2009

INTSORMIL 2009 Annual Report

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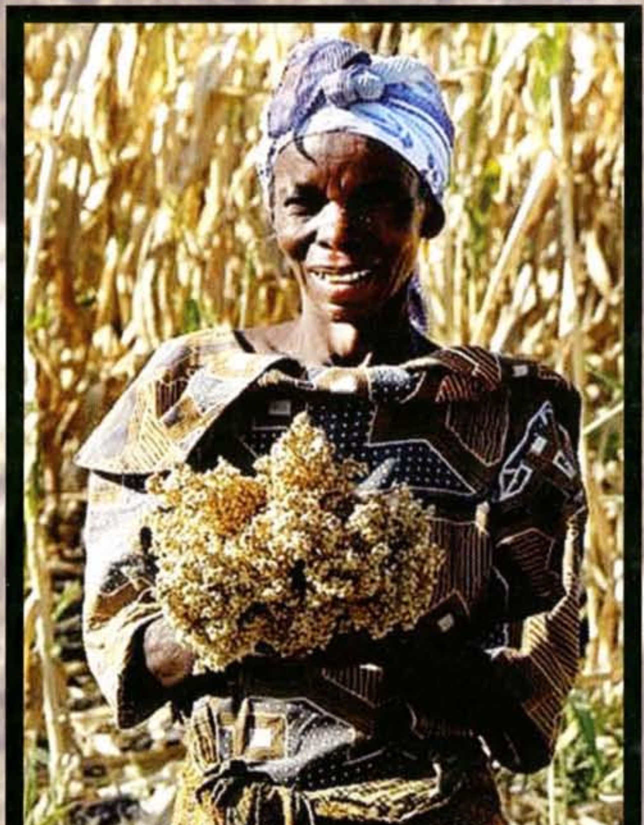
Sorghum, Millet and other Grains Collaborative Research Support Program (CRSP)



Widow, whose family depends solely on the income from her farm in Zambia, participating in the growing of tan plant white grain sorghums to sell to SABMiller for Eagle lager production.

Photo Courtesy of Gary Peterson, Texas A&M University

INTSORMIL
Sorghum, Millet and Other Grains CRSP

2009 ANNUAL REPORT

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

INTSORMIL Publication 09-01

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

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Kansas State University
Ohio State University
Purdue University
Texas A&M University
University of Nebraska – Lincoln
USDA-ARS, Tifton, Georgia
West Texas A&M University

Contents

Introduction and Program Overview

Project Reports

Sustainable Plant Protection Systems

Grain Molds, Mycotoxins and Stalk Rots of Sorghum and Millet
John Leslie (KSU 101) ... 3

Ecologically-Based Management of Sorghum and Pearl Millet Insect Pests in Africa and the United States
Bonnie Pendleton (WTU 101) ... 9

Sustainable Production Systems

Integrated Soil, Water, Nutrient and Crop Management Strategies for Improving Productivity in Sorghum and Millet Based Cropping Systems
P.V. Vara Prasad & Scott Staggenborg (KSU 104) ... 19

Crop, Soil and Water Management to Optimize Grain Yield and Quality for Value-Added Markets in Eastern and Southern Africa
Charles Wortmann (UNL 101) ... 33

Germplasm Enhancement and Conservation

Breeding Pearl Millet with Improved Performance, Stability and Resistance to Pests
Jeffrey Wilson (ARS 101) ... 41

Breeding Sorghum for Improved Resistance to *Striga* and Drought in Africa
Gebisa Ejeta (PRF 101) ... 47

Developing Sorghum with Improved Grain Quality, Agronomic Performance, and Resistance to Biotic and Abiotic Stresses
Mitch Tuinstra (PRF 104) ... 53

Breeding Sorghum for Improved Grain, Forage Quality and Yield for Central America
William Rooney (TAM 101) ... 59

Breeding Sorghum for Improved Resistance to Biotic and Abiotic Stresses and Enhanced End-Use Characteristics for Southern Africa
Gary Peterson (TAM 102) ... 65

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
Joe Hancock (KSU 102) ... 73

Market Development in Support of Sorghum and Millet Farmers in Tanzania and Zambia
Donald Larson and J. Mark Erbaugh (OSU 101) ... 77

Product and Market Development for Sorghum and Pearl Millet in West Africa
Bruce Hamaker (PRF 102) ... 87

Development of the Input and Product Markets in West Africa for Sorghum and Millet
John Sanders (PRF 103).. 93

Product and Market Development for Sorghum and Pearl Millet in Southern African and Central America
Lloyd Rooney (TAM 103) 101

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
David Jackson (UNL 102) 107

Host Country Program Enhancement

Central America
William Rooney 113

Horn of Africa
Gebisa Ejeta 121

Southern Africa
Gary Peterson 125

West Africa
Bruce Hamaker and Bonnie Pendleton 139

Educational Activities

Educational Activities 153

Appendices

INTSORMIL Sponsored and Co-Sponsored Workshops 2006-2009 159

Acronyms 161

Introduction and Program Review

The 2009 INTSORMIL Annual Report presents the progress and notable achievements by the Sorghum, Millet and Other Grains CRSP during the period of September 30, 2008 through September 29, 2009. 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, 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 for floral arrangements. These emerging markets, for sorghum and pearl millet, are results of the training and collaborative international scientific research that INTSORMIL has supported both in the United States and collaborating countries.

Although there have been significant advances in the improvement and production of sorghum and millet in the regions in which INTSORMIL serves, population growth continues to exceed rates of increase in cereal production capacity. Thus, there remains an urgent need to continue the momentum of our successes in crop improvement, improved processing and marketing of sorghum and millet, and strengthening the capabilities of NARS scientists to conduct research on constraints to production, utilization and marketing of sorghum and millet.

The INTSORMIL program maintains a flexible approach to accomplishing its mission. The success of INTSORMIL can be attributed to the following strategies which guide the program in its research and linkages with technology transfer entities.

Developing institutional and human capital: INTSORMIL provides needed support for education of agricultural scientists in both developing countries and the United States. The results of this support include strengthening the capabilities of institutions to conduct research on sorghum and millet, development of international collaborative research networks, promoting and linking to technology transfer activities and dissemination of technologies developed from research, and enhancing national, regional, and global communication linkages. INTSORMIL provides essential support to bridge gaps between developing countries and the United States. A major innovative aspect of the INTSORMIL program is to maintain continuing relationships with scientists of collaborating countries upon return to research posts in their countries after training. They become members of research teams with INTSORMIL and NARS scientists who conduct research on applications of existing technology and development of new technology. This integrated relationship prepares them for leadership roles in their national agricultural research systems and regional networks in which they collaborate.

Conserving biodiversity and natural resources: Results of the collaborative research supported by INTSORMIL include development and release of enhanced germplasm, development and improvement of sustainable production systems and development of sustainable technologies to conserve biodiversity and natural resources. The knowledge and technologies generated by INTSORMIL research also enhance society's quality of life and enlarge the range of agricultural and environmental choices available both in developing countries and the United States.

INTSORMIL promotes the conservation of millet and sorghum germplasm, resource-efficient cropping systems, integrated pest management strategies that conserve natural control agents and cultivars with improved nutrient and water use efficiencies and evaluates the impacts of sorghum/millet technologies on natural resources and biodiversity.

Developing research systems: Collaboration in the regional sites, in countries other than the United States, has been strengthened by employing multi-disciplinary research teams composed of U.S. and NARS scientists focused on unified plans to achieve common objectives. INTSORMIL scientists provide global leadership in biotechnology research on sorghum and pearl millet. The outputs from these disciplinary areas of research are linked to immediate results. INTSORMIL uses both traditional science of proven value and newer disciplines such as molecular biology in an integrated approach to provide products of research with economic potential. These research products, which alleviate constraints to production and utilization of sorghum and pearl millet, are key elements in the battle against hunger and poverty because they provide means for economic growth, generation of wealth, and improved health. New technologies developed by INTSORMIL collaborative research are extended to farmer's fields and to processors and marketers of sorghum and millet products in developing countries and the United States through partnerships with NGOs, research networks, national extension services and the private sector. In addition, economic analyses by INTSORMIL researchers play a crucial role in enabling economic policymakers to more intelligently consider policy options to help increase the benefits and competitiveness of sorghum and pearl millet as basic food staples and as components of value-added products.

Supporting information networking: INTSORMIL research emphasizes working with both national agricultural research systems and sorghum and millet networks to promote effective technology transfer from research sites within the region to local and regional institutions 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/Mali. 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 2008-2009, there were 40 students from 28 different countries enrolled in an INTSORMIL advanced degree program and advised by an INTSORMIL principal investigator. Approximately 73% of these students came from countries other than the U.S. The number of students receiving 100% funding by INTSORMIL in 2008-2009 totaled 3. An additional 37 students received partial funding from INTSORMIL. INTSORMIL places high priority on training of women. During the period 2008-2009, 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, 10 host country scientists improved their education as either postdoctoral scientists (2) or visiting scientists (8). Their research activities were in the disciplines of agronomy, breeding, food science and pathology. These scientists came to the United States as postdoctoral scientists or visiting scientists from El Salvador, Egypt, India, Burkina Faso, Malawi, Croatia, Turkey, Zambia and the USA. In addition to non-degree research activities there were 724 participants (342 male and 382 female) who were supported by INTSORMIL for participation in workshops and conferences.

Networking

The Sorghum/Millet CRSP global plan for collaborative research includes workshops and other networking activities such as newsletters, publications, exchange of scientists, and exchange of germplasm. The INTSORMIL global plan is designed for research coordination and networking within ecogeographic zones and, where relevant, between zones. The Global Plan:

- Promotes networking with IARCs, NGO/PVOs, regional networks (ASARECA, ECARSAM and others) private industry and government extension programs to coordinate research and technology transfer efforts.
- Supports INTSORMIL participation in regional research networks to promote professional activities of NARS scientists, to facilitate regional research activities (such as multi-location testing of breeding materials), promotes germplasm and information exchange and facilitates impact evaluation of new technologies.
- Develops regional research networks, short-term and degree training plans for sorghum and pearl millet scientists.

Established networking activities have been accomplished with ICRISAT in India, Mali, Niger, Kenya, Ethiopia, Uganda and Tanzania; Central America and with CORAF and ASARECA/ECARSAM in Africa and SICNA and the U.S. National Grain Sorghum Producers Association for the purpose of coordinating research activities to avoid duplication of effort and to promote the most effective expenditure of research funds. There also has been efficient collaboration with each of these programs in co-sponsoring workshops and conferences, and for coordination of research and long-term training. INTSORMIL currently cooperates with ICRISAT programs in east, southern and West Africa.

Regional Activities and Benefits

West Africa

The West Africa Regional Program now encompasses five countries of the Sahelian region – Burkina Faso, Mali, Niger, Nigeria, and Senegal.

Multi-agency, multi-disciplinary teams of agronomists, entomologists, food scientists, plant breeders, plant pathologists, poultry scientists, extension educators, and others from Burkina Faso, Mali, Niger, Nigeria, and Senegal are developing, evaluating, and transferring technologies to improve production and marketing of sorghum and pearl millet and manage Striga in West Africa. The West Africa regional program with collaboration among scientists at Institut D'Economie Rurale in Mali, Institut National de la Recherche Agronomique du 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 are contributing to INTSORMIL objectives to facilitate markets; improve food and nutritional quality to enhance marketability and consumer health; increase stability and yield through crop and natural resources management; develop and disseminate information on stresses to increase yield and quality; enhance stability and yield through genetic technologies; and better the lives of people dependent on sorghum and pearl millet.

The collaborating scientists are using seed multiplication, on-farm testing, and exchange of varieties of sorghum and millet with the goal of disseminating the best cultivars in combination with fertilizer and other crop management options such as legumes in crop rotations and crop protection options. They also are identifying storage disease and insect pests and control measures to manage grain harvesting and storage practices. They are developing base populations of cultivars of sorghum and millet with known adaptation, stability, and acceptability through multi-environment experiments and resistance to pests and drought. They are using conventional and/or marker-assisted recurrent selection to generate adapted dual-purpose varieties, open-pollinated varieties, and hybrid parental lines for targeted environments.

Food utilization, processing and marketing research collaboration is being coordinated from Senegal. This involves coordination of "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 from Burkina Faso, Niger, and Nigeria, and poultry scientists from Niger. The Niger project focuses on processed food and animal-feed markets and their expansion through development of good-quality, competitive millet- and sorghum-processed products and greater use of sorghum in poultry feed.

The overall goal is to enhance urban markets for hybrid and improved sorghum and millet cultivars, where farmers can sell their surplus grain and thus be able to purchase production inputs that enhance production. Emphasis is also being placed on development and transfer of improved technologies to farmers, NGOs, food processing and marketing entrepreneurs, and consumers with emphasis being placed on processed products that contribute to development of markets for sorghum and millet. Technologies for production of breads and other products based on sorghum, and millet were transferred; local processing groups were assisted by disseminating new processing technologies and in initiating businesses; and sorghum and millet are being characterized as "functional foods" for health. The goal was to have competitive composite flour and other products in the marketplace. For animal feed, use of sorghum in poultry feed in West Africa is being validated and education provided on availability of low-tannin varieties and aflatoxin-free grain, with the goal to increase the use of sorghum for poultry.

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 now encompasses four countries – Zambia, Mozambique, South Africa and Botswana.

The Southern Africa regional program is composed of 12 research projects directed by 14 scientists representing 8 agencies in 4 countries. Eight U.S. based principal investigators collaborate with the regional scientists. Countries and agencies represented are the Botswana College of Agriculture; the Mozambique National Agrarian Research Institute; in South Africa the University of the Free State, the ARC-GCI (pending acceptance of MOU), the University of Pretoria, and the Medical Research Council, and in Zambia the Zambia Agricultural Research Institute and the University of Zambia. The scientists represent the disciplines of agronomy (1), breeding (3), socio-economics (2), entomology (3), food science (1), and pathology (1). 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 were selected for the 2006-2011 program with the expectation each has expertise to contribute to achieving the goal of improving sorghum and millet for the farmers and end-users. Individual work plans are developed using a format similar to that for U.S. investigators. Each scientist is expected to specify where activities fall within the regional plan and to provide performance indicators and outputs. Progress listed in the individual annual reports should be used to evaluate progress and performance. Each collaborating scientist brings to INTSORMIL individual collaborators including Future Harvest Centers, NGOs, and other governmental or private organizations. Each also has other grant funds - other donors, grants and commodity organizations - that provide reciprocal leveraging of resources. 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.

Central America

The Central America Regional Program now encompasses two countries - El Salvador and Nicaragua.

The INTSORMIL regional programs are designed to support national research programs in 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. Historically, the Central American Regional Program has been a robust and active program. Given the new INTSORMIL program, the Central American program is in the process of re-organization including but not limited to development of new program priorities and project development.

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

Associate Award

In 2007 INTSORMIL received a three year (September 29, 2007 – September 30, 2010) $250,000/year award "Transfer of Sorghum, Millet Production, Processing and Marketing Technologies in Mali" from the USAID/EGAT/AG/ATGO/ Mali. The project was based on successful activities through the INTSORMIL West Africa Regional Project and was designed to rapidly move sorghum and millet production technologies onto farmers' fields, link farmers' organizations to food and feed processors and commercialize processing technologies so as to enhance markets and to significantly expand the existing project, especially into the northern areas of Mali. The award allowed INTSORMIL to significantly increase its impact in Mali by (1) expanding to new sites with more concentration in the poorer northern Tombouctou region where food insecurity is a severe problem for the small scale farmers who depend on sorghum and millet for their daily diet, (2) upscaling the research and (3) upscaling the technology transfer component. The Cooperative Agreement was modified in 2008 to provide four year funding at $1,250,000 per year (2008-2009 to 2011-2012) to expand all activities and to develop institutional capacity by adding a degree and short term training component to the Cooperative Agreement.

The Cooperative Agreement consists of four components: 1) Production - Marketing activities led by John Sanders, Purdue University Marketing Economist; 2) Food Processing Technology and Training activities, led by Bruce Hamaker, Purdue University Cereal Chemist, 3) Décrue Sorghum (post water recession sorghum planted at the edges of the Niger River and Lakes after the rainy season has ended) production activities led by Vara Prasad and Scott Staggenborg, Kansas State University Agronomists and 4) Academic Training led by Jess Lowenberg -Deboer, Purdue University. Activities are conducted in collaboration with IER.

Significant progress was achieved in 2009 through meeting Project objectives as set forth in the workplan:

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

Network Establishment

Décrue sorghum - Partnerships have been developed through visits to Mali and include, INTSORMIL PIs, IER scientists, USAID /EGAT Team, local administrators of the Lake Faguibine revitalization program in Goundam and farmers from two villages surrounding the lakes Bintagoungou and Mgoudou. Participation in the USAID/Mali Mission Partner's meeting in Bamako, December 2009 provided an opportunity to develop additional partnerships to increase impact in the Tombouctou Region. In 2010, collaboration with the Direction Regionale Agriculture (DRA), Mopti and the ONGs (Non-Governmental Organizations = NGOs) ACAS, Gao; RGCOP, Tombouctou; and CONFIGES will be initiated to conduct demonstration plots on improved décrue sorghum technologies.

Production-Marketing - A strong network had already been established prior to the initiation of this project. That network involves, IER, USAID, ICRISAT, Sasagawa2000, ULPC Dioila, AMEDD, INTSORMIL PIs and the food processors; Mam Cocktail, Beau Céreale, Sahélienne de l'Alimentation, Musola Jama Sewa, DANAYA Céreales, La Maraîchere, Corbeille and UCODAL. Participation in the USAID/Mali Mission Partner's meeting in Bamako, December 2009 provided the opportunity to increase the network. Collaboration with AMEDD and IICEM (USAID's Integrated Initiatives for Economic Growth in Mali) in 2010 is expected to triple the land area and number of collaborating farmers.

Food Processing - The processing component has strong linkages with a wide array of stakeholders in Mali. This includes IICEM (expertise in value-chains and markets), The Malian Food Processors Association (FENATRA), Women Food Processors Association (GIE), PCDA (World Bank Financed with expertise in cereal technology), Catholic Relief Services and a group of food processing entrepreneurs.

Technology Adoption and Farmer Incomes

Five new technologies were introduced by the Production-Marketing component. The number of farmers (and hectares) under the Production-Marketing component doubled in 2009 from 500 in 2008 to 1,000 in 2009 (Year 2). Projections are to increase the number of farmer cooperators using the improved technologies and marketing strategies from 1,000 in 2009 to 3,000 in 2010. Income gain due to the increased yields ranged from 43-121%. Training of farmer associations (cooperatives etc.) in the Production-Marketing Project began in 2008. This approach was expanded to several new villages in 2009. The farmers' organizations have been acquiring identities as successful economic units. They buy inputs, store and sell the grain. Repayment rates for the inputs have been very high, generally over 95%. Grain price increase due to the marketing strategy was 31%.

Alternative Market Development

Extensive progress was made in developing new markets for sorghum as a poultry feed. There appears to be significant potential for the use of sorghum as a poultry feed in Mali and other West African countries. Food processing incubator units were installed in IER Mopti and Sotuba and in several entrepreneurial groups. Entrepreneurial units in Mopti, Bandiagara and Gao are now fully mechanized for processing of decorticated and milled products. IER technologists have trained personnel at each of seven entrepreneurial units and several workshops have been conducted. Training at workshops included 1) Entrepreneur unit operation, 2) Management, 3) Engaging the market and 4) Financial matters.

Décrue System Production Technology

Management practices evaluated in farmers' fields and compared to farmer's cultural practices include varieties, planting date, plant density, row spacing, fertilizer levels and seed treatment. Practices that increase yield were identified. Planting date had a significant effect on germination and plant population. Thirty three sorghum cultivars were evaluated by farm women in a participative selection. The women chose the cultivar 'Niatichama' as the cultivar with the best grain quality. The men also selected 'Niatichama' among the top three cultivars for production.

Sorghum and Millet Seed Production

Partnerships were developed to promote the production of sorghum and millet seed of high yielding and good grain quality varieties suitable for human food and poultry feed. The Production-Marketing component is collaborating with WASA and farmer seed producers in Garasso and Kaniko to produce quality seed. Farmers' received training in seed production, including hybrid seeds and marketing concepts. Training will be expanded to additional sites in Year 3. Activities conducted by IER décrue scientists include cultivar collections and testing to identify most suitable cultivars for the region.

Dissemination of Technology

In June a workshop was conducted for food processing entrepreneur partners at IER/Mopti on the topic: "Primary education of technologies of processing of high quality, competitive millet and sorghum products, the fundamentals of quality management and packaging, and contracting farmers for high quality grains." A second workshop was conducted in late summer in Gao. The workshop topic was "Marketing and management of a unit of local cereal transformation." The Production-Marketing and Décrue components held field days to promote production technology. Articles describing the project were placed on the INTSORMIL website <http://intsormil.org> under "ME Presentations" (PowerPoint presentations) and quarterly and annual reports were added under "Mali Award Reports." An article describing the project was placed on the USAID/Mali Mission's website under "Partners."

Institutional Capacity Building

A subcontract for training was awarded to Purdue University with funding starting April 1, 2009.

Five candidates were identified by IER and recommended for MSc degree training in the USA.

All candidates first enrolled in English Language Training Program at the Indiana Center for Intercultural Communication (ICIC) in Indianapolis before taking up their graduate studies. The IER scientists are: Aly Ahamadou (Ag Economics- Purdue), Mamadou Dembele (Ag Economics- Purdue) Bandiougou Diawara (Agronomy-Kansas State University), Fatimata Cisse (Food Science-Purdue) and Sory Diallo (Agronomy-Kansas State University).

Future Directions

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

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

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

During the past 29 years, INTSORMIL has educated more than one thousand scientists through degree programs, visiting scientist experiences, postdoctoral training, workshops, and conferences. About one-third of those trained are from the U.S. and two-thirds are from developing countries. The bridges built by this training are crucial to maintain scientific and peaceful linkages between the United States and developing countries. The collaborative research supported by INTSORMIL continues to produce benefits for both developing countries and the United States. Food production, utilization and marketing in both developing countries and the United States are strengthened by INTSORMIL. The health benefits of the two nutritious cereals, sorghum and millet, are enjoyed by millions of people. Sorghum is a significant element in the food chain of the United States, being a key feed for livestock. So what is the future for collaborative, international sorghum and millet research supported by INTSORMIL? The future is bright.

