. The benefits of the program are the value of the additional yield and the increased revenue from the higher prices. The quantity reimbursed was greater than the yield increase (532 kg v. 488 kg/ha). This paid for the inputs and made a profit for the farmers' association as they obtained this grain valued at the harvest price and sold it at 115 CFA/kg. The farmers increased profits were the remaining yield (1,642-532) times the price increase of 30 CFA/kg or 33,300 CFA/ha ($71/ha at an exchange rate of 470 CFA/$). It was amazing how well the farmers followed the agronomic recommendations as well as supporting their farmers' associations by letting them sell all their additional cereal. The forage production from Grinkan was also highly appreciated. (Figure 2 and 3)

In a nearby village of Kaniko with farmers planting on poor soils and not following the recommendations Grinkan yields were inferior to the traditional cultivars. This illustrates the importance of dedicating good sites and attention to these new cultivars. It also indicates the problem of scaling up. Moving to larger areas will depend upon excellent farmer orientation to the requirements of the technological package. Otherwise it will not be successful even in good rainfall years such as 2008.The price their association obtained of 132.5 CFA/kg was substantially better than that obtained by Garasso of 115. They were selling in June which makes it difficult to use the funds for the input credit for that crop year. Also they were in their third year of the project so they should understand sorghum markets better and Kaniko is on a main road close to Koutiala. Garassso is much further off the paved road and a longer distance from Koutiala.

Dioila is an interesting case where a strong association of cooperatives largely frustrated our marketing strategy and undermined farmers' incentives. This is unfortunate because many agencies have been working here hence there are good varieties and excellent storage facilities. Two improved cultivars were introduced. Soumba, an ICRISAT identified improved cultivar did well with yield gains ranging from minimal (28 kg/ha) to substantial (604 kg/ha). Natchtichama, an IER improved variety, was always inferior to the locals in the three villages planted. The cultivars arrived late for Dioila and the farmers did not follow the recommended practices and were especially neglectful with the weeding of Natchichama. The price at harvest was 85 CFA/kg and the farmers were paid 100 CFA/kg. ULPC, the union of farmers' cooperatives, sold the sorghum at 125 and 135 but did not share these profits with the farmers. The differences were kept by ULPC. These profits were utilized in 2008 to buy office furniture and association officials said that in 2009 they would be used to buy equipment. This is the type of centralized, paternalistic decision making that ends up stifling member incentives to undertake the improved, but labor intensive agronomy necessary to increase yields[5]. The second part of our program of introducing improved marketing practices is fundamental in order to increase the farmers' incentives to utilize the labor intensive agronomic practices necessary for higher yields.

In 2008 after three years of program operation Tingoni had graduated from our program with farmers following well the technology recommendations and operating their own storage facilities. With the revolving fund operated by their farmers' association, they maintained their own program. Along with Tchari in Senegal Tingoni was our most successful operation in millet. Mean yields were 1,211kg/ha (1138 by crop cut) on 150 ha with approximately 100 farmers. Rainfall was down in September and farmers attribute that to be the explanation for mean yields being less than 1.5 t/ha. Yield gains over traditional cultivars were modest, only 142 kg/ha. Input costs were high (CFA 61,800/ha) with three sacks of fertilizer being used. Rather than the CFA 100/kg harvest price the association let farmers repay at a price of CFA 121/kg. They repaid 500 kg/ha with 100% repayment. The cooperative then later sold these grain repayments at 128 CFA/kg. The individual farmers (with one ha of production) then sold 131 kg and consumed 580 kg. There is a preference for home consumption of Toronoiu over local cultivars due to the higher flour conversion. Valuing the home consumption at the same price as the sales and considering the value sold by farmers times the increased price gives an increased income from the project of CFA 20,377 ($43.30 at an exchange rate of 470 CFA/$). Tingoni has had a large effect in creating interest among farmers in the region and became the prototype model for the scaling up to 500 ha (eight new farmers' associations) of new millet technology in the Segou region in 2010.

The yields of Seguifa (sorghum) in Kolikani have been good, ranging from 1349 to 1553 in the three villages involved. This is an early caudatum and has had trouble with late rains leading to mold. Caudatums are more sensitive to molds because of the more compact heads than Guineas. The mold reduces yields and decreases germination. We need a longer season cultivar crossed with a Guinea to give some more tolerance to the mold problem and higher yields than an early cultivar. The yield gains in this good rainfall year ranged from 490 to 761 kg/ha. Table 1 indicates the utilization of the harvest in the three villages. 47% to 66% was

3 Note that we have to wait until the summer after the harvest to do this evaluation since the prices are an important component of the income effect of the program. The associations and farmers are encouraged to wait to sell until the price recovery. But the association has to sell before the next planting season as the loan repayments are designed to be a revolving fund to support input purchases especially fertilizer.

4 This included two sacks of 15-15-15 and one sack of Urea. After 2008 we changed the recommendation to one sack of DAP and one sack of Urea.

5 This includes thinning, replanting, and timely weeding.

Figure 1. Production and Area Planted of Cotton from 1998 to 2008 in Koutiala Source: CMDT, Koutiala. Data organized by Jeanne Coulibaly

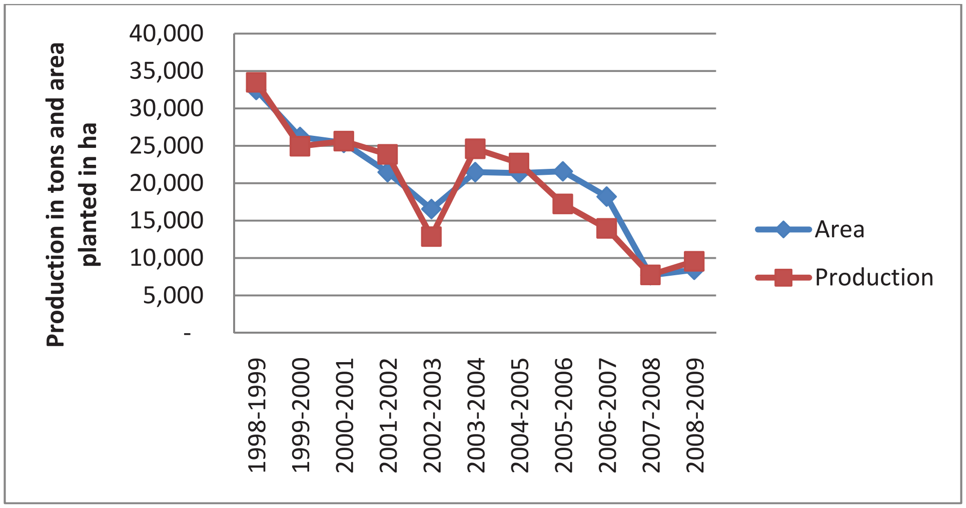

Figure 2. Area Planted for Sorghum, Millet and Maize in Koutiala region from 1998 to 2008 Source: Ministry of Agriculture. Data organized by Jeanne Coulibaly

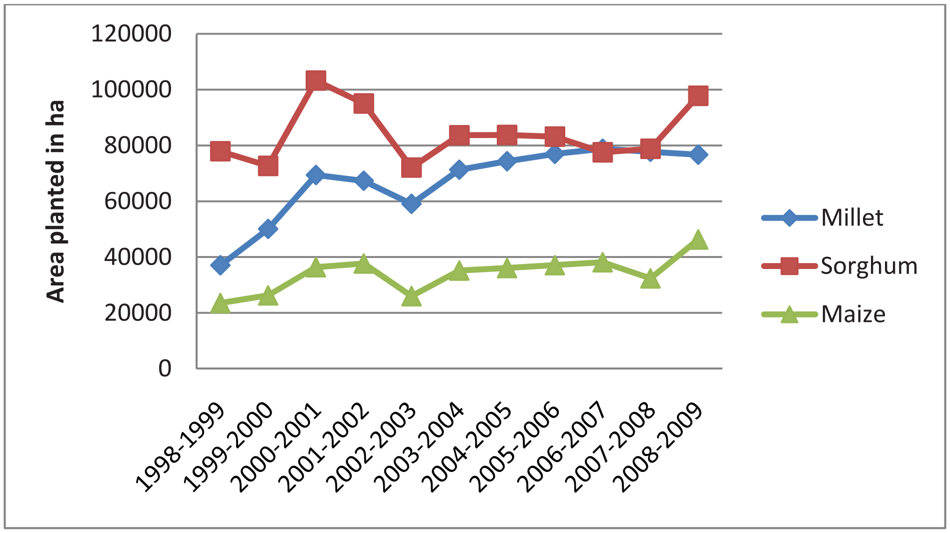

Figure 3. Yields of Millet, Sorghum and Maize in the Koutiala region from 1998 to 2008 Source: Ministry of Agriculture

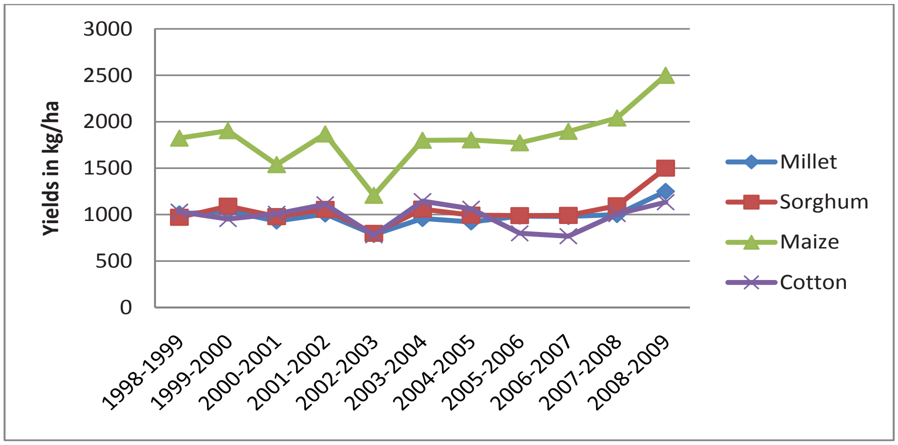

Table 1. Yields and Disposition of Sorghum in Kolokani in 2008

		Yield (kg/ha)	Quantity Repaid (kg)	Surplus Sold to Coop (kg)	Home Consumption (kg)
Tongoye	Mean	1350	520	200	630
	(%)		39%	15%	47%
Tioribougou	Mean	1548	489	142	917
	(%)		32%	9%	59%
Tienbougou	Mean	1553	358	166	1030
	(%)		23%	11%	66%

Source: Unpublished interview data of Jeanne Coulibaly

used for own consumption[6]. Seguifa is preferred in taste over the local cultivars so farmers prefer to keep Seguifa for own consumption and sell the local millets. 9 to 15% of the harvest was sold to the coop in addition to the repayment of the input credits. Farmers benefitted by an average gain of price of 50% from selling through the farmers' association.

Networking Activities

Farmer group training: As part of the Production-Marketing project Ouendeba, Sanders and Niaba Teme visited the farmers' associations in the project once before the crop season and three times during the crop season. The objective here is for the farmers and the farmers' association officials to understand well all the program components and for us to review performance over time. These repeated field visits are also useful to make sure that inputs arrive on time and that the agronomy recommendations are followed. During harvest time the visits reinforce the need for repayment of input credit, threshing on the "bache" to produce clean millet and selling later in the spring to avoid the post harvest price collapse.

Mini-Workshops. After the West African regional meetings in Burkina Faso in May short workshops were organized for intensive chicken producers and given by Joe Hancock and Botorou Ouendeba in both Ouagadougou, Burkina Faso and Niamey, Niger.

Publications and Presentations

Baquedano, F.C., J.H. Sanders, and J. Vitale, 2010. "Increasing Incomes of Malian Cotton Farmers: Is Elimination of U.S. Subsidies the Only Solution?" Agricultural Systems, 103: 418-432.

Coulibaly, Jeanne, 2010. Evaluation des technologias de Production et de Commercialisationdu Sorgho et du Mil dans le Cadre du Projet IER-INTSORMIL/Mali. Campagne Agricole 2008-2009.Bulletin IER-INTSORMIL No 10, Departement d'Economie Agricole, Universite de Purdue, West Lafayette, IN, 36 pages.

6 Small quantities of sorghum are sold locally on market days to finance other small purchases. Farmers consider this to be part of home consumption.

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

- 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.
- Improve the food and nutritional quality of sorghum to enhance its marketability and image as grains that promote healthy, wholesome convenience foods.
- 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 M.S. and Ph.D. programs.
- 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 M.S. 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 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. University of Pretoria has a strong program in food science and technology with significant numbers of graduate students from African countries.

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

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 phenolics.

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 tannin bran extracts with corn starches significantly reduced the EGI in porridges. Cooking starches with tannin sorghum extracts significantly decreased EGI and enhanced resistant starch because the tannins reacted with protein and other components in porridges.

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

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.

Interest in gluten-free breads and other baked products exists in Central America and elsewhere. The addition of sorghum milled fractions to produce foods containing high levels of antioxidants and other beneficial compounds will increase. We still need larger supplies of these sorghums, but the increasing demand will be met in the near future. Several companies have expressed interest in these materials with some new sources of supply under development.

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, although preference for sorghum use 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, presented several 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. The CTI information was critically important.

Large bakeries as well as small ones are utilizing sorghum composite flours for baked products. Some of them do not acknowledge its use. 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 have been reduced. 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 programs conducted each spring for an EAP student. They are provided training in cereal technology and related activities. This program has been active for several years.

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, M.S. 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 M.S. 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.

Gluten-free products using sorghum were developed and methods for baking were presented. Celiacs like sorghum for baked products because of its bland flavor, light color and low cost. Sorghum bran provides high levels of dietary fiber and antioxidants in gluten-free products. Sorghum tannin bran is a natural colorant with good flavor.

Sorghum brans added to wheat flour produced excellent, naturally dark-colored flour tortillas with improved nutritional values. Sorghum tannin bran blended with wheat flour made excellent baked products with enhanced levels of antioxidants and dietary fiber.

The Sorghum Checkoff Program sponsored a two-day conference on use of sorghum in healthy foods including gluten-free and high antioxidant products. Our lab was a major contributor to the program with four presentations on sorghum food and nutritional properties.

Training (Degree and Non-Degree)

Two M.S. degrees 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.

Ms. Constance Chiremba, Ph.D. student, University of Pretoria, spent 7 months working and auditing classes at Texas A&M University. She conducted analyses on sorghum from South Africa. She participated in IFT and sorghum food workshops plus cereal chemistry classes. She conducted research on hardness evaluation of sorghum and maize.

These "sandwich" degree programs reduce costs enabling education of more students while providing them exposure to US universities and related technologies.

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.

Short Courses: Ms. Pinilla assisted Ms. V. Calderon and Mr. K. Duville, CENTA, El Salvador in developing 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 is completing her M.S. thesis on analysis and testing of flours produced in El Salvador.

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, Ms. Arciniega-Castillo, from El Salvador who was a senior at Escuela Agricola Panamericana (EAP), Zamorano, Honduras. She participated in classes, short courses and assisted with research.

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.

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Abstracts

Asif, M., L.W. Rooney, M.N. Riaz, and C.A. Mack. 2010. Gluten-free breakfast cereals and snacks. Institute of Food Technologists Annual Meeting, July 17-20, Chicago, IL.

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Conference or Symposium Proceedings

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

Project UNL 102

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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 addresses 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, the team planned for and sought funding to host a Sorghum Food Business/Entrepreneurship Workshop in the region that will involve presentations by business and food professionals, participation in our sorghum entrepreneur workshop, and sharing of curricular materials designed for both farmers and processors. Participants and speakers are to be invited from the entire continent; U.S.-based INTSORMIL PIs involved in Food and Marketing projects would also be involved. 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 provide an M.S. education to another collaborator (from the Tanzania Food and Nutrition Center). 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 is 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 include the following.

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

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

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

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

These program objectives specifically address the overall CRSP objectives to "Facilitate the growth of rapidly expanding markets for sorghum and pearl millet," "Improve the food and nutritional quality of sorghum and pearl millet to enhance marketability and consumer health," and "Develop effective partnerships with national and international agencies engaged in the improvement of sorghum and pearl millet production and the betterment of people dependent on these crops for their livelihoods." Primary implementation sites are: 1) Tanzania, 2) Zambia, and 3) training for scientists in Nebraska.

Research Methodology and Strategy

Members of the interinstitutional, 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), and Food Scientists/Economists on staff at the University of Zambia (UNZA).

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

Participating processors/entrepreneurs were to be self-identified, but 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.

SUA, UNL and UNZA scientists were to identify a tentative locale for the regional workshop, and prepare a program and review budget needs by January 2010. Additional funding was to be sought through regional programs, NGOs, USAID, USDA and the Gates Foundation. A target date for the workshop was to be late in the INTSORMIL program's initial 5-year funding cycle.

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 will complete his degree on or before May 2011, and the Ph.D. student will complete her degree on or before December 2011.

Research Results

During the first year of the most recent two-year work plan, most of the activities as planned were achieved. Continued support to existing six processors in Dar es Salaam, Tanzania including business plan development was provided and a modest support program in Zambia was initiated. Four additional sorghum processors from Dar es Salaam were identified and visited, plus two processors in Lusaka, Zambia were identified for subsequent collaboration [CRSP Objectives 1 & 2].

Through the first-half of the budget year, >115 stakeholders including farmers / entrepreneurs / processors / interested parties received training and demonstrations on best practices for sorghum post-harvest handling and processing through workshops in Dar es Salaam, Morogoro, the Dodoma region and the Mpwapwa region. A significant number of the new and continuing stakeholders were women. Linkages and coordinated activities with district-level, national-level, and regional-level (African) professionals were established (e.g., assisting two processing groups in marketing at a well-recognized farmers' show in Dar es Salaam) [Project Objectives 1, 2, 3 and 4; CRSP Objectives 1, 2 and 7].

Planning and solicitation for external funding for a regional Sorghum Food Business workshop was undertaken. A decision was made to team with the INTSORMIL Southern Africa regional group and the National Institute for Scientific and Industrial Research (NISIR) of Zambia to hold a joint Sorghum Food Enterprise and Technology Development in Southern Africa Workshop in Lusaka, Zambia in December 2010. Over 60 attendees from the eastern and southern countries of Africa, Texas A&M University, The Ohio State University and UNL are expected to attend the workshop [Project Objectives 4 and 5; CRSP Objectives 1, 2 and 7].

Educational programs at UNL for 1 M.S. student (Onesmo Mella from Tanzania Food and Nutrition Center) and 1 Ph.D. student (Nyambe Mkandawire from UNZA) were continued. Onesmo has completed coursework requirements and is expected to complete his research and thesis portions of his M.S. degree program requirements by May 2011. Nyambe will soon sit for her comprehensive examination as part of her Ph.D. degree requirements with a target of completing all requirements for her degree by December 2011 [Project Objective 6; CRSP Objectives 1, 2 and 7].