There continues to be a need for highly qualified researchers for these two crops both in developing countries and the United States. INTSORMIL fulfills a unique role in providing postgraduate training (M.S. and Ph.D. level) to meet this need. As the demand for water in cities continues to put greater pressure on the use of water for irrigated crop production, sorghum and millet, which are for the most part rainfed, will gain increased importance in meeting the caloric needs of developing countries, particularly in the semiarid tropics, and needs of the livestock feed industry in the United States. Recent INTSORMIL research on the nutritional benefits of sorghum and millet forms a strong base for future research to enable the commercialization of nutritionally superior sorghum Based on its achievements, the INTSORMIL team is well positioned to contribute even more effectively to ending hunger and raising incomes. With the increasing strength of scientific expertise in developing countries, INTSORMIL is now able to more effectively reduce constraints to production and utilization of sorghum and millet to the mutual benefit of developing countries and the United States. Advances in sorghum and millet research over INTSORMIL's 29 years and the training of sorghum and millet scientists in the United States, Africa and Central America by INTSORMIL now enables these scientists from developing countries and the United States to jointly plan and execute mutually beneficial collaborative research. These collaborative relationships are key components to INTSORMIL's success and will continue as fundamental approaches to meeting the INTSORMIL mission. In the future, INTSORMIL will target NARS collaborative ties that reflect regional needs for sorghum and/or millet production. These ties are in the sorghum and millet agroecological zones of western, eastern, and southern Africa, and Central America. By concentrating collaboration in selected sites, INTSORMIL optimizes its resources, builds an enhanced scientific capability on sorghum and millet, and creates technological and human capital that has a sustainable and global impact.

Sustainable Plant Protection Systems

INTSORMIL

Grain Molds, Mycotoxins and Stalk Rots of Sorghum and Millet

Project KSU 101
John F. Leslie
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Principal Investigator

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Dr. Neal McLaren, University of the Free State, Bloemfontein, South Africa
Drs. Michael Wingfield and Brenda Wingfield, University of Pretoria, Pretoria, South Africa

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 disease complex. Separating and identifying the roles and risks associated with the various members of this complex fungal community is necessary to estimate the risks posed by different members of the community and to provide breeders with the correct targets for resistance breeding. Fungi that cause grain mold also are linked with stand establishment problems as the seeds that are produced may germinate poorly or the germinated seedlings may be killed by fungi that accompanied the seed.

Fusarium spp. and the secondarily invading *Aspergillus* spp. may produce mycotoxins such as aflatoxins, fumonisins, ochratoxin, deoxynivalenol and zearalenone. These toxins may reduce the quality of the grain as a food/feed source as well as the value of the grain in a cash market scenario. These toxins are associated with a variety of human and animal health problems including 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* recovered from sorghum and millet have long been a taxonomist's nightmare. Many species lack morphological characters that can be used to clearly and cleanly differentiate them from other related species, and many cultures are misidentified, if identified at all. Many of these cultures al-so have been identified as *Fusarium moniliforme*, a name that has now been abandoned due to the numerous species that it has been associated with. As all strains with the *F. moniliforme* name often were assumed (incorrectly) to be equivalent in terms of pathogenicity, breeding materials often were challenged with an improper strain with correspondingly inconsistent results. For example, *F. verticillioides* is a common pathogen of maize that once was termed *F. moniliforme*, as was *F. thapsinum*, a major cause of sorghum stalk rot. Challenging sorghum plants with *F. verticillioides* when screening for stalk rot resistance results in unpredictable results, as the only plants that become diseased are those infected by *F. thapsinum* due to natural causes. A similar challenge with *F. thapsinum*, however, can effectively flatten an experiment planted with a sensitive variety. Results from previous studies sponsored by INTSORMIL have indicated that the dominant Fusarium species varies by location, e.g., *Fusarium andyazi*, in southern Africa, *F. thapsinum* in West Africa, *F. proliferatum* in Egypt, and an as yet unnamed new species that is common from West Africa through Egypt and East Africa (Kenya and Uganda). Within region variation suggests that as many as 20 additional species remain to be described. Until they have been effectively separated it is difficult to determine which species are common in one area and less common in others. Such studies also are needed to enable breeders to effectively challenge the materials in their programs. The *Fusarium* species associated with pearl millet and finger millet also have been examined in a somewhat cursory manner. *Fusarium pseudonygamai* is the dominant species on pearl millet, while finger millet is host to an amazingly diverse group of *Fusarium* spp. (between 40 and 60 from samples taken in Uganda in 2000). The Fusarium species on these crops are not known to be associated with production problems, but may produce mycotoxins that could contaminate grain. Identifying the toxins produced, if any, and their levels is particularly important for strains found on finger millet as this grain often is used to produce a weaning food for children. These children would be particularly susceptible to the reductions in mental and physical development that can result from sub-acute exposure to these toxins.

Objectives and Implementation Sites

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

Contribution to INTSORMIL Objectives

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

Research Methodology and Strategy

Species Identification

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

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

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

Mycotoxin Production

In vitro assessment of mycotoxin production requires collaboration with other scientists who are equipped with the necessary apparati for chemical analyses. The presence of the fumonisin, beauvericin and fusaproliferin mycotoxins can be evaluated after growth on rice in laboratory culture for up to 30 days. The contents are extracted in acetonitrile:water, run through a clean-up column to remove contaminants, derivatized, if necessary, to enable detection, and finally quantified 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. Three mycotoxins were tested: fumonisin, fusaproliferin and beauvericin. Fumonisins are important due to their association with esophageal cancer and neural tube defects in humans, their ability to cause a number of diseases in domesticated animals, and their effects as trade barriers. Fusaproliferin and beauvericin are not associated with a disease syndrome of humans or domesticated animals but are toxic to cells maintained in cell culture. Beauvericin is insecticidal and yeasts that synthesize this compound have been used as bio-control agents. Beauvericin also is very effective in permeabilizing cell membranes and thereby facilitating the entry of other mycotoxigenic molecules.

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, some AFLP comparisons have been run, enabling preliminary working groups of strains to be identified. These AFLP comparisons are being rerun with different primer pairs to confirm the preliminary results. Most of the observed patterns are significantly different from those of known species. Molecular work on this group has been limited as we worked to develop highly fertile mating type testers needed for description and for practical identification purposes of the new species. We have recently (after a series of some 15 backcrosses and sib crosses) tentatively identified suitable strains for use as testers for both mating types in this fungus. These testers are now being tested for their utility in identifying the species through crosses with field-collected isolates.

Species Identification – Uganda

A group of 400 strains from finger millet collected in Uganda are in a more advanced state of evaluation. Approximately 20% of the group appeared morphologically to belong to *Fusarium verticillioides*, a species known to produce fumonisins. Following AFLP tests, this set could be subdivided into two groups. The members of one group (32 strains) crossed readily with the tester strains of *F. verticillioides* and produced fumonisin B1 and B2 mycotoxins (Table 1). These strains were polymorphic at tub-2 (28 strains sequenced) with 21 strains with the usually dominant allele and seven strains with an allele that is usually rare. In tef-1, there were five alleles present, an unusually high number, with three of them being new for this species, another unusually high number. Five nucleotide positions were altered in one or more of the alleles, with one change at a silent (no amino acid change) location in the coding sequence and the other four in one of the introns. All but one strain was capable of serving as both a male and a female parent in a cross, suggesting that sexual recombination is both frequent and important in the F. verticillioides life cycle in this environment. The high levels of female fertility are unusual as other populations of this fungus often have 50%, and sometimes

Table 1. Toxin and fertility status of strains of *F. verticillioides* collected from finger millet in Uganda. N.D. – No Data.

Strain Number	Location	*MAT* Allele	♂/♀ Fertility	Fumonisin (µg/g) B_1	Fumonisin (µg/g) B_2
9374	Apac Kole, Akolo	*A-2*	♂ + ♀	N.D.	N.D.
9397		*A-2*	♂ + ♀	30	60
9401		*A-2*	♂ + ♀	980	990
9646	Tororo, Tororo, Mukuja	*A-1*	♂ + ♀	N.D.	N.D.
9669		*A-2*	♂ + ♀	790	440
9689		*A-2*	♂ + ♀	96	38
9705		*A-2*	♂ + ♀	1,030	430
10069	Bugiri, Bukawli, Kapyanga	*A-1*	♂ + ♀	N.D.	N.D.
10072		*A-2*	♂ + ♀	N.D.	N.D.
10076		*A-1*	♂ + ♀	5,700	4,200
10077		*A-1*	♂ + ♀	N.D.	N.D.
10082		*A-2*	♂ + ♀	8	4
10084		*A-1*	♂	12,400	6,200
10086		*A-1*	♂ + ♀	740	560
10087		*A-1*	♂ + ♀	160	110
10089		*A-2*	♂ + ♀	290	140
10090		*A-2*	♂ + ♀	N.D.	N.D.
10093		*A-1*	♂ + ♀	450	340
10099		*A-1*	♂ + ♀	750	620
10108		*A-2*	♂ + ♀	460	490
10112		*A-1*	♂ + ♀	12	8
10115		*A-1*	♂ + ♀	1300	450
10116		*A-1*	♂ + ♀	250	190
10120		*A-2*	♂ + ♀	74	54
10125		*A-2*	♂ + ♀	2	1
10133		*A-2*	♂ + ♀	56	34
10134		*A-1*	♂ + ♀	540	175
10136		*A-2*	♂ + ♀	230	130
10137		*A-2*	♂ + ♀	60	490
10139		*A-2*	♂ + ♀	130	60
10142		*A-2*	♂ + ♀	N.D.	N.D.
10143		*A-2*	♂ + ♀	1100	480

Table 2. Toxins produced by 55 strains of *Fusarium sp. nov.* isolated from finger millet in Uganda. All strains are male fertile, with female fertility still being tested. N.D. – No Data; T – trace (0.1-0.99 µg/g). None of the strains produced detectable levels of fusaproliferin or enniatins.

Strain Number	Location	*MAT* Allele	Total Fumonisins (µg/g)	Beauvericin (µg/g)
9440	Apac Kole, Akolo	*K-2*	39	1410
10314	Serota, Serrere	N.D.	3.1	< 1.0
10316		*K-2*	1.0	< 1.0
10317		*K-2*	1.7	2,700
10319		*K-1*	2.5	3,500
10320		*K-1*	1.5	740
10323		*K-1*	< 0.1	< 1.0
10324		*K-2*	N.D.	N.D.
10325		*K-1*	T	< 1.0
10329		*K-1*	< 0.1	1,400
10330		*K-2*	< 0.1	< 1.0
10336		*K-2*	N.D.	N.D.
10339		*K-1*	N.D.	N.D.
10340		*K-2*	T	4,200
10341		*K-1*	< 0.1	< 1.0
10342		*K-1*	< 0.1	N.D.
10344		*K-2*	N.D.	1,700
10347		*K-1*	T	560
10349		*K-1*	< 0.1	< 1.0
10350		*K-2*	< 0.1	< 1.0
10351		*K-2*	< 0.1	830
10352		*K-2*	< 0.1	< 1.0
10353		*K-1*	N.D.	N.D.
10354		N.D.	< 0.1	< 1.0
10355		*K-1*	< 0.1	160
10356		*K-1*	T	930
10357		*K-1*	< 0.1	4,500
10359		N.D.	N.D.	N.D.
10361		*K-1*	< 0.1	610
10362		*K-1*	N.D.	N.D.
10363		*K-1*	< 0.1	6,400
10364		*K-1*	< 0.1	2,000
10365		*K-1*	< 0.1	1,600
10366		*K-1*	< 0.1	860
10367		*K-1*	T	47
10368		N.D.	< 0.1	5,500
10369		*K-1*	T	590
10370		*K-1*	< 0.1	1,300
10371	Serota, Serrere	*K-1*	< 0.1	600
10372		*K-1*	T	1,000
10373		*K-1*	< 0.1	3,700
10376		*K-1*	< 0.1	1,200
10377		*K-1*	N.D.	N.D.
10378		*K-2*	n.d.	830
10379		*K-2*	T	940
10380		*K-1*	T	990
10381		*K-1*	N.D.	N.D.
10382		*K-1*	T	2,100
10385		*K-1*	< 0.1	930
10386		*K-1*	T	380
10387		*K-1*	< 0.1	130
10388		*K-1*	< 0.1	2,000
10389		*K-1*	< 0.1	770
10390		*K-1*	< 0.1	810
10392		*K-1*	< 0.1	2,200

fewer, of the strains that can function as female parents. The high levels of polymorphism and sexual recombination in this strain set are typical of those found in an area near the center of diversity for a species. The levels of toxin these strains can produce suggests that they are of potential concern as contaminants of finger millet grain when it is processed into human food.

The second group of strains (Table 2) is a new biological species that remains to be named and formally described. This species is a part of the Liseola section of the genus, i.e., the section to which most of the other Fusarium strains isolated from sorghum and millet belong. Although it is morphologically indistinguishable from F. verticillioides, the new species can be differentiated on the basis of toxin production (produces beauvericin but little or no fumonisins), AFLP banding patterns, DNA sequence data for the tef-1 and tub-2 loci, and cross fertility amongst members of the species but not with members of F. verticillioides. This biological species also appears to be quite fertile. In preliminary tests that are now being verified, most of the isolates can serve as both the male and the female parent of a cross. Thus, sexual recombination is frequent in this species. Unlike the new species from Mali, identification of good female fertile tester strains was easily accomplished following a single intercross of two field strains. A few of the strains in the new Ugandan species produce low to trace levels of fumonisins, but most produce significant quantities of beauvericin. Beauvericin production is important because of its insecticidal properties. 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 against larvae of various stalk borers.

Strengthening Research Capacity

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

Networking Activities

Editorial and Committee Service (2008)

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

Research Investigator Exchanges (2008)

- Hungary – September 2-6
- Italy – February 13-24; August 29 – September 2; September 26 – October 4
- Kenya – September 20-25
- Malaysia – June 14 – July 3
- Mozambique – October 25-31
- Norway – April 15-25
- South Africa – November 1-20
- South Korea – May 18-25
- Turkey – August 3-10

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 2008 (Other than Collaborators)

- Ridao Azucena, University of Buenos Aires, Buenos Aires, Argentina.
- Peter Cotty, USDA-ARS, University of Arizona, Tucson, Arizona.
- 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.
- Robert H. Proctor, Mycotoxin Research Unit, NCAUR, USDA-ARS, Peoria, Illinois.
- David Schmale, Dept. Plant Pathol. & Weed Science, Virginia Tech. Univ., Blacksburg, VA.
- Keith Seifert, Agriculture and Agri-Foods Canada, Ottawa, Ontario, Canada.
- Amir Sharon, Department of Plant Sciences, University of Tel Aviv, Tel Aviv, Israel.
- Bettina Tudzynski, Westfaelische Wilhelms University, Muenster, Germany.
- Cees Waalwijk, DLO Institute for Plant Protection, Wageningen, The Netherlands.

Publications and Presentations (2008)

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

Norwegian National Veterinary Institute, Oslo, Norway – April, 2008.
Faculty of Agricultural & Life Sciences, Seoul National Univ., Seoul, Korea – May, 2008.

Science University of Malaysia, Penang, Malaysia – June, 2008.
University of Malaysia Terranganu, Terranganu, Malaysia – July, 2008.
IUMS International Mycology Congress, Istanbul, Turkey – September, 2008.
Pan-African Environmental Mutagenesis Conf., Cape Town, So. Africa – November, 2008.
FABI, University of Pretoria, Pretoria, South Africa – November, 2008.

Books (2008)

Leslie, J. F., R. Bandyopadhyay & A. Visconti, eds. 2008. Mycotoxins: Detection Methods, Management, Public Health and Agricultural Trade. CABI, Kew, UK. 476 pp.

Journal Articles (2008)

Bentley, A. R., J. F. Leslie, E. C. Y. Liew, L. W. Burgess & B. A. Summerell. 2008. Genetic structure of Fusarium pseudograminearum populations from the Australian grain belt. Phytopathology 98: 250-255.

Bowden, R. L., I. Fuentes-Bueno, J. F. Leslie, J. Lee & Y.-W. Lee. 2008. Methods for detecting chromosomal rearrangements in Gibberella zeae. Cereal Research Communications 36 (suppl. B): 603-608.

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

Project WTAMU 101
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Introduction and Justification

Entomologists, breeders, pathologists, economists, and extension agents in Mali, Niger, Mozambique, Botswana, and the US are educating students and farmers in IPM and developing, evaluating, and transferring pest management technologies for insects of sorghum and millet. Development and adoption of ecologically-based technologies will decrease loss by insects in the field and storage, reduce pesticide use, conserve soil and water without contamination by pesticides, and increase yield of food and feed for domestic use and income from marketing. Sorghum and millet are damaged by such biotic stresses as greenbug, Schizaphis graminum, and yellow sugarcane aphid, Sipha flava, in the US 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 US and maize stalk borer, Busseola fusca; and spotted stem borer, Chilo partellus in Africa tunnel in stalks, causing susceptibility to disease and lodging. Grain storage can take advantage of greater market price but result in more damage by insects that annually destroy 35% of grain worldwide. Pests of stored grain include the maize weevil, Sitophilus zeamais.

Objectives and Implementation Sites

This project is contributing to INTSORMIL objectives to facilitate markets by managing insects that damage yield and quality of sorghum and millet; improve food and nutritional quality to enhance marketability and consumer health by grain not contaminated by pests or pesticides; increase stability and yield through crop and natural resources management by IPM strategies not dependent on pesticides; develop and disseminate information on biotic stresses to increase yield and quality by integrated management strategies against insects; enhance stability and yield through genetic technologies by determining differences among strains of insects and speeding development of resistant cultivars with yield and quality; and develop partnerships with agencies improving sorghum and millet and betterment of people through collaboration among scientists at West Texas A&M University, Texas AgriLife Research, and 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 with scientists in Africa and the US to develop and deliver IPM strategies against insects that damage sorghum and millet in the field and storage by improved understanding of biology, ecology, and population dynamics of insect pests and damage they cause; evaluation of potential arthropod pests; agronomic practices to prevent damage by insects and reduce pesticides; cultivars with greater yield and resistance to biotic and abiotic stresses; 3) provide education for students; and 4) develop partnerships with ICRISAT and PVOs engaged in improvement of sorghum and millet production and betterment of people. By presentations and publications, extension and other agencies will be assisted with transferring pest management information to farmers, scientists, and others in Africa and the US.

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 determined the effect of yellow sugarcane aphids on biomass of sorghum. A M.S. student used pheromones to monitor seasonal abundance of southwestern corn borer moths in Texas. Using agronomic practices to manage pests. Intercropping grasses to draw stalk borers from sorghum or millet was evaluated by Dr. Yaro in Mali and Mr. Chitio in Mozambique. Developing germplasm resistant to biotic constraints. The PI and African entomologists collaborated with breeding projects in Mali, Mozambique, Niger, and Texas, and Milo Genetics and Monsanto 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 a color brochure and posters for hundreds of farmers to manage storage pests in Mali. A M.S. student determined what grain stage maize weevil infests sorghum in the field and evaluated resistance of stored sorghum grain. Electron microscopy and energy dispersive spectroscopy were used by Dr. Michael Pendleton 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 in Mozambique and two sorghums and three millets to hundreds of farmers in Niger. Field demonstrations, workshops, brochures, posters, and training manuals were used or being prepared to teach farmers, extension, and others to recognize pest problems and evaluate, adapt, and implement IPM options. Undergraduate and graduate university students in the US, Botswana, and Niger assisted with research and were educated in entomology and IPM.

Research Results

Undergraduate Jody Gilchrest evaluated 14:10 and 10:14 light:dark hour photoperiods 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 significantly affected greenbugs and should be considered when evaluating for resistance. Only 55 and 60% of biotype E and I greenbugs at 10:14 light:dark hours survived to produce offspring, while all produced nymphs at 14:10 light:dark hours. Biotype E and I greenbugs began producing nymphs in 14.0 days at 10:14 light:dark hours but only 9.5 and 9.6 days at 14:10. Fecundities of biotype E and I greenbugs were 2.3 and 2.7 times greater at 14:10 than 10:14 light:dark hours. Longevities of biotype E and I greenbugs were 1.3 and 1.4 times longer at 14:10 than 10:14 light:dark hours. (Table 1)

Master's student Zachary Eder evaluated the effect of yellow sugarcane aphids on biomass of sorghum ATx399 x RTx430. Plants at the third true-leaf stage were infested with 0, 10, 25, or 40 aphids per plant for 14 days. Plants infested with 40 aphids weighed less than 1/5 as much and were 1/2 as tall as check plants with no yellow sugarcane aphids. (Table 2)

A M.S. student from Colombia monitored southwestern corn borer moths in pheromone traps from May to October in Texas. Numbers of moths varied among locations and differed with weather. Moths of the 1st generation were trapped from late-June until mid-July, with a peak on 1 July. Second-generation moths were trapped from the 1st week of August through 1st week of September, with more than 50% captured before the middle of August.

Dr. Yaro assisted five farmers from each of Finkolo and Zanradougou villages in different agroecological zones with Sudan climate in the Sikasso region of Mali who evaluated Andropogon gayanus in three border rows 50 cm apart with 30 cm between plants to attract stalk borers away from 15 x 10-m plots of millet. Andropogon was transplanted on 7 and 8 July and millet planted on 18 and 17 July 2008 at Finkolo and Zanradougou. Ten millet plants were sampled from diagonals of the plot and Andropogon plants were sampled from each compass direction. Numbers of pests and natural enemies, percentages of deadhearts, and numbers of larvae and pupae of other borer species were counted on Andropogon and millet at the vegetative stage 30 days after emergence, tillering (70-80 DAE), and harvest (100-110 DAE). Damage was more at Finkolo than Zarandougou. Millet surrounded by millet (check) was more damaged (5.3) than by Andropogon (1.7), while 3.6% of Andropogon plants had deadhearts from borers. (Table 3)

Table 1.

Photoperiod (light:dark hours)	Greenbug biotype	Pre-reproductive period(days)	Reproductive period (days)	Total fecundity (nymphs)	Longevity (days)
10:14 (winter)	E	14.0 a A	15.7 a A	25.7 a A	37.9 a A
	I	14.0 a A	17.2 a A	23.5 a A	39.5 a A
14:10 (summer)	E	9.5 a B	23.5 a B	59.6 a B	50.7 a B
	I	9.6 a B	23.7 a A	63.5 a B	54.0 a B

Means followed by the same lower-case letter for a photoperiod or by the same upper-case letter for the same biotype in a column do not differ significantly.

Table 2.

Yellow sugarcane aphids per plant	Weight (g)	Height (cm)
0 (check)	0.93	65.1
10	0.32	46.5
25	0.17	34.0
40	0.18	32.6

Table 3.

Village	Farmer	% deadhearts of vegetative millet infested by stalk borers		
		Millet surrounded by millet	**Millet surrounded by *Andropogon gayanus***	***Andropogon gayanus***
	Diakalia BALLO	10.3	1.5	2.0
	Issouf BALLO	4.3	1.5	3.0
	Abdoulaye KONE	5.2	2.8	5.5
Finkolo	Seybou KONE	6.6	2.3	7.1
	Oumar TRAORE	2.5	0.5	4.6
	Nouhoum DJOURTHE	0.0	3.7	1.2
	Siaka DJOURTHE	12.0	0.0	3.0
Zanradougou	Tidiani SANOGO	1.5	1.5	2.4
Mean		5.3	1.7	3.6

Table 4.

Village	% plants infested by stalk borers		
	Millet without *A. gayanus*	**Millet with *A. gayanus***	***Andropogon gayanus***
Finkolo	9.1	7.8	4.4
Zanradougou	10.2	7.9	5.0

Dr. Yaro assisted farmers using Andropogon gayanus to attract stalk borers to 5 rows 20 m long and 10 m apart intercropped with local millet planted 6-9 July 2009 at Finkolo and Zanradougou. A randomized complete block with 10 farms was used at each village. Millet was intercropped with millet (check) or Andropogon. Natural enemies, and deadhearts and empty spikelets caused by stalk borers were sampled on 10 millet and 10 grass plants randomly selected on 5-8 September from diagonals of the plots. Millet was 19% less damaged surrounded by Andropogon than millet. (Table 4)

Mr. Chitio used napier grass as a border of three rows and Desmodium grass between rows of sorghum to trap stalk borers at Nampula Research Station in Mozambique. Rainfall stopped early, and the grass did not grow adequately to obtain results.

Mr. Abdou Kadi Kadi and millet breeder Mr. Issaka Ahmadou assessed at the Regional Agricultural Research Center in Kollo, Niger, damage by millet head miner and yield of HKB, H80-10GR, Taram, SOSAT–C, Mangarana, HKP-GMS, ICMV IS89305, Zatib, Mangarana x ICMV IS89305, SOSAT-C x HKB, SOSAT-C x ZATB, and Tchoumo pearl millets developed at INRAN. The design was a completely randomized block with three replications. Each sub-plot was 12 m2 with 4 rows 3 m long and 1 m between rows and hills. Five spikes of each genotype per replication were randomly selected and tagged. Five days later and until maturity, spikes were checked for larvae, pre-pupae, and pupae of millet head miner. At maturity, spikes were cut and damage assessed using a 1-9 scale where: 1 = <10, 2 = 11-20, 3 = 21-30, 4 = 31-40, 5 = 41-50, 6 = 51-60, 7 = 61-70, 8 = 71-80, and 9 = >81%. The percentage of infested spikes ranged from 24.2 to 62.4% for Tchoumo and SOSAT-C88 and was correlated with damage that ranged from 1.9 for Tchoumo to 4.3 for HK_ GMS (20-50% mined spikes). The percentage of infested spikes was 38.4 and 40.9% on HKB and Taram (local varieties from Gaya zone in Dosso); damage was 1.9 and 2.1 (10-30% mined spikes). H80-10GR, SOSAT-C88, and HKP GMS millets were transferred to farms. (Table 5)

At Bazaga (Birni N'Konni), sorghum midge-resistant SSD-35 and its early maturing female parent Mota Maradi were less damaged (1.5 = 10-20% and 3.0 = 20-31% damaged spikelets) by sorghum midge and yielded more (862.5 and 737.5 kg ha-1) than local El Mota (4.3 and 587.5 kg ha-1). At the 1st planting at Doguérawa, damage by sorghum midge was 1.0 (<10% damaged spikelets) for SSD-35, 3.9 (31-40% damaged spikelets) for Mota Maradi, and 2.9 (21-30% damaged spikelets) for El Mota. At the 2nd planting, damage to SSD-35 was 1.3 (<10% damaged spikelets), 3.9 (31-40%) for Mota Maradi, and 2.0 (11-20% damaged spikelets) for El Mota. SSD-35 yielded 687.5 and 700.0 kg ha-1 from the 1st and 2nd plantings. Yield of Mota Maradi did not differ between the 1st (937.5 kg ha-1) and 2nd plantings (1,000.0 kg ha-1). Yield of El Mota was greater in the 1st (743.8 kg ha-1) than 2nd planting (562.5 kg ha-1). (Table 6)

In 2009, SSD-35 and Mota Maradi were introduced on farms in seven villages of Birni N'Konni and Madaoua, Niger. Nine extension agents, 28 farmers, and "Taymako" organization of 80 farmers at Doguéraoua multiplied seed of SSD-35 on 3.5 hectares. SSD-35 was evaluated by 48 farmers and produced by 184 farmers on 67 hectares in two areas of Tahoua, Niger. In six villages, 104 and 67 farmers adopted SSD-35 and Mota Maradi planted on 24 and 16 hectares, respectively. Seed of SSD-35 was multiplied on 43 hectares by 84 farmers from five villages, and Mota Maradi was multiplied on 12 hectares by eight farmers from three villages. In 2008, the two varieties were introduced at farms in five villages of two regions by four extension agents, 20 farmers, and "Taymako" who did four tests with two planting dates at a site. Bagged grain of SSD-35 is sold by the private company "Semences Améliorées ALHERI" at Doutchi.

Twenty-five sorghums from the Mozambique breeding program and 17 varieties from the U.S. differed significantly in damage (1-5 scale) by stalk borers at Namialo Agriculture Research Center. Twelve varieties differed significantly in resistance to sugarcane aphid. ICSB654 was resistant to stalk borers. Sima was little damaged by stalk borers, aphids, and sorghum midge. (Table 7)

Table 5.

Millet evaluated at Kollo, Niger	Damage (1-9 scale)	% spikes infested by millet head miner
Tchoumo	1.9 ± 1.0 a	24.2 ± 1.6 a
Mangarana	2.9 ± 2.0 b	28.4 ± 2.2 b
HKB	1.9 ± 1.1 a	38.4 ± 2.1 c
Taram	2.1 ± 1.2 b	40.9 ± 1.5 c
ICMV IS89305	2.2 ± 1.2 b	44.2 ± 2.6 ab
Zatib	2.8 ± 1.9 b	44.9 ± 2.3 ab
Mangarana x ICMV IS89305	2.5 ± 1.4 b	52.8 ± 3.1 bc
SOSAT-C x HKB	2.7 ± 1.3 b	55.6 ± 2.9 bc
H80-10 GR	2.8 ± 1.4 b	57.3 ± 1.3 abc
HKP GMS	4.3 ± 2.7 c	58.1 ± 1.7 abc
SOSAT-C 88 x Zatib	3.1 ± 1.5 ab	59.7 ± 3.3 abc
SOSAT-C88	3.8 ± 2.2 ab	62.4 ± 3.8 cd
CV (%)	2.8	47.2
LSD	2.5	52.3

Table 6.

Sorghum	Damage by sorghum midge (1-9)			Yield (kg ha^{-1})		
	Bazaga	1st planting, Doguérawa,	2nd planting, Doguérawa,	Bazaga	1st planting, Doguérawa,	2nd planting, Doguérawa,
SSD-35	1.5 ± 0.3c	1.0 ± 0.1c	1.3 ± 0.3a	862.5 ± 13.6a	687.5 ± 9.7a	700.0 ± 12.3b
Mota Maradi	3.0 ± 0.4b	3.9 ± 0.4c	3.6 ± 0.3b	737.5 ± 14.7b	937.5 ± 17.3c	1,000.0 ± 7.9c
El Mota (check)	4.3 ± 0.7a	2.9 ± 0.7b	2.0 ± 0.6c	587.5 ± 10.9c	743.8 ± 12.4b	562.5 ± 10.5a
C.V (%)	35.5	43.2	36.8	48.6	39.7	45.4
L.S.D	1.5	1.9	0.3	139.0	193.7	137.5

Table 7.

25 sorghums	Stalk borer damage	17 sorghums	Stalk borer damage	12 sorghums	Sugarcane aphid damage
104GRD	1.25c	04CS-452-4-1	1.083b	SDS-3047/722E-8	1.01c
ICSB654	1.25c	04CS-573-3-1	1.3ab	Sima	1.15bc
Ent#64DTN	1.27bc	02CS-30932	1.31ab	GV SIMS710E-2	1.16bc
SPV1411	1.30abc	02CS-30445	1.37ab	SDS-1958-1-3-2/724E-5	1.16bc
ICSB324	1.63abc	03CM-15012-BK	1.62a	(SDS-5006*USV-187)E-4	1.30ab
E36-1	1.68ab	04CS-798-7-1	1.62a	ZSV-15-4/723E-3	1.30ab
ICSV700	1.73ab	03CM-1104-BK	1.65a	Macia	1.37ab
ICSR93034	1.75a			ICSV-93010-1/708E-9	1.45a
CV% =17.56		CV% =11.53		CV% =10.91	

The PI evaluated 54 sorghum hybrids developed by Monsanto for resistance to greenbug biotypes E and I, with most more resistant than the check. The PI evaluated 441 sorghum lines Milo Genetics developed for resistance to greenbug biotype I, with most more resistant than the check.

M.S. student Suhas Vyavhare put three female and two male newly emerged maize weevils into each of 10 vials with 5.0 g of kernels from sorghum plants at different growth stages in a field. Each grain in the 10 vials was evaluated for damage on a scale of 1-5, numbers of live and dead weevil adults were counted, grain in each vial was weighed, and moisture was determined. After 1 week, 23.1% of kernels at the hard-dough stage but only 6.1 and 12.0% of kernels at the soft-dough and physiological maturity were damaged. (Table 8)

Suhas Vyavhare evaluated 26 genotypes of stored sorghum for resistance to maize weevils. 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. Eighteen new weevils were produced per gram of B.HF8 by 63 days after infestation. At 84 days after infestation, weight loss ranged from 55.6% for B.HF8 to 12.7%. (Table 9)

Dr. Michael Pendleton developed a technique to relate the location of starch in sorghum grain to resistance to maize weevil. Cross sections of grains were subjected to iodine vapor that produced a stable complex with starch. The iodine molecules were detected using a scanning electron microscope equipped with an

Table 8.

Sorghum stage	Grain moisture (%)	% damaged kernels 1 week after infestation
Soft dough	50	6.1
	34	15.4
Hard dough	32	23.1
	25	16.7
Physiological maturity	16	12.0

Table 9.

Sorghum Genotype	Cumulative new maize weevils/g of grain by 63 DAI	% weight loss at 84 DAI
(5BRON151/(7EO366*GR107B-90M16)*Tegemeo)-HG7-CC2-CABK-CABK	3.1	12.7
(SV1*Sima/TS23250)-LG15-CG1-BG2-(03) BGBK-LBK-PRBK	2.9	13.8
Sureño	4.2	14.5
(B35*B9501)-HD9	5.9	18.9
(Dorado*Tegemeo)-HW15-CA1-CC2-LG1-CABK	5.0	20.4
(Dorado*Tegemeo)-HW13-CA1-CC2-LGBK-CABK	4.8	21.3
(Macia*TAM428)-LL9	4.4	22.3
Tegemeo	4.6	22.8
(Kuyuma*5BRON155)-CA5-CC1-CABK-CABK	5.3	23.4
(VG153*(TAM428*SBIII)-23-BE2-EE2-BE1	7.5	25.1
(9MLT176/(MR112B-92M2*TX2880)*A964)-CA3-CABK-CCBK-CABK-CABK	7.4	26.5
Macia	6.8	27.1
(Dorado*Tegemeo)-HW14-CA1-CC2-CABK-CABK	6.2	27.4
(Macia*TAM428)-LL2	6.1	27.7
(5BRON151/ (7EO366*GR107B-90M16)*Tegemeo) -HG1-LGBK-CABK-CABK	7.0	30.2
(M84-7*VG153)-LBK-PR7-L4-L2-	8.4	30.8
(6BRON161/(7EO366*Tx2783)*CE151) -LG5-CG2- (03)-BG1-BG2-LBK-PR	6.0	31.4
(850G4300-5*Tx2782)-SM5-CM2-SM2-SM1-CABK-CMBK-CMBK	11.0	32.4
CE151	9.9	35.8
B409	11.5	36.5
(Segaolane*WM#322) LG2-LG2-(03)-BG1-LG1-LGK-PRBK	7.8	39.9
*Tx2864*PI550607)))))-PR3-SM6	12.0	36.9
(9MLT176/(MR112B-92M2*TX2880)*A964)-LG8-CABK-LGBK-LGBK-CABK	11.9	40.8
(Tx2864*PI550607)))))-PR3-SM6	14.2	44.5
(A964*P850029)-HW6-CA1-CC1-LGBK-CABK	14.6	51.9
B.HF8	17.7	55.6

energy dispersive spectroscopy (EDS) detector. Information from the EDS detector was related to the image of the sorghum grain so areas with concentrations of starch/iodine complex were determined. The greater the depth of the concentration of starch granules from the surface, the more resistant was the grain to maize weevil. Starch was concentrated 60 micrometers from the surface of the grain of the most resistant genotype but only 20 micrometers from the surface of less resistant sorghum.

Ten and 9 hectares of Macia and Sima were planted at IIAM research stations at Namapa, Namialo, Nampula, Manetil, Mapupulo, Mutuali, and Sussundenga in Mozambique. A total of 5.5 hectares each of Macia and Sima was planted on farms at Liomagurue, Nametil, Malema, and Murrupula. Totals of 185,500 and 153,000 kg of Macia and Sima were produced at the seven research stations, and 26,125 and 36,300 kg were produced at the four farms to distribute to farmers or sell to NGOs to give to farmers.

To enhance germplasm, 12 local sorghum varieties were collected in Montepuez, Namuno, Ancuabe, Balama, Chiure, Ribaue, and Malema districts in Nampula and Cabo Delgado provinces in Mozambique. The sorghums resist storage pests because the grain is flint but matures late in 6 months. Farmers wanted varieties not damaged by birds or pests in the field or storage and were willing to use intermediate sorghum to overcome periods without cereal.

Networking Activities

Workshops and Meetings. The PI and students attended and presented research at the Sorghum Improvement Conference of North America and Great Plains Sorghum Conference, Amarillo, TX, 10-12 August 2009; 6th International Integrated Pest Management Symposium, Portland, OR, 24-26 March 2009; 57th Meeting of the Southwestern Branch of the Entomological Society of America, Stillwater, OK, 23-26 February 2009; and the 56th Annual Meeting of the Entomological Society of America, Reno, NV, 16-19 November 2008.

Research Investigator Exchanges

From 16-27 October 2008, the PI discussed and reviewed research with scientists from INRAN in Niger and IER in Mali. From 5-16 March 2009, the PI traveled with Drs. John Sanders, Ouendeba Botorou, Jeremy Foltz, and Niamoye Yaro to Finkoloni, Kaniko, Magnabougou, N'Garasso, Piza, Tingoni, and Wallo in Mali to meet with 199 farmers including 71 women, give them a color brochure written in French, and tell them how to manage insect pests in stored grain. From 16-28 April 2009, the PI discussed and reviewed research and education with scientists and students from IIAM in Mozambique and Botswana College of Agriculture. The PI met in Mali with the coordinators of the West Africa regional program to discuss and prepare workplans and budgets from 26-30 August 2009.

Research Information Exchange

The PI advised extension, National Sorghum Producers, and seed companies on management of sorghum insects. Four hundred ninety-five sorghums developed for resistance to biotype E and I greenbugs were evaluated for Milo Genetics and Monsanto. 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. The PI, Dr. Yaro in Mali, Mr. Abdou Kadi Kadi in Niger, and Dr. Alain Ratnadass, Entomologist, CIRAD/ICRISAT Niger, discussed collaborative entomology research for the "Cereals for the Drylands" proposal to the Bill and Melinda Gates Foundation. The PI and Dr. Yaro prepared a color brochure entitled "Les Insectes Nuisibles du Sorgho Stocke et La Gestion Integree des Insectes Nuisibles des Stocks" and traveled in March with Drs. John Sanders, Ouendeba Botorou, and Jeremy Foltz to tell hundreds of farmers how to manage storage pests. During release of SSD-35, Mr. Abdou Kadi Kadi worked with eight extension agents, 28 farmers, "Taymako" association of 80 farmers from Doguéraoua, and a student intern from Faculté d'Agronomie, Université Abdou Moumouni de Niamey, Niger. Forty farmers in Niger were informed about sorghum midge through field training on identification, biology, damage assessment, and control. Eight extension agents were informed how SSD-35 was developed and trained how to identify and control insect pests of millet and sorghum in Niger. While collaborating with Dr. Kadri Aboubacar, Faculté d'Agronomie, Université Abdou Moumouni de Niamey, Mr. Abdou Kadi Kadi was involved with field practical training, supervising writing of reports, and the committees of five student interns in 2008. In 2009, he supervised two interns involved with testing and adoption of SSD-35 at Doguéraoua and surveying farmer knowledge of sorghum insect pests at Madaoua, Niger.

Germplasm Conservation and Distribution

H80-10GR, SOSAT-C88, and HKP GMS millets were transferred to farms in Niger. Sorghum midge-resistant SSD-35 and Mota Maradi were introduced on farms in seven villages of Birni N'Konni and Madaoua. Nine extension agents, 28 farmers, and "Taymako" organization of 80 farmers at Doguéraoua multiplied SSD-35 on 3.5 hectares. SSD-35 was evaluated by 48 farmers and produced by 184 farmers on 67 hectares in two areas of Tahoua. In six villages, 104 and 67 farmers adopted SSD-35 and Mota Maradi planted on 24 and 16 hectares, respectively. Seed of SSD-35 was multiplied on 43 hectares by 84 farmers from five villages, and Mota Maradi was multiplied on 12 hectares by eight farmers from three villages. In 2008, the two sorghum varieties were introduced at farms in five villages. Bagged grain of SSD-35 is sold by the private seed company "Semences Améliorées ALHERI" at Doutchi.

Ten and 9 hectares of Macia and Sima were planted at seven IIAM research stations and 5.5 hectares each on four farms in Mozambique. Totals of 211,625 and 189,300 kg of Macia and Sima were produced to distribute to farmers or sell to NGOs to give to farmers. To enhance existing germplasm 12 local sorghum varieties were collected in Montepuez, Namuno, Ancuabe, Balama, Chiure, Ribaue, and Malema districts in Nampula and Cabo Delgado provinces.

Publications and Presentations

Journal Articles

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

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Pendleton, B.B., and S. Veerabomma. 2008. Effects of soil water and nitrogen on fitness of greenbug (Hemiptera: Aphididae) on sorghum. Southwestern Entomologist 33: 281-287.

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Peterson, G.C., K. Schaefer, and B.B. Pendleton. 2009. Registration of 16 sorghum germplasm lines. Journal of Plant Registrations 3: 203-205.

Proceedings

Garzon, C.A., B.B. Pendleton, J. Michels, and R. Fegley. 2009. Monitoring to establish a model of southwestern corn borer (Lepidoptera: Crambidae) dynamics for the Texas High Plains. In Proceedings of the 57th Annual Meeting of the Southwestern Branch of the Entomological Society of America and the Annual Meeting of the Society of Southwestern Entomologists, 23-26 February 2009, Stillwater, OK. P. 1.

Miscellaneous

Yaro Diarisso, N., and B.B. Pendleton. 2009. Les insectes nuisibles du sorgho stocke. La gestion integree des insectes nuisibles des stocks.

Presentations

Eder, Z., and B.B. Pendleton, Yellow sugarcane aphid effects on sorghum yield; Gilchrest, J.R., and B.B. Pendleton, Effect of photoperiod on fitness of greenbug biotypes E and I on sorghum; and Pendleton, M., E.A. Ellis, F.M. Chitio, and B.B. Pendleton, Using scanning electron microscopy with energy dispersive spectroscopy to identify starch in sorghum grain resistant to maize weevil. Sorghum Improvement Conference of North America and Great Plains Sorghum Conference, 10-12 August 2009, Amarillo, TX.

Pendleton, B.B. IPM for insect pests of sorghum and millet. Global Food Shortages: Role of IPM. 6th International Integrated Pest Management Symposium, 24-26 March 2009, Portland, OR.

Garzon, C.A., B.B. Pendleton, J. Michels, and R. Fegley. Monitoring to establish a model of southwestern corn borer (Lepidoptera: Crambidae) dynamics for the Texas High Plains. 57th Annual Meeting of the Southwestern Branch of the Entomological Society of America, 23-26 February 2009, Stillwater, OK.

Bowling, R., B.B. Pendleton, and G.J. Michels, IPM Program insect monitoring program in the northwest Texas Panhandle; Garzon, C.A., B.B. Pendleton, R. Bowling, and G.J. Michels, Monitoring to establish a model of southwestern corn borer (Lepidoptera: Crambidae) dynamics for the Texas High Plains; and Pendleton, M.W., B.B. Pendleton, E.A. Ellis, and A. Holzenberg, Two methods of conductive coating for scanning electron microscopy of maize weevils, Sitophilus zeamais, compared by energy dispersive spectroscopy. 56th Annual Meeting of the Entomological Society of America, 16-19 November 2008, Reno, NV.

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 asses their long-term impact on yields and economic stability. Farmers are key players in decision making of technologies to be tested. Therefore, during the first year 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 M.S. from Ghana and one Ph.D. 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 to farmers field; and
- To initiate short-term and long-term training opportunities to host country students and scientists.
- 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:

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

Research Methodology and Strategy

Host Country: Ghana

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

Objectives: The main objectives of this experiment were to (i) compare effects of conventional and no-till on growth and yield of sorghum; (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).

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).

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 6 cropping systems and tillage system and two P fertilizer rates. Cropping and tillage systems (Factor 1) were cowpea/sorghum rotation in conventional till (T1), cowpea/sorghum rotation in no-till (T2), cowpea/sorghum relay rotation in conventional till (T3), cowpea/sorghum relay rotation in no-till (T4), sorghum/cowpea intercrop rotation in conventional till (T5), and sorghum/cowpea intercrop rotation in no-till (T6). Phosphorus rates (Factor 2) were 0 and 26 kg P ha-1. These treatments were replicated in 15 farmers' fields at each location.

Host Country: Niger

Experiment 1: Integrated Sorghum – Cotton Cropping System to Control Striga on Grain Sorghum

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

Treatments and Experimental Design: This research was conducted at Konni. The treatments comprised of four cropping systems (sorghum – sorghum, sorghum – cotton, cotton – sorghum, and cotton – cotton) and four nitrogen fertilizer treatments (0, 50, 100 and 150 kg ha-1) applied to sorghum. Experimental design was a latin square design with cropping systems as rows and fertilizer treatments as columns, with four replications.