No workshops specific to Zambia, similar to those held in Tanzania, were able to be held due to the lack of supporting funds for UNZA participants after they purchased of a decorticator and a hammermill. The two machines are anticipated to be used in subsequent training of Zambian stakeholders at UNZA.

Inconsistent record keeping and miscommunication resulted in incomplete records relative to participation by women in stakeholder training and workshops. Greater diligence in record keeping and reemphasis of need for such data collection is anticipated.

More clear understanding of clients/stakeholders assisted and value of assistance, quantified in terms of sorghum production, food products developed/sold, and income increases will come from the Sorghum Food Enterprise and Technology Development in Southern Africa Workshop to be held in December 2010 [Project Objectives 1, 2 and 3; CRSP Objectives 1 and 2]. 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 and Dr. Curtis Weller traveled to Tanzania and Zambia in May 2010. They arrived on May 2 at Sokoine University of Agriculture in Morogoro, Tanzania. There they had a chance to meet with various faculty members and administrators including local leader Dr. Joseph Mpagalile, tour the university, review progress on project activities and discuss topics and participants for the upcoming December workshop in Zambia. One and a half days were spent in Dar es Salaam visiting four sorghum processors including one women's group to visual state of the industry and the products available in the market place. Two days were spent in Zambia; one spent traveling to the Golden Valley region to see production areas and meet producers and extension educators with the other spent in Lusaka meeting with UNZA and ZARI researchers and educators including Mr. Bernard Moonga. One theme of the conversations in Zambia was the planning for upcoming December workshop. While in Zambia, Drs. Jackson and Weller also had a chance to meet with UNL students from the College of Journalism and Mass Communication who were in the area working on the Communications/Media Development Project for INTSORMIL. They departed from Lusaka on May 8.

Host Country Program Enhancement

Central America (El Salvador, Nicaragua)

William Rooney
Texas A&M University

Regional Coordinators

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Country Coordinators

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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. Reina Flor de Serrano, Plant Pathologist, CENTA, San Andres, El Salvador

Alfredo Alarcón, Agronomy, CENTA, San Andres, El Salvador

Edgard Ascencio, Agronomy, CENTA, San Andres, El Salvador

Margarita Alvarado, Food Scientist, CENTA, San Andres, El Salvador

Rodolfo Valdivia, Agronomist, INTA/CNIA, Managua, Nicaragua

Pascual López, Agronomist, INTA/CNIA, Managua, Nicaragua

Ing. Nury Gutiérrez, Plant Breeding/Agronomy, INTA/CNIA, Managua, Nicaragua

Ms. Eliette Palacio, Food Scientist, INTA/CNIA, Managua, Nicaragua

Dr. Lloyd W. Rooney, Dept. of Soil & Crop Sciences, Texas A&M University, College Station, Texas 77843-2474

Dr. Joe D. Hancock, Dept. of Agronomy, Kansas State University, Manhattan, Kansas,

Collaborative Program (Regional Program Description)

The regional programs of the INTSORMIL program are designed to support national research program efforts to develop dynamic, competent institutional research programs which contribute to productivity, economic growth, natural resource conservation and improved nutrition of people in the region. By accessing available expertise and infrastructure in the region, support from INTSORMIL is designed to facilitate and promote interaction between national programs, NGOs, international research centers, private sector and scientists from the U.S. land grant universities to achieve the goals of improving producitivity, profitability, economic growth and food security for producers and consumers as well. 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 2009-2010, 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.

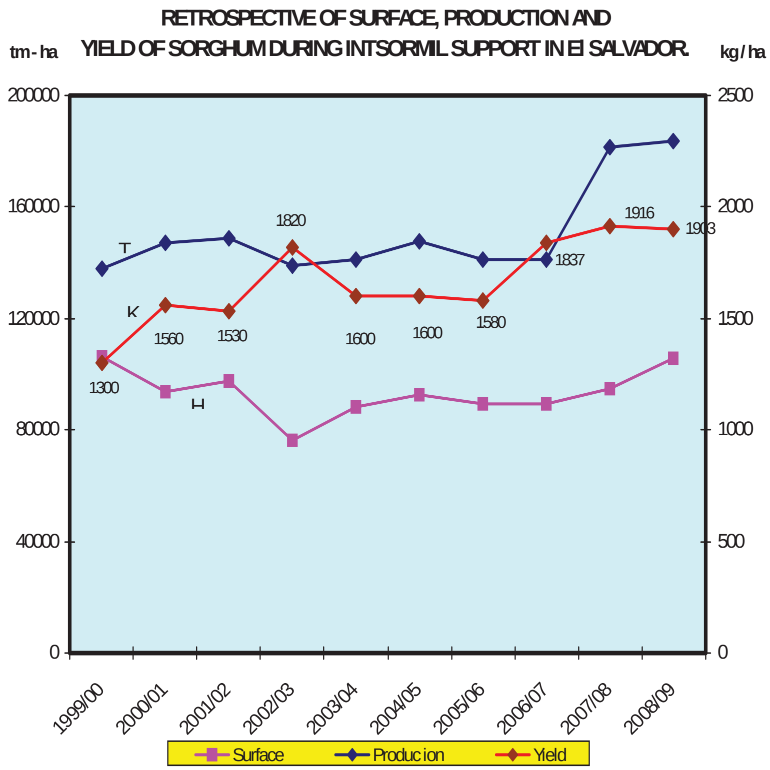
Small-scale Central American farmers are burdened with low productivity and limited land resources. Intercropping provides a means to increase total productivity per unit land area and reduce the risk of dependence on one crop. The dominant cropping system is maize intercropped with maicillos criollos (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 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 2009 (May – December 2009).

Figure 1.



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 nine locations were planted and grown throughout Central America. Due to drought in Nicaragua, data on eight locations was obtained. In El Salvador and Nicaragua, INTSORMIL collaborators conducted these PCCMCA trials. In 2009, the trial had 7 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. (Table 1)

Agronomy

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

Evaluation of two improved Macio-type photoperiod sensitive sorghums (varieties 99ZAM686-2 and 99ZAM911-3) was

Table 1. Results of the 2009 PCCMCA sorghum trial, combined across seven locations in Central America (tests were in Panama, Nicaragua, El Salvador and Guatamala).

	Híbridos	Flor (días)	Alt planta (cm)	Alt hoja (cm)	Excerción (cm)	Largo panoja (cm)	Pta/m2	Panoja/m2	Rend (t/ha)	Enf (1-5)	Unif (1-5)	Color grano
1	MSG 551	56	161	118	16.6	28.9	20.45	22.46	6.80	2.7	1.6	Rojo
2	MSG 540	61	168	127	17.4	28.6	19.48	24.29	6.38	2.5	1.5	Rojo
3	SR-450	60	143	94	19.0	31.1	16.08	21.84	6.33	1.2	1.3	Blanco
4	AMBAR (T)	59	155	117	14.5	26.2	21.29	23.75	5.67	2.2	1.5	Rojo
5	MSG 549	54	154	109	17.6	29.4	18.50	23.00	5.63	2.7	1.6	Rojo
6	83P-17	55	133	88	16.3	29.3	18.71	21.96	5.43	3.4	2.1	Rojo
7	SR-340	59	116	72	15.9	27.9	17.68	22.13	4.99	3.6	1.4	Rojo
	Promedio	58	147	104	16.8	28.8	18.88	22.77	5.89	2.6	1.6	
	DMS $_{0.05}$	1	5	4	1.7	1.3	1.59	2.77	0.40	0.3		
	C.V. (%)	3.4	6.6	10.5	13.6	7.1	19.1		10.3	20.6		

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

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

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

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

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

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

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

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

In May 2008 this seed was distributed to 900 producers (individual and cooperative) in the departments of Esteli, Madriz, Chinandega and Matagalpa. The producers will use this seed to plant between 13,000 to 43,000 manzanas in in association with maize. In addition, local extension will assist producers in using this seed effectively to produce the next crop, partition a quantity to use as seed and market the remaining as either seed or grain.

Grain Utilization – Food Use

Due to its wide distribution and acceptance, corn products are part of the daily diet and they are an appropriate vehicle to deliver micronutrients to the population. Unprocessed maize is a great source of vitamins, essential amino acids, iron and zinc, however since these nutrients are retained in the outer layers of the grain, losing a significant proportion during the process of nixtamalizado (removal of pericarp and loss of soluble solids during cooking). The Act requires the fortification of flour nixtamalizadas as an important to improve the nutritional situation of consumers and to restore nutrients lost during the process of developing strategy. Sorghum is an important source of protein, fiber, vitamins of the B complex, smaller elements as iron, manganese, zinc and antioxidants. The incorporation of sorghum/maize nixtamalized masa is importance to provide plenty of micronutrients, vitamins, fiber, protein, which restituiría part of the amount of micro-nutrients lost during the nixtamalization and would reduce the need to enrich these products with a greater amount of micronutrients and would increase the cost effectiveness of the process.

The work was carried out in the laboratory of food in the period from July 2009 to May 2010. The variety of corn used was the variety Platinum (biofortificado) and the variety of sorghum RCV. These varieties were processed under the traditional process of nixtamalizacion using calcium carbonate (CAL 1: 1). The nixtamalizacion and milling of both grain boiled corn mill, fresh masses were mixed in the proportions laid down (50% maíz-50 sorghum %) and then proceeded to assess its physico-chemical features such as particle size and nutritional content (FAT, protein, carbohydrates, crude fiber, minerals etc.) Variables evaluated during the maize and sorghum nixtamalizacion were the percentage of pericarp and loss of stock preparation (Brix)-soluble solids removal. Variables assessed mass were: size of particle mass, mass and nutritional content of fresh from each of the varieties and their mixtures mass color.

Table 2. Results of quality nutrition mass of maize and sorghum and both cereal mixtures.

Masa sample	Prot %	Fat	Raw fiber	CEN %	CARB %	CA mg / 100 g	Faith mg/100 g	Mg mg/100 g
Maize	9.7	4.52	0.42	1.26	82.88	0.07	0.37	0.13
Sorghum	8.71	3.18	1.92	1.14	82.23	0.08	0.48	0.18
Mixed	11.3	4.03	2.01	1.21	83.42	0.12	0.54	0.16

Preparation time was greater for corn than sorghum, due to several factors characteristic of grain corn, such as the thickness of the pericarp and the hardness of the endosperm (Table 2). More preparation time favored the loss of the stock preparation, also affect the content and quality of the nutrients in the corn masa.

The loss of soluble solids during the BREW of maize is greater than the loss of soluble solids for sorghum. This may be due to the type of endosperm, the thickness of the pericarp and the physical structure of the grain, as well as the time of preparation. Time of preparation in sorghum is much lower than the corn, avoiding lost more nutrients. The corn masa is higher in nutrients such as ash, fat, carbohydrate and protein, but sorghum is higher in dietary fiber, iron and magnesium. The nutritional content of mixing maize and sorghum dramatically increases in all of its components, so we recommend the addition of mass of sorghum maize for the manufacture of tortillas and other products.

Technology Transfer

Seed production of released varieties of sorghum (Sorghum bicolor L. Moench)

For the past three years, CENTA–INTSORMIL, in cooperation with the NGOs CARE, CARITAS and INTERVIDA, has been working to to improve small sorghum farmers' productivity (goal of 10%) and efficiency especially in the northeast of El Salvador. The project covered the departments located in the north including Chalatenango, Cabañas, Cuscatlán y San Vicente. These areas were selected because they have the lowest sorghum production levels. Additional emphasis was in La Libertad, La Paz, San Miguel, Usulután y la Unión. In these areas, artisanal sorghum seed of the varieties 85SCP805, Soberano, RCV, CENTA S-3 and Jocoro was distributed in the areas.

The project worked in three phases. First, technicians were trained so that they could train farmers in the process of sorghum seed production. Second, seed from improved varieties of sorghum were deistributed to small farmers trained in seed production. Concurrently, new varieties were produced in farms and at San Andres-CEDA experimental station.

This action was coordinated with basic grains technicians as well as with researchers from CENTA-INTSORMIL to provide training about artisan sorghum seed production and sorghum flour industrialization. The training was given to 12 technicians of the extension services offices located at Texistepeque, Nueva Concepción, Chalatenango, Chalchuapa; two technicians from CARITAS Chalchuapa, two CARITAS' women farmer groups from Ahuachapán and San Juan Opico. In total, 35 people were trained (20 man and 15 women). In 2009, a total of 30 farmers were trained in the artisanal sorghum seed production process and eight of them are already selling seed to other farmers.

In order to establish 420 plots of 7,000 m2 each, seed of the photosensitive cultivar 85SCP805 was distributed. Likewise, 1,800 plots of 7,000 m2 each were also established using the photo insensitive cultivars RCV, Soberano, Jocoro and S-3. The distributed seed came originally from the stock produced by the basic seed unit and other fraction from what was bought from the trained farmers (Table 3).

Production of variety seed in farms & at San Andres CEDA experimental station.

A total of 11,569.87 kg of sorghum seed were produced at CEDA-Izalco's experimental station from three varieties (RCV: 4,990.92 kg; CENTA S-3:3,039.93 kg; Soberano:3,539.02 kg). This seed will be distributed during 2010 through the previously mentioned extension services offices, NGOs, local governments and farmers groups. Additionally, we are also considering buying 2,268.60 kg of the photo sensitive cultivar 85SCP805 from three farmers in the program at Cabañas.

The yield reached by the varieties distributed by CENTA-INTSORMIL (Table 4) outyielded the check (a local variety) by approximately 50%. The new varieties also outyielded the traditional variety (S-3) by 25%. Viewing it either way, this represents a significant improvement in yield if these varieties are fully adopted.

Sorghum Utilization

In 2007-2008, the cost of wheat flour quadrupled in El Salvador. Bakers across the country requested government solutions to the problem that consisted of subsidies, tax elimination, credits, etc. This situation provides an outstanding opportunity to promote and stimulate the use of sorghum flour as a substitute for part of the wheat flour in baked products. At the current price of wheat flour, sorghum is approximately ½ the cost. In response to this situation, in March CENTA, through the Food Technology lab published two newspaper articles and appeared on three different news broadcasts describing the use of sorghum as a flour substitute for wheat (http://www.centa.gob.sv/Videos.aspx ; http://www.laprensagrafica.com/departamentos/1004993.asp ; http://www.laprensagrafica.com/economia /1004098.asp)

Table 3. Seed delivery (100 lb) to extension services offices and NGOs.

Extension service office at	85SCP805	RCV	Jocoro	S-3	Soberano
1.Guacotecti.	20	8	0	0	0
2. Cojutepeque.	1	15	0	0	0.7
3. Nueva Concepción.	9.5	21	6	1	21
4. Santa Cruz Porrillo.	0	10	0	0	1
5. San Francisco Gotera.	0	8	1	1	0
6. Lempa Acahuapa.	0	2	0	1	0.3
7. San Pedro Nonualco.	0	3	0	0	0
8. Chalatenango.	12	130	0	2	5
9. Zapotitan.	0	7	0	0	0
10. La Libertad.	0	5	0	0	0
11. San Martin.	0	4	0	0	0
12. Sonsonate.	0	2	0	1	0
13. Atiocoyo.	0	15	0	0	0
14. ONGs INTERVIDA.	0	37	1	10	6
15. ONGs CARITAS.	0	7	0.95	0	1
TOTAL	42.5	157	8.95	7	36

Table 4. Demonstration and on farm test yields of improved varieties and local farmer varieties in multiple locations in El Salvador. Grain yields are reported in quintals/hectare (1 qq = 1 ha)

Imp. Variety	Yield MT/ha	Local Variety (various) MT/ha	No. environments
85SCP805	1.80	1.18	125
RCV	1.74	1.22	210
Jocoro	1.90	1.10	20
Soberano	2.04	1.17	32
S-3	1.56	1.23	15

This promotion piqued the interest of many people from the food and bakery industries, and additional information and training was requested from CENTA's food lab. In the past year, CENTA food scientists have conducted four training sessions and educated approximately 100 participants. These demonstrations had two objectives: 1) to produce sorghum flour using a small mill (Omega VI) donated by INTSORMIL and 2) to demonstrate the utilization of sorghum flour as a substitute of wheat in different products.

During both 2008 and 2009, sorghum utilization experts at CENTA have conducted at least 40 workshops on sorghum utilization for food and flour production and 5 additional workshops to demonstrate Omega VI mill functionality to interested people. From these demonstrations, there is now one large scale sorghum flour producer in country and approximately 125 small bakeries using sorghum flour to some extent in their operation. These bakeries are associated with the Artisan Bakers Association (data provided from the president of the bakers association, Nelson Calderon). Finally, there are at least eight small food industries using sorghum in their commercial and mass distributed products.

Ms. L. Taylor, Compatible Technology International (CTI) Volunteer presented workshop on the utilization and production of Omega VI attrition mills for use in grinding sorghum and other grains. This workshop was instrumental in gaining significant interest in locally producing the grinders using blueprints and key parts from CTI. The Omega VIs in Salvador continue to perform efficiently and interest in their use is growing. They are relatively inexpensive to buy and maintain. They are useful for grinding other commodities as well. The Children's Relief Foundation close to CENTA's headquarters have used the grinders to prepare blends of sorghum flour with wheat/maize to produce more foods with existing resources. The sorghum based foods have been readily accepted and are less expensive.

The WINROCK Foundation approved a two week Farmer to Farmer program for a specialist to spend two weeks in Salvador working with the use of the mills and developing information on food processing using sorghum blends. Ms E. Pinella, Graduate Student, Cereal Lab, TAMU will be the volunteer.

Ms. Eliette Palacios, INTA, in Nicaragua has utilized the Omega VI mill to improve sorghum processing similar to what has been done in El Salvador. The interest is high and a substantial increase in consumption of sorghum foods is occurring where the technology has been introduced. Ms Palacios received $2500 from FAO to expand her activities. The results in Salvador are being transferred to Nicaragua with similar positive results especially for the small producers and bakeries.