Experiment 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 1 technology 1, 17,000 plant ha-1, rock phosphate 130 kg ha-1; C. Medium 2 technology 17,000 plant ha-1,and micro-dose (6 g NPK); D: High technology, triple super phosphate 30 kg P2O5 ha-1, and Karate (insecticide) 2.5 l ha-1 in three applications. Genotypes were HKP (millet) and TN-5-78 (cowpea). Split application of N @ 30 kg ha-1 was applied in medium and high technology treatments. 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 which consisting of genotype, fertilizer practice and cropping system to improve productivity of sorghum and pearl millet cropping system.

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

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

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

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

Host Country: Mali

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 treatment (comprised of combination of no-till, reduced, tillage, conventional tillage and weeding practices), and two genotypes of millet (local landrace, Toroniou and improved variety, SO x SAT). Experimental design was a factorial randomized block with four replications.

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

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

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

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

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

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

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

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

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

United States of America

Experiment 1: Characterization of Genetic Diversity in Sorghum Association Panel in Field Conditions

Objectives: The main objective of this experiment was to characterize the genetic diversity in sorghum association panel under field conditions for traits associated with drought tolerance and grain yield.

Treatments and Experimental Design: The sorghum diversity panel (300 lines) was grown under rain-fed and irrigated conditions in Manhattan, KS with two replications. Data on phenology (flowering), physiological traits (chlorophyll fluorescence, canopy temperature and chlorophyll content), and yield traits (harvest index from single plant samples, and grain yield from 2-m rows) were measured. Few new potential high yielding and drought tolerant lines were identified for further analyses. In addition, all the grain samples from last two years were ground and prepared for analyses of bioenergy traits (carbohydrate analyses).

Experiment 2: Characterization of Genetic Diversity in Sweet Sorghum Pane in Field Conditions

Objectives: The objective of this experiment was to characterize the sweet sorghum panel for traits associated with bioenergy production.

Treatments and Experimental Design: Sweet sorghum panel (280 lines, Experiment 1) was grown under irrigated (2007) and rainfed, and irrigated (2008) conditions in Manhattan, KS. Data on phenology (flowering), physiological traits (chlorophyll fluorescence, canopy temperature and chlorophyll content), and sugar traits (brix, juice volume, fresh and dry weights) were measured.

Experiment 3: Effects of Chemical Sterilent on Stalk Yield and Quality of Sweet Sorghum

Objectives: The main objective of this field study was to investigate effect of foliar spray of chemical sterilents and de-heading (panicle removal) at anthesis on brix and juice volume of sweet sorghum.

Treatments and Experimental Design: Sweet sorghum genotypes (Dale, Keller, M81E and Top76-7) were grown under field conditions with four treatments [untreated control; p-caumaric acid spray (500 ppm); t-cinnamic acid spray (1000 ppm); and deheading]. The experimental design was randomized complete block design with four replications. Deheading was done at anthesis and chemical sprays were given at anthesis using hand operated sprayers. At maturity data on plant growth (plant height, leaf numbers), brix content, juice volume, fresh weight and dry weights were recorded.

Experiment 4: Sensitivity of Sweet Sorghum to Drought Stress in Controlled Environments

Objectives: The main objective of this study was to investigate and quantify the impact of various levels of drought stress during flowering stage on juice volume, brix, and sugar yield of sweet sorghum.

Treatments and Experimental Design: Four sweet sorghum genotypes (Awanlek, Smith, Tracy and Wray) were grown in controlled environment greenhouse conditions in 15-L pots filled with soil, sand and vermiculite from sowing to flowering under fully irrigated conditions. Thereafter, plants were exposed to four treatments (100% pot capacity, fully irrigation; 70% pot capacity, mild drought stress; and 30% pot capacity, severe drought stress). Duration of stress was 16 days. Plants were fully irrigated prior to start of stress and after completion of stress period. Data on physiological processes (leaf photosynthesis, chlorophyll content, stomatal conductance) were recorded at 4 d intervals during stress period. At maturity data on growth (plant height, leaf numbers, internode length), dry matter production, juice quality (brix content) was determined.

Research Results

Host Country: Ghana

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

Results: The cowpea components of this experiment were reported in last year annual report.

In brief, there was no influence of tillage practice or fertilizer application on cowpea yield. There was significant effect of cropping system on pod and grain yield of cowpea. Cowpea – sorghum intercrop rotation produced highest biomass, pod and seed yield of cowpea.

There were significant main effects of tillage, cropping system and fertilizer application on sorghum stover dry weight. There were no interactive effects on sorghum biomass or grain yield. Sorghum stover dry matter was significantly higher under conventional tillage (CT, 1441 kg ha-1) than under no tillage (NT, 958 kg ha-1) and in sole sorghum (1399 kg ha-1) than when intercropped (1000 kg ha^{-1}) with cowpea (Table 1). Similarly, stover dry weight was enhanced with the application of 26 kg P ha-1 or combination of N and P fertilizer compared with no fertilization or application of only 40 kg N ha-1 (Table 1). In contrast to biomass production, there was no significant effect of tillage or cropping system on sorghum grain yield but fertilizer application had a significant effect. Application of only 26 kg P ha-1 or a combination N and P fertilizer gave significantly higher grain yield than without fertilizer or the application of only N at 40 kg ha-1.

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

Results: Nitrogen fertilization significantly ($P<0.05$) influenced sorghum dry matter accumulation (Table 2). There was no significant effect of tillage and variety or the interaction on sorghum dry matter production. The local variety, Chere, was significantly taller than the improved varieties Kapaala and Dorado (Table 3). The local variety, Chere, produced significantly higher stover dry matter than the improved varieties, Kapaala and Dorado. In contrast, the local variety Chere, produced significantly lower grain yield than the varieties Kapaala and Dorado. Application of N fertilizer significantly increased stover dry matter compared with no N fertilizer.

Similar amount of water was used by the crops irrespective of the tillage system and tended to increase with N fertilizer rate. The local sorghum variety (Chere) used significantly more water than the improved varieties, Kapaala and Dorado under both CT and NT systems (Table 4). Water use efficiencies (WUE) were calculated on the basis of grain yield. The improved varieties, Kapaala and Dorado had significantly higher WUE than the local variety, Chere, under both CT and NT (Table 5). Application of N fertilizer also increased WUE compared with no fertilizer for all varieties.

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

Results: At Piisi and Nakor in the Wa district, there were significant effects of cropping system and P fertilizer application on cowpea biomass, pod and grain yield. Biomass, pod, and seed yield of cowpea intercropped with sorghum were significantly higher than first year sole cowpea in the cowpea-sorghum rotation or cowpea relay cropped with sorghum (Table 6). Application of P fertilizer significantly increased cowpea biomass, pod, and seed yield compared with no P application. Tillage did not significantly affect cowpea biomass, pod, and seed yield.

At Silbelle in the Sissala district, cowpea biomass and grain yield were significantly higher under CT than under NT (Table 7). Cropping system had no effect on cowpea biomass but significantly influenced grain yield. Cowpea intercropped with sorghum produced significantly higher grain yield than sole cowpea or when relay cropped with sorghum. Application of P fertilizer also produced higher biomass and grain yield than without P. Since 2008 was the first year of the experiment, there is no rotation effect of cowpea on sorghum growth and grain yield. Also there was no grain yield for sorghum in the cowpea-sorghum relay intercropping

Table 1. Main effects of tillage, cropping system and fertilizer amount on stover and grain yields of sorghum during the 2008 season at Wa, Ghana.

Main Effects	Stover yield	Grain yield
	kg ha^{-1}	
Tillage system		
CT	1441a	1145a
NT	958b	997a
Cropping system		
Continuous sorghum	1399a	1083a
Cp/Sg intercropping	1000b	1059a
Cp-Sg relay		
Fertilizer rate (kg ha^{-1})		
0	854a	777a
40 N	1003a	961ab
26 P	1481b	1337c
40 +26 (N+P)	1460b	1209bc

Means within a column followed by similar letters are not significantly different.

Table 2. Main effect of N fertilization on sorghum dry matter accumulation (kg ha^{-1}) during the 2008 season at Wa, Ghana

N rate	Days after planting			
(kg ha^{-1})	34	48	63	78
0	463a	738a	1209a	2510a
30	744ab	1600b	2678b	4225b
60	922b	1498b	3228b	4684b
90	765ab	1608b	2629b	5021b
120	817b	1647b	2956b	4861b

Means within a column followed by similar letters are not significantly different.

Table 3. Main effects of tillage, fertilizer rate and variety on plant height, stover and grain yield of sorghum during the 2008 season at Wa, Ghana.

Main effects	Plant height (m)	Stover yield (kg ha^{-1})	Grain yield (kg ha^{-1})
Tillage system			
CT	2.5a	3797a	1379a
NT	2.7a	3161a	1641a
Variety			
Kapaala	1.9a	2218a	1941a
Dorado	1.4a	2555a	1694a
Local (*Chere*)	4.4b	5663b	895b
Fertilizer rate (kg ha^{-1})			
0	2.3a	1973a	912a
30	2.6a	4112b	1395a
60	3.1a	3828b	1462a
90	2.4a	3632b	2276b
120	2.5a	3848b	1506a

Means within a column followed by similar letters are not significantly different.

Table 4. Effect of tillage, N fertilizer and variety on total water use (mm) during the 2008 cropping season at Wa, Ghana

Tillage system	Variety	Nitrogen fertilizer rate (kg ha^{-1})				
		0	30	60	90	120
CT	Kapaala	316a	399a	393a	435a	403a
	Dorado	390a	390a	389a	386b	383b
	Local (*Chere*)	504b	542b	549b	517c	519c
NT	Kapaala	392a	385a	409a	392a	389a
	Dorado	397a	387a	386a	384a	398a
	Local (*Chere*)	513b	532b	522b	532b	529b

Means within a column followed by similar letters are not significantly different.

Table 5. Effect of tillage, N fertilizer and variety on water use efficiency of sorghum during the 2008 cropping season at Wa, Ghana.

Tillage system	Variety	Nitrogen fertilizer rate (kg ha^{-1})				
		0	30	60	90	120
				kg ha^{-1} grain mm^{-1}		
CT	Kapaala	3.5a	3.5a	4.9a	4.2a	3.8a
	Dorado	2.9a	4.5a	4.4a	4.9a	5.6b
	Local (*Chere*)	0.8b	1.9b	1.6b	1.8b	1.9c
NT	Kapaala	2.9a	3.3a	3.7a	4.0a	3.3ab
	Dorado	2.9a	4.4a	4.8a	4.6a	4.6b
	Local (*Chere*)	1.1b	2.3b	1.7b	1.5b	2.4c

Means within a column followed by similar letters are not significantly different.

Table 6. Main effects of tillage, cropping system and P fertilizer on cowpea biomass, pod, and grain yield in farmers' fields at Wa, Ghana.

Main effects	Biomass (kg ha^{-1})	Pod yield (kg ha^{-1})	Grain yield (kg ha^{-1})
Tillage system			
CT	2595a	1020a	651a
NT	2740a	1039a	678a
Cropping system			
Cp-Sg rotation	2399a	803a	523a
Cp-Sorghum relay	2493a	929b	601b
Cp/Sg intercrop	3110b	1357c	869c
P fertilizer (kg P ha^{-1})			
0	2303a	922a	594a
26	3031b	1137b	735b

Means within a column followed by similar letters are not significantly different.
CT=conventional tillage; NT= no-till; Cp =cowpea; Sg=sorghum

Table 7. Main effects of tillage, cropping system and P fertilizer on cowpea biomass and grain yield at Silbelle in the Sissala district of Ghana.

Main effects	Biomass (kg ha^{-1})	Grain yield (kg ha^{-1})
Tillage system		
CT	2019a	714a
NT	1718b	682b
Cropping system		
Cp-Sg rotation	1875a	663a
Cp-Sg relay cropping	1850a	474b
Cp/Sg intercrop	1880a	957c
Phosphorus rate (kg ha^{-1})		
0	1713a	622a
26	2023b	774b

Cp =cowpea; Sg=sorghum

treatment due to the erratic rainfall pattern at the beginning of the season which delayed sowing and the abrupt end of the season.

At Nakor in the Wa district, there was no significant difference in grain yield of sorghum intercropped with cowpea on either conventional tillage or no-till. Similarly, there was no significant effect of P fertilizer application on sorghum grain yield (Table 8). At Silbelle in the Sissala district, sorghum intercropped with cowpea under CT produced higher stover and grain yield than under NT (Table 8). Application of P fertilizer gave higher sorghum stover and grain yield than without P fertilizer (Table 8).

Host Country: Niger

Experiment 1: Integrated Sorghum – Cotton Cropping System to Control *Striga* on Grain Sorghum

Results: There were no significant differences between various cropping systems during the first season for population of striga or yield traits of sorghum or cotton, with an exception of stover yields of both sorghum and cotton which were significantly greater under continuous cropping compared to crop rotations. Application of 100 kg N ha^{-1} produced maximum grain and stover yields which were on par with those with 150 kg N ha^{-1} (Table 9). Similar effects were observed for fiber yield of cotton. Application of 150 kg ha^{-1} of N to cotton was detrimental and caused yield reduction. As for stover yield, successive increases in fertilizer application produced greater stover yield, with maximum production with 150 kg N ha^{-1}.

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. The overall productivity of millet and cowpea in this field was extremely low. However, among various systems sole cropping produced significantly greater grain yields of millet or cowpea compared to intercropping or strip cropping or continuous cropping (Table 10). There were no significant differences between rotations and intercropping for stover yields, both of which were significantly greater than continuous cropping.

Among various technologies tested, medium-2 and high technology packages produced similar and significantly greater yields than low input or medium input with natural rock phosphate (Table 11). Maximum grain yields of millet were obtained by medium technology (planting density of 17,000 ha^{-1} with application of micro-dose - 6 g hill of 15:15:15 of chemical fertilizers at planting and 30 kg N ha-1 in split application); and high technology (planting density of 20,000 ha^{-1}, with application of 30 kg P2O5 ha-1 and N and three applications of insecticide) compared to low or medium 1 technology.

However, for cowpea among various systems, sole crop rotations or continuous cropping on par, but produced significantly greater grain yields compared to intercropping or strip cropping (Table 10). There were no significant differences among various cropping systems on stover yields. Among various technologies high technology (high planting density, with application of chemical fertilizers of both P and N) produced significantly greater yields than any other treatments (Table 11). The medium technology with microdose application produced lowest yields (even when compared to low input) due low emergence and germination. This might be due to errors in placement of micro-dose which might have caused phytotoxic effects leading to poor germination.

Overall, despite significant effects of cropping systems and technologies the production of both millet and cowpea were low due to occurrence of extreme drought during reproductive stages (flowering) of crop development and abrupt end of rainy season. In addition, the planting was delayed due to soil moisture conditions. If crop can be planted early it will help to escape drought conditions during sensitive stages of crop development.

Host Country: Burkina Faso:

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

Results: During this first season, there were no significant differences among various water conservation treatments on grain yields due to extreme wet weather and establishment of treatments and large variation among replications. However, numerical yields were greater in grass strip and stone row treatments when compared to no conservation treatments (Table 12). Overall, there were significant effects of management practices on stover yields, where grass strips and stone rows produced significantly higher yields. Improved cultivar (Sariaso 14) was significantly higher than the local landrace (Nongomsoba) with either grass strips or stone rows.

Host Country: Mali

Experiment 1: Impact of Reduced Tillage on Millet Yield

Results: The improved millet genotype, SOxSAT, produced significantly higher (21%) than the local genotype Toroniou (Table 13). However, farmers have a preference for the local millet due to their adaptation to its grain quality, which is better than that the improved millet. The control (no weeding) produced grain yield of 708 kg ha^{-1} of millet. This yield is close to the national millet grain yield of 735 kg ha^{-1}. One single weeding was the best weeding/tillage option with grain yield of 1281 kg ha^{-1} of millet. This treatment also allows some degree of soil cover by weeds without extra time for mulching. 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 of Yield

Results: The effect of millet-cowpea and millet-groundnut intercropping on grain production of Toroniou and SOxSAT is given in Table 14.

Delaying the seeding of cereal by 15 d significantly reduced growth and yield of both millet genotypes. Despite a non-significant interaction, millet grew better when it was intercropped with

Table 8. Effect of tillage, cropping system and P fertilizer on stover and grain yields of sorghum on farmers' fields at Nakor and Silbelle villages in Ghana.

Tillage system	Cropping system	P rate (kg ha^{-1})	Stover yield (kg ha^{-1})	Grain yield (kg ha^{-1})
		Nakor		
CT	Cp/Sg intercrop	0	1298±98	871±58
		26	1332±100	984±79
NT	Cp/Sg intercrop	0	1205±76	981±76
		26	1336±97	1020±38
		Silbelle		
CT	Cp/Sg intercrop	0	3092±49	1147±52
		26	3242±52	1233±51
NT	Cp/Sg intercrop	0	3072±70	1119±67
		26	3161±62	1128±72

Table 9. Effect of N fertilization on striga weight, yield and yield components of sorghum and cotton at on-station trials in Konni, Niger.

Urea rates	Sorghum yields (kg ha^{-1})				Cotton yield (kg ha^{-1})	
	Striga weights (kg ha^{-1})	Panicle	Grain	Stover	Fiber	Stover
F1 (check)	381	2363	1523	7421	2403	3906
F2 (50 kg ha^{-1})	230	3137	2070	8438	2187	6641
F3 (100 kg ha^{-1})	253	3594	2441	10156	2852	7813
F4 (150 kg ha^{-1})	488	3242	2305	984	2148	9180
P value	0.63	0.03*	0.07	0.07	0.74	0.10

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

Table 10. Effect of cropping system on yield and yield components of pearl millet and cowpea at on-station trials in Kollo, Niger.

Cropping System	Millet yields (kg ha^{-1})			Cowpea yield (kg ha^{-1})		
	Head	Grain	Stover	Pod	Grain	Stover
I. Sole crop rotation	390	218	633	140	106	67
II. Intercropping	196	116	648	78	61	42
III. Strip cropping	153	93	515	96	74	60
IV. Continuous cropping	254	137	432	105	82	52
LSD	108	66	155	38	31	31
P value	0.004**	0.01*	0.04*	0.03*	0.05*	0.40

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

Table 11. Effect of fertilization cropping system on yield and yield components of pearl millet and cotton at on-station trials in Kollo, Niger.

Cropping System	Millet yields (kg ha^{-1})			Cowpea yield (kg ha^{-1})		
	Head	Grain	Stover	Pod	Grain	Stover
A. Low technology (no input)	86	45	230	116	90	74
B. Medium 1 technology (with rock phosphate)	193	106	433	112	88	49
C. Medium 2 technology (with NPK microdose)	353	212	737	23	17	12
D. High technology (intensive cropping)	361	200	829	168	131	86
LSD	108	66	155	38	31	31
P value	0.004**	0.01*	0.04*	0.001***	0.001***	0.002**

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

Table 12. Effect of water conservation techniques on number of harvested hill, stover and grain yield of two sorghum genotypes at onstation trials in Saria, Burkina Faso.

Tillage system	Genotype	Harvested hills (no ha^{-1})	Stover yield (kg ha^{-1})	Grain yield (kg ha^{-1})
Grass strips	Nongomsoba	620	1964	833
	Sariaso 14	594	2944	733
Stone rows	Nongomsoba	630	1837	811
	Sariaso 14	635	3092	881
Control	Nongomsoba	559	1629	805
	Sariaso 14	562	2736	740

Table 13. Impact of genotype and tillage/weeding on millet yield (kg ha^{-1}) in Mali.

Treatments	Grain yield
Genotype (G)	
Toroniou - local	831 b*
SOxSAT improved	1008 a
Tillage/weeding (T)	
Weeding on need	844 c
Weeding ridges on need	823 c
Weeding furrows on need	885 c
Weeding ridges + ridging	1094 b
Weeding ridges + mulching furrows	927 bc
Control – no weeding	708 cd
Weeding – only once	1281 a
Weeding ridges + mulching ridges	792 c
Interaction GxT	NS**
CV (%)***	21

* Means (same column) followed by the same letter are not significantly different at P = 0.05, NS = not significant; *** Coefficient of variation.

Table 14. Influence of millet-cowpea and millet-groundnut intercropping on grain yield of millet genotypes.

Treatments	Yield (kg ha^{-1})
1. Toroniou and cowpea – simultaneous seeding	344 a
2. Toroniou – 15 days after cowpea	156 c
3. SO X SAT and cowpea – simultaneous seeding	281 ab
4. SO X SAT – 15 days after cowpea	188 c
5. Toroniou and groundnut – simultaneous seeding	375 a
6. Toroniou – 15 days after groundnut	156 c
7. SO X SAT and groundnut – simultaneous seeding	385 a
8. SO X SAT – 15 days after groundnut	271 ab

groundnut, due to higher biomass production from cowpea (Table 14). Similarly, delaying the seeding of the legume crops 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 decreasing competition, thus improving or maintaining the yield for the main crop. Millet-cowpea or millet-groundnut intercropping had no impact on the growth and yield of legumes (Table 15). 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). This suggests that millet is not competitive enough to influence the establishment and growth of these legumes.

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

Results: Data from both station and on-farm experiments were analyzed, using each site as replication. Thus, the data in Table 16 is compilation of 7 replications. Impact of selected soil and fertilizer practices such as contoured ridge tillage (ACN), site specific fertilizer management by NuMaSS (Nutrient Mangement Support System), reduced tillage and crop residue management are indicated in Table 16. There were significant effects of both ACN and fertilizer application b y the NuMaSS approach. In fact, cultivating on ACN's has significantly increased grain yield by 36%. These impacts are due to reduced runoff (by 22%), increased infiltration (deeper wetting front to 2 m), and better fertilizer use efficiency. Applying N and P according to NuMaSS has provided 44% more sorghum grain yield. The interaction effect between ACN's and NuMaSS provided 61% yield increase. Leaving crop residues on the field has increased grain yield by 43%. This impact is due to years of accumulation of small portions (8 – 12%) of crop residues. Soils are annually cultivated with the small portions of crop residues, which are left over after free grazing by livestock and other uses (home uses, composting, etc.). Combining ACN's, NuMaSS and crop residues increased yield by 72%. Reducing the number of tillage (2 less tillage for weeding) had no significant impact on yield. A switch will be made to another form of reduced tillage: direct seeding (that is keeping the ridges for years). Direct seeding and crop residues are being implemented by the Cotton Program of IER, with promising results.

United States: Manhattan, Kansas

Experiment 1: Characterization of Genetic Diversity in Sorghum Association Panel in Field Conditions

Results: There were wide variability in canopy temperatures and grain yield (Figure 1). Based on this we have identified few lines in different races and sub races of sorghum that have potential for increased grain yield under both irrigated and dry land conditions in Kansas. These selected lines were planted in replicated trials at Manhattan in June 2009 for further evaluation.

Experiment 2: Characterization of Genetic Diversity in Sweet Sorghum Pane in Field Conditions

Results: The results suggested strong genotypic difference in biofuel traits (brix, juice volume and sugar yields). Overall, drought caused reduction in bioenergy traits (Table 17). The percent decrease in sugar yield (estimated as product of juice volume and brix percentage) from irrigated (average of 2007 and 2008) and rainfed (2008) was about 60%. Based on this research about 15 lines showing better performance for bioenergy traits over the three seasons (2007 irrigated and 2008 irrigated and dryland) were identified. We conclude that (a) sweet sorghum panel has large variability for brix, juice volume and sugar yield; and (b) drought significantly decreases sugar yields. Lines with high sugar yield and drought tolerance were identified. Similarly, a total of 45 lines with contrasting (high, medium and low) brix and biomass production were identified. These are further being tested in the current season.

Experiment 3: Effects of Chemical Sterilent on Stalk Yield and Quality of Sweet Sorghum

Results: The results suggested that manipulation of reproductive sink (either through deheading or spraying of chemical sterilents) can have significant influence of the bioenergy traits of sweet sorghum. Deheading increased brix and juice volume (Figure 2) in stems due to no competition for stored carbohydrates. Chemical sterilents decreased seed-set and seed yield, thus increase juice volume, brix and sugar yield in three out of four varieties.

We conclude that improvement in brix, juice volume and sugar yield can be achieved through manipulation of sink strength (reduced seed-set) by deheading or application of chemical sterilents. This is caused through distribution of carbohydrates towards stalks.

Experiment 4: Sensitivity of Sweet Sorghum to Drought Stress in Controlled Environments

Results: Genotype tracy produced significantly higher stem fresh weight, juice volume and sugar yield than other genotypes, while genotype awanlek had significantly lowest values for all traits. The interaction between genotype and drought stress was significant for juice volume and sugar yield (Figure. 3). Genotype tracy produced similar juice volume and sugar yield under fully irrigated and mild stress conditions, while severe stress decreased juice volume and sugar yield by about 45 to 50%. There was no significant difference between the mild and severe stress in genotypes awanlek and smith. The juice volume and sugar yield of tracy under severe stress was significantly (about 100 to 120%) higher than genotypes awanlek and smith even under fully irrigated conditions.

Overall, we conclude that genotype tracy produced more brix, juice volume and sugar yield compared to other genotypes under both irrigated and drought conditions. Results also suggest that genotype tracy was relatively more tolerant to drought stress.

Achievement and Status of Activities Proposed in Work Plan

See Table 18

Contributions to INTSORMIL Strategic Plan Objectives

Our research was mainly aimed at Strategic Objective – 3

Table 15. Influence of millet-cowpea and millet-groundnut intercropping on the growth and yields of cowpea and groundnut.

Treatments	Cowpea (kg ha^{-1})		Groundnut (kg ha^{-1})	
	Pods	Grains	Pods	Hay
1. Toroniou and cowpea – simultaneous	592	396	-	-
2. Toroniou – 15 days after cowpea	625	458	-	-
3. SO X SAT and cowpea - simultaneous	571	396	-	-
4. SO X SAT – 15 days after cowpea	594	427	-	-
5. Toroniou and groundnut - simultaneous	-	-	128	385
6. Toroniou – 15 days after groundnut	-	-	149	531
7. SO X SAT and groundnut - simultaneous	-	-	107	375
8. SO X SAT – 15 days after groundnut	-		129	413

Table 16. Impact of ISFM practices on sorghum yield and soil carbon in Fansirakoro, Sotuba, Konobougou, Cinzana and Oumarbougou.

Technologies	Treatments	Sorghum yield (kg ha^{-1})	C in soil (%)
CAN	Check	894 b	0.20 b
	CAN	1212 a	0.32 a
Fertilizer	Check	911 b	0.22 b
	NuMaSS	1347a	0.29 a
Residue Management	Left	1299 a	0.36 a
	Removal	929 b	0.20 b
Tillage	Full tillage	1301 a	0.21 b
	Reduced tillage	1224 a	0.23 b

Table 17: Mean, range and coefficient of variation of sweet sorghum panel.

Trait	Mean	Range	CV
Brix value (%)	13.4	4.2 – 21.9	24.6
Juice volume (ml $plant^{-1}$)	436	85 – 1185	40.5
Sugar yield (ml $plant^{-1}$)[a]	56.3	10.0 – 130	9.5
Relative sugar yield reduction (%)[b]	60.6	1.0 – 98	23.6

a = sugar yield was measured from the product of brix and juice volume divided by 100.
b = relative reduction due to drought [under rainfed (dryland) and irrigated conditions (2007 vs. 2008)

Table 18. Status of activities proposed in the work plan on 2008.

Year/ Month	Activities	Status
2008		
July – Sep 08	Initiation and establishment of experiments in on-station and on-farm conditions	Complete
Oct – Dec 08	Data collection and harvest of different experiments	Complete
Jan – Mar 09	Data analysis and evaluation of various experiments for on-farm evaluation.	Complete
Apr – June 09	Re-defining and planning of treatments for experiments at each site. Discussion and workshop with farmers about perceptions of various technologies tested	Complete
Jul – Sep 09	Continuation of second season of selected experiments under on-farm and on-station conditions. Starting academic training of second graduate student (from Ghana) in US.	Complete

Figure 1. Genotypes with differential leaf temperature and grain yields under full irrigation at Manhattan, KS. Mean maximum air temperature during measurements was 32°C. SD = standard deviation. Quadrants are numbered 1 through 4 in the respective boxes.

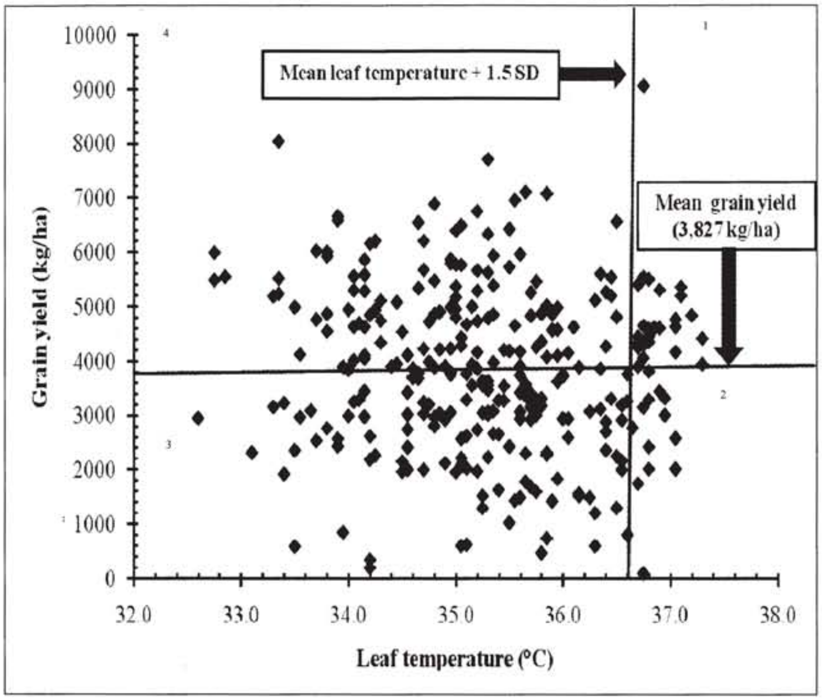


Figure 2. Effect of deheading and chemical sterilents on brix and juice volume of four sweet sorghum genotypes.

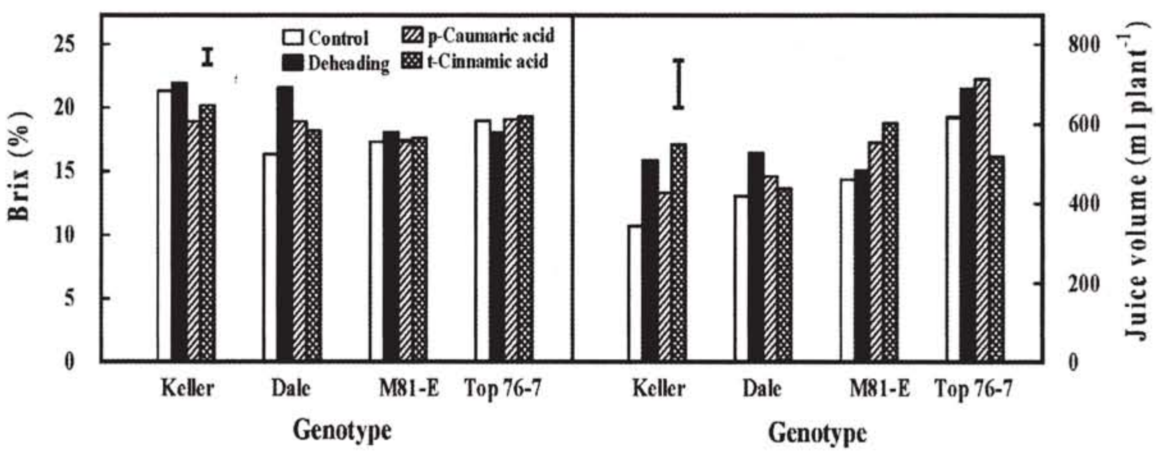
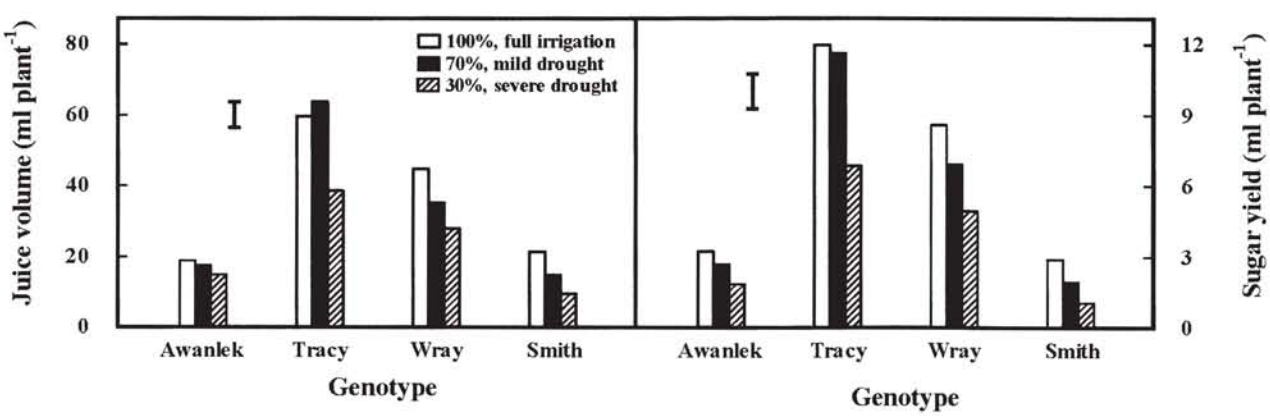


Figure 3. Effect of different levels of drought stress on juice volume and sugar yield of four sweet sorghum genotypes.



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

Training (Degree and Non-Degree)

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

1. Mali: Mr. Alassane Maiga, started his Ph.D. program at Kansas State University (KSU) in Fall 2008 and is going through course work and initiated his research experiments
2. Burkina Faso: Mr. Boukare Sawadago, is continuing his M.S. program at Ouagadougou University.
3. Ghana: Mr. George Mahama Yakuba, student from Ghana started his M.S. program at KSU in fall 2009.

In addition, two students from Kenya (Mr. Raymond Mutava and Ms. Rachel Opole) and one student from India (S. Subramanian) are continuing Ph.D. programs at KSU (leveraging money from other sources – Kansas Grain Sorghum Commission and Center for Sorghum Improvement).

Networking Activities

We have initiated ties with ICRISAT to train students working on sorghum and millet at KSU. Dr. Hari D. Upadhyaya (ICRISAT – India) and Dr. J.B. Naab (PI from Ghana) visited KSU. One PhD student has shown interest in working in ICRISAT for a season as part of her Ph.D. research. Drs. Prasad and Staggenborg visited all four host countries to initiate the current project and extend network with other scientists in the region.

Publications and Presentations

Journal Articles and Presentations

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

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Mutava, R. 2009. The Role of Agriculture in Rural Development in Sub-Saharan Africa (Oral Presentation). African Issues Symposium: Food Security, Environmental Sustainability and Human Health. Kansas State University, March 30th – April 1st, 2009

Subramanian SK, Prasad PVV, Staggenborg SA, Yu J and Vadlani PV. 2009. Effect of Water Stress During Early Seed-Filling (Milking) on Sugar and Juice Volume of Sweet Sorghum Genotypes in Controlled Environments. Great Plains Sorghum Conference, Aug 11-12, Amarillo, TX, USA

Subramanian SK, Prasad PVV, Staggenborg SA, Yu J and Vadlani PV.2009. Effect of Deheading and Chemical Sterilents on Juice, Stalk and Seed Yield of Sweet Sorghum Genotypes Under Field Conditions. Center for Sustainable Energy Annual Meeting, May 5, Kansas State University, Manhattan, KS, USA

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

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Introduction and Justification

Research and extension activities were implemented in four countries of eastern and southern Africa and in Nebraska supporting the INTSORMIL objective of improving crop and soil management for increased and more stable yields. Promising management practices have been identified and integrated into management packages. These practices are being promoted through extension activities in Ethiopia, Uganda and Nebraska while research continues. In Ethiopia, research and extension activities on water conservation, water use efficiency, and nutrient management targeted to striga infested and non-infested areas continued with increased emphasis on extension. A paper was published reporting results of tied ridging by fertilizer use research. Research on the main and interaction effects of tied ridging and skip-row planting of sorghum was completed in Ethiopia in 2008 and has been accepted for publication; the field work for similar research for maize, using buy-in resources, will be completed in 2009. Research on reduced tillage for teff production was initiated in northern Ethiopia in 2008 with less grain yield for reduced compared with conventional tillage. Extension activities continue to promote soil management technology. In striga-infested areas of eastern Uganda, extension continues 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. An atlas of sorghum production for eastern and southern Africa was published. Basin and tied-ridge tillage was superior to strip tillage in Singida area of central Tanzania. Collaboration in Mozambique has continued addressing issues of fertilizer nutrient use efficiency in diverse cropping systems through on-farm research. Institutional capacity building has included technical support to research and extension activities and the visit of a young Zambian researcher to the University of Nebraska. Research and extension in Nebraska continued with: completion of field research on efficiency of sweet sorghum as a biofuel crop, agronomic practices for sweet sorghum production, and nutrient uptake by sweet sorghum relative to grain crops; and continuation of research on water use efficiency of sweet and grain sorghum and maize to better allocate scarce water among these crops. Four journal papers, one extension paper, and the sorghum atlas were submitted, in-press, or 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, tillage and striga management research and extension in Uganda and Tanzania; development of decision guidelines to soil fertility management in Mozambique; and improved responsiveness to variable weather conditions. A third objective "Enhanced demand for sorghum with activities in Uganda and Ethiopia on feeding of livestock and activities in Uganda on grain supply to breweries" was not addressed because of high current and expected future demand globally and in Africa for basic commodities. These objectives support the Sorghum, Millet and Other Grains CRSP vision to improve food security, enhance farm income, and improve economic activity in the major sorghum and pearl millet producing countries in Africa.

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

The implementation sites 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) in Tanzania; and Nampula, the Nacala Corridor, and Manica in Mozambique.

Research Plan

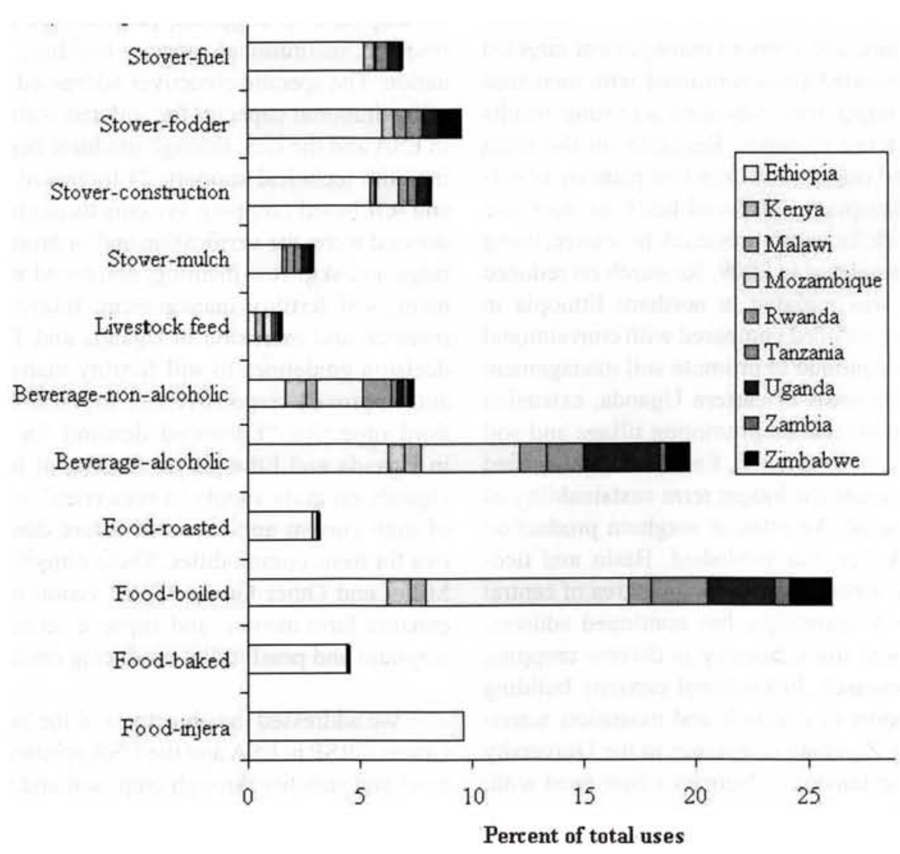
Role of host country scientists. T. Mesfin and G. Brhane continued as the main collaborators in Ethiopia. Dr. Kaizzi Kayuki continued to lead collaborative activities in Uganda with a research and extension focus on nutrient supply and tillage for water conservation. E. Letayo collaborated in on-farm tillage research in central Tanzania while continuing to promote *striga* management practices with a possible extension of activities to the southeastern Lake Province. Ricardo Maria collaborated in soil fertility research in Mozambique. The interdisciplinary team in Nebraska includes Drs. Mason, Ferguson, Lyon, Dwekait, and Martin representing agronomy, soil science, plant breeding, and irrigation engineering. A meeting was held with the APSIM model development team (www.apsim.info/) to calibrate it for skip-row planting of sorghum but actual calibration was postponed to begin in 2010. Outreach partners are numerous including the Teso Diocese Development Organization (TEDDO) working in five districts of Uganda, the Soroti Catholic Diocese, and various government and non-government extension partners and community-based organizations.

Research Results

The Atlas of Sorghum Production in Eastern and Southern Africa was published with information for Malawi, Rwanda, Zambia, Zimbabwe, Ethiopia, Kenya, Uganda, Tanzania, and Mozambique. It addresses 3.4 million ha in 39 production areas. Forty three yield constraints were evaluated; the top six constraints were water deficits, stem borers, N deficiency, striga, weeds, and quela quela. The major uses of grain are for boiled foods such as ugali and uji and for brewing (Fig. 1). Stover use accounted for approximately 30% of the crop value overall but greater than 40% in some production areas of Ethiopia. Approximately 34% of the grain was marketed.

The first experiment to evaluate reduced tillage for tef production was conducted in the 2008 main cropping season at Laelay Maichew woreda (140 07'N, 380 44'E, 2050 m asl) at Dura Farmers Training center (FTC) in Tigray region, Northern Ethiopia. Grain yield was about 30% less with reduced tillage (one tillage) compared to the traditional tillage practice of 4 or more passes with the traditional plow. Teff yield was not increased with N and P application. Weed biomass at harvest was reduced with one 2,4-D application; the 1.5 kg ha-1 was more effective than the 0.75 kg ha-1 application rate and application at the 6-leaf compared with the 5-leaf stage was more effective. Grain and biomass yields were, however, reduced with the higher rate of 2,4-D application

Figure 1. The relative importance of alternative uses, expressed as a percentage of total value of sorghum in eastern and southern Africa



compared with manual weeding alone. Experimentation in more environments is needed before conclusions can be drawn.

A series of experiments over several years on tillage, skip-row planting, and fertilizer use effects on grain sorghum have been completed in Ethiopia. Tied-ridging and skip-row planting were found to result in increased grain yield in northern Ethiopia but not in the Central Rift Valley. Planting 2 rows and skipping one row was the most promising configuration in northern Ethiopia and it did not result in yield loss or gain in the Central Rift Valley. The results have been published or are in press in two journals. On-farm trials and demonstrations are being conducted in the Central Rift Valley with increasing emphasis on climate risk management. Planting a shallow rooted, early maturing crop, such as common bean in the skipped areas is being investigated.

In a study of tillage and skip-row planting effects on maize in the Central Rift Valley, supported by buy-in funding, the mean yield increase with tied-ridging compared with flat tillage over two years was 55% with an overall mean yield of 3.94 Mg ha-1. There was no advantage to skip-row planting with plant 2 : skip 1 equal to all rows planted while plant 2 : skip 2 had less yield. In Australia, skip-row planting had an advantage with sorghum grain yields up to 2.5 Mg ha-1. In Nebraska, the breaking point was 4.5 Mg ha-1 but higher for maize; the research in Nebraska was with no-till and good cover compared with tilled, bare soil surfaces in Ethiopia.

Research to evaluate the sustainability of low input approaches to soil fertility management under different tillage systems continued. Extension activities were expanded with field demonstrations in 7 districts of eastern Uganda and partnerships with Soroti Catholic Diocese Development Organization (SOCADIDO), Teso Dioceses Development (TEDDO), government extension, NAADS service providers, CBO's, NGO's, etc. The soil test and trials results of 80 on-farm trials-demonstrations are summarized in Tables 1and 2. On average, the generally loamy sand soils had low soil organic matter ranging from 0.4 to 4.0% and moderate P availability ranging from 1.4 to 41 ppm. Mean grain yields were generally low but were increased by 520 and 1090 kg ha-1 with N and N plus P application.

In Tanzania, mean grain sorghum yield for six on-farm trials conducted in Singida Region was less with reduced tillage compared with tied-ridging and pot-hole tillage (Fig. 2). The reduced tillage consisted of ripping a planting strip using the Zambian Magoye ripper.