INTSORMIL funded research on sorghum milling capacity is increasing its use. In 2008 four Omega VI mills were purchased by INTSORMIL and our currently being used in El Salvador to produce sorghum flour. The Omega VI mill has a capacity of 2 pounds per minute. To get good particle size (flour pass through a mesh of 80) the flour must pass through the Omega VI at least four times but this is less than seven (what was required in a nixtamal mill). In addition, our research has testedother systems and is providing information on their effectiveness and cost to local producers. Deployment of all these mills, located in strategic points, will likely be more effective to supply sorghum flour than a large milling company in a single location, primarily because of transportation costs and logistics. To supplement this work, an additional five omega mills were distributed at strategic locations throughout the country. Training for their use was provided as part of the INTSORMIL technology training. (Figure 2 and 3)

La Colina a food processor specializing in Central American Ethnic Foods also requested training related to sorghum and flour production. A meeting with CENTA's cereal program personnel and the food lab personnel was conducted; CENTA is producing 3 hectares of food quality sorghum to be harvested in November, 2008; they will use the grain for flour production. GUMARSAL Company is going to mill all the sorghum produced and the flour is going to be used at La Colina's bakery to elaborate a diversity of sweet breads, cookies and healthy products to export to the USA. This company actually is exporting a diversity of products like frozen fruits, processed vegetables, chutneys, tamales, semitas and other Salvadorian ethnic foods. Last week CENTA's food lab provided La Colina with 200 pounds of fine flour to start conducting trials. CENTA's technicians will be involved in the trials. In addition to these examples, there are numerous other opportunities to use sorghum as a wheat substitute. CENTA is exploring and acting on these opportunities as appropriate. INTSORMIL is supporting this effort as well.

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 5). Quality will continue to be a critical component as grain is moved for commercial food use purposes.

Interest in sorghum as a supplement to wheat flour is now gaining interest in Nicaragua. Ing Eliette Palacios, INTA sorghum specialist who was trained as part of INTSORMIL activities in El Salvador has is now developing a program in Nicaragua and will be training interested bakery owners on milling and using sorghum flour in their bakery operation.

Networking

Several INTSORMIL collaborators attended and made presentations at the 54th annual PCCMCA meetings held in Mexico in September 2009. 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 Nicaragua, Honduras and El Salvador during harvest season to review programs and project

Figure 2.

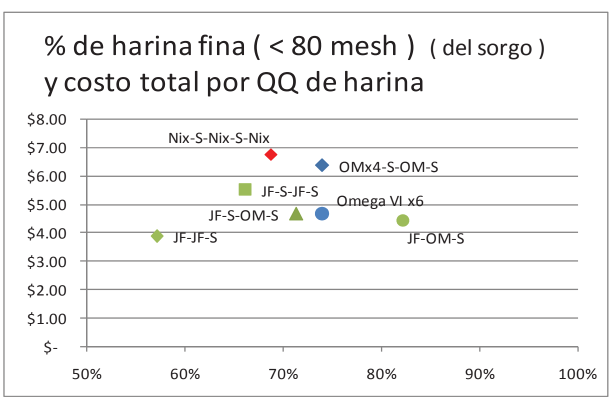


Figure 3.

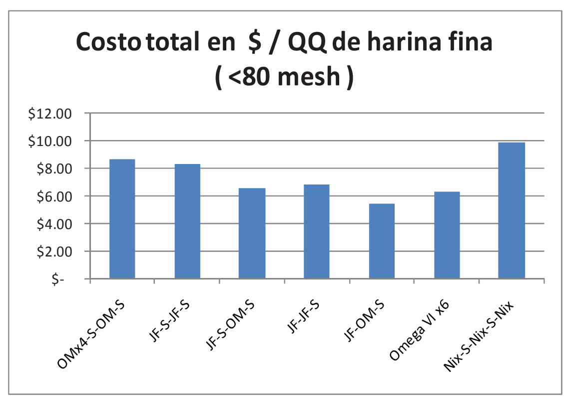


Table 5. Grain quality parameters and milling quality of grain from El Salvador Macio Criollos grown commercially in 2008.

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

activities. Ing Nury Gutierrez of INTA traveled from Nicaragua to El Salvador to learn sorghum hybridization techniques from INTSORMIL supported CENTA staff. Drs. Joe Hancock and Lloyd Rooney traveled to the region to review and participate in collaborative research project related to animal feeding and food uses of sorghum. An agreement between CARE and INTSORMIL was formalized in the spring of 2008 to cooperate on the development and extension of sorghum into El Salvador for a period of two years. 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, MS student and U.S. Citizen bilingual in Spanish will complete her MS 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 now encompasses four countries of the Horn of Africa Region: Tanzania, Uganda, Ke¬nya and Ethiopia. As the Horn of Africa Regional Program goes forward, the September 2008 planning workshop participants determined that we need to take what has been accom¬plished and then develop a strategy to build on the strengths of the past. Declining human capacity is the biggest detriment to prog¬ress at the present time. This is due to lack of financial support and the cost of advanced training in the US.

Sorghum/Millet Constraints

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 quela quela. 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., improved seed 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/SMOG objectives for regional development.

Institution Building

Dr. Gebisa Ejeta (Purdue) has continued collaboration with EIAR scientists in conducting research on sorghum resistance to Striga in Ethiopia. Experimental sorghum hybrids with Striga resistance that have high yield potential have been identified, and can be utilized for catalyzing a seed business activity once their Striga resistance is confirmed in field tests in Africa.

Charles Wortmann (UNL) and collaborators in Ethiopia, Uganda, and Tanzania working in the area of crop, soil and water management to optimize grain yield and quality for value-added markets progressed with their research objectives in the areas of promoting information on tie-ridging and fertilizer use in Ethiopia, skip-row planting in Ethio¬pia and expanded dissemination for soil fertility management options in Uganda through community based farmer facilitators. Their monumental Atlas of Sorghum Production in Eastern and Southern Africa was also published in 2009, wherein they evaluated 43 production constraints affecting sorghum producers in the area.

Mark Erbaugh and Don Larson (OSU) and collaborators advanced their research activities in Tanzania to identify value chain factors that affect the use of improved sorghum and millet seed, to study the feed concentrate and fortified food value chains, examine the supply chain for sorghum-based clear beer and to collect information on seasonal variability of sorghum and millet prices.

David Jackson (UNL) and colleagues advanced in their project for developing products and markets for sorghum in Tanzania through entrepreneurial assistance to existing clients, identifying new clients and conducting training workshops for food processing entrepreneurs and educational programs for sorghum and millet producers.

Human resource development objectives for the region are being met through training of graduate students and collaborations with faculty based in the areas where specific studies are being conducted. Farmer facilitators were trained in Uganda to assist with extension of soil fertility management options. Ms. Salome Maseki, a masters degree student in agricultural economics at Sokoine University of Agriculture, is conducting the study in Tanzania on the improved sorghum and millet seed value chain as her thesis research. The feed concentrate study in Tanzania is being conducted by Mr. Joseph Mgaya in pursuit of his M.Sc. degree in Agricultural Economics at the OSU. This candidate has completed his coursework at the OSU and is currently collecting data for the feed concentrate value chain study in Tanzania. Freddy Kilima and Emmanuel Mbiha are Sokoine University of Agriculture faculty leading the fortified food value chain study in Tanzania. Jeremia Makindara, a faculty member of Sokoine University of Agriculture and Ph.D. candidate, is conducting the sorghum beer supply chain analysis in Tanzania. Collaborators from Sokoine University of Agriculture developed the protocol for collecting the monthly price data to assess sorghum and millet seasonal price fluctuations.

Networking

The INTSORMIL/SMOG 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 USAID missions in each country. The scientists include Mark Erbaugh (rural sociologist) and Don Larson (agricultural economist) at The Ohio State University, Charles Wortmann (soil scientist) and David Jackson (food scientist) at the University of Nebraska, Gebisa Ejeta (plant breeding and Regional Program Coordinator for the Horn of Africa) at Purdue University, as well as collaborating scientists in Ethiopia, Kenya, Tanzania and Uganda. Numerous outreach partners in host countries include government and non-government agencies and community-based organizations.

U.S. PIs met at the University of Nebraska in Lincoln to coordinate regional activities. Eleven publications, listed in the individual reports for the HOA region, appeared in Year 4 of this project.

In addition to data collection trips and interviews conducted by the research teams, two 2-day introductory processor workshops were held at Sokoine University of Agriculture involving sorghum processors, farmers, non-university researchers and extension officers in Tanzania to teach potential new clients about sorghum based products. Current sorghum processor clients were also facilitated by the Project to attend the farmers shows to display their products and meet other sorghum processors and producers.

Research Accomplishments

Crop, soil and water management to optimize grain yield and quality for value-added markets in eastern and southern Africa

Project coordinated by Charles Wortmann, University of Nebraska

As part of SMOG/CRSP project UNL-101, an experiment conducted on tef agronomy in the Tigray region of Ethiopia suggested that reduced tillage resulted in lower yields, N and P applications did not increase yield and weed control was effective with one low dose application of 2,4-D. Results of several experiments on grain sorghum production in Ethiopia evaluating tillage, skip row planting and fertilizer application were published. Tied-ridging and plant 2: skip 1 appears to be a promising configuration in northern Ethiopia. Planting beans in the skipped row is being investigated as a production option for the region. Tied-ridging also increased maize production in the Central Rift Valley but skipped row planting had no yield advantage. In eastern Uganda, soil sampling from 80 on-farm trial demonstrations showed that the sandy loamy soils had low organic matter and moderate P availability. Mean grain yields there were quite responsive to N and N plus P applications. In Tanzania, mean grain sorghum yield was less with reduced tillage compared with tied-ridging and pot-hole tillage based on six on-farm trials conducted in the Singida region.

Identifying ways to improve production and stabilize and develop markets for sorghum and millet farmers in Tanzania

Project coordinated by J. Mark Erbaugh and Donald W. Larson, The Ohio State University

Operating under SMOG/CRSP project OSU-101 a study was conducted to follow the sorghum-based clear beer value chain in Tanzania. The study showed that sorghum beer has increased in clear beer market share from 0 to 4% over the previous 2 years. In addition to lager beer, two potentially valuable by-products (spent grains and yeast) are generated through processing the sorghum. These by-products could be marketed for use in animal feeds. Brewers buy sorghum through traders from small farmers and would generally like to increase those purchases, but have concerns about consistent and high quality grain from small farmer producers. Long term sustainability of the sorghum-based clear beer value chain depends on potential demand of buyers. Poor transportation and storage infrastructure continues to constrain the sorghum beer value chain by increasing cost. Profitability for all value chain members is necessary for success. Lack of trust and effective contract enforcement also remain a constraint on the sorghum clear beer value chain. Lack of access to modern production technologies remains a constraint on sorghum production for smallholder farmers. Low sorghum prices at harvest that increase substantially during the year may create farm storage opportunities. Investors perceive high business risks in sorghum processing because of supply and market demand uncertainties.

Product and market development for sorghum and pearl millet in east Africa

Project coordinated by David Jackson, University of Nebraska

Under INTSORMIL project UNL-102, entrepreneurial assistance for sorghum and millet processors continues with existing clients in Tanzania. Workshops in grain processing and products were conducted for potential new clients. These new clients were also provided with assistance to develop their initial business plans. Workshop offerings for food processing entrepreneurs were strengthened and educational programs for sorghum and millet producers were developed.

During the first year of the most recent two-year work plan, most of the activities as planned were achieved. Continued support to existing six processors in Dar es Salaam, Tanzania including business plan development was provided and a modest support program in Zambia was initiated. Four additional sorghum processors from Dar es Salaam were identified and visited, plus two processors in Lusaka, Zambia were identified for subsequent collaboration [CRSP Objectives 1 & 2].

Planning and solicitation for external funding for a regional Sorghum Food Business workshop was undertaken. A decision was made to team with the INTSORMIL Southern Africa regional group and the National Institute for Scientific and Industrial Research (NISIR) of Zambia to hold a joint Sorghum Food Enterprise and Technology Development in Southern Africa Workshop in Lusaka, Zambia in December 2010. Over 60 attendees from the eastern and southern countries of Africa, Texas A&M University, The Ohio State University and UNL are expected to attend the workshop [Project Objectives 4 and 5; CRSP Objectives 1, 2 and 7].

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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. 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). 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 2006-2011 program 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.

The goal of the collaborative program is to develop and transfer technology for increased production and use of pearl millet and sorghum. Component projects conduct research specific to the project goals but which has implications to research in other projects. Projects interact to develop new technology and the interaction will increase as additional opportunities and funding become available. The local scientists are encouraged to collaborate across country boundaries.

Sorghum/Millet Constraints

Sorghum and pearl millet are major indigenous food crops in the southern Africa region. Both crops form part of the basic staple foods for many rural communities in Africa. Sorghum is used to make opaque beer and as a livestock feed. Sorghum is the major cereal in Botswana and parts of Zambia and Mozambique while pearl millet is the major cereal in Namibia and parts of Mozambique, Zambia, and Zimbabwe. In many areas the stalks are used as forage for animal feed, as building material for fences and traditional storage facilities, and sweet sorghum juice as a source of sugar. In some areas sorghum and pearl millet are considered as food security crops, especially in regions where rainfall is a limiting factor for maize and rice production.

Constraints 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 lack of promotion of sorghum for the end-use food and feed markets hinder development of a diversified sorghum and millet industry. Policy constraints can 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 beyond the farm gate market channels should be improved as sorghum grain with the required quality to meet commercial requirements frequently has inconsistent production and supply. The inconsistent supply of quality grain is frequently cited as a major factor in deciding to use maize as opposed to sorghum. A major constraint to increased farmer production and productivity is the lack of adequate seed systems to distribute improved varieties. The adoption rate of improved varieties is largely unknown due to inadequacies of the seed system. Consequently farmers continue to use their local varieties which have low productivity potential. Availability of a consistent supply of improved quality sorghum and pearl millet for processing into value added urban products is a major constraint limiting utilization. Food companies will use but cannot consistently acquire sufficient quantities of high quality sorghums for processing. A system of identity preservation for production, marketing, and processing is urgently needed. 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 resistance to abiotic (drought tolerance) or biotic (disease and insect) stress, improved end-use traits (for food, feed and forage), and other desirable traits are in development by national programs. Reduced stored grain loss, with some estimates of a 30 - 50% loss annually, will increase the availability of high quality grain. Exotic sorghums and pearl millets are continually introduced into the region as sources of needed traits. Identification of regionally adapted sorghum or pearl millet cultivars or hybrids with stable grain yield and multiple stress resistance will assist the NARS teams in developing lines, varieties, and hybrids for the diverse environments and production systems in each country and in similar environments. Research is on-going to improve disease and insect pest management and to improve sorghum and pearl millet processing techniques to improve use in value added foods. In developing new uses technology has been developed: to produce 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 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. 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 can potentially harbour high fumonisin producing *Fusarium* species.

Institution Building and Networking

Workshops and Meetings

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

Research Investigator Exchanges

Gary Peterson visited Zambia and South Africa, November 7-21, 2009. In Zambia met with Dr. Medson Chisi to discuss status of the regional program and interview potential short-term and graduate student candidates. In South Africa met with Dr. Neal McLaren, University of the Free State plant pathology collaborator to, discuss status of research and plan future research, and interviewe a potential new graduate student. In Johannesburg met with Charles Coe, SABMiller consultant and Gerry van den Houten, SABMiller Technical Director to discuss possible collaboration in developing sorghums for improved brewing and malting quality. In Pretoria, discussed development of a program to develop sorghums for improved brewing and malting quality with Prof John Taylor and Dr. Medson Chisi. In Cape Town, met with Medical Research Council collaborators Drs. Hester Vismer and Gordon Shephard, to discuss status of research and plan future collaborative research activity.

John Leslie visited Zambia and South Africa, November 2009. Is Zambia, present a version of the scientific writing class to staff from the University of Zambia and the Zambia Agricultural Research Institute. In South Africa, met with collaborators at the University of the Free State and the Medical Research Council to review research and training activities and plan future activities.

Don Larson and Mark Erbaugh traveled to Zambia, January 24-28, 2010. Discussions were held with UNZA collaborators on the status of graduate programs for Bernadett Chimai and Rebecca Lubinda, progress in completing the sorghum value study, status of new clear-beer value chain studies, and progress on publications.

Gary Peterson traveled to Botswana, Mozambique, South Africa and Zambia, February 27 – March 14, 2010. In Botswana met with Dr. David Munthali, Botswana College of Agriculture entomologist, to discuss research progress. In Mozambique met with Joaquim Mutaliano, sorghum breeding collaborator to discuss development of his research program and evaluation of germplasm selected from Texas and other program. In South Africa met with Dr. Neal McLaren, University of the Free State plant pathologist, to discuss graduate training and evaluation of sugarcane aphid resistant germplasm for disease resistance at Cedara. In Zambia met with Dr. Medson Chisi and F.R. Muuka breeding collaborators from the Zambia Agricultural Research Institute Sorghum and Millet Improvement Program, and reviewed status of the regional program.

Bonnie Pendleton traveled to South Africa, Mozambique, and Botswana, May 9-15, 2010. In Mozambique, she met with Fernando Chitio, entomologist, and Joaquim Mutaliano, breeder, to view research projects. In Botswana, met with entomologists Drs. David Munthali, Obopile, and Amadie who are researching resistance of sorghum to stalk borers and sugarcane aphids. Research by students was viewed in the field and in the laboratory. Dr. Munthali also was studying resistance of stored grain of 22 sorghum varieties to maize weevils. Dr. Munthali is compiling results from multiple years of research on sorghum into printed materials to distribute to farmers and others in Botswana.

David Jackson and Curtis Weller traveled to Tanzania and Zambia, May 2-8, 2010. In Tanzania they toured Sokoine University of Agriculture in Morogoro. Discussions were held with various faculty members and administrators including local leader Dr. Joseph Mpagalile to review progress on project activities, and discuss topics and participants for the December Sorghum Food Enterprise workshop in Zambia. In Dar es Salaam visits were made to four sorghum processors including one women's group to view the state of the industry and the products available in the market place. In Zambia, they met with UNZA and ZARI researcher and educators, and traveled to the Golden Valley region to view production areas and meet producers and extension educators. Plans for the December Food Enterprise Workshop was discussed. A meeting was held with UNL students from the College of Journalism and Mass Communication who were Zambia working on the Communications/Media Development Project for INTSORMIL.

Research Information Exchanges

Texas A&M University is working with the University of Pretoria and the Zambia Agricultural Research Institute on a program to develop sorghum cultivars with improved malting and brewing quality. The research will be conducted in collaboration with SABMiller. Discussions are at last nearing finalization with SABMiller Africa for a MOU with INTSORMIL in respect to providing a framework for technology support in respect of SABMillers' use of sorghum in brewing across Africa.

Through a collaborative agreement between the University of Pretoria and AFGRI-Labworld, a major South Africa agricultural company, a new grain science laboratory has been built at the Department of Food Science. The Grain Science Laboratory is well-equipped with state of the art instrumentation and accommodation for graduate research students and post-doc fellows, and has dedicated technical staff.