Mozambique-INIA led the implementation of trials to verify and fine-tune promising practices on-station and on-farm in northern Mozambique in collaboration with Zonal Research Centers in Nampula and Manica. Trials to evaluate the effect of green manure in rotation with sorghum were also conducted and the treatments included were: sorghum fertilized with standard fertilizer (urea + NPK); sorghum fertilized with urea; sorghum rotation with cowpea; sorghum without soil amendment; and sorghum following crotalaria. Foliar application of fertilizer was evaluated.

Sweet sorghum as a biofuel crop in Nebraska was evaluated in seven rainfed trials conducted across southern Nebraska. Biomass and sugar yields were affected by N rate and planting density in one trial only. Total N uptake was less and the maximum rate of N uptake was less with sweet sorghum compared with corn and grain sorghum. In addition, more N uptake occurred late in the

Figure 2. Tillage effects on mean sorghum grain yield from six on-farm trials conducted in Singida Region of Tanzania in 2008-2009. The Y-bar represents LSD 0.05

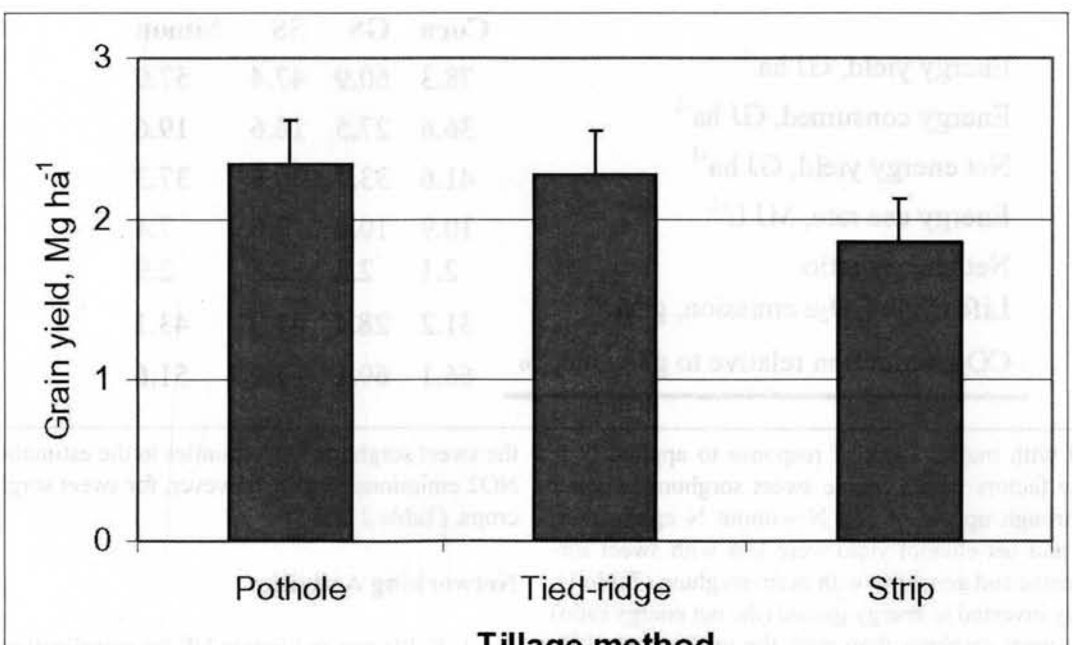


Table 1. Mean values of soil properties for on-farm trial sites in eastern Uganda for study of alternative soil fertility management practices.

Soil parameter	Mean	Critical value
pH (1 soil:2.5 water)	6	5.2
OM (%)	1.25	3
Extract. P (mg/kg soil)	8.15	5
Extract. K ($cmol_c$/kg soil)	8.1	3.9
Extract. Ca ($cmol_c$/kg soil)	11.5	17.5
Sand (%)	70.85	na
Silt (%)	17.6	na
Clay (%)	11.55	na

Table 2. Mean grain yield results for soil fertility treatments from 80 on-farm trials/demonstrations conducted in 11 countries in eastern Uganda in 2008 and 2009.

Soil fertility management practice	Grain yield t ha-1
Farmer practice	1.08
30 kg N ha^{-1}	1.60
30 kg N + 10 kg P ha^{-1}	2.17
4.0 t ha^{-1} manure	1.51
15 kg N + 5 kg P + 2.0 t manure ha^{-1} manure	1.60
30 kg N + 4.0 t manure ha^{-1}	1.97
$LSD_{5\%}$	0.25

Table 3. Mean yields, energy balances, and calculated CO_{2e} emissions for maize, grain sorghum (GS), and sweet sorghum (mean of all cultivars (SS) and of cv.Simon alone) at seven site-yr in Nebraska.

	Corn	GS	SS	Simon
Energy yield, GJ ha^{-1}	78.3	60.9	47.4	57.0
Energy consumed, GJ ha^{-1}	36.6	27.5	16.6	19.6
Net energy yield, GJ ha^{-1}	41.6	33.4	30.8	37.3
Energy use rate, MJ L^{-1}	10.9	10.4	7.6	7.4
Net energy ratio	2.1	2.2	2.8	2.9
Life cycle CO_2e emission, g MJ^{-1}	31.2	28.4	41.9	43.1
CO_2e reduction relative to gasoline, %	66.1	69.1	52.9	51.6

season compared with maize. Lack of response to applied N is attributed to these factors which enable sweet sorghum to better meet its needs through uptake of soil N without N application. Theoretical total and net ethanol yield were less with sweet sorghum than with maize and generally with grain sorghum (Table 1). The ratio of energy invested to energy gained (the net energy ratio) was higher with sweet sorghum than with the grain crops. Life cycle CO2e emission was higher with sweet sorghum compared with grain crops largely because of NO2 loss from the bagasse of the sweet sorghum. Uncertainties in the estimation of post-harvest NO2 emissions remain, however, for sweet sorghum and the grain crops. (Table 2 and 3)

Networking Activities

U.S. PIs met in Lincoln NE for coordination of activities. The sorghum atlas for 9 countries of ESA was published. A young visiting scientist from Zambia was hosted and a proposal for collaborative research was developed.

Publications

Journal Articles

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

Mamo, M. and C. Wortmann, 2009. Phosphorus sorption as affected by soil properties and termite activity in eastern and southern Africa. SSSAJ, in press.

Mesfin, T., G.B. Tesfahunegn, C.S. Wortmann, M. Mamo, and O. Nikus. 2009. Skip-row planting and tie-ridging for sorghum production in semi-arid areas of Ethiopia. Agron J. in press.

Mesfin, T., G. B. Tesfahunegn, C.S. Wortmann, O. Nikus, and M. Mamo. 2009. Tie-ridging and fertilizer use for sorghum production in semi-arid Ethiopia. Nutr. Cycl. Agroecosys. http://www.springerlink.com/content/25715u878nujt500/fulltext.pdf

Regassa, T. and C.S. Wortmann. 2009. Sweet sorghum as a bioenergy crop: literature review. J. of Biomass and Bioenergy submitted.

Wortmann, C.S., A.J. Liska, R.B. Ferguson, D.J. Lyon, R.N. Klein, and I. Dweikat. 2009. Dryland performance of sweet sorghum and grain crops for biofuel. Agron J submitted

Other Publication

Wortmann, C.S., M. Mamo, C. Mburu, E. Letayo, G. Abebe, K. C. Kayuki, M. Chisi, M. Mativavarira, S. Xerinda, T. Ndacyayisenga (2009). Atlas of sorghum (Sorghum bicolor (L.) Moench) production in eastern and southern Africa.

Wortmann, C., Richard Ferguson, Robert Klein, Drew Lyon, and Steve Melvin. 2009. Skip-row planting of grain sorghum for improved drought tolerance. NebGuide (in press).

Germplasm Enhancement and Conservation

INTSORMIL

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

Project ARS 101
Jeffrey P. Wilson
USDA-ARS

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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 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.

Genetic Improvement of Nematode Resistant Pearl Millets

Root knot nematodes are important yield constraints in pearl millet and in peanut and cowpea, which are frequently grown in intercropping and rotations with pearl millet in Africa. Advanced inbred progeny derived from African varieties P3Kollo, Sosat-C88, Zongo, and Gwagwa were selected based upon resistance to Meloidogyne incognita in greenhouse evaluations. F5 progeny with greatest seed availability were distributed to collaborators in Mali, Nigeria, and Burkina Faso. Fifteen progeny from each of P3Kollo, SoSat-C-88 and Gwagwa, and ten progeny from Zongo were evaluated for downy mildew resistance and yield in two replications at each location. Downy mildew incidence and agronomic traits were recorded.

Research Results

Downy mildew incidence was significantly affected by location, variety, and entry within variety. Over all locations, downy mildew incidence was greatest at Mali (33.9%), intermediate at Burkina Faso (29.1%) and least at Nigeria (22.2%) (lsd0.05 = 6.8). Mean downy mildew incidence over all locations were Gwagwa (22.2%), P3Kollo (24.5 %), SoSat-C88 (32.8 %), and Zongo (36.9 %) (lsd0.05 = 7.9). There was a significant GxE interaction. The most striking example was that overall, the SoSat-C88 selections were most susceptible in Mali, the origin of SoSat-C88, whereas it was resistant in Nigeria. P3Kollo was more resistant in Burkina Faso and Mali than in Nigeria. Only a few inbreds were resistant across all locations, notably, entries 52 through 55, derived from Gwagwa. Two entries were susceptible across all locations; entries 31 and 32 derived from Zongo. The most common reactions appeared to be site specific reactions where resistance was effective at some locations, but not at others. Downy mildew incidence at Mali and Burkina Faso were correlated ($r=0.44$, $P=<0.01$), suggesting that pathogen virulence was similar between the locations. Although not specifically designated as a variable for evaluation, some observations at several locations indicated that striga infestation was lower in the plots of pearl millet varieties with root knot nematode resistance.

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

A Modified Cost and Time Effective Procedure for Genotyping Pearl Millet in Resource-limited Laboratories

The need to genotype large mapping populations in pearl millet has increased for the improvement of various traits and for linkage mapping studies but the cost of production of per data unit remains a major impediment to fully harness the benefits of molecular genetic technology. We focused on reducing the cost and time for microsatellite genotyping from DNA extraction to PCR amplification to separation of PCR product using PAGE. A DNA extraction procedure was based on the premise that SSR markers require a relatively low concentration (5ng - 50ng) of average quality DNA Post-PCR multiplexing of two or more SSR markers involving the simultaneous separation of PCR amplified products in a single gel lane requires prior information about base-pair sizes or differences between SSR primers used for PCR amplification of DNA samples. We experimented with techniques to save time and costs by eliminating some protocol steps and reducing volumes of various reagents used for DNA extraction, PCR amplification and multiplexing of PCR products during PAGE electrophoresis in resource limited laboratories.

Results

Through eliminating or changing several steps used in DNA extraction, PCR amplification and PAGE electrophoresis, we developed a modified procedure that reduced the cost of consumables and required less time without compromising data quality. In the revised procedure, DNA was extracted by incubating 0.5-0.7g ground young leaf tissue in 2% CTAB/β-mercaptoethanol followed by refrigerated differential centrifugations with phenol: chloroform:isoamylalcohol. Steps such as additional phenol/chloroform treatments, DNA pellet drying followed by RNase treatments and incubation were eliminated, reducing use of costly and corrosive chemicals, and saving time. DNA produced from 174 genotypes exhibited an average concentration of 640ng/µL and average optical density ratio of 1.9. PCR amplification of SSR markers with this DNA produced clear and scorable bands following ethidium bromide stained agarose and silver stained polyacrylamide gel eletcrophoresis. Post PCR duplexing of two or more microsatellites based on different lengths of base pairs reduced the time and cost per unit data generation by up to half as compared to single marker per PAGE. The procedure is an intermediate between maxi- and mini-prep DNA extractions suited for resource limited laboratories engaged in molecular breeding requiring large volume of genotyping.

Objective 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.

Development and Evaluation of a Pearl Millet Thresher

A barrier to increased commercialization of pearl millet in the African setting is the lack of improved technologies for post-harvest processing. Partnerships have been developed with Compatible Technology International, St. Paul, MN to develop effective technology for post harvest processing. Prototype devices developed by Compatible Technology International (CTI) for threshing, winnowing, and decorticating pearl millet were evaluated by the USDA-ARS at Tifton, GA. The CTI prototypes were developed from the following premises: Villages have 10 to 100 families with approximately 10 persons / family. The village would own the thresher, separator and a grinder for flour, which cost approximately $800 (available through microloans). Families would use the village machines on an as-needed basis. Thresher mechanisms were to be developed for hand-operation. As higher capacity threshers are developed, opportunity exists to scale up capacity through the use of motors for commercial grain markets.

The processes for effective threshing consist of stripping the grain and florets from the rachis, dislodging the grain from the florets, and separating the grain from the chaff. Decortication requires removal of the seed coat from the grain. Identifying effective mechanisms to perform these operations were evaluated in stage 1 prototypes in 2008. Stage 2 prototypes that incorporated the most promising mechanisms were assessed in the current studies. After hand stripping panicles, the effectiveness of the Leary and Ewing threshers and the Wenkel separator were evaluated. Criteria considered were 1) ease of operation, 2) capacity, and 3) ability to produce clean, unbroken grains.

Results

Pearl millet florets can be hand stripped from the rachis reasonably quickly with sturdy devices. A box wrench was found to be highly effective for the process. Advantages of the Leary thresher were its comparative ease of operation and high capacity. Disadvantages included a higher frequency of cracked grain and a high level of chaff contamination in the final product. A winnowing step prior to the separation step improved the output quality by reducing residual chaff. Advantages of the Ewing thresher were its versatility, options for decortication, and the high quality of the resulting grain. Disadvantages included difficulty of feeding strippings into the device, difficulty with material discharge and cleaning after processing, and poorer performance when hand-cranked compared to the electric motor driven option. The Wenkel separator was modified by moving the hand crank to the discharge end of the shaft. Sieve screen sizes selected by CTI appear to be reasonably effective, but modifying the lengths of the sieve sections and providing an input hopper may improve the design. It will be necessary to develop shielding to prevent losses from scattering and flow controls to collect the output fractions more effectively. The Ewing device could be used as a decorticator, however, excessive grain breakage occurred with the pearl millet variety used in the evaluation. Additional evaluation is necessary to determine if breakage was due to the pearl millet variety used, or is an inherent property of the device. The Leary thresher showed some promise for processing sorghum. Modifications will be required to effectively thresh sorghum without breaking the grain. The Ewing device was ineffective for threshing sorghum. When coupled with the other technologies in these trials, the Leary thresher could produce 50 kg of pearl millet grain in 10.9 hours, whereas the Ewing thresher with metal blades and electric motor would require 16.5 hours. It was recommended that the processing steps should be examined to determine if output can be improved to compare to the 5 to 11 woman-hours required to process 50 kg of grain by using traditional threshing and winnowing processes. If the capacity or quality achieved by the existing prototypes cannot meet this goal, additional prototype designs should be considered.

Results and recommendations from these evaluations were shared with the Battelle Institute. CTI and the Battelle Institute have developed a stage 3 prototype based on the recommendations from the ARS evaluation. This advanced prototype has eliminated the hand-stripping step, and instead has incorporated a stripping mechanism at the feeding stage. A fan winnower has been developed to eliminate the need for the separator. These two modification should significantly increase throughput rates. The stage 3 prototype will be evaluated in Mali in December, 2009. The progress of the thresher development can be viewed at: http://onelabinitiative.blogspot.com/

Networking Activities

Workshops and Meetings

Presented "Post-Harvest Processing Technology for Pearl Millet and Developmental Needs" to Lemelson-MIT InvenTeam, Bridgewater NJ (via distance seminar technology) 9 Jan 09

Presented "Application of the Brazilian Pearl Millet Model to the U.S." at the Pearl Millet Consortium meeting, Ft. Valley St. University, Ft. Valley. 27 February 09

Presented "Progress in Pearl Millet Improvement and the Importance of Genetic Resources. USDA-ARS Plant Genetic Resources Conservation Unit, Griffin, GA. 5 May 09

Presented "Progress and Priorities in Pearl Millet Improvement" at the UGA Institute of Plant Breeding, Genetics, and Genomics retreat. Griffin GA. 2 Jun 09

Presented "No-Till Production and Niche Marketing of Pearl Millet" Rillington Fields, Tifton GA. 4 Sep 09 (Invited SARE field day presentation)

Research Information Exchange.

Consulted by Compatible Technology International (CTI), St. Paul, MN and the Battelle Institute to assess pearl millet threshing and winnowing prototypes and deployment for evaluations in sub-Saharan Africa. Nov 08 – Jul 09

Provided pearl millet diseases images requested by the Bureau of Animal and Plant Health Inspection and Quarantine, Council of Agriculture, Taiwan, for use in quarantine data base for BAPHIC staff training and reference. 1 Dec 08.

Consulted by USDA-APHIS on disease implications of pearl millet illegally imported from Pakistan via Canada and being sold in Indian food markets in the U.S. 4 Dec 08

Consulted by Semetes Adriana (Brazil) 3 times to diagnose foliar and stalk rot diseases of pearl millet and for control recommendations Feb-Sep 09

Consulted by Invasives.org and the Bugwood Network to correct taxonomic problems with pearl millet and yellow foxtail. Nomenclature problems caused the crop to be classified in national databases as a noxious and invasive weed in subject to regulatory action. Mar 09.

Consulted by Plantation Seed Conditioners to diagnose pearl millet cropping problem and to recommend control measures in a 1000 acre planting. Newton, GA. 3 Jun 09

Consulted by Tommy Dollar of First United Ethanol LLC (Camilla GA) for information on ethanol production and DDGS quality from pearl millet feedstocks. 10 Jun 09.

Consulted by Bioversity International (Italy) to develop relevant key descriptors for researchers to access and utilize pearl millet genetic resources. 16 Jul 09

Met with representatives of the Mali Ministry of Livestock and Fishery - Mamadou Coulibaly (National Director of Production and Animal Industries), Fode Traore (Project Coordinator of Livestock Development in Liptako-Gourma Region) and Vincent Farley (Honorary Consul of Mali). Responded to request from the Consul of Mali to outline an action plan policy paper to address aflatoxins in Malian diets. Aug 09

Germplasm Conservation and Distribution

Prepared 11 MTAs and provided 212 pearl millet germplasms upon request to Alabama A&M Univ (AL), BioDimensions Inc (TN), Emory Univ (GA), Ft. Valley St. Univ (GA), Jefferson Institute (MO), Nu-Life Market (KS), Operation Double Harvest (VA/Haiti), Univ. GA (GA), Univ. Arizona (AZ), Universidad del Zulia (Venezuela), and Vibha Seeds (India)

Publications and Presentations

Journal Articles

Rajewski, J.A., Ni, X., Wilson, J.P., Dweikat, I., Buntin, G.D. 2009. Evaluation of resistance to chinch bug in pearl millet in temperate and subtropical environments. Online. Plant Health Progress doi:10.1094/PHP-2009-0112-01-RS.

Scully, B.T., Krakowsky, M.D., Ni, X., Wilson, J.P., Lee, R.D., Guo, B.Z. 2009. Preharvest aflatoxin contamination of corn and other grain grops grown on the U.S. Southeastern Coastal Plain. Toxins Reviews. 28(2-3):169-179

Miscellaneous Publications

Ni, X., Coy, A.E., Buntin, G., Wilson, J.P. 2008. Sorghum Midge Resistance in 16 Grain Sorghum Hybrids - 2008. GA Agric. Experiment Station Report. http://www.swvt.uga.edu/2008/sysrsn08/RR718-SR-midge.pdf

Abstracts

Gulia, S.K., Singh, B.P., Wilson, J.P., Ma, X. 2009. Successful application of new cost-effective procedures for genotyping pearl millets for genetic diversity and linkage mapping. 15th Biennial Agricultural Research Director's Symposium, Atlanta, Georgia. March 28 - April 1, 2009. p. 118.

Gulia, S.K., Whitehead, W., Singh, B.P., Wilson, J.P. 2009. Grain yield and component traits of pearl millet genotypes at different row spacing. 15th Biennial Agricultural Research Director's Symposium, Atlanta, GA. March 28-April 1, 2009. pp. 117-118.

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.

Research Objectives

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

1. Create genetic variation in epicuticular wax (EW) production in sorghum through chemical mutagenesis for future studies on the contribution of EW to drought resistance.

2. Develop an effective chemical mutagenesis protocol for generating EW variants (bloomless and sparse bloom mutants) in sorghum.

3. Determine, through allelism tests, how many different loci affecting EW production are present in the mutagenized populations.

Research Methods

Create Genetic Variation in EW Production in Sorghum Through Chemical Mutagenesis

Seed from two drought-tolerant inbred *Sorghum bicolor* (L.) Moench cultivars designated P898012 and P954035 were treated with chemical mutagens and planted on the same day at the Purdue Agronomy Center for Research and Education in West Lafayette, IN and M1 plants grown to produce M2 seed heads. M2 plants were grown in a winter nursery in the Banderas Valley of Southwestern Mexico. Visual selection of the P898012- and P954035-derived mutant populations for plants with reduced visual deposition of EW (reduced glaucousness) on abaxial sheath surfaces was conducted during the pre-boot and boot stages from among the segregating M2 head rows. Nine mutants (initially designated bm1-bm4, bm4A-bm8) were isolated from the P898012 mutagenized population and 29 mutants (initially designated bm10-bm38) were isolated from the P954035 mutagenized population. The M2 mutant plants were self-pollinated to produce M3 seed. Up to 20 normal sibs from each segregating head row containing a mutant were self-pollinated in order to find heterozygotes in which single gene inheritance for the corresponding mutant allele could be established as well as a homozygous normal sib that could be propagated as an isogenic counterpart for each mutant.

Develop an Effective Chemical Mutagenesis Protocol for Generating EW Variants (Bloomless and Sparse Bloom Mutants) in Sorghum

P898012 and P954035 seed were soaked in diethyl sulfate (DES) and ethyl methanesulfonate (EMS) at concentrations of 5.7 mM DES, 7.6 mM DES, or 11.5 mM DES for 3 hrs at room temperature; and at concentrations of 4.7 mM EMS or 9.4 mM EMS for 18 hrs at room temperature. Seeds were then rinsed in distilled water for 1 hr and dried with a blow dryer. They were planted immediately after.