At the University of Pretoria small company specific research projects are being undertaken with SABMiller affiliated companies across Africa, and with other companies involved in sorghum milling, malting and brewing.

Prof John Taylor participates in the South African Sorghum Forum (sorghum stakeholders group).

Germplasm Conservation and Distribution

The Zambia pearl millet program produced 5.5 tons of foundation seed of 8 released varieties to supply to producers Certified and/or Quality Declared Seed.

The Zambia sorghum breeding program produced 2.9 tons of Kuyuma and 1.4 tons of Sima for distribution in Masumba, Petuake and Luangwa. The quantity of seed is sufficient to supply seed to 2,000 small holder farmers and plant 530 hectares.

The Mozambique sorghum program characterized, self pollinated, and increased seed of 12 land race varieties previously collected. On-station foundation seed production resulted in 11.95 tons of Macia and Sima (combined total). This will represent an area of certified seed production of 1,195 hectares. The seed was to be sold to research partners (Lonzane farm, Pannar, Agakan and small seed producers).

Spreading Research Results

The Mozambique sorghum breeding program has strong collaboration with breeding programs (SMIP-Zambia, IER-Mali, ICRISAT and INTSORMIL), NGOs (Aghakan, Helvetas_Mozambique, FHI-USAID, Lonzane Farm, Dengo Commercial and PANNAR), the Spanish Cooperation Agency, USEBA (Unity of Basic Seed Production at IIAM) and extension services for technology transfer.

The Zambia pearl millet program collaborates with the Golden Valley Agricultural Research Trust (GART), University of Zambia (UNZA), Henwood Foundation (HF) and the department of Agriculture in Zambia; the Namibian and Botswana programs in Southern Africa; programs in Niger, Nigeria, Mali, Ghana, etc in western Africa; ICRISAT Centre in India; Coastal Experiment Station at Tifton, Georgia and the University of Nebraska in the USA.

The Zambia sorghum program collaborates with the University of Zambia - School of Agriculture, Japanese International Cooperation Authority (FoDIS Project) and several NGOs including World Vision and CARE International.

Human Resource Development Strategy

For degree programs, the primary mechanism is to upgrade the research and sorghum and millet science skills of university lecturers and scientists in research institutes in sub-Saharan Africa. During the past year, there were seven graduate students studying Food Science at the University of Pretoria.

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. In 2010, more than 25 persons from the industry in southern Africa are taking the course.

Lloyd Mbulwe, ZARI sorghum breeding program, participated in a short-term training program at Texas A&M University. Activities were conducted at College Station, Corpus Christi and Lubbock to provide expertise on breeding activity, and for utilizing molecular biology to enhance selection efficiency in breeding programs.

In addition to students listed in the degree training table the following students have/are receiving graduate degree training at the Dept. of Food Science, University of Pretoria: MSc – C.J. Schoeman (South Africa); PhD – Laura de Silva (South Africa), Johanita Kruger (South Africa) and Charlotte Serrem (Kenya); PostDoc – Abdul-Rasau Adebewola (Nigeria).

Bernadette Chimai (Zambia) is a graduate student at the Ohio State University. Primary support is from the OSU project with the regional program providing some additional support.

Research Accomplishments

Entomology

Mozambique

More than 70% of the Mozambique population lives in rural areas. Their major activity is agriculture and nearly all farmers use very rudimental subsistence production techniques. Grain storage is a major problem and according to some estimates 30 to 50% of the country's production is lost in storage annually. Genetic resistance to control damage by major field and storage pests is an economically productive mechanism to reduce damage.

Three experiments were conducted in 2009-10. Another attempt to study push-pull technology to control stem borer in sorghum was made. The theory is that early planting of Napier grass and Desmodium around sorghum fields will reduce the incidence of stem borer in sorghum. The experiment was not successful due to poor germination of Desmodium. To study the effect of Stiophilus zeamais on stored grain 10 local varieties were evaluated. Seven months after infestation the varieties Tocoli-1 and Ribawe-1 sustained no damage. The varieties Noculukume-3 and Ribawe-2 sustained moderate damage. Generally, local varieties were less damaged than introduced varieties. Entries in the National Performance Trials were evaluated for damage caused by stem borers, sorghum midge and sugarcane aphid. Infestation level for each pest was generally low. Results indicated there were differences in response to each pest. Introductions from Zambia generally expressed at least a moderate level of resistance to each pest. Introductions from Texas were susceptible to stem borers and moderately susceptible to sorghum midge. Due to the inconsistent level of infestation the experiments will be repeated in 2010-11.

Botswana

Primary research activity is to develop varieties resistant to the sugarcane aphid (Melanaphis sacchari (Zehntner)). The sugarcane aphid infests sorghum during all growth stages, but infestations of economic significance usually occur during the late growth stages, more commonly during dry periods. Yield losses to sugarcane aphids can be as high as 46-78% annually where insecticides are not used. Management of the sugarcane aphid by using resistant sorghum cultivars will reduce the usage of insecticides and save on input costs for purchasing insecticides without sacrificing crop yield. It will also provide a solution to resource poor farmers who cannot afford insecticides for control of the sugarcane aphid. Promising high yielding sorghum genotypes resistant to sugarcane aphid had been developed by INTSORMIL and are nearly ready for on-farm trials and quality evaluation.

Pest abundance on 25 sorghum cultivars, including Texas bred sorghum lines that were at the "yield trial" stage as well as local varieties that are cultivated in the SADC region were evaluated from the vegetative growth stage to the grain filling and maturation stages during the 2009-10 cropping season. Field abundance of natural enemies such as coccinellid predators was assessed at different phenological stages of sorghum plants to determine the relationship between crop stage, abundance of pests and their natural enemies. Grain yield losses caused by sugarcane aphid damage on each of the 25 cultivars were estimated. It is anticipated that the results will enable selection of germplasm that have high yielding potential and minimum yield losses due to pest attack. It is also anticipated that understanding these relationships will enable scientists to determine whether application of hazardous synthetic pesticides against pests of sorghum is necessary or when to apply them if necessary.

None of the 25 sorghum varieties evaluated during the 2009-10 cropping season were completely resistant to the sugarcane aphid. In order to determine the effect of sugarcane aphid infestations on grain yield production on each of the sorghum cultivars, the plants were grouped into three damage levels: those displaying minimum (scores 1 & 2); moderate (scores 3 & 4) and severe (score 5) damage level, based on the percent damaged leaves recorded per plant. Plants that had suffered minimum sugarcane aphid damage were assumed to produce grain weights per panicle that were closer to amounts expected from pest free plants. Effect of sugarcane damage on yield was estimated by comparing yield obtained from plants that suffered moderate leaf damage (scores 3 & 4) and that produced by plants that suffered severe leaf damage (score 5) during the cropping season with the yield produced by plants that only had minimum leaf damage (score 1 & 2).

Sorghum cultivar Ent62/SADC produced the highest (102.5 g) while (A964*P850029)-HW6-CA1-CC1- LGBK-CABK produced the lowest (13.2 g) average amount of grain per panicle. Other cultivars that produced large quantities of grain were: Kuyuma, (Macia*TAM428)-LL9 and (Macia*TAM428)-LL2, which produced 70.8, 70.5 and 68.8 g/panicle respectively. These cultivars have great potential for use in breeding programs because of their high yielding properties. Inclusion of these cultivars in breeding programs for resistance to crop pests would ensure that the germplasm that is developed is both pest resistant and high yielding.

Eight varieties: TAM428, Kuyuma; Ent62/SADC, (Macia*TAM428)-LL9; SV1*Sima/IS23250)-LG15-CG1-BG2(03)BGBK-LBK-PRBK; (Segaolane*WM#322)-LG2-(03)BG1-LG1-LBK-PRBK; (6BRON161/7EO366*Tx2783)*CE151)-LG5-CG2(03)BG1-BG2-LBK-PRBK and (Macia*TAM428)-LL2 did not suffer severe damage throughout the growing season and could be regarded as the most tolerant or resistant to sugarcane aphid while the varieties: (Dorado*Tegemeo)-HW13-CA1-CC2-LGBK-CABK; (5BRON151/(7EO366*GR107B-90M16)*Tegomeo)-HG1-LGBK-CABK-CABK and Phofu showed severe damage, and could be regarded as the most susceptible to sugarcane aphid damage.

Comparison of percentage yield losses caused on sorghum cultivars that only suffered moderate sugarcane aphid damage throughout the cropping season shows that yield losses differed significantly among the eight cultivars. The greatest yield reduction (73.8%) occurred on (SV1*Sima/IS23250)-LG15-CG1-BG2(03)BGBK-LBK-PRBK plants while the smallest was on cultivars TAM428, Ent62/SADC, (Macia*TAM428)-LL9 and (Segaolane*WM#322)-LG2-(03)BG1-LG1-LBK-PRBK (with 27.7, 20.5, 17.3 and 24.4% grain weight reduction per panicle, respectively). The four sorghum cultivars which had the lowest grain yield losses due to sugarcane aphid damage were relatively more resistant to pest damage while cultivar (Macia*TAM428)-LL9 was comparatively more susceptible to aphid damage. Cultivars TAM428, Ent62/SADC, (Macia*TAM428)-LL9 and (Segaolane*WM#322)-LG2-(03)BG1-LG1-LBK-PRBK would be the most suitable for use in further inclusion in breeding programs for resistance to the sugarcane aphid.

Food Science

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 brewing. 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.

Research is being carried out in four areas: 1) development of very simple and rapid end-use quality assessment methods; 2) understanding the scientific basis of sorghum quality attributes; 3) development of a simple system for sorghum end-use quality assessment; 4) creation of a database on end-use quality attributes of sorghum varieties in southern Africa.

Research on sorghums with different kernel hardness led to the conclusion that hard sorghums give the highest meal and flour yield. It has been found that the amount of water taken up by sorghum grain immersed in water is inversely related to grain hardness. Water uptake can be used as a simple screening test for sorghum hardness.

Although white, tan-plant sorghum types appear to be an alternative to white maize for porridge making, they invariably produce darker porridge than maize. White sorghums show considerably higher levels of the enzyme polyphenol oxidase than white maize. Further, sorghum porridge whiteness is inversely proportion to the level of polyphenol oxidase activity in the flour. Polyphenol oxidase activity seems to be a valuable screening assay for selection of white sorghums.

In South Africa, because of the 14% Value Added Tax on sorghum, sorghum products are considerably more expensive than their maize equivalents. Hence, 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. Two areas are being investigated: 1) development of nutritious sorghum-based foods, particularly cookies, which have high antioxidant activity due to them being rich in polyphenols and are protein-rich through fortification with soya; 2) development of sorghum protein-based microparticles (microspheres) as encapsulating agents for nutraceuticals and other health-promoting agents. Based on research on microparticles a patent application has been filed: Patent Cooperation Treaty Application 2010. WO 2010/041203 A1 Process for Producing Protein Microparticles, University of Pretoria, inventor J Taylor and JRN Taylor.

Through rat bioassay, we have shown that that soya fortified red non-tannin sorghum cookies have similar protein and food efficiency ratios to high quality animal protein. A patented process has been developed for producing the sorghum protein-based microparticles. Further, we have shown that the microparticles can encapsulate sorghum antioxidants and release them in a controlled way in a simulated human digestive system. Excellent technical progress has been made with development of sorghum-based cookies. We now need to actively market the concept of sorghum cookies for school feeding in southern Africa. Development work is now being undertaken to enable commercial exploitation of the sorghum protein-based microparticles.

Commercial sorghum brewing, both lager and stout brewing and traditional opaque beer brewing, 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 of sorghum brewing. Two areas are being investigated: 1) research has been undertaken to optimize extract (fermentable sugar yield) from sorghum in lager brewing. It has been found that at non-tannin, low protein sorghum type that have high starch pasting properties give the highest yield of extract. 2) research is commencing to reduce raw material input and extend the shelf-life of opaque beer. There are strong indications that complexing lipids with starch will enable the production of opaque beer using less raw materials.

Market Development

The research strategy is to identify new market opportunities, related constraints in the supply chain and ways to better link farmers to markets so as to improve the income and food security of small-scale sorghum and millet farmers in Zambia. The main objective has been to understand the different participants in the value chain and to identify the factors that determine the low level of technology used.

The study found that sorghum and millet farm yields are low (about 0.5 ton/ha) and have been stagnant for over 20 years. Government of Zambia subsidies for fertilizer, seed and price supports for maize growers have expanded the area planted to maize even in regions of the country that are drought prone where sorghum and millet are more suited crops to grow. Adoption of improved seed and fertilizer is very low among sorghum and millet growers with growers are using the same sorghum and millet for an average of 13.7 years when the recommended replacement rate is about three years. There is a large discrepancy between research station yields (3 to 5 t/ha) and farmers' fields yields (0.3 t/ha).

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 are mainly subsistence.

Improved maize hybrid seed is distributed mainly through formal channels while sorghum and millet and OPV maize seed are distributed through both the formal and informal channels. Millet is largely distributed through informal channels and mainly between farming households. The study also found that formal seed companies viewed investment in sorghum and millet as unprofitable due lack of stable markets and low demand for the improved seed. Farmers lack awareness and understanding of consumer preferences and market demand. . This has resulted in their inability to take advantage of market opportunities that exist in the sorghum 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.

Pearl Millet Breeding

Zambia

The program has three broad objectives: 1) Develop and evaluate technologies, maintain indigenous genetic diversity and acquire appropriate exotic genetic materials for the improvement of pearl millet grain for food and feed; 2) Promote improved technologies to enhance adoption and utilization; and 3) Develop and promote commercial end-use technologies and products that generate household income and food security.

Potential appropriate agronomic packages were evaluated in one experiment to bridge the yield gap between researchers and farmers. Seven (7) different replicated experiments with entries ranging from 30 to 61 varieties and/or hybrids were conducted. The quality of the experiments was good with grain yields ranging 352 – 7153 $kgha^{-1}$ for open-pollinated varieties and 595 – 7837 kgha-1 for experimental hybrids while the coefficient of variation (cv) values ranged from 10.67 – 23.27% among the trials. Thirty-six (36) open-pollinated varieties and twenty-three (23) hybrids were superior to check varieties and or hybrid parents. The evaluated materials have wide range of useful characteristics including different maturities, heights, tolerance to diseases and grain damage by birds, grain size and color, etc which offer choice to farmers, processors and consumers. Twenty-seven (27) pearl millet varieties were given to the Food Science Department of the University of Zambia for determination of grain quality along with

Table 1. Performance of the Pearl Millet Protogyny Population Experimental Hybrids at LongeTechnological Assessment Site, Kaoma District, Zambia during the 2009-2010 season.

Genotype	Grain Yield	Threshing %	Tillers/ plot	Flowering	Height	Exertion	Head Length	Head Girth
	Kg/ha			days	cm	cm	cm	cm
Lubasi x HHVBC- Tall	6766	74	3.7	57	287	7.8	31	11.2
Sosat – C88 x Sepo	6627	93	3.2	63	308	8.8	32	8.7
Sosat – C88 x SDMV 93033	6627	72	3.6	62	310	7.4	32	10.1
Sosat – C88 x CIVT	6442	74	2.6	63	307	4.5	39	9.3
Lubasi x Sepo	6435	74	4.2	54	295	8.4	33	9.7
Sosat – C88 x HHVBC – Tall	6336	76	2.9	58	305	7.5	35	11.6
Sosat – C88 x 570028R1w	6177	74	3.1	61	312	11.2	36	9.3
Dola x Sosat- C88	6111	72	3.7	53	307	10.8	30	11.1
Sosat-C88 x Sosank	6071	76	3.5	57	298	11.6	28	10.4
Sosat – C88 x Taram	5994	74	3.2	61	300	6.4	27	9.4
Lubasi x570028 R1w	5906	70	4.5	53	297	7.9	32	7.8
Dola x SDMV 93033	5873	74	3.8	53	292	7.7	39	10.3
Lubasi x SDMV 93033	5866	77	3.8	55	308	8.7	27	9.5
Sosat - C88 x Lubasi	5635	74	3.6	55	298	8.5	35	9.5
Lubasi x Sosat-C88	5549	73	4.4	57	282	8.5	32	9.0
Sosat – C88 x LCIC 9702	5331	74	3.4	54	285	8.3	33	9.3
Sosat – C88 x Kangara	5311	78	3.2	51	297	12.1	25	8.9
Lubasi x Arrow	5298	76	3.2	48	297	5.8	32	8.7
Dola x HHVBC- tall	5258	69	3,8	51	290	7.0	34	13.6
Sosat – C88 x Manganara	5225	75	3.0	58	285	7.2	28	11.5
Lubasi x Sosank	5192	68	3.0	51	292	8.4	30	9.3
Dola x LCIC 9702	5192	75	3.9	51	288	8.7	32	9.3
Mean of Sosat – C88 Hybrids	5186	76	3.1	58	294	8.5	31	9.9
Dola x 570028 R1w	5165	72	5.0	53	298	7.3	38	7.9
Mean of Lubasi Hybrids	5136	74	3.8	53	285	8.1	31	9.5
Lubasi x Dola	5093	74	3.5	54	280	5.8	32	9.6
CIVT	5093	74	3.2	58	283	8.8	32	9.2
Lubasi x CIVT	5059	76	3.3	52	278	8.1	38	8.4
Dola x Taram	5026	70	3.8	53	287	8.0	35	8.9
Dora x Sosank	5020	71	3.1	52	290	8.1	33	8.7
Dola x Sepo	4974	69	3.7	52	295	7.0	35	8.5
Dola x Kangara	4815	73	3.8	50	285	7.0	34	10
Lubasi x Manganara	4783	77	3.6	50	285	8.9	28	10.5
Dola x Lubasi	4782	71	3.4	52	288	6.7	30	9.4
Mean of Dola Hybrids	4747	72	3.7	51	287	7.7	34	9.8
Lubasi x LCIC9702	4603	83	2.9	52	292	7.7	34	10.1
Dola x Okashana -1	4431	75	3.4	49	278	9.3	31	9.5
Sosank	4411	74	2.4	61	285	6.0	27	11.6
Dola x Arrow	4372	74	3.7	50	287	7.6	35	9.2
Sosat – C88 x Okashana – 1	4319	76	2.9	52	280	8.9	28	10.2
Lubasi x Kangara	4233	75	3.8	51	272	9.1	28	9.4

Table 1. – cont'd Performance of the Pearl Millet Protogyny Population Experimental Hybrids at LongeTechnological Assessment Site, Kaoma District, Zambia during the 2009-2010 season.