Since seed head tissues represent sectors derived from cell lineages originating directly from the seed meristem, the mean number of meristem cells in the original dormant M0 seed that were serving as target cells for mutagenesis can be calculated. Assuming 3:1 wildtype to mutant segregation for all mutant loci (i.e., nuclear recessive mutations), the average segregation ratio of wildtypes to mutants was calculated by simply predicting segregation of 3:1 in the M2 head row if one target meristem cell were present in the M0 seed. Assuming two equal sectors derived from two target cells (i.e., 3:1 for mutated sector and 4:0 for wild-type sector), the M2 segregation ratio would be 7:1. Three sectors (from three target cells) would generate an 11:1 segregation, four sectors a 15:1 segregation, five sectors a 19:1 segregation, and so forth.

Determine, Through Allelism Tests, How Many Different Loci Affecting EW Production are Present in the Mutagenized Populations

Of the original 38 mutants isolated, seven lines were not advanced, because either they were difficult to classify under some environmental conditions (bm12, bm14, bm23, and bm29) or they were completely or partially male and/or female sterile and thus difficult to propagate (bm13, bm36, and bm37). Thirty one distinct mutants were selected for the allelism test.

Efforts were made to obtain genetic stocks containing the previously reported epicuticular wax loci *bm1, bm2, h1, h2, h3* and h4 (Weibel, 1986a,b; Peterson *et al.*, 1982). Unfortunately representatives of only two of these loci (*bm2 and h3*) were available. The *bm2* locus was represented by Txbm1 (first bloomless line received from Texas A&M) and CK60bm (Combine Kafir-60 bloomless) and the *h3* locus was represented by Neb31h. The epicuticular wax traits of these stock lines all had single gene recessive inheritance.

Regardless of whether mutants were the bloomless or sparse-bloom types, crosses were made for all possible genotype pairs of the 31 selected mutants and three available representatives of loci *bm2* and *h3*. Mutants were shown to have single gene nuclear inheritance based on 3:1 segregation within the F3 population derived from heterozygotes in the original M2 population. Hence only non-reciprocal crosses were made. Nevertheless, two or more test crosses were made for each combination of all independent mutants. Nonallelism was indicated when two or more wild-type plants arose in an F1 population and, the resulting F2 segregated for wild-type and mutant phenotypes. Allelism was indicated when no wildtype appeared in the F1.

Research Results

Sorghum EW Mutants

Segregating F3 head rows derived from heterozygotes in the original M2 population were tested for a 3:1 segregation ratio as would be expected from epicuticular wax mutations resulting from a single gene with nuclear inheritance. Chi-square tests for single gene recessive inheritance (Table 1) were calculated for individual head row families with 1 degree of freedom per family. Families were excluded if the expected value for either category was less than 5. In addition, outliers were excluded. Outliers were defined as families that gave nonhomogenous ratios compared to the majority of families for a mutant. Of the 31 original mutants tested for allelism, single gene inheritance was established by this method for 20. These were bloomless mutants bm2, bm3, bm4, bm4A, bm15, bm16, bm18, bm20, bm21, bm22, bm27, bm30, bm31, bm33, bm35, and bm38, plus sparse-bloom mutants bm11, bm19, bm24, and bm34. In addition, single gene inheritance was established by this method for one sparse-bloom mutant (bm23) that was not tested for allelism because of difficulty in classifying mutants.

In six other independent mutants that were tested for allelism (bloomless mutants bm6, bm7, bm8, and bm26, and sparse-bloom mutants bm1 and bm28) and one bloomless mutant that was not tested for allelism (bm14), heterozygotes were not among the wild-type seed heads gathered from the original segregating head rows. Nevertheless, each of these showed segregation ratios in the F2 populations from the allelism studies consistent with single gene recessive mutations (data not shown). For these six original mutants, F2 segregation ratios were approximately the expected two loci ratios of 9:7 in bm-type crosses with other bm-types, and the expected 9:3:4 ratio in bm-type by h-type crosses. In addition, the test crosses allowed each of these mutants to be placed directly into allelic groups. Moreover, F2 populations generated from crosses of these six mutants with male sterile genotypes had observed segregation ratios consistent with the expected 3:1.

Five of the sparse-bloom mutants that were tested for allelism (bm5, bm10, bm17, bm25, and bm32) and two sparse-bloom mutants that were not tested for allelism (bm12 and bm29) had segregation ratios that did not fit the expected 3:1 ratio (Table 1). Nevertheless, it is still likely that these are in fact single gene recessive mutations. Based on our visual assessment, a lack of 3:1 segregation likely resulted from difficulties in distinguishing between wild-type and sparse-bloom phenotypes in our Indiana field plots. In these sparse-bloom lines, the visual wax phenotypes differed only slightly from the wild-type and these phenotypes were affected by precipitation that often removed visible waxes. Because of this difficulty, essentially all allelism studies between sparse-bloom mutants were conducted in a winter nursery in Banderas Mexico where there was no precipitation and plants were watered using sub-irrigation. Under conditions in Mexico, the sparse-bloom phenotypes could easily be distinguished from wild-type wax phenotypes. In Mexico, F2 segregation ratios from the allelism studies were consistent with single gene recessive mutations.

Finally, three bloomless mutants that were not included in allelism tests (bm13, bm36, and bm37) had segregation ratios that did not fit the expected 3:1 ratio (Table 1). In each of these cases, the number of mutants present in the population was very low. These mutants had extreme alterations in their phenotypes, being dwarfed, having wrinkled leaves, and with poor development of flowering heads. We interpreted this low proportion of mutants in segregating populations as being due to either low germination of mutant seeds, a failure in mutant fertilization, or inhibited mutant seed development. Further studies are needed to test these hypotheses. The bm13, bm36, and bm37 mutants were not included in allelism studies due to these questions about inheritance.

A few mutants had phenotypic differences from wildtype other than a reduction in visible epicuticular waxes alone. Of these, many were slightly reduced in height compared to wildtype. Besides a small height reduction, bm38 developed slightly chlorotic leaves, had no basal tillers, and the flower heads appeared later; bm24 had slightly wrinkled leaves and lacked basal tillers; bm16 and bm20 had more erect leaves and lacked basal tillers; and bm2, bm6, bm22, and bm33 had a rapid-water-loss phenotype. It is likely that these phenotypes were due to plieotropy of a single gene mutation since the multiple phenotypes of these lines always cosegregated in segregating populations derived from backcrosses with the wildtype.

These mutants can be used in future studies investigating the contributions of EW load (amount of visible waxes) and chemistry (specific wax constituents) to drought resistance. It is believed that EW contributes to drought resistance in sorghum by reflecting excess radiation during hot dry spells (reflective cooling) and reducing non-stomatal water loss (dehydration avoidance). Several loci affecting specific wax characteristics are represented in these mutagenized populations and therefore this germplasm will be valuable in testing the role of EW in overall drought resistance in sorghum.

Chemical Mutagenesis

Within the sorghum mutagenized populations, the epicuticular wax mutants segregated at a frequency of 0.88% of M2 head rows (Table 2). The highest mutation rate of 1.17% was found for the M2 population derived from seeds soaked in 4.7 mM EMS. The lowest rate of 0.39% was found for the M2 population derived from seed treated with 7.6 mM DES (Table 2). Overall, the EMS treatments produced higher average mutation rates of 1.13% than the DES treatments of 0.66%.

Table 3 shows the M2 segregation ratios for wildtypes to wax mutants in each of the mutants derived from the wild-type parent P954035. The overall average number of target meristem cells in the M0 seed was 5, with a range of predicted values of 2 to 13.

Allelism Tests

Our test of allelism with the 31 independent EW mutants selected for allelism studies allowed us to identify one existing EW locus and 18 new EW loci (Table 4). Of these, one locus represented the existing bm mutant locus bm2, nine represented new bm mutant loci, and nine others represented new h mutant loci (Table 4). The bm2 locus, previously described by Peterson et al. (1982), had the greatest number of alleles with six. In this study, four new bm2 alleles were identified. The bm3, bm4, bm6, and h7 loci had three alleles each, whereas the bm5 locus had two allelic members. Only six out of 19 loci with new mutants reported here had more than one allele. Therefore, thirteen new loci were represented by only one allele. In addition, all of the new EW loci were found to be independent of the existing sparse-bloom locus h3.

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

A group of US sorghum seed industry plant breeders visited Purdue sorghum research and walked our nurseries. We also had visitors from South America interested in sorghum as biofuel.

Gebisa Ejeta returned to Nairobi, Kenya and visited colleagues at the Alliance for Green Revolution in Africa.

Publications and Presentations

Peters, P.J., M.A. Jenks, P.J. Rich, J.D. Axtell and G. Ejeta. 2009. Mutagenesis, selection and allelic analysis of epicuticular wax mutants in sorghum. Crop Science 49: 1250-1259.

Rich, P.J. and G. Ejeta. 2008. Towards effective resistance to Striga in African maize. Plant Signaling & Behavior 3: 618-621.

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

Table 1. Segregation ratios and sums of chi-square values from tests for single recessive gene inheritance predicted as a 3:1 ratio for segregating populations. Individual chi-squares were calculated for separate F3 families (head rows) derived from self-pollinated M2 heterozygotes. Individual chi-squares for separate families each had one degree of freedom. Sum of chi-square values were compared to sums of tabulated values for the individual family tests. Nonsignificant chi-square indicates acceptance of the hypothesized 3:1 ratio for single gene recessive inheritance. Mutants bm1-bm8 were derived from P898012, whereas bm10-bm38 were derived from P954035.

Mutant	Wildtype	Mutant	$\sum\chi2$	df
bm2	450	142	19.03	10
bm3	272	112	16.14	8
bm4	680	213	13.64	12
bm4A	589	207	13.41	10
bm5	651	77	126.29 **[1]	10
bm10	1227	152	190.21**	11
bm11	1004	335	11.02	11
bm12[2]	1292	124	220.89**	12
bm13[2]	924	162	80.38**	9
bm15	659	186	6.93	6
bm16	781	251	9.55	8
bm17	903	100	146.54 **	9
bm18	839	268	4.05	9
bm19	360	119	16.16	8
bm20	503	150	6.33	8
bm21	622	214	7.19	10
bm22	344	113	4.15	8
bm23[2]	318	83	5.2	6
bm24	434	107	20.58	9
bm25	786	83	134.91 **	9
bm27	420	156	4.75	8
bm29[2]	593	258	216.12 **	6
bm30	1149	349	13.57	11
bm31	447	144	12.27	5
bm32	274	551	1143.92**	12
bm33	786	250	6.29	12
bm34	796	233	24.57	11
bm35	581	156	15.81	12
bm36[2]	928	91	149.62**	8
bm37[2]	723	162	88.2**	9
bm38	684	192	17.17	9

[1]*, ** Significantly different from 3:1 ratio at 0.05 and 0.01 levels, respectively.
[2] Mutant not tested for allelism.

Table 2. DES (diethyl sulfate) and EMS (ethyl methane sulfonate) mutagenesis treatments and mutation frequencies for epicuticular wax mutants of the Sorghum bicolor lines P898012 and P954035. Mutants bm1-bm8 arose from P898012, whereas bm10-bm38 arose from P954035.

Treatment	Mutation Rate[1]	Mutation Freq. (%)	Mutants Generated[2]
5.7 mM DES	NA	NA	bm8
7.6 mM DES	3/780	0.39	bm22-bm24
11.5 mM DES	11/1340 0.82		bm1-bm4, bm4A, bm33-bm38
4.7 mM EMS	NA[3]	NA	bm6-bm7
4.7 mM EMS	13/1110 1.17		bm5, bm10-bm21
9.4 mM EMS	8/744	1.08	bm25-bm32

1 Actual number of mutants per M2 head rows.
2 Designation for original mutant isolates [these do not represent loci].
3NA Data not available.

Table 3. Segregation ratios in the M2 head rows for the original P954035 derived epicuticular wax mutant isolates and estimates of the number of meristem cells in dormant M0 seed.

Mutant	M2 Segregation Ratios Wildtype:Mutant	Estimated Number of Meristem Cells in M0
bm10	30:1	8
bm11	24:5	2
bm12	36:3	4
bm13	36:3	4
bm15	34:1	9
bm16	52:3	5
bm17	37:4	3
bm18	37:3	4
bm19	26:2	4
bm20	46:3	5
bm21	27:2	4
bm22	28:1	8
bm23	21:2	3
bm24	46:1	13
bm25	26:3	3
bm26	25:3	3
bm27	30:2	4
bm28	32:2	5
bm29	29:1	8
bm30	25:6	2
bm31	34:4	3
bm32	26:1	7
bm33	33:1	9
bm34	26:2	4
bm35	33:5	2
bm36	37:2	5
bm37	30:6	2
bm38	36:1	10
Mean		5.1

Table 4. New bloomless (bm) and sparse-bloom (h) loci and their allelic members identified by allelism studies. The members of each group represent the isolates named in the original screens with the new designators presented. The original mutant isolates designated bm1-bm8 arose from P898012, whereas bm10-bm38 arose from P954035. Two or more test crosses were made for each combination of all independent mutants.

Locus	Number of Alleles	Original Isolates with New Loci and Allelic Designation in Parentheses
bm2[1]	6	bm2 (bm2-1), bm6 (bm2-2), bm22 (bm2-3), bm33 (bm2-4), Txbm1 (bm2-5), CK60bm (bm2-6)
bm3	3	bm3 (bm3-1), bm4 (bm3-2), bm4A (bm3-3)
bm4	3	bm8 (bm4-1), bm15 (bm4-2), bm18 (bm4-3)
bm5	2	bm16 (bm5-1), bm20 (bm5-2)
bm6	3	bm21 (bm6-1), bm27 (bm6-2), bm30 (bm6-3)
bm7	1	bm26 (bm7-1)
bm8	1	bm7 (bm8-1)
bm9	1	bm31 (bm9-1)
bm10	1	bm35 (bm10-1)
bm11	1	bm38 (bm11-1)
h3[1]	1	Neb31h (h3-1)
h5	1	bm1 (h5-1)
h6	1	bm5 (h6-1)
h7	3	bm11 (h7-1), bm19 (h7-2), bm32 (h7-3)
h8	1	bm10 (h8-1)
h9	1	bm25 (h9-1)
h10	1	bm28 (h10-1)
h11	1	bm17 (h11-1)
h12	1	bm24 (h12-1)
h13	1	bm34 (h13-1)

1 Previously described loci (Peterson et al., 1982. Crop Sci 22: 63)

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 sorghum into farmer-accepted 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% (FAO, 2005). Most of the grain produced in WA is used to prepare foods and beverages for human consumption including traditional stiff or thin porridges (e.g. tô and fura), granulated foods (e.g. couscous), and beer production (e.g. dolo) (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

Recent research workshops of INTSORMIL scientists in West African and the United States highlighted the need to actively transfer technologies developed in previously funded research to improve sorghum crop production, performance, and value (West Africa Technology Transfer Working Group, 2007). These meetings and feedback from sorghum producers in developed and developing countries indicated the need 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.).

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, INRA, NIGERIA

Deploy traits that enhance resistance to biotic stresses into 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:

- Soumana Soumana, INRAN, NIGER
- Mountaga Kayento, IER, MALI
- Hamidou Traore, INERA, Burkina Faso
- Daniel Aba, INRA, NIGERIA
- David Aupperle, Reginald Young, and John Beitler, DuPont Crop Protection, USA
- Gebisa Ejeta, Purdue University, 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
- Dr. Scott Bean, USDA-ARS, Manhattan, KS USA

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

Collaborative research efforts are focused in West Africa and are supported through short and long-term training programs, germplasm exchange and evaluation, and basic research. The overarching objective 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 plant breeders.

The effort to develop and commercialize new herbicide tolerance traits in sorghum are focused on creating new tools for managing weed pests in the crop. Herbicides are an important component of most weed management programs in sorghum; however, preplant herbicides often fail or perform poorly in the dry conditions where sorghum is grown. New herbicides are needed to control broadleaf and grassy weeds. In 2005, a natural sorghum mutant with tolerance to ALS-inhibiting herbicides was identified. Genetic crossing and backcrossing are being used to transfer this trait into elite grain sorghum varieties. In 2006, a sorghum mutant with resistance to several ACCase inhibiting herbicides was identified. This trait also is being incorporated into elite sorghum parent lines through genetic crossing and backcrossing. In the United States, inbred lines used for hybrid seed production are being converted to ALS and ACCase herbicide tolerance to facilitate commercialization of this technology. In Africa, the ALS herbicide tolerance trait can be used with seed treatments to control parasitic witchweed infestations (Tuinstra et al. 2009). Seed treatments that combine herbicides, fungicides, and insecticides are being evaluated for efficacy in improving sorghum productivity through research collaborations with private industry collaborators in the United States and NARs scientists in West Africa.

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 search for genes involved in complex traits at a population level using natural diversity rather than through individual bi-parental crosses. It tests for relationships between molecular polymorphisms at the gene level with phenotypic variation among diverse genotypes. An association mapping (AM) panel of 300 sorghum genotypes collected from around the world has been assembled that represents much of the natural genetic variation of sorghum. The PI is collaborating with Drs. Yu and Bean to characterize 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 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 germlasms 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 and early-maturing hybrids for food production and use in the malting industryies. Field trials in 2009 identified several hybrid combinations that appear to be highly productive and well-adapted to environments in Niger and Nigeria.

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 for sorghum. Striga is recognized as a growing problem and it is estimated that more agricultural land in WA (3.5 million ha) is infested with Striga than in any other region. Efforts to breed for improved Striga resistance have been successful; however, no single technology has been shown to be 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 imazapyr or 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 2008-9, replicated trials in Niger, Burkina Faso, and Mali indicated that seeds treated with metsulfuron-methyl (MET) had fewer *Striga* attachments and the greatest delay in attachment (Table 1).

A major focus of our crop improvement program is to develop ALS herbicide tolerant guinea and non-guinea sorghum hybrids that are adapted in the West Africa region. N223 is one of the important food-grade sorghum seed parents being used in West Africa. Two ALS herbicide resistant derivatives of N223 (PU-KS10 and PU-KS11) were jointly released by Purdue University and Kansas State University in 2009 (Table 2). These seed parents can be used to produce interracial guinea-type and caudatum-type hybrids. Preliminary observation trials of testcross hybrids produced using these seed parents suggest that these sorghums will provide an effective tool for deploying herbicide seed treatment technology for controlling *Striga* infestations in sorghum.

Weed control is an important problem for sorghum producers in the United States. The ALS herbicide tolerance trait and a second acetyl coenzyme A carboxylase (ACCase) herbicide tolerance trait are being incorporated into U.S. sorghum germplasm to allow use of these herbicides for grassy weed control in sorghum. In 2009, Purdue University and Kansas State University jointly released 11 ALS herbicide resistant lines, 14 ACCase herbicide resistant lines, and six ALS+ACCase herbicide resistant lines (Table 2). The PI is collaborating with researchers from DuPont Crop Protection and Kansas State University to conduct field and laboratory research needed to commercialize ALS and ACCase herbicides as part of an integrated weed management strategy that incorporates post-emergence herbicide applications to control broad-leaf and grassy weed problems in sorghum.

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

A project was initiated to systematically identify and exploit natural genetic variation in the sorghum genome using the genome

Table 1. Efficacy of metsulfuron methyl (MSM) seed treatments at controlling *Striga* infestation in field trials in Niger and Burkina Faso.

Seed Treatment	*Striga* Emergence	*Striga* at 60 d	*Striga* at 90 d	Sorghum Yield
	(days)	(*Striga* m^{-2})	(*Striga* m^{-2})	(kg ha^{-1})
0 herbicide	44.6	6.2	14.0	262.2
0.003 mg MSM	52.5	2.0	13.5	321.0
0.006 mg MSM	51.1	2.1	13.3	401.1
0.0125 mg MSM	56.7	0.9	10.9	371.3
0.025 mg MSM	58.7	0.6	8.8	498.3
LSD	5.0	1.9	4.8	161.3
P-value	0.0001	0.0001	0.1578	0.06

Table 2. The germplasms PU-KS1 to PU-K31 were jointly released by Purdue University and Kansas State University in 2009. These lines are tolerant to acetolactate synthase (ALS) and/or acetyl co-enzyme A carboxylase (ACCase) herbicide inhibitors.