Genotype	Grain Yield	Threshing %	Tillers/ plot	Flowering	Height	Exertion	Head Length	Head Girth
Dola x Lagrap	4200	73	3.0	51	273	6.3	33	10.9
Taram	4167	71	2.9	57	275	8.3	36	8.2
Sosat – C88 x Dola	4067	76	4.0	62	288	6.9	33	10.0
Sepo	4001	75	2.8	56	290	6.9	38	8.8
Lubasi x Lagrap	3843	73	2.7	52	278	11.1	31	11.5
ZN 20	3796	72	3.1	54	270	9.4	30	8.9
Dola	3664	71	2.8	55	288	8.1	32	11.3
Sosat – C88	3542	73	2.2	59	260	8.6	29	9.4
Dola x Manganara	3452	60	3.7	48	270	8.4	27	10.4
Lubasi x Okashana-1	3274	72	4.2	53	255	7.7	28	8.2
Arrow	3155	73	2.9	51	270	6.7	38	8.9
Lubasi	3148	73	2.5	57	272	7.3	31	9.9
SDMV 93033	3089	71	2.2	67	283	5.3	36	8.5
Sosat – C88 x Arrow	2890	75	2.4	55	280	11.0	28	8.9
570028 R1w	2718	72	2.3	61	280	11.2	35	7.1
Okashana – 1	2705	73	2.6	48	253	9.1	25	10.2
Dola x CIVT	2540	76	3.4	54	272	5.3	38	9
Lagrap	2526	80	2.6	52	255	7.0	28	10.0
Manganara	2493	74	2.3	51	257	8.4	29	11.0
LCIC 9702	2480	75	2.2	53	255	6.3	29	8.9
Kangara	2242	74	2.3	48	257	9.5	27	10.2
HHVBC – Tall	1263	64	2.2	59	192	5.8	27	13.0
Sosat - C88 x Lagrap	741	80	1,3	57	263	6.5	23	11.5
Trial Mean	4512	72	3.2	55	280	8.3	32	9.4
LSD0.005	91.62							
CV (%)	17.81							

Table 2. Brix % and other traits of 8 sorghum varieties grown at GART, Fringilla, Zambia 2009-2010.

Designation	Days to 50% anthesis	Plant height	Solution Ph	Brix %	Brix %
		m		Dough Stage	Maturity
Wray	82	3.4	4.1	13.6	17.7
Madhuta	81	3.1	4.0	13.3	16.8
Cowley	83	3.4	4.1	14.0	15.8
Keller	83	3.4	4.6	10.9	15.4
GE2	84	3.7	4.3	13.0	15.0
TSI	83	3.2	4.5	14.6	15.0
Praj	82	3.7	4.3	15.3	12.1
Sima	80	3.1	4.1	14.3	10.7
Test Mean	82	3.4	4.2	13.6	14.8
LSD.05	3	7	5	10	16
CV(%)	2	7	5	10	16

a sorghum variety (Sima), a cowpea variety (Lutembwe) and a cassava variety (Chila) for comparison. Various genetic materials including elite varieties and different types of hybrid parents were maintained by selfing, hand crossing or in isolation plots.

Forty-four (44) protogyny population hybrids were evaluated together with their 16 parental varieties and the local land race variety ZN20 from the Zambian National Gene Bank (Table 1). Twenty-three (23) hybrids were found promising with grain yields superior to the best parental variety CIVT (5093 kgha-1). The mean yield of 44 hybrids was 5023 kgha^{-1}, 58% higher than the mean of the 16 parental varieties (3168 kgha^{-1}). The land race (3796 kgha^{-1}) was inferior to most hybrids. Grain yields ranged from 595 – 7837 kgha^{-1} with the trial mean of 4512 kgha-1; LSD0.005 of 91.62 kgha^{-1} and CV of 17.81%. On average hybrids flowered earlier, were taller, had more productive tillers and higher threshing percentage than the parental varieties.

Development of varieties with light colored grain to address consumer preferences was initiated. Numerous experimental hybrids were developed based on either the protogynous nature of pearl millet or different types of cytoplasmic male sterility systems. Some of these will be used in the PI's Ph.D. research study. Ten (10) new open-pollinated varieties were developed from 5 composites undergoing improvement by recurrent selection. Dola, a released Zambian bristled variety that has some tolerance to grain damage by birds in the fields has attracted demand in Zambia as well as other countries.

The seed store was rehabilitated to address the perennial problem of rats and rapid loss of seed viability. More than 2,000 plastic seed containers with screw lids were purchased for long term use to address the problem of seed storage pests. Harvesting bags were bought in advance for use next season. Due to financial limitations, no follow up was done on the seed supplied through GART and HF to farmers last season.

Sorghum Breeding

Zambia

The program uses a multi-disciplinary approach where issues of diseases, pests, other important traits take center stage. This approach involves an entomologist and a pathologist at various levels of evaluation. To ensure that the developed technologies are relevant to farmers, the program uses a participatory rural appraisal approach [Participatory Rural Appraisal] whenever possible. In this approach the program obtains feedback from farmers during field days and any other forum on what traits or qualities they are looking for in sorghum. Because the program involves farmers, the research is becoming more and more relevant to the end users of the technologies.

Sweet sorghum research is focused on assessing the performance of promising lines for grain yield and sugar content [sugar percentage-Brix content]. Sweet sorghum lines such as Sima can be used as a dual purpose crop. This basically means that grain can be used for human consumption and sweet stalks for ethanol and/or sugar production. Promising lines for this research includes other materials such as Cowley, GE2, Keller, Madhuta, Praj, TSI and Wray. These 7 materials are as a result of germplasm introductions from India. The materials are being assessed against local materials as well such as Sima. No significant differences were observed among the entries for sugar content. Sugar percentages [Brix content] ranging from 10.7 to 17.7% have been observed depending on the physiological maturity of the crop. More work will be carried out in the coming season to verify these figures (Table 2).

Forage sorghums are also being assessed to evaluate the performance of promising forage sorghum hybrids for yield. The target for this research is the beef and dairy industry for animal feed. The justification for this research is that sorghum is used as green forage for animals, or as silage for dairy animals in many other countries. Promising materials include ZSH 107 with total biomass yields of about 30 tons per hectare, FSH 201 and MMSH1252 with yields of approximately 24 tons and 23 tons per hectare respectively (Table 3).

The materials in the Sorghum Advanced Variety Trials (20 entries) for Region I and II [SAVT I and II] are all drought tolerant lines. The objective is to develop materials with the ability to withstand moisture and heat stress in this area. Other areas of research in this trial include developing lines that can stand diseases like long smut and loose smut. Test mean was 3679 kg/ha with and LSD.05 of 726 kg/ha. Superior materials so far in terms of yield are ZSV-15 (kg/ha), Kuyuma (4961 kg/ha), ICSV112 x WSV187]15-1-1-1-1 (5711 kg/ha), [Framida x SDS3843]16-2-2 (4658 kg/ha), ICSV112 x WSV3136]1-13-1 (4897 kg/ah), and [Framida x SDS3845]F6-5 (4675 kg/ha).

Brown sorghum and white sorghum hybrid trials have been conducted. The major advantage of hybrids is the hybrid vigor that tends to make them produce higher yields. Hybrids are usually stable across many environments within the country. Test mean in the Brown Sorghum Hybrid Trial was 3515 kg/ha (LSD.05= 1232kg/ha. ZSH-213 (4989 kg/ha) and MMSH-1194 (4508 kg/ha)were seen to be performing better among the brown sorghums. In the White Hybrid Sorghum Trial (mean = 3903 kg/ha, LSD.05 = 345 kg/ha) MMSH-1077 (4736 kg/ha) and MMSH-707 (4883 kg/ha) produced the highest yield. Other white grain hybrids that produced over 4000 kg/ha were MMSH-1376 (4633 kg/ha), MMSH-1257 (4528 kg/ha), MMSH-1346 (4494 kg/ha) and ZSH-210 (4222 kg/ha).

The Zambia Sorghum and Millet Improvement Program initiated a technology transfer activity to assist in transferring improved technology to farmers. The activity has three objectives: 1) assist with issues of seed production and distribution systems at the village level and help with Institutional development of the seed supply system; 2) deliver sorghum varieties and hybrids with improved quality traits for food, beverage making, forage, feed, and disease and pest resistance; 3) deliver market tailored research technology in sorghum to small scale farmers for economic development. Primary areas targeted were Chongwe District (Rufunsa, Shikabeta, Lunsefwa, and Lubalashi), Luangwa, Sinazongwe (Siameja, Muuka, Siampondo, Kanchindu, Maamba and Sulwegonde), Sesheke (Lusinia, Mwandi and Ngweze) and Siavonga (Kapululila, Siangwemu, Kabanana, Kayuni, Lusitu Bridge, Sikongo, Sub Centre, Lakeshore).

A total of 1,059 'new' smallholder farmers in all the districts listed above were beneficiaries of improved sorghum varieties Kuyuma, ZSV-15, Sima and [Framida X SDS 3845]16-2-2. The farmers were given 2 kilograms packs of seed and were expected

Table 3. Fresh plot weight and other agronomic traits for 10 forage sorghum hybrids, GART, Fringilla, Zambia, 2009-2010.

Designation	Days to 50% anthesis	Plant height	Fresh plot weight	Dry matter	Moisture
		M	Kgs/ha	%	%
ZSH-107	75	2.9	30972	35	65
MMSH-1040	82	2.5	24222	39	61
FSH-201	79	2.3	24074	35	65
MMSH-1252	80	2.6	22704	39	61
FSH-6	81	2.3	22694	35	65
SIMA	81	1.7	20556	25	75
MMSH-1276	76	2.8	20296	36	64
FSH-7	75	2.4	15333	35	65
MMSH-1258	73	2.4	14222	25	75
MMSH-1038	80	2.2	13806	30	70
MEAN	78	2.0	20703		
LSD.05	7	1.2	17166		
CV%	4	10	29		

to plant a quarter of a hectare [one Lima], from the seed supplied. About 265 hectares was sown to sorghum. Farmer training on sorghum growing was conducted in Sinazongwe (184 farmers), Siavonga (300) and Sesheke (175). Monitoring of the crop was done with the assistance of extension officers from the Department of Agriculture (District offices), Harvest Help and Food Crop diversification project (FoDis). Though the intervention measures put in place to ease demand for improved seed seem to be working, a lot more needs to be done to improve the situation. This activity includes the study of soil fertility issues on smallholder farms and the use of cover crops.

Mozambique

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 have provided an array of germplasm in which to selection. Collections of local landrace varieties preserve the indigenous genetic diversity and provide additional populations for selection.

The 12 local landrace varieties, collected in Cabo Delagado and Nampula Provinces, were observed to be segregating for seed color and plant type. The lines are being evaluated for several traits including grain yield potential and pest (disease and/or insect) resistance. Tan plant landraces with white seed were selected for crossing with improved varieties (Macia and Sima) and introductions. Approximately 70 introductions have been increased and are being evaluated in multiple location trials, 34 A-, B- or R-lines were crossed for seed increase and 14 inbred lines were selected for regional trials.

National Performance Trials were conducted at four locations (Namialo, Mamapa, Susundenga and Mapupulo) to identified germplasm suitable for potential release as varieties. Twelve introductions from Zambia were evaluated and 8 introductions will be proposed for release. The 8 introductions – ZSV-15/709E-1 (ICSV112*WSV387), GVSIMA/710E-2 (SDS 2302-1), ZSV-15-4/723E-3 (ICSV112*WSV387), (SDS5006*WSV387) E-4, SDS-1958-1-3-2/724E-4, ELITI16/705E-7 (ICSV112*SDS3136)-20-1-1, ICSV-93010-1/708E-9, SDS 2302 – expressed excellent grain yield and adaptation in two years of trials. Their average yield performance was 3.0 t/ha across three environments under rain-fed conditions, which represents a yield increase of 42% when compared with the lowest yielding varieties. Performance of 17 introductions from Texas A&M University continued. The lines represent a diverse array of germplasm and represent resistant to sorghum midge, grain mold resistance, disease resistance, drought tolerance and improved adaptation. It is anticipated that suitable candidates for release will be identified following another year of testing. Performance of twenty-five sweet sorghum varieties was evaluated at three locations (Mapupulo, Namialo, Sussundenga) for two years. The germplasm was obtained from organizations outside Mozambique. In 2009/10, mean yields at Namialo and Sussundenga exceeded 2.5 t/ha. Several experimental entries exceeded 3.0 t/ha at both locations.

Plant Pathology

Sorghum germplasm obtained from the National Cultivar Trials and the INTSORMIL breeding program (Texas A&M University) are evaluated annually for adaptation and disease resistance, including foliar diseases, root rots and grain molds under southern African conditions. During 2009/2010 trials were conducted at Cedara where the environment is normally particularly conducive for disease development. INTSORMIL nurseries included during 2009/10 include the ADIN, SCA and SCAY nurseries.

Yields of entries were determined from 5 heads covered with fine mess bags to prevent bird damage. Highly significant differences in the mean grain mass per head were recorded and 10 ADIN (Table 4), 9 SCA and 6 SCAY entries proved particularly well adapted to Cedara conditions. The lines will be re-evaluated in an advanced screening nursery.

Infection of entries by plant pathogens was dependent on natural inoculum. Foliar disease development during 2009/2010 was poor and only sporadic late infection was observed. Root rot was severe and, in commercial cultivars ranged from 28 - 52 %. Root rot severity was significantly related to yield of cultivars and contributed significantly to yield reductions equivalent to 53 kg per percentage increase in root rot severity based on regression analysis. Severe lodging occurred due to root rots and lodging scored in the SCA, SCAY and ADIN (Table 4) nurseries. Similarly, grain mold ratings were high as indicated and only 8 of the 117 entries yielded grain mold ratings ≥ 2 on a 0-5 scale. These entries will be re-evaluated during 2010/11 to determine the stability of the less susceptible response and to compare mycotoxin levels in these entries with more severely infected grains.

Germplasm data collected over seasons is being pooled and used to determine the reliability of screening data and the stability of disease responses over seasons. Lines and cultivars submitted to the evaluation trials vary from year to year as new entries are added and older or poorer genotypes are removed. This results in missing data for multi-season evaluations. Seasonal data trends were modelled and missing data estimates were generated by Residual Maximum Likelihood Analysis (REML, Genstat 4.3, IACR-Rothamsted, Harpenden, Hertfordshire). REML, introduced by Patterson and Thompson (1971), provides efficient estimates of treatment effects in unbalanced designs with more than one source of error. Data are being analysed using Analysis of Variance and the Additive Main Effects and Multiplicative Interaction Model (AMMI) (Genstat 4.3). Analyses for Grain molds have been completed and prepared for publication.

Analyses of variance for cultivar multi-season reactions to leaf blight, anthracnose, root rots and lodging and line evaluations for grain mold severity according to the best AMMI fit showed that the effects of genotype, environment and GxE interaction on disease severity were highly significant. Variance components based on sums of squares indicate that the effects of genotype, environment and GxE interaction are respectively 31.2 %, 13.6 % and 23.2 % for cultivar response to leaf blight, 55.4 %, 17.3 % and 11.1 % to anthracnose, 30.2 %, 30.4% and 6.8 % to lodging and 15.1, 70.5, and 9.1 to root rots. The effects of genotype, environment and GxE interaction for line responses to grain molds are respectively 28.8 %, 49.1 % and 8.36 %. Environment was clearly the primary influence on grain mold, root rot and lodging severity with genetic components having a considerably smaller effect on the recorded variation. In contrast results for leaf blight and anthracnose show lower environmental effects implying that, with exception, results from a single screening may be regarded as a reliable indication of cultivar response to these diseases. The results of grain molds and root rots, on the other hand are consistent with numerous studies and explain why progress in the selection of stable resistance is slow.

The ability of *Fusarium* spp. to produce mycotoxins that have detrimental health effects for both humans and animals make it 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 harbour high fumonisin producing Fusarium species.

An unidentified new *Fusarium* species isolated from sorghum and millet needed further investigation and their toxin profiles determined. All the tested isolates produced FUM levels ranging from very low (1 mg/kg) to very high (6020 mg/kg) in the culture materials used, irrespective from which grain they were originally isolated. The control (MRC 826), a known high FUM producer, produced the highest levels, i.e. 13624 mg/kg on maize patties, and somewhat lower levels on white (8102 mg/kg) and red sorghum (7546 mg/kg) patties. FUM levels on millet patties were higher (9088 mg/kg) than those produced on sorghum patties by this control. *F. proliferatum* isolates originating from either maize or sorghum that produced higher levels of FUM (766-4020 mg/kg) in maize patties produced even higher FUM levels in white (up to 5069 mg/kg) and red sorghum (up to 6478 mg/kg). The unidentified *Fusarium* isolate originally from millet turned out to be a relatively low FUM producer on all the grain media tested (3-43 mg/kg). Six of the ten isolates originally isolated from maize did not produce MON. Generally higher levels of MON were produced on white sorghum (31-5427 mg/kg), red sorghum (7-6110 mg/kg) and millet (10-8892 mg/g) than on maize patty cultures (2-6102 mg/kg). The unidentified *Fusarium* sp., originally from millet (MRC 8723), produced extremely high MON levels (144400 mg/kg) in maize patties, slightly lower in red sorghum patties (124500 mg/kg), but much higher levels were detected in white sorghum (222400 mg/kg) and millet patty (184000 mg/kg) cultures. The MON control (MRC 8279) produced relatively high MON levels in maize patties (33100 mg/kg.

There are variations in the potential or ability of *F. proliferatum* isolates to produce either FUM or MON. By growing these isolates on various grain media, those with the potential to produce either toxin tended to produce higher levels on white sorghum (a trend more marked for FUM than for MON) than on any of the other grain media. This indicates that these fungi can use grains as a source for toxin production irrespective of their original hosts. Also, new and unidentified *Fusarium* species can occur on sorghum and millet and have the ability to produce large quantities of toxins under conducive conditions, but several aspects of the strains need to be studied further.

Publications

Developments in our understanding of sorghum polysaccharides and their health benefits. Taylor, J.R.N. and Emmambux, M.N.

Table 4. Evaluation of ADIN nursery for grain mold and adaptability at Cedara, South Africa: 2009-2010

Entry	Pedigree	Plant color†	Grain color‡	Grain mold§	Grain mass per head	Lodging	Flag Leaf height	Head height	Uniformity¶
					g	%	m	m	
1	IS12555 der./SC35-6/Durra	P	LY	4.0	33.2	3	0.6	1.0	1
2	IS3758 der./Nigricans	P	W	3.3	51.3	0	0.6	0.8	1
3	IS2508 der./CauKaf	P	W	3.5	34.8	2.5	0.6	0.8	1
4	(R5646*SC326-6)	T	W	2.5	43.7	0	0.6	0.8	1
5	Sooty, Stripe Res.	T	W	2.0	39.3	12.5	1.1	1.5	1
6	Macia	T	W	3.5	45.8	7.5	1.3	1.7	1
7	(MR63/(Tx430*MR6)*Tx2766)	P	W	3.0	34.7	1	0.6	0.8	1
8	(SC719-11E*SC630-11E)-1-3/92B1941	P	R	2.5	25.8	7	0.6	1.3	3
9	Mali Pop der. Headbug Res.	T	W	2.0	30.5	25	1.3	1.5	1.5
10	Striga Res.	T	LY	3.0	38.6	0	0.8	1.1	3
11	((SC423*CS3541)*E35-1)-1-2/M62650/VG146	T	W	3.0	35.1	0	1.6	1.8	1
12	((SC120*Tx7000)*Tx7000)-10-4-6/R8505	T	W	3.0	47.2	3	0.6	1.1	1
13	(SC110 der.*Capbam)	P	R	3.5	28.1	9	0.8	1.1	1
14	B.Var,B.Var1,BVG1	T	W	2.0	30.9	0	1.1	1.5	1
15	(BTx3197*SC170-6)	RP	W	3.3	22.0	0	1.1	1.5	1
16	(BTx378*SC110-9)*BTx631)-4-3-4	T	W	3.5	37.6	4.5	1.3	1.7	1
17	(Tx2536*SC170-6)	P	W_YE	3.0	38.9	8	0.6	0.8	1
18	IS110 der.,IS12610 der.,Zerazera	P	W	1.5	40.9	1.5	0.6	0.9	1
19	IS415,Combine 7078	P	R	4.0	27.8	3	0.6	0.9	1
20	IS413,Redlan	P	R	4.5	37.7	13	0.8	1.1	1
21	(86EO361*90EON343)-HD12-	T	W	3.5	48.8	13	0.9	0.9	1
22	(B1*BTx635)-HF14-	T	W	3.0	33.3	2	0.6	1.1	1
23	(B.BON34*B9502)-LD6wxy	T	W	4.3	26.5	0	0.6	1.1	1
24	(Macia*Dorado)-HD12	T	W	4.3	54.0	0	0.8	1.3	1
25	(Tx2862*(Tx2868*PI55607))-LG35	T	R	3.5	33.2	6	0.6	1.1	1
26	96GCPOBS124/GR134B-LG56-BG1-L2-BG1-LGBK	T	R	3.0	25.4	0	0.8	1.1	1
27	(91BE7414/(R8505*(R5646*SC326-6))*GR107-90M18)-LG51	T	W	2.5	31.1	3.5	0.8	1.1	1
28	(91BE146*Tx2864)-LG12	T	W	4.0	31.5	0	0.6	1.3	1
29	(6OB124*((Tx2862*(Tx2868*PI550607))-LG53-LG3))-LG5-LG1-CG2-CG1	T	R	3.0	20.0	16	0.6	1.4	3

Table 4. – cont'd Evaluation of ADIN nursery for grain mold and adaptability at Cedara, South Africa: 2009-2010

Entry	Pedigree	Plant color†	Grain color‡	Grain mold§	Grain mass per head	Lodging	Flag Leaf height	Head height	Uniformity¶
30	(Tx631*GB102B)	T	W	2.0	39.6	0	0.6	1.3	1
31	(Tx2783*SRN39)	T	W	2.5	24.9	0	0.6	1.3	1
32	(Tx436*(Tx2794*(Tx2864*(Tx436*(Tx2864*PI550607)))))-PR1-LG6-CG1-CG2-CG1-CG1	T	W	3.5	13.5	0	0.6	1.3	2
33	(Tx436*(Tx2862*(GR107-90M17*(Tx2783*PI550607)))-PR8-PR1)-LG5-CG2-LGBK	T	R	3.0	27.3	2	0.6	0.9	1
34	(Tx2880*(86EO361*(Tx2880*PI550507)))-PC3-PR11-LG13-CG1-LG2-CG1-LGBK-BGBK-CG2-LG1	T	W	2.5	31.8	1.5	0.6	1.1	1
35	(Tegemeo*Tx2783)-HW5-CA1	T	W	2.5	52.7	1	0.6	1.1	2
36	((88C445*Tx2862)-HG62-BG2-CG3*RTx430)-CS1-CA2-CS1	T	R	2.5	30.9	2.5	0.6	1.1	1
37	(RTX437*R9117)-CS7-CS4-BE1	T	R	3.3	37.3	4.5	0.8	1.4	1
38	(96GCPOBS124*PI851171)-CS3-CS1	T	R	4.0	24.0	0	0.6	0.8	1
39	(RTx2919*SURENO)-LB1-CS2	T	W	3.0	28.6	7.5	0.6	0.6	1
40	(BTX635*(ATX623/3/*SPROPINQUEM)*RTX430)-CS2-CA1	T	W	3.0	19.4	36	0.6	0.6	1
41	(BHF14/DLON357)-Hdop-BE1-LB3	T	W	3.0	18.2	0	0.8	1.1	1
42	(BHF14/DLON357)-Hdop-BE3-LB2	P	R	3.0	45.4	3.5	0.6	1.1	2
43	(BHF14/B9501)-Hdop-BE4-LB1	T	R	2.5	22.9	16.5	0.6	1.1	1
44	((BTX630*BTX629)-B3-B1-T1-T2*BTX635)-B6-B1-B1-BE2	T	W	3.5	22.5	0	0.6	0.9	1
45	(B01720-1/Australia*B9306)-CS8-CS2-BE1	P	DR	2.0	53.8	8.5	0.8	1.3	1
46	(B1*BTx635)-L7-CCBK-BE1	T	W	3.0	32.9	0	0.8	1.1	1
47	(B807*BTx631)-CS6-CS1-BE1	P	W	3.3	47.5	0	0.8	1.1	1
48	(B9411*B807)-CS4-CA2-CS1	T	R	2.5	31.8	1	0.8	1.1	1
49	(B155*BTx399)-C6-C2-T9-L3-C2-C3-C3-C3-CS2-CS4	T	W	2.5	32.6	0	0.6	1.1	1
50	(BTX635*(BTX623(bmr)*BTXARG-1)-F1)-CS1-PR1-CS2	T	W	2.5	16.9	0	0.6	0.8	1
LSD (P>0.05)				1.1	12.8	24.6	0.16	0.7	-

†P=purple, RP=reddish purple, T=tan.
‡R=red, DR=dark red, W=white, LY=lemon yellow, YE=yellow endosperm.
§Rated on a scale of 1=no grain mold to 5=grain completely covered with grain mold and some deterioration.
¶Rated on a scale of 1=very uniform to 5=very uneven for height

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

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Regional Program Description

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, 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 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.

Mamourou Diourté from Mali coordinated the production component of the regional project"Increasing farmers' and processors' incomes via improvement in sorghum, pearl millet, and other grain production, processing, and marketing systems". 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 options. They are educating farmers how to manage storage disease and insects through grain harvesting and storage practices. They are developing cultivars of sorghum and millet with adaptation, 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.

Hamidou Traoré from Burkina Faso coordinated the regional project "Integrated *Striga* and nutrient management for sorghum and pearl millet". Involved are Mountaga Kayentao from Mali, Nouri Maman and Souley Soumana from Niger, and Moctar Wade from Senegal. Goals are 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.

Ababacar N'Doye from Senegal coordinates the processing and marketing systems component of the regional project "Increasing farmers' and processors' incomes via improvement in sorghum, pearl millet, and other grain production, processing, and marketing systems." The processing and marketing sub-project involves food scientists Boniface Bougouma from Burkina Faso, Moussa Moustapha from Niger, and Iro Nkama from Nigeria, Yara Kouressi from Mali, Ababacar N'Doye from Senegal, 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 expand 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 are 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 breads and other products based on sorghum and millet were transferred; local processing groups were assisted to disseminate new technologies and initiate businesses; and sorghum and millet are being characterized as "functional foods" for health. The goal is to have competitive composite flour and other products in the marketplace. 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 USAID Mali Mission and directed by John Sanders and Bruce Hamaker provided collaborative assistance with production and marketing aspects of the West Africa regional program.

Sorghum/Millet Constraints Researched

Teams of scientists, extension educators, and farmers in Burkina Faso, Mali, Niger, Nigeria, and Senegal are developing, evaluating, and transferring technologies to improve production and marketing of sorghum and millet and to manage *Striga*. Sorghum and millet, the staple foods of people in Sub-Saharan Africa, suffer yield loss because of poor soil fertility, scarce and erratic rainfall, warm temperature, and insect, disease, and weed pests such as *Striga*. FAO estimates $7 billion annual crop losses from *Striga* that affects 100 million people in Africa. Other major 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. Cultivars of sorghum and millet with adaptation, stability, and acceptability and 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 diseases, insects, and *Striga* 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 lines and hybrids are advancing. Enhanced urban markets need to be developed for farmers to sell surplus sorghum and millet grain. Processed quality products such as competitive composite flour and precooked agglomerated foods will contribute to development of markets for sorghum and millet along with transfer of technologies to entrepreneurs to initiate businesses. Research on nutritional and health value of sorghum and millet can be used to promote them for urban buyers. Use of sorghum in poultry feed in West Africa was validated and education provided on availability of low-tannin varieties. 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 to increase farm incomes and agricultural development.

Institution Building

Sorghum and millet scientists who worked in West Africa during the year included food scientist Bruce Hamaker, animal scientist Joe Hancock, entomologist Bonnie Pendleton, plant breeder Mitch Tuinstra, agronomists Vara Prasad and Scott Staggenborg, economist John Sanders, and Short Heinrichs. Graduate degree training is ongoing through the INTSORMIL USAID-Mali Production-Marketing program for five students at Purdue, Kansas State, and Mississippi State universities.

Individual projects also led to institution building. At INRAN, Niger activities at the cereal processing incubation center resulted in a participating entrepreneur, Mme. Liman to obtain a loan to establish her own mechanized processing unit that now consists of 1 decorticator, 1 hammer mill, 1 couscous agglomerator, couscoussier, 3 solar dryers, and 2 packaging machines. Additionally, each of 10 women processors' groups was equipped with 1-2 solar dryers reproduced from the incubation unit at INRAN, 1 packaging machine, and couscousier, plastics, storage box, spoons, and pots to make couscous. Ten women processors' associations of 15-30 members were trained to make biscuits and cookies with 50% improved sorghum and millet grains, December 2009, INRAN, Niamey, Niger. At University of Maiduguri in Nigeria, a grain roaster, oven, grain dehuller, and grinding machine were purchased/constructed and installed through INTSORMIL assistance for training 10 small- to medium-scale entrepreneurs in Nigeria. Seven rural women, two men, and a Trainer of Trainees coordinated by Iro Nkama were trained and two small-scale value-added product enterprises established in two localities on behalf of the Community Based Agricultural and Rural Development Program, Yobe State, in Partnership with Intellectual Property and Technology Transfer Office of the University in Nigeria. Products processed included weaning foods, biscuits, couscous, and dakuwa (snack food like chocolate). Women processors' associations also received training in food safety and hygiene management.

Two color posters in French produced by Niamoye Diarisso and Bonnie Pendleton to identify and manage insects of stored grain were distributed to hundreds of farmers in villages in Mali.

Salissou Issa from Niger defended his dissertation and graduated in December 2009 with a Ph.D. in Animal Science from Kansas State University. Students trained through the West Africa poultry project were Emilie Sabine (Senegal, M.S.), Kigabagoui Adah (Mali, M.S.), Pierre Paul Sanon (Burkina Faso, M.S.), Hamani Bachir and Korombe Amza (Niger, B.S.), and Ibrahim D. Kwrari (Nigeria, Ph.D.). Hame Abdou Kadi Kadi collaborated with Dr. Kadri Aboubacar, Agronomie, Université Abdou Moumouni de Niamey, Niger, to supervise internships of seven students in pest management. In Nigeria, 1 Ph.D. and 2 M.S. graduates and more than 15 undergraduate students assisted and were trained through INTSORMIL. The Ph.D. program of Amina Jato from the Department of Food Science and Technology, University of Maiduguri, was supported in part by INTSORMIL. Adama Sanou, a student of Rural Development Institute of University of Bobo-Dioulasso, Burkina Faso, is earning his degree with INTSORMIL assistance in agricultural engineering. He is evaluating in laboratory, greenhouse, and field at Kouaré 15 sorghum varieties from the region.

Networking

Workshops and Meetings

Approximately 45 host-country and U.S. scientists participated in a biennial all-PI meeting for the West Africa program in Ouagadougou, Burkina Faso May 19 to 21, 2010. The purpose was to share results and plan regional project activities, including those of a new regional technology transfer project awarded through the INTSORMIL ME.

Participatory exchange/meetings were held for farmers, processors, scientists, farmers, private NGOs, and extension on adoption of sorghum and millet grain and processing technologies in Niger. Salissou Issa and Joe Hancock had meetings and visits in Senegal, Mali, Burkina Faso, Niger, and Nigeria to share with the West Africa poultry industry use of sorghum in poultry diets and how to reduce heat stress in poultry houses. An INTSORMIL USAID-Mali Production-Marketing workshop was held in Bamako in November to bring together producers and processors for discussions on the value-chain and contracting for quality grain from farmers. A Poultry Workshop was held in Ouagadougou on May following the all-PI meeting in collaboration with Ouendeba Botorou and National Project for Rural/Family Poultry Development in Burkina Faso; and Poultry Workshop was held in Niamey at the ICRISAT Training Center in the same month in collaboration with INRAN and Niamey University. Presented during the workshops were state of the poultry industry in Burkina Faso, Mali, Niger, Nigeria, and Senegal; INTSORMIL regional marketing; INTSORMIL poultry project; biosecurity on farm; poultry nutrition and heat stress. The workshop ended with a farm visit at the University of Niamey. During a visit by J. Hancock to Maiduguri, Nigeria, scientists, laboratories, farms, and a feed mill at the departments of animal science and food science at the university were visited. For the future poultry research program, training for two MS and one Ph.D. students in feed technology were discussed.

I. Nkama, M. Diarra, and A. Jato attended the Nigerian Institute of Food Science and Technology Annual Conference in Yola, Adamwa State, from October 12-16 and presented two talks on INTSORMIL-funded projects 'Proximate composition of some pearl millet hybrids and their couscous production potential' and 'In- vitro carbohydrate digestibility of some pearl millet hybids and couscous produced from them'.

Research Information Exchange

Networking with other projects funded by McKnight foundation, Sinergie, Afrique Verte, Alliance for Green Revolution in Africa (AGRA), Sasakawa Global 2000, and ICRISAT/HOPE-Gates Foundation were initiated to facilitate and reinforce activities on technology transfer of sorghum and millet processed products. In Niger, farmers were trained on production of improved sorghum varieties in Niger; were provided seeds, fertilizer, and advice at each stage of crop development; and were linked with entrepreneur food processors to contract and sell. Demonstration plots of tied-ridge technology were grown in Tillabery, Niger. In Niger, 80 farmers, eight extension agents, and seven interns were trained to identify and control insect pests of stored sorghum and millet. Sixty farmers at Tounfafi, Niger were taught to identify and control insects on sorghum in the field. *Striga* management strategies were introduced to 298 farmers in 15 communities in Senegal.

Exchange of experience in procurement of appropriate processing equipment and potential for planning joint marketing of sorghum and millet products was organized in March between leading processing entrepreneurs from Niger and Burkina Faso. Salissou Issa visited the layer, broiler, and day-old chick production units of Labo Farm, the largest poultry farm in Niger where sorghum is used in diets, and recommended improvements for production and profitability.

Germplasm Distribution

Seeds of *Striga*-resistant F2-20 were given to 250 farmers in Senegal. Improved sorghum varieties were distributed in Niger: IRAT204 in Tillabery; Sepon82 and 90SN7 in Dosso; SSD35, 90SN7, and IRAT204 in Tahoua; and Sepon82, SSD35, S35, and 90SN7 in Maradi. Sorghum midge-resistant SSD-35 and early maturing Mota Maradi sorghum were given to 238 farmers in 14 villages of Madaoua and Birni N'Konni, Niger.

Research Accomplishments

Note: activities are reported under the three regional projects operating in the INTSORMIL West Africa program, and under direction of the corresponding three project leaders (identified above).

Project 1. "Integrated Striga Management in Sorghum and Pearl Millet in West Africa"

An integrated *Striga* management system for guinea sorghum and non-guinea zones of West Africa is being developed and transferred. Effects of herbicide seed treatments on crop performance and *Striga* management were determined at Kamboinse, Burkina Faso; Sotuba and Samanko, Mali; Konni, Niger; and Bambey, Senegal. Two ALS herbicide-tolerant, food-grade sorghums and one susceptible were evaluated in replicated experiments with four metsulfuron methyl seed treatments in *Striga*-infested plots. A randomized complete block design with three replications was used. The treatments were evaluated in single row plots (3 x 1.6 m). Sorghum was planted with 10 seeds per hill and infested with *Striga* seeds at planting. Traits measured in each plot included day until *Striga* emergence, *Striga* plants at 60 and 90 days, and time to 50% sorghum flowering (Table 1). Although not significantly different, *Striga* emerged first on Sariaso9 44.3 days after planting and last on SRN39 at 62.3 days. Although not significantly different, numbers of *Striga* were least on Mota Galmi and greatest on Sariaso9, F2-20, CSM388, Sariaso14, and CEF322/35-1-2 (>100 plants/plot). Yield of straw of Sariaso14 was 6,528 kg/ha. Weight of grain ranged from 1,208 for ICSV1049 to 417 kg/ha for F2-20.

An agar gel technique was used to determine maximum germination distance 48 and 96 hours after infestation by *Striga* seeds collected from sorghum from different countries. SL246, SRN39, and Brhan sorghums were most resistant to *Striga* (Table 2).

Ndiaga Cisse in Senegal observed 48 *Striga* plants/m2 in 2009 compared to 32 in 2008 after two successive millet plantings (continuous millet). Symptoms of damage by *Striga* were severe. In plots with integrated management (2.5 tons/ha of sheep or goat manure + 150 kg/ha NPK + 100kg/ha of urea + mechanical weeding 15, 35, and 65 days after planting), the number of emerged *Striga* plants decreased to 4 per m2 from 11 per m2 in 2008. Treat-

Table 1. 2010 *Striga* trial data from Burkina Faso.

Sorghum at Kouaré, Burkina	1st Striga DAS	Striga 60 DAS	Striga 90 DAS	Days to 50% flowering	Plants harvested	Kg/ha dry straw	Kg/ha grain
Sariaso9	44.3	14.7	138.0	84.0 a-d	12.3 b-d	3472	889
F2-20	59.0	7.0	132.7	85.3 a-c	10.0 de	4028	417
CSM388	49.7	2.0	115.0	87.0 ab	14.3 a-c	3889	1153
Sariaso14	53.7	8.0	114.3	78.3 ef	13.7 a-d	6528	792
CEF322/35-1-2	47.7	9.3	110.3	87.7 a	5.3 f	1805	431
SL-246	51.7	5.0	95.0	75.3 f	16.7 a	4305	667
Lina3	45.7	8.7	94.0	89.0 a	12.7 a-d	5565	694
Wassa	49.3	6.3	93.0	86.7 ab	14.3 a-c	2917	569
Seguetana	47.3	2.0	84.0	81.7 b-e	16.0 ab	5695	986
CE145-66-V	53.0	3.3	70.3	79.0 d-f	13.7 a-d	4167	1083
ICSV1049	59.7	1.0	37.7	80.0 c-f	6.7 ef	5833	1208
Malisor92-1	59.0	1.3	28.0	77.3 ef	5.7 f	5000	486
SRN39	62.3	2.0	27.3	76.0 f	10.7 c-e	4028	778
Mota Galmi	56.3	1.7	22.0	69.7 g	5.7 f	1389	625
Brhan	58.3	1.0	16.3	78.3 ef	5.7 f	2778	667
Mean	53.1	4.9	78.5	81.0	10.9	4092	755
Standard Error	1.6	1.087	10.89	0.9	0.7	96.6	13.3

Table 2. Maximum germination distance at 48 and 96 hours.

Sorghum			Germination distance (cm) of Striga seed from different countries			
			48 hours			96 hours
Variety	Origin	Resistance	Kouaré, Burkina Faso	Sotuba, Mali	Konni, Niger	Konni, Niger
SL246	Senegal	Tolerant	0.00	0.00	0.00	0.00
SRN39	Niger	Resistant	0.02	0.00	0.08	0.00
Brhan	Niger	Resistant	0.13	0.00	0.03	0.17
Seguetana	Mali	Tolerant	0.11	0.05	0.05	0.35
CSM388	Mali	Susceptible	0.34	0.12	0.28	0.35
ICSV1049	Burkina Faso	Resistant	0.10	0.00	0.22	0.43
Sariaso9	Burkina Faso	Susceptible	0.35	0.08	0.07	0.28
CE145-66V	Senegal	Resistant	0.46	0.00	0.08	0.25
Mota Galmi	Niger	Susceptible	0.31	0.03	0.02	0.55
Sariaso14	Burkina Faso	Resistant	0.16	0.21	0.00	0.57
CEF322/35-1-2	Burkina Faso	Resistant	0.10	0.13	0.06	0.83
Lina3	Mali	Resistant	0.47	0.04	0.06	0.55
F2-20	Burkina Faso	Resistant	0.08	0.00	0.07	1.08
Malisor92-1	Mali	Resistant	0.27	0.08	0.11	0.98
Wassa 199	Mali	Resistant	0.39	0.02	0.16	1.42
GR24*			1.82	0.22	0.69	2.33

*Striga from Bambey, Senegal germinated 1.17 cm on GR24 ment resulted in greatest yield (1,206 kg/ha) compared to 384 kg/ha for the check. *Striga* management strategies were introduced to 298 farmers in 15 communities through a USAID development project. Seeds of *Striga*-resistant F2-20 were given to 250 farmers in Senegal.

Project 2. "Increasing Farmers' and Processors' Incomes via Improvement in Sorghum, Pearl Millet, and Other Grain Production, Processing, and Marketing Systems" Production Project

Breeding

Souley Soumana at INRAN used the pedigree method to advance F3 to F5 generations. The backcross program was continued by sterilization of L28 to develop adapted A lines for hybrids. Breeder seed of improved Sepon82, IRAT204, 90SN from 1 to 7, SSD35, Sureno, Macia, S35, NE223AB, 150AB, 12AB, and 3009AB was increased and spread through Niger (Figure 1): IRAT204 in Tillabery; Sepon82 and 90SN7 in Dosso; SSD35, 90SN7, and IRAT204 in Tahoua; and Sepon82, SSD35, S35, and 90SN7 in Maradi. Six farmers were trained on crop production for improved varieties and linked with entrepreneur food processors to contract and sell products.

Figure 1. A farmer's field with 100 hectares of improved Sepon82 sorghum 90 km from Niamey, Niger

Ndiaga Cisse found S-644-2, S-618-1, and S-658 sorghums yielded well in the northern zone of Senegal. S-622-1 and S-621-2 were most productive and preferred by farmers in central zones. The sorghums yielded more than 2 tons per hectare in farmers' fields. The lines as varieties will soon be released. Seed will be multiplied and distributed in 2011.

Abocar Oumar Touré and Abdoulaye G. Diallo planted 30 F2 progeny lines, 114 F3 progeny lines, and 466 F5 progeny lines in Mali. They are testing adaptability and yield potential of advanced breeding lines in different agroecological zones. Sixty-five early-maturing lines are being tested at Béma and Cinzana, 91 intermediate at Kolombada and Sotuba, and 90 late-maturing lines at Kebila, Kita, and Farako. The crops are not yet ready to harvest.

Niaba Temé in Mali has been developing four sorghum populations for stay green, grain quality, and resistance to *Striga*. The populations were at BC1F2 level for stay green introgression and F2 for resistance to *Striga*. Transfer of stay green and grain quality is through backcross, marker-assisted selection, and evaluation in the field. Parents for stay green were B35 and Tiandougou while the donor for grain quality was CSM63E. Pedigrees of populations for stay green or grain quality introgression were Tiandougou x (Tiandougou x CSM63E) = stay green and grain quality; CE151 x (Tiandougou x CE151) = stay green; B35 x (CSM63E x B35) = stay green and grain quality. Resistance to *Striga* was from Seguetana CZ. The pedigree for *Striga* resistance was CSM219E x Seguetana CZ. The sorghums will be evaluated in the field in 2011, while the marker study will be done when the new Biotechnology Laboratory is functional.

Ignatius Angarawai in Nigeria through collaboration with Jeff Wilson of USDA-ARS, Tifton, Georgia identified high-yielding, medium-maturing PEO5684 and PEO5532 millet selected by farmers in 12 villages each with 200 families currently put on OFAR for 2010 in 7 states of Nigeria. He generated new dual-purpose varieties, open-pollinated varieties, and hybrid parental lines adapted to Nigeria. He genotyped the stay-green mapping population for drought tolerance QTL in millet at Devos Katrein's Laboratory, University of Georgia, and lines were phenotyped at Tifton, Georgia. He identified PS563 monodii as a source of *Striga* resistance to improve Ex-Borno. Lake Chad Research Institute identified Alh Kamisu as the farmer entrepreneur of Dazigau Nangere Local Government through Yobe State CBARDP to grow and sell improved varieties to food and feed processors in local and regional markets. The farmer grew 6 hectares of popular LCICMV-1 millet, also known as SOSAT-C88.

Agronomy

At Sotuba, Mali, Abdoul Wahab Touré evaluated optimal plant population, fertilizer rates, and planting dates for tan sorghums. A strip-plot design with four blocks was used. Plant populations 0.75 x 0.50 m - 2 plants per hill 53,333 plants/ha, 0.75 x 0.50 m - 3 plants per hill 79,999 plants/ha, 0.75 x 0.25 m - 2 plants per hill 106,666 plants/ha, 0.50 x 0.40 m - 1 plant per hill 50,000 plants ha, 0.50 x 0.40 m - 2 plants per hill 100,000 plants ha, and 0.50 x 0.40 m - 3 plants per hill 150,000 plants/ha were used. CSM388 (check), Séguifa, Tiandougou, and Niatichama were used. Twenty-four treatments were in each block. Fertilizer was 100 kg/ha of diammoniac phosphate at planting and 50 kg/ha of urea 30-40 days after planting. Harvested plant population averaged 46,365 per hectare; most was 64,684 and least 21,111 per hectare. Compared to recommended (53,333 plants per ha), CSM388 (local), Séguifa (improved), and Tiandougou (improved) had 53,889, 49,537, and 40,663 plants per hectare. Tiandougou and Niatichama (improved) had plant populations less than 50,000 per hectare. Tiandougou yielded 2,000 kg/ha. Varieties were grouped into classes of yield <2,000 kg/ha and plants <50,000 per hectare, and yield >2,000 kg/ha and >50,000 plants per hectare. Regression analysis of harvested plants on yield produced the equation: yield (kg/ha) = 0.02295 * number of stalks + 937.49 ($R2 = 31.8$). A change of 10,000 in plant population will lead to 230 kg/ha more of yield.

In Niger, Seyni Sirifi coordinated demonstrations of millet technology developed through INRAN/INTSORMIL for poor sandy soil continuously planted with millet by 10 farmers in Dallol Bosso region in Harikanassou area. Improved technology combined NPK microdose (6g/hill) seeded with millet, 20 units/ha phosphorus, and 30 units/ha nitrogen. Only a few plots have been harvested but the improved method yielded more grain and stover than the traditional. The demonstration impacted the region, with several thousand farmers wanting to adopt the new technology on several thousand hectares, and will increase millet productivity in most of Niger.

An integrated millet-cowpea system was studies at Kollo, Niger. Rotation, intercropping, strip cropping, and continuous cropping and low, medium1, medium2, and high amounts of mineral fertilizers were used with HKP millet and TN5-78 cowpea planted on 30 July and 12 August. Plant stands were not good for millet but were for cowpea. Crops are not harvested yet. Seyni Sirifi demonstrated tied-ridge technology developed with assistance through INTSORMIL from studies of seedbed preparation in different agroecological zones in Niger. Five demonstration plots were installed in Tillabery region. Germination, establishment, and yield were better in plots with tied-ridge improved technology compared to the traditional. A field day for farmers, rural development organizations, political and traditional leaders, researchers, and media showed the usefulness of tied-ridge technology, and all farmers attending wanted to adopt.

Plant Protection

In Niger, Hame Abdou Kadi Kadi helped introduce sorghum midge-resistant SSD-35 and early maturing Mota Maradi sorghum to farmers in 14 villages of Madaoua and Birni N'Konni regions (Table 3). Involved were 72 farmers and a farmer organization of 74 men and six women. Twenty farmers were surveyed for acceptance of SSD-35. Farmers, a farmer association, private seed producers, and INRAN Seed Unit are multiplying seed of SSD-35 for farmers, farmer groups, projects, and institutions. With use of SSD-35, yield can be improved to 1,200 kg/ha, 24.4-46.8% over El Mota. At INRAN Konni Station, cost to produce seed on 1 hectare is 355 000 FRS CFA ($700). If 1 kg of seed is sold for 500 FRS CFA ($1), the price for 1,200 kg would be 600 000 FRS CFA ($1,200), a benefit of 245 000 FRS CFA ($490) per hectare.

In Mali, Mamourou Diourté found leaf anthracnose caused by Colletotrichum graminicola to be the most destructive disease of sorghum at Sotuba, Mali. The objective of the rating was to ascertain the susceptibility to the disease under natural conditions in three advanced breeding experiments, GI-DT (42 lines and 3 checks), GII-DT (20 lines and 5 checks), and GIII-DT (15 lines and 4 checks). All 42 breeding lines in GI-DT scored 2 (scale 1-9) and were not susceptible. In GII-DT, the new breeding lines 08KOF5DT-45, 08KOF5DT-70, and 08KOF5DT-81 had the same score as resistant checks Grinkan, Nietichama, and Darellken. In GIII-DT, only breeding line 07KOF5DT-57 of 15 scored was resistant to anthracnose.

Niamoye Yaro Diarisso and Mamourou Diourté set up an experiment in Mali to secure production and conservation of sorghum seeds to meet needs of farmers in the INTSORMIL regional project (Table 4). In general, grain of improved sorghums used by farmers in the project if not stored properly is destroyed by insect pests before time to sell. When sorghum is harvested this fall, grain will be dried, cleaned, and stored in plastic barrels for 6 months to protect against pests such as lesser grain borer, meal moth, and mites. Storage pests will be monitored before the start of planting in 2011. Training including posters on grain conservation following guidelines by INTSORMIL entomologists will continue before planting at Koutiala.

In Niger, grain storage experiments were also carried out. Through Hame Abdou Kadi Kadi, 16 extension agents, and four interns from Agronomie, Université Abdou Moumouni, Niamey, surveyed 280 men and 40 women farmers on storage insects of millet and sorghum and control. During the study, 80 farmers, eight extension agents, and seven interns were trained how to identify and control insects of millet and sorghum.

Table 3. Transfer of sorghum midge-resistant variety SSD-35.

Madaoua and Birni N'Konni, Niger, 2008-10	Variety tested	No. farmers	Hectares
Adoption (14 villages)	SSD-35	156	76
	Mota Maradi	82	48
Seed production (10 villages – SSD-35, and 6 villages – Mota Maradi	SSD-35	115	98
	Mota Maradi	32	22

Table 4. Production of improved sorghum seed for storage study in Mali.

Improved sorghum variety	Location in Mali	Number of farmers	Hectares	Planting date
Tiandougou	Koulikoro	14	9.25	9-20 July
Tiandougou	Yanfolila	5	1.5	5-22 July
Tiandougou	Beleco	4	1.0	10-27 July
Tiandougou	Koutiala	8	6.5	5-22 July
Tiandougou	Kolokani	1	0.5	5-22 July
Tiandougou coura	Yanfolila	4	3.75	9-20 July
Grinkan	Yanfolila	4	3.0	9-20 July

Table 5. Niger survey results on sorghum insects and their control.

Insect pests farmers said attacked sorghum	% respondents	Plant stage	% respondents	Period
Termites	100.0	Storage	100.0	--
Oedaleus senegalensis	100.0	Boot-grain fill	86.6	Morning-afternoon
Poophilus sp.	93.3	Boot	93.3	1200-1400 hours
Schistocerca gregaria	60.0	Boot-grain fill	60.0	Morning-afternoon
Stenodiplosis sorghicola	33.3	Panicle-flower	33.3	Afternoon
Spilostethus sp.	26.7	Grain fill	26.6	1800-0900 hours
Mylabrys	26.6	Flower	26.6	1800-0900 hours
Spodoptera exempta	20.0	Boot	20.0	Afternoon
Spodoptera frugiperda	20.0	Boot	20.0	Afternoon
Heliothis armigera	20.0	Panicle	20.0	Afternoon
Helicoverpa zea	13.3	Panicle	13.3	Afternoon
Ants	13.3	Storage	13.3	--
Amsacta albistriga	6.7	Early development-boot	6.6	Afternoon

Sixty farmers at Tounfafi, Madaoua, Niger were surveyed on knowledge of sorghum insects and control (Table 5). Visits to fields verified their answers. Data were discussed and validated at a village assembly. All farmers said termites attacked sorghum in storage and the grasshopper Oedaleus senegalensis damaged sorghum in the morning and afternoon from booting to grain-filling. Few farmers (33.3%) knew sorghum midge attacks during flowering.

Project 3. "Increasing Farmers' and Processors' Incomes via Improvement in Sorghum and Pearl Millet Production, Processing and Marketing Systems" Processing and Marketing Project

Food Processing

In Senegal, food scientist Ababacar N'Doye and associates (M. Gueye, I. M'Baye, J. Diedhiou, O. Sambou, N. N'Diaye, D. Traore, Y. N'Diaye, and O. Sagna) from the Institut de Technologie Alimentaire (ITA), Dakar, and food scientist N. Ndoumouya from the University of Maiduguri developed with part INTSORMIL assistance a new concept of economic millet couscous from semolina instead of traditional flour for incubation, and developed millet/peanut-based bread for school children who are lactose intolerant. Activities using the couscous line were tests for preparation of couscous from thin particles (Sankhal: semolina with particles size <1mm) of millet and maize to optimize the line set; sensory evaluation tests; incubation contracts signed with millet and maize mills based in Fatick "AGRIDEV"; and preparation of packaging for a market test of couscous from grits. Packaging was designed (Figure 2).

Promotion of dietary diversity using locally available nutritious foods is effective in low-income families to improve the quality of children's diets and, hence, their growth and development. This is especially true when children have lost performance at school because their parents did not give them enough to eat before they left home in the morning. To solve lack of school performance, milk is given to children during the morning break at 1000 hours. Because of lactose intolerance of some children, millet/peanut/wheat composite-flour bread was proposed as a solution (Figure 3). Formulation of the composite flour bread was tested.

Figure 2. Package label for new economic couscous (note INTSORMIL insignia adjacent to ITA)

Acceptability of the best bread formula developed was tested at the Dakar International Agricultural Fair. The composition of the best bread was wheat flour (85%), millet (15%), peanut (21%), fat (10%), salt (1.5%), and yeast (1.5%).

Moustapha Moussa at INRAN helped initiate partnership contracts among 13 processors and farmer entrepreneurs at Ouallam, Kollo, N'Konni, and Maradi, respectively, to grow 25 tons of SS-D35, Sepon82, and IRAT204 sorghum and HKP millet for agglomerated products, instant flour, and composite bread. A mechanical threshing machine was used to produce clean grain. Farmers, processor entrepreneurs, and INRAN scientists are defining grain-quality standards, pricing and purchasing conditions for contracting.

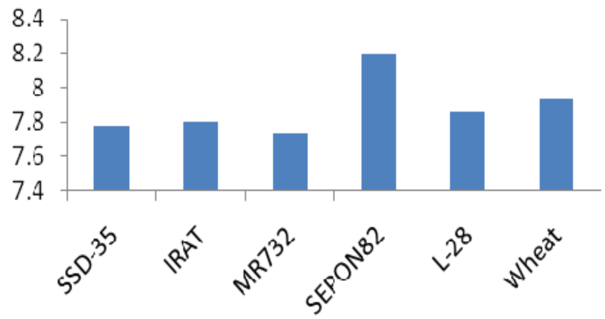

Figure 3. Sensory testing of bread containing 30% sorghum flour in Niamey, Niger, April.

The INRAN processing unit received funding from INTSORMIL and collaborating partners to purchase medium- to large-scale processing equipment (mechanical thresher to produce clean grain, gas drier, gas steamer, food mixer, pasteurizer for milk-degue, and packaging machine) to complete the INTSORMIL-assisted Incubation Center for sorghum- and millet-processing entrepreneurs. Thirteen food processor groups of 15-30 members each were trained at and used the INRAN Processing Incubation Center. After optimizing and measuring processing parameters and product quality, more than 15 tons of sorghum and millet grain were processed, mainly by entrepreneur groups, into flour and agglomerated products. Products were promoted and marketed by participating entrepreneur processor groups in more than 30 stores in Niamey and other areas of Niger. Entrepreneurs and women processors' associations making sorghum and millet foods increased to more than 20 in Niger, with more than 10 in Niamey. One entrepreneur, Mme. Liman, procured funding in the previous year to build a private unit and in this year increased by one decorticator, one hammer mill, one agglomerator, three solar dryers, two packaging machines, and two storage boxes. Mme Liman's stores for couscous and degue increased to 19. Need for grain of improved HKP and Sepon at her private enterprise for millet and sorghum foods in Niamey increased to 20 tons per year. More than 10 processor associations increased their equipment. Composite bread making was initiated with three bakeries. Acceptability of bread with 30% sorghum was tested in Niamey. Results of baking tests with improved varieties are shown in Table 6 and Figure 4.

Figure 4.

In Nigeria, food scientist Iro Nkama and millet breeder Ignatius Angarawai from Lake Chad Research Institute worked with food scientists, engineers, and technologists to prepare traditional foods and new couscous, extruded fura, weaning foods, and biscuits and test quality of the grain samples; evaluate malting prop-

Table 6. Optimum baking conditions for composite flour breads in Niger.

	Variety					
	SSD-35	**IRAT204**	**MR732**	**Sepon82**	**L-28**	**Wheat**
Temperature after mixing(°C)	22.3	25.8	21	25	25	28
Baking time(mn)	22	22	22	22	22	22
Final loaf diameter (cm)	6	6.2	6.2	6	7	7.3

Table 7. Dolo brewing results from Burkina Faso.

Titer	**pH**	**Specific gravity (g/cm^3)**
Enzymatic extract	5.37 ± 0.16	1.0685 ± 0.0024
Acid	3.91 ± 0.15	1.0297 ± 0.0125
Concentrate	3.61 ± 0.07	1.0317 ± 0.0073
Yield (liter of dolo/kg of malt)	6.65 ± 2.06	
	3 dolo makers	**Ouagadougou dolo**
Alcohol (% v/v)	4.2 ± 0.9	3.3 ± 0.9
pH	3.16 ± 0.18	3.69 ± 0.16
Acidity (g eq lactic acid/liter)	24.37 ± 6.23	6.97 ± 1.25
Specific gravity ($SG_{20/20}$) (g/ml)	1.0063 ± 0.003	1.0187 ± 0.009

erties of varieties; and test the pilot plant equipment (baking oven and groundnut roaster).

In Burkina Faso, brewing by three dolo makers was monitored and dolo compared with 56 samples from Ouagadougou (Table 7). The brewing was a single mash process. Yield was 6.65 ± 2.06 and better than brewhouse yield of 3.99 ± 0.96 liter of dolo/kg of sorghum malt. The dolo was better quality and more lactic and fermented (pH = 3.16 ± 0.18, alcohol = 4.2 ± 0.9% (v/v), and SG20/20 = 1.0063 ± 0.003 g/cm3) than samples from Ouagadougou.

In partnership with SODIGAZ (a private enterprise selling gas) 20 women brewers were trained on new dolo-brewing technology and five were equipped with gas stoves for dolo production. Their dolo was better and earned more money because of better quality and yield.

Poultry

In Burkina Faso, contacts with the Programme de Développement de l'Aviculture Villageoise and with Maison de l'Aviculture scheduled experiments using sorghum in poultry diet. Protocols were written and the experiment will be started after harvest.

In Niger, Salisou Issa used 2,000 day-old chicks (41 g) to determine effects of cereal and particle size on growth and carcass characteristics. There were 25 chicks/pen and four pens/treatment in Burkina Faso, Mali, Niger, Nigeria, and Senegal. Cobb 500 broiler chicks were used in Burkina Faso, Mali, Niger, and Senegal, and Arbor Acre broiler chicks were used in Nigeria. The check diet was maize with fish, peanut, cotton seed, and soybean meals as primary protein supplements. The diet was formulated to 1.30 and 1.07% Lys for days 0-21 and days 21-42, respectively, with other nutrients at or more than NRC recommendations. Sorghum grain replaced white maize on a wt/wt basis, and particle size was cereals ground through 6.4 versus 2-mm screen. Average daily gain and gain-to-feed ratio were greater for birds fed maize- than sorghum-based diet. Carcass characteristics were similar for birds fed maize- versus sorghum-based diet, but yield improved for birds fed grain ground through small screen size (2 mm).

Totals of 2,840 day-old broiler chicks and 450 day-old layer chicks were used to determine the nutritional value of maize- and sorghum-based diets in poultry and swine. In broiler experiments, birds fed maize had greater daily gain. Broilers fed maize- versus sorghum-based diets had similar carcass weight. Particle size did not affect growth or carcass characteristics in broilers or pigs. Layer birds fed sorghum had heavier bodies at day 126, ate more, started laying earlier, and produced more eggs than birds fed maize-based diets. There was no difference in egg weight among birds fed maize or sorghum.

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 78% of these students come from countries other than the U.S. which shows the emphasis placed on host country institutional development (Figure 1).

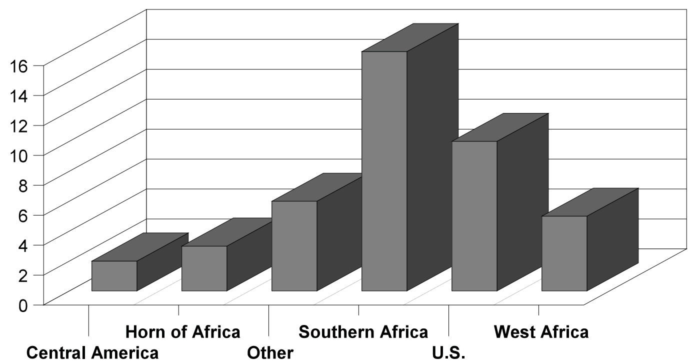

Figure 1. Degree Participants by Region

INTSORMIL also places a high priority on training women which is reflected in Figure 2. From 2009-2010, 48% of all INTSORMIL graduate participants were female. Forty-four of the 46 students received partial INTSORMIL funding and 2 received full INTSORMIL scholarships.

All 46 students worked directly with INTSORMIL principal investigators on INTSORMIL projects. These students are enrolled in graduate programs in seven disciplinary areas, agronomy, animal nutrition, breeding, economics, entomology, food science, and pathology.

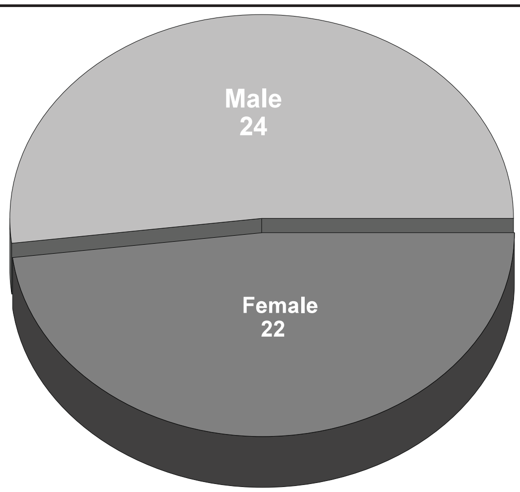

Figure 2. Degree Participants by Gender

The number of INTSORMIL funded students has decreased gradually over the years. This is related to decreases in program budget and the loss of U.S. principal investigators. In 1993-94 there were 25 U.S. PIs with the program and in 2009-2010 there were 16.

Graduate degree programs and short-term training programs have been designed and implemented on a case by case basis to suit the needs of host country scientists. Three postdoctoral scientists and 8 visiting host country scientists were provided the opportunity to upgrade their skills in this fashion from 2009-2010.

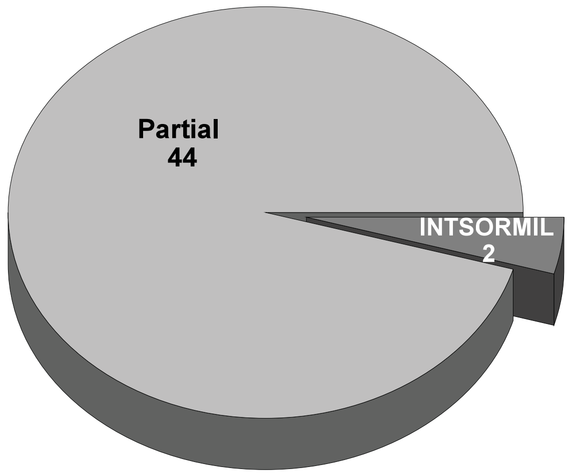

Figure 3. Degree Participants Funding

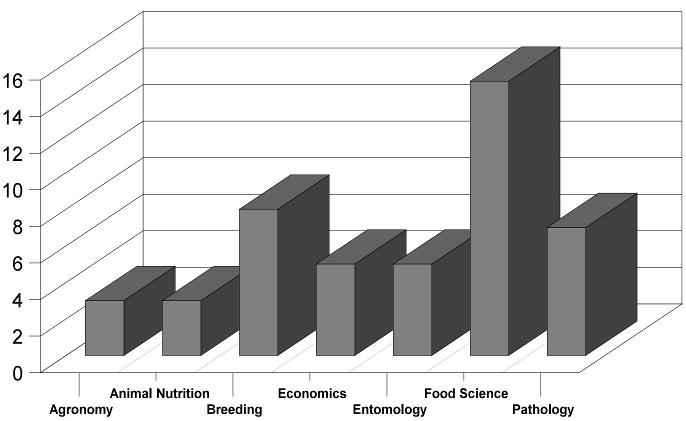

Figure 4. Degree Participants by Discipline

Year 4 INTSORMIL Degree
Training Participants
September 30, 2009 – September 29, 2010

Name	Country	Univ.	Discipline	Advisor	Degree	Gender	Funding
Liben, Feyera	Ethiopia	Haramaya U	Agronomy	Charles Wortmann	M.S.	M	P
Nansamba, Angela	Uganda	Makerere U	Agronomy	Charles Wortmann	M.S.	F	P
Maria, Ricardo	Mozambique	UNL	Agronomy	Charles Wortmann	Ph.D.	M	P
Paulik, Chad	USA	KSU	Animal Nutrition	Joe Hancock	M.S.	M	P
Williams, Scott	USA	KSU	Animal Nutrition	Joe Hancock	M.S.	M	P
Issa, Salissou	Niger	KSU	Animal Nutrition	Joe Hancock	Ph.D.	M	I
Barrero Farfan, Ivan	Colombia	PRF	Breeding	Mitch Tuinstra	M.S.	M	P
Bergsma, Benjamin	USA	PRF	Breeding	Mitch Tuinstra	M.S.	M	P
Mambwe, Sally	Zambia	UNZA	Breeding	Medson Chisi	M.S.	F	P
Corn, Rebecca	USA	TAMU	Breeding	William Rooney	Ph.D.	F	P
Limei, Liu	China	TAMU	Breeding	Jeff Wilson	Ph.D.	F	P
Muuka, F.P.	Zambia	UNZA	Breeding	Medson Chisi	Ph.D.	M	P
Packer, Dan	USA	TAMU	Breeding	William Rooney	Ph.D.	M	P
Portillo, Ostillo	Honduras	TAMU	Breeding	William Rooney	Ph.D.	M	P
Chimai, Bernadette	Zambia	OSU	Economics	Erbaugh/Larson	M.S.	F	P
Mgaya, Joseph	Tanzania	OSU	Economics	Erbaugh/Larson	M.S.	M	P
Villacis, Alexis	Ecuador	PRF	Economics	John Sanders	M.S.	M	P
Coulibaly, Jeanne	Coite d'Ivoire	PRF	Economics	John Sanders	Ph.D.	F	P
Ibrahim, Abdoulaye	Niger	PRF	Economics	John Sanders	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	I
Eder, Zachary	USA	WTAMU	Entomology	Bonnie Pendleton	M.S.	M	P
Garzon, Camilo	Colombia	WTAMU	Entomology	Bonnie Pendleton	M.S.	M	P
Vyavhare, Suhas	India	WTAMU	Entomology	Bonnie Pendleton	M.S.	M	P
Anyango, Joseph	Zimbabwe	U of Pretoria	Food Science	John Taylor	M.S.	M	P
Boswell, Sara	USA	TAMU	Food Science	Lloyd Rooney	M.S.	F	P
Burger, Jean-Marie	South Africa	U of Pretoria	Food Science	John Taylor	M.S.	F	P
Chiremba, Constance	Zambia	TAMU	Food Science	John Taylor	M.S.	F	P
Jacobs, Helena	South Africa	U of Pretoria	Food Science	John Taylor	M.S.	F	P
Lindsay, John	USA	TAMU	Food Science	Lloyd Rooney	M.S.	M	P
Mugode, Luke	Zambia	U of Pretoria	Food Science	John Taylor	M.S.	M	P
Pinilla, Eliana	Colombia	TAMU	Food Science	Lloyd Rooney	M.S.	F	P
Yang, Liyi	China	TAMU	Food Science	Lloyd Rooney	M.S.	F	P
Asif, Muhammad	Pakistan	TAMU	Food Science	Lloyd Rooney	Ph.D.	M	P
Barros, Fred	Brazil	TAMU	Food Science	Lloyd Rooney	Ph.D.	M	P
Chiremba, Constance	Zambia	U of Pretoria	Food Science	John Taylor	Ph.D.	F	P
Diarra, Mohamed	Mali	PRF	Food Science	Bruce Hamaker	Ph.D.	F	P
Hikeezi, Doreen	Zambia	U of Pretoria	Food Science	John Taylor	Ph.D.	F	P
Mkandawire, Nyambe	Zambia	UNL	Food Science	David Jackson	Ph.D.	F	P
Fuentes-Bueno, Irazeuma	USA	KSU	Plant Pathology	John Leslie	M.S.	F	P
Parau, Jose	South Africa	U of Free State	Plant Pathology	Neal McLaren	M.S.	M	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
Janse van Resnburg, B.	South Africa	U of Free State	Plant Pathology	Neal McLaren	Ph.D.	F	P
Mavhunga, Mudzuli	South Africa	U of Free State	Plant Pathology	Neal McLaren	Ph.D.	F	P
Nor, Nik	Malaysia	KSU	Plant Pathology	John Leslie	Ph.D.	M	P

I = Completely funded by INTSORMIL **P = Partially funded by INTSORMIL** **IC = InterCRSP funding**

KSU = Kansas State Univ. **TAM = Texas A&M Univ.** **USDA = Tifton, Georgia**
OSU = Ohio State Univ. **TTU = Texas Tech Univ.** **WTU = W. Texas A&M Univ.**
PRF = Purdue Univ. **UNL = Univ. of Nebraska - Lincoln**

Year 4 INTSORMIL Non-Degree Training Participants September 30, 2009 – September 29, 2010

Name	Country	Univ.	Discipline	Advisor	Activity	Gender	Funding
Aba, Daniel	Nigeria	PRF	Breeding	Tuinstra, M.	VS	M	P
Angarawai, Ignatius	Nigeria	USDA	Breeding	Wilson, J.	VS	M	P
Mbulwe, Lloyd	Zambia	TAMU	Breeding	Peterson, G	VS	M	I
Toure, Abocar	Mali	PRF	Breeding	Tuinstra, M.	VS	M	P
Dighe, Nilesh	India	TAMU	Breeding	Rooney, W	PD	M	P
Stefaniak, Thomas	USA	TAMU	Breeding	Rooney, W.	PD	M	P
Arciniega Castillo, Ana	Ecuador	TAMU	Food Science	Rooney, L.	VS	F	P
Chiremba, Constance	Zimbabwe	TAMU	Food Science	Rooney, L.	VS	F	P
Hien Yeri, Esther	Burkina Faso		Food Science	Bougouma	VS	F	P
Postic, Jelena	Croatia	KSU	Plant Pathology	Leslie	VS	F	P
Saleh, Amgad	Egypt	KSU	Plant Pathology	Leslie	PD	M	P

VS = Visiting Scientist   PD = Post Doctoral

Year 4 INTSORMIL Conference/Workshop Activities September 30, 2009 – September 29, 2010

			Participants		
Name	**Location**	**Date**	**Male**	**Female**	**Total**
Eder, Zachary	Indiana	December 13-16, 2009	1	0	1
Garzon, Camilo	Indiana	December 13-16, 2009	1	0	1
Gilchrest, Jody	Indiana	December 13-16, 2009	0	1	1
Brhane, Gebreyesus	Uganda	January, 2010	1	0	1
Ebiayu, John	Uganda	January, 2010	1	0	1
Kayuki, Kaizzi	Uganda	January, 2010	1	0	1
Mesfin, Tewodros	Uganda	January, 2010	1	0	1
Nansamba, Angela	Uganda	January, 2010	0	1	1
Eder, Zachary	Mexico	April 11-14, 2010	1	0	1
Gilchrest, Jody	Mexico	April 11-14, 2010	0	1	1
Mesfin, Tewodros	Kenya	April, 2010	1	0	1
Vyavhare, Suhas	Mexico	April 11-14, 2010	1	0	1
Vyavhare, Suhas	Nebraska	August 11-12, 2010	1	0	1
Scientific Writing Workshop	Korea	October, 2009	11	16	27
Scientific Writing Workshop	Malaysia	October, 2009	58	85	143
Scientific Writing Workshop	Zambia	November, 2009	19	13	32
Scientific Writing Workshop	Malawi	November, 2009	12	16	28
Scientific Writing Workshop	Argentina	March 2-5, 2010	50	59	109
Fusarium Laboratory Workshop	Argentina	March 7-12, 2010	14	15	29
Scientific Writing Workshop	USA	March 18-21, 2010	22	18	40
Scientific Writing Workshop	USA	May, 2010	96	98	194
Scientific Workshop	Tanzania	2010	73	24	95
Scientific Workshop	Tanzania	2010	35	21	56
TOTAL			**400**	**368**	**768**

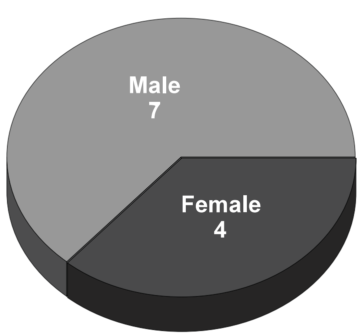

Figure 5. Total Non-Degree Participants by Gender

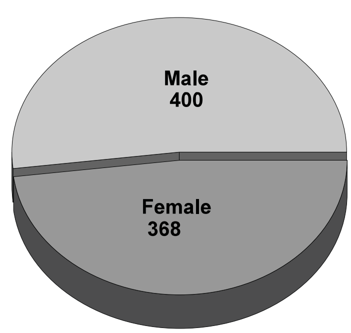

Figure 6. Total Conference/Workshop Participants by Gender

Appendices

INTSORMIL

INTSORMIL Sponsored and Co-Sponsored Workshops 2006-2010

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