Number	Entry	Pedigree	Herbicide Tolerance
PU-KS1-R	09WL47	Tx2737/[Tx2737///Tx2737//90SN7/Tw]	ALS
PU-KS2-R	09WL53	Tx2737/[Tx2737///Tx2737//90SN7/Tw]	ALS
PU-KS3-R	09WL68	Tx430/[Tx430///Tx2737//90SN7/Tw]	ALS
PU-KS4-R	09WL69	Tx430/[Tx430///Tx2737//90SN7/Tw]	ALS
PU-KS5-R	09WL77	Tx430/[Tx430///Tx2737//90SN7/Tw]	ALS
PU-KS6-R	09WL80	Tx430/[Tx430///Tx2737//90SN7/Tw]	ALS
PU-KS7-R	09WL88	Tx430/[Tx430///Tx2737//90SN7/Tw]	ALS
PU-KS8-R	09WL90	Tx430/[Tx430///Tx2737//90SN7/Tw]	ALS
PU-KS9-R	09WL92	Tx430/[Tx430///Tx2737//90SN7/Tw]	ALS
PU-KS10-B	09WL101	N223///N223//N223/Tw	ALS
PU-KS10-A	09WL102	N223///N223//N223/Tw-A	ALS
PU-KS11-B	09WL119	N223///N223//N223/Tw	ALS
PU-KS11-A	09WL120	N223///N223//N223/Tw-A	ALS
PU-KS12-R	09WL1037	Tx2737//Tx2737/[Tx2737///Tx430//Tx430/Bol-71]	ACCase
PU-KS13-R	09WL1045	Tx2737//Tx2737/[Tx2737///Tx430//Tx430/Bol-71]	ACCase
PU-KS14-R	09WL1047	Tx2737//Tx2737/[Tx2737///Tx430//Tx430/Bol-71]	ACCase
PU-KS15-R	09WL1068	00MN7645//00MN7645/[00MN7645///Tx430//Tx430/Bol-71]	ACCase
PU-KS16-R	09WL1091	01MN7951//01MN7951/[Tx2737///Tx430//Tx430/Bol-71]	ACCase
PU-KS17-B	09WL1093	OK11/[OK11///Tx623//Tx623/Bol-71]	ACCase
PU-KS17-A	09WL1094	OK11/[OK11///Tx623//Tx623/Bol-71]-A	ACCase
PU-KS18-B	09WL1145	Tx2752/[Tx3042///Tx623//Tx623/Bol-71]	ACCase
PU-KS18-A	09WL1146	Tx2752/[Tx3042///Tx623//Tx623/Bol-71]-A	ACCase
PU-KS19-B	09WL1179	Tx3042//Tx3042/[Tx3042///Tx623//Tx623/Bol-71]	ACCase
PU-KS19-A	09WL1180	Tx3042//Tx3042/[Tx3042///Tx623//Tx623/Bol-71]-A	ACCase
PU-KS20-B	09WL1255	Tx3042///Tx3042//Tx3042/[Tx3042///Tx623//Tx623/Bol-71]	ACCase
PU-KS20-A	09WL1256	Tx3042///Tx3042//Tx3042/[Tx3042///Tx623//Tx623/Bol-71]-A	ACCase
PU-KS21-B	09WL1259	Tx3042///Tx3042//Tx3042/[Tx3042///Tx623//Tx623/Bol-71]	ACCase
PU-KS21-A	09WL1260	Tx3042///Tx3042//Tx3042/[Tx3042///Tx623//Tx623/Bol-71]-A	ACCase
PU-KS22-B	09WL1273	Tx399///Tx399//Tx399/[Tx399///Tx623//Tx623/Bol-71]	ACCase
PU-KS22-A	09WL1274	Tx399///Tx399//Tx399/[Tx399///Tx623//Tx623/Bol-71]-A	ACCase
PU-KS23-B	09WL1281	Tx399///Tx399//Tx399/[Tx399///Tx623//Tx623/Bol-71]	ACCase
PU-KS23-A	09WL1282	Tx399///Tx399//Tx399/[Tx399///Tx623//Tx623/Bol-71]-A	ACCase
PU-KS24-B	09WL1231	Tx378//Tx378/[Tx3042///Tx623//Tx623/Bol-71]	ACCase
PU-KS24-A	09WL1232	Tx378//Tx378/[Tx3042///Tx623//Tx623/Bol-71]-A	ACCase
PU-KS25-B	09WL1283	Tx623//Tx623/[N223(ALS)///Tx623//Tx623/Bol-71]	ACCase
PU-KS25-A	09WL1284	Tx623//Tx623/[N223(ALS)///Tx623//Tx623/Bol-71]-A	ACCase
PU-KS26-R	09WL2002	[Tx2737///Tx2737//90SN7/Tw]/[Tx2737///Tx430//Tx430/Bol-71]	ALS+ACCase
PU-KS27-R	09WL2050	[Tx430///Tx2737//90SN7/Tw]/[Tx2737///Tx430//Tx430/Bol-71]	ALS+ACCase
PU-KS28-R	09WL2040	[Tx2737///Tx2737//90SN7/Tw]//Tx2737/[Tx2737///Tx430//Tx430/Bol-71]	ALS+ACCase
PU-KS29-R	09WL2037	[Tx2737///Tx2737//90SN7/Tw]//Tx2737/[Tx2737///Tx430//Tx430/Bol-71]	ALS+ACCase
PU-KS30-B	09WL2167	Tx623/[N223(ALS)///Tx623//Tx623/Bol-71]	ALS+ACCase
PU-KS31-B	09WL2181	Tx623/[N223(ALS)///Tx623//Tx623/Bol-71]	ALS+ACCase

DNA sequence as a tool to identify and relate variation in specific genes with phenotypic variation represented in the sorghum germplasm collection. We are collaborating with Dr. Jianming Yu, Kansas State University and Dr. Scott Bean, USDA-ARS, Manhattan, Kansas to collect phenotypic trait data in the association panel and relate that to gene function through a process called 'association mapping'. This information will allow us to target genes for selective modification to enhance sorghum performance. In preliminary studies, we are targeting genetic variation at the dw3 locus. The dw3 allele used in the commercial U.S. sorghum sector has been reported to be unstable resulting in increased seed production costs and height mutants resulting from instability at this locus. We are using the sorghum genome sequence to develop strategies whereby a stable dw3 allele can be identified for commercial use.

Networking Activities

Workshops and meetings

Health, Research, and Entrepreneurship: Sorghum Food for Celiac Patients. Naples, Italy, October 19, 2009

Third Annual Plant Breeding Conference, Plant Breeding Coordinating Committee, Madison, Wisconsin, August 3-5, 2009

Sorghum Field Day, Purdue University, West Lafayette, IN, September 9, 2009

Research information exchange

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

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

Sorghum Field Day, Purdue University, West Lafayette, IN, September 9, 2009

Meeting with representatives from DuPont Crop Protection to discuss herbicide trait development and Striga management, West Lafayette, IN September 9, 2009

Germplasm Conservation And Distribution

Released and distributed 31 ALS, ACCase, and ALS+ACCase sorghum inbred lines to the U.S. seed industry.

Distributed tissue of 300 sorghum lines representing the sorghum association panel to Dr. Clifford Weil to initiate an eco-tilling project to study natural genetic variation in sorghum.

Distributed seed of the sorghum association panel to Dr. Kartik Krothapalli to evaluate genetic variation in forage quality traits.

Distributed a replicated experiment 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

Background

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

Within the region, there are two distinct sorghum production systems. The first is a traditional hillside sorghum production system that uses landrace and/or improved sorghum cultivars known as Maicillos Criollos. These sorghums are a very distinct and unique group because they are very photoperiod sensitive, meaning that they require short daylengths to induce reproductive growth. In fact, Maicillos require even shorter daylengths to initiate flowering than most photoperiod sensitive sorghum from other regions of the world (Rosenow, 1988). They are primarily grown in intercropping systems with maize on small, steeply sloping farms where the maize matures before the Maicillos begin to flower. Because they are drought tolerant, they are grown primarily as food security crop where the grain is used extensively primarily to produce tortillas. The forage and excess grain produced by these crops are valued as animal feed. Traditional landrace Maicillos Criollos varieties are typically low yielding with relatively low grain quality. Previous research has resulted in the release and distribution of several improved Maicillos Criollos cultivars with higher yield potential and better grain quality (Rosenow, 1988). In addition to Maicillos Criollos, hillside production systems also utilize earlier maturing sorghum (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. These F1's are being grown in winter nurseries and F2 populations will be sent to El Salvador for selection in the fall of 2009. Many of these crosses were made between photoperiod sensitive material and photoperiod insensitive types to introduce specific traits such as disease resistance or enhanced forage or grain quality. Emphasis in selection is placed on improved food-type and Macio tan-plant cultivars as well as hybrids (where feasible).

Photoperiod Insensitive Line and Cultivar Breeding

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

Forage Sorghum Breeding

Forage sorghums have become increasingly important in the Central American region; development of new varieities 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.

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

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

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. Two different populations were planted for anthracnose evaluation in 2009 in three US locations. Unfortunately, the environments in 2009 were not conducive to the development of the disease and scoring was not possible in the main growing season. Currently, there are plans to repeat this evaluation in 2010.

Sorghum Downy Mildew Resistance

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

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

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

Another group of specialty sorghum receiving interest is the health food sorghums. These are grain sorghums with high levels of tannin and/or unique colors (primarily black); they possess very high levels of unique phenolic compounds that show high levels of antioxidant activity. Our program has developed a set of parental lines for use developing a series of lines designed to combine these traits into a single sorghum hybrid that could be grown as a "health" grain. While this does not directly affect efforts within Central America, it does provide the potential opportunity to be used in food products in the area. This work is in cooperation with the TAMU cereal quality lab (L. Rooney) and labs in Central American in CENTA (El Salvador) and at the Escuela Agricola Panamerica (J. Bueso). In 2008 and 2009 our program produced 30 experimental hybrids that were planted in replicated yield trials in four locations (Weslaco, Corpus Christi, College Station, and Halfway, Texas) to evaluate their relative agronomic potential, their antioxidant content and the effect of environment and genotype x environment interaction on those traits. These trials have been harvested and analysis is currently underway. From these trials, it is apparent that both genotype and environment influence antioxidant compound production and degradation and that certain environments are more conducive to their production than others.

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 will join our program in January 2010 to pursue a Ph.D in plant breeding.

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

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

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

Project TAM 102
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Introduction and Justification

Sorghum is a 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 constrained by less than desired yield, biotic (insect pests and disease pathogens) and abiotic (primarily pre- and post-flowering drought) stresses that reduce yield, lower value of grain and forage quality, and government policy. Primarily a feed-grain in the U.S. demand for sorghum for ethanol production and as a food grain or nutraceutical is increasing. Sorghum is an ideal crop to enhance the economic viability of U.S. Great Plains agriculture through improved utilization of limited water resources and increased yield, quality (grain and forage), and marketing opportunities. The overall objective for this project is to develop new genetic technology (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. Restorer lines (pollinators or males in A1 cytoplasm) have been selected for disease resistance, improved weathering resistance, and wide-adaptation. Analysis of data from on-station replicated grain yield trails led to the identification of several parental lines that will produce at least 5% more grain than a common check hybrid. The superior lines will undergo additional evaluations in subsequent years. If the results are confirmed the lines will be made available to private seed companies for further evaluation and possible commercialization.

In Mozambique several experimental breeding lines have been identified for possible release as varieties and replicated trials were conducted at several locations to evaluate for adaptation and grain yield potential. The lines represent nine different pedigrees and were selected from nurseries developed for resistance to sorghum midge, grain weathering, and drought tolerance. In South Africa and Botswana, potential new varieties express a high level of resistance to sugarcane aphid and grain yield potential at least equal to the standard checks.

Objectives and Implementation Sites

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

Segregating populations are developed in Texas and selected for adaptation and resistance to selected diseases and/or drought tolerance, and grain mold/weathering resistance. Appropriate germplasm provided to host country collaborators provides the opportunity 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 that provide geographic diversity for selection and evaluation include the Coastal Bend for tropical adaptation and resistance to grain weathering, sorghum midge and disease(s) and the Southern High Plains for a semi-arid temperate adaptation for yield potential and drought tolerance. A Puerto Rico winter nursery provides an extra growing season to reduce development time for new varieties, parental lines, or hybrids. Southern Africa locations provide additional evaluation environments - yield potential and adaptation nurseries in Zambia (Golden Valley Agricultural Trust at Chisamba), Mozambique (Nampula), Botswana (Sebele), and South Africa (Cedara), insect resistance screening in glasshouse and field facilities at the Botswana College of Agriculture (Sebele) and at the ARC-GRI (Potchefstroom) and Cedara, and disease resistance evaluation at Cedara (anthracnose, grain mold, and ergot). Cereal quality laboratories at the Univ. of Pretoria or the ARC-Grain Crops Institute Quality Laboratory (Potchefstroom) will provide the opportunity to analyze advanced germplasm for milling qualities in comparison with local checks. Collaboration with the ARC-Grain Crops Institute at Potchefstroom has been suspended due to lack of a signed memorandum.

Research Methodology and Strategy

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

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. As needed, populations to combine drought tolerance with biotic stress resistance are developed. 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 facilitates identification and evaluation of new genetic technology. New genetic technology will be available to private industry through material transfer agreements.

Research Results

Research in the U.S. was hindered by extreme drought in the Texas Coastal Bend. Lack of rainfall resulted in insufficient soil moisture to establish research plots and selection nurseries. No plots planted in the region in 2009 reduced the scope of research activities.

Sugarcane aphid (Melanaphis sacchari (Zehntner)) trials were provided to collaborators at the University of the Free State and the Botswana College of Agriculture (BCA-Sebele). Research in South Africa was hindered by the seed shipment from the U.S. being held in South African customs and neither the sender or recipient receiving notification in time to plant the trails. The trials will be planted in the 2009-2019 growing season.

Trials planted at Cedara, South Africa in the 2008-09 growing season were from remnant from superior entries in previous years trials. A sugarcane aphid screening/yield trial of with 24 entries was planted at Cedara. The trail consisted of 16 entries from the 2008-09 sugarcane aphid trial, six entries from the 2008-09 sugarcane aphid yield trial and two local hybrid checks. Severity of infestation was evaluated when the majority of panicles reached the milk stage. Severity of infestation was evaluated on a 1 to 5 scale, where 1 = no aphids present on plants, 2 = light infestation with aphids present on a few leaves (no dead leaves), 3 = moderate infestation with aphids present on two to three leaves (one or two dead leaves may be present), 4 = high infestation with aphids on nearly all leaves (many dead leaves) and 5 = majority of plants in plot dying. Plants with a rating of 1 or 2 were considered resistant, while a rating of 3 indicated an intermediate level of resistance. Plants with a rating of 4 and 5 were considered susceptible.

Results indicated that 42% of the entries rated 1 on the scale, indicating none to very little damage (Table 1). Thirty-three percent of the entries were rated 2, 17% rated 3, and 8% were highly susceptible with a rating of 4. The high level of resistance expressed was not unexpected as the entries had been previously screened for resistance, and only those with a high level of resistance selected for subsequent evaluation. Yield of the experimental entries, all cultivars, varied between 0.94 and 4.5 tons per hectare. The standard hybrid checks produced grain yield of 2.13 t/ha (PAN 8420) and 2.87 t/ha (PAN 6848). The grain yield of five experimental cultivar entries was significantly better that the hybrid PAN 8420 and one of the entries also produced significantly more grain than the hybrid PAN 6848. Cultivars producing more grain yield than hybrids is unusual but encouraging and indicates the potential usefulness of the experimental germplasm. Hybrid should be made using the experimental cultivars for subsequent evaluation. While cultivars will initially work for small-holder farmers sustainable development progress will be greater with hybrids and the associated availability and access to inputs, primarily fertilizer. Culti-

Table 1. Evaluation of sorghum lines for sugarcane aphid resistance and grain yield at Cedara, South Africa.

Pedigree/Designation	Sugarcane aphid damage†	Grain Yield t/ha
(Segaolane*WM#322)-LG2-LG2-(03)BG1-LG1-LBK	1	4.46#$
(Macia*TAM428)-LL2	1	3.59#
CE151	4	3.52#
(6BRON161/(7EO366*Tx2783)*CE151)-LG5-CG2-(03)BG1-BG2-LBK	1	3.17#
(Macia*TAM428)-LL9	1	3.15#
PAN 6848 (standard check)	1	2.87
Tegemeo	2	2.73
(9MLT176/(MR112B-92M2*Tx2880)*A964)-CA3-CABK-CCBK-CABK	3	2.36
(LG35*WM#322)-BE40-LG1-CA1-LGBK-CABK	2	2.14
PAN 8420 (standard check)	3	2.13
(9MLT176/(MR112B-92M2*Tx2880)*A964)-LG8-CABK-LGBK-LGBK	2	2.06
TAM428	2	1.90
(5BRON151/(7EO366*GR107B-90M16)*Tegemeo)-HG7-CC2-CABK	2	1.85
Segaolane	3	1.66
(Dorado*Tegemeo)-HW13-CA1-CC2-LGBK	2	1.54
(5BRON151/(7EO366*GR107B-90M16)*Tegemeo)-HG1-LGBK-CABK	2	1.43
(Kuyuma*5BRON155)-CA5-CC1-CABK	1	1.43
Kuyuma	1	1.42
(A964*P850029)-HW6-CA1-CC1-LGBK	2	1.42
(Dorado*Tegemeo)-HW14-CA1-CC2-CABK	3	1.38
SRN39	4	1.31
Ent62/SADC	1	1.22
(Dorado*Tegemeo)-HW15-CA1-CC2-LG1	2	0.94

† Rated on a scale of 1 = no aphids present on plants, 2 = light infestation with aphids present on a few leaves (no dead plants), 3 = moderate infestation with aphids present on 2 or 3 leaves (one or two dead leaves may be present), 4 = high infestation with aphids on nearly all leaves (many dead leaves) and 5 = majority of plants in plot dying.
# Significantly higher yield than the standard hybrid check PAN 8420.
$ Significantly higher yield than the standard hybrid check PAN 6848.

vars can be developed and released by the collaborative program but production and marketing of hybrids will require the participation of private seed companies.

Botswana College of Agriculture collaborators planted two trials provided by this project - a 22 entry advanced trial composed of 15 experimental lines previously evaluated for resistance to sugarcane aphid resistance and 7 local checks, and a 45 entry preliminary screening trial. In the advanced trial, average abundance of the sugarcane aphid infestation was significantly affected by genotype and plant age. Three experimental entries - (Macia*TAM428), (6BRON161*CE151), and (Segaolane*WM#322) - did not differ from the resistant check TAM428 for mean aphid numbers. In a grain yield trial at Cedara, South Africa the three entries produced the most grain yield in a yield trial and produced significantly more grain than the hybrid check PAN 6848. This indicates that a high level of sugarcane aphid resistance has been incorporated into lines with high grain yield.

Aphid infestation increased with plant age and the abundance of infested plants could be arranged in the order of 74 days old > 54 days old > 47 days old > 40 days old. The sugarcane aphid infestation rapidly increases with once initial infestation has occurred with an approximate 9.9x increase in proportion of infested plants. Thus maximum aphid infestation occurs later in the season and coincides with grain fill and maturation.

Entries in the preliminary screening trial exhibited no significant differences in the average abundance of sorghum plants attacked by the sugarcane aphid. However, damage ratings varied from 1 (0-20% damage) to 3 (41-60% damage) indicating that the entries express different levels of resistance. Lines rated a 1 or 2 at both 47 and 74 days after emergence would be classified as resistant. The trial will be repeated in the 2009-2010 cropping season and if the preliminary results are confirmed the entries will be advanced to a yield trial.

The purpose of the sugarcane aphid resistance breeding program is to develop improved cultivars suitable for use in smallholder production systems with resistance to sugarcane aphid. 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 indicated that sugarcane aphid resistance has been incorporated into elite cultivars with grain yield potential equal to a standard local hybrid check and significantly better than common cultivar checks. Grain will be grown during the next growing season in on-farm trial to better identify performance in the local production system. The overall objective of the program is too release at least one improved variety. The research program is making excellent progress toward this objective.

The Mozambique national sorghum breeding program continued to evaluate the grain yield potential of germplasm from Texas A&M University sorghum trials provided to the National Agrarian Research Institute (IIAM). In 2008-09 lines were in replicated yield trials at several locations in Mozambique to evaluate for grain yield, adaptation and biotic (disease and insect) resistance. Designation/pedigree of the lines are:

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

Preliminary data analysis indicated that several of the lines express grain yield better than the local check Macia (2.54 t/ha). Multi-location evaluation trials will continue and selections compared with the local checks Macia and Sima. Eventually, experimental entries that produce acceptable grain yield and end-use quality will be released varieties in Mozambique.

Due to drought the sorghum midge resistant breeding nursery was not planted at Corpus Christi. The drought was extensive and no other locations were available to plant the nursery in an environment to obtain a damaging pest population density at anthesis. The program will be resumed in 2010 if there is sufficient planting moisture at Corpus Christi.

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 2008. 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 was to generate data that might be more relevant to private industry. The text mean was 5281 lbs/A. The standard checks ATx2752*Tx2783, ATx631*RTx430, ATx2752*RTx430, ATx399*RTx430 and ATx399*Tx2737 produced 7659, 7447, 7113, 6839, and 6286 lbs/A, respectively. Twenty-one hybrids produced more grain than the test mean with yield ranging from 5393 to 7340 lbs/A. The two best experimental hybrids both had the same pollinator, Tx2945, a tan plant and red grain line released in 2006. Test weight of the higher grain experimental hybrid was at least a good as the standard checks. All of the hybrids would be classified as medium maturing with days to anthesis of 54 to 58 days after planting. Grain yield of hybrids on proprietary A-lines did not differ from that of standard A-line checks. Thus while the proprietary A-lines may have different genetics the standard A-lines will produce useful data for identifying superior pollinators.

Yield trial 2 evaluated the combining ability of experimental tan plant and white or red grain pollinators on the standard A-line ATx631 and included 49 experimental hybrids and 5 standard checks. Grain yield of the standard checks ATx2752*Tx2783, ATx2752*RTx430, ATx399*RTx430 and ATx399*Tx2737 was 7206,6585, 5984 and 4825 lbs/A, respectively. The standard tan plant white grain check ATx631*RTx436 produced 5017 lbs/A (Table 4). Nineteen hybrids produced more grain than the test mean of 5246 lbs/A. One experimental hybrid, ATx631*6BRON277, produced more grain than four of the five standard checks. Test weight was not different between the checks and the experimental entries. Additional research will be conducted to evaluate the combining ability and grain yield potential of the experimental pollinators.

Yield trial 3 was to evaluate the grain yield potential of experimental tan plant and white or red grain pollinators on proprietary A-lines. The purpose was to generate data that might be more relevant to private industry. In the 72 entry test there were 5 standard checks (including traditional purple plant and red grain hybrids) and 67 experimental entries. Grain yield of the standard checks ranged from 7765 lbs/A for ATx631*Tx2737 to 7743 lbs/A for ATx2752*RTx430 to 6040 lbs/A for ATx399*RTx430 to 5801 lbs/A for ATx399*Tx2737. Twenty-eight hybrids produced grain yield better than the test mean (5213 lbs/A). The experimental pollinator 4BRON262 produced a hybrid with grain yield in excess of 7,400 lbs/A. Four of the top five hybrids are experimental entries with the two ATx631*6BRON277 and ATx631*03BRON172 produced 6680 and 6434 lbs/A respectively. Test weight was similar to the standard check.

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 nutraceuticals in sorghum. Seed samples of 54 lemon-yellow grain color germplasms representing 7 different pedigrees were analyzed for presence of eriodictyol and naringenin. All of the samples are from tan plants, a prerequisite for high levels of the flavonones. Six samples had high concentrations of the compounds. Two samples with the pedigree of B.HF14*B8PR1011 are potential A-lines for hybrid production and will be entered into a sterilization nursery. Selections were made in new additional segregating populations to for lemon yellow grain color and better agronomic traits. Three experiments were initiated to study the accumulation of the flavonones. The first study involves the effect of sunlight on compound accumulation. Five panicles in different lines with known compound concentations were bagged (a paper bag placed over the panicle prior to anthesis). Grain from bagged and unbagged panicles will be analyzed for compound concentration. The second study involves compound concentration accumulation during grain maturation. Panicles of Tx2953 were harvested at 7 days post-anthesis, and then every 7 days for 7 weeks. The third study is to evaluate growing of grain mold fungi and their potential use of the compounds as a food substrate. Seven lines with known concentrations were sprayed with a fungicide 1, 2 and 3 weeks after flowering. The fungicide should control growth of the grain molds. Samples from each study were collected but grain analysis has not been completed at the time of this report.

Interest in using sorghum for brewing and malting is increasing. The contribute to research in Southern Africa seed of the original sorghum malting cultivar 'Barnard Red' was obtain. The cultivar was crossed to elite adapted cultivars to initiate the process of developing populations to select for enhanced levels of brewing and malting quality in elite adapted cultivars and to develop populations for potential graduate student research. Two additional cultivars, ICSV400 and ICSV111, were obtained and will be sent to the Puerto Rico winter nursery to develop populations for selection and research.

A Puerto Rico winter sorghum nursery contributed to research progress. The nursery was used produce samples for a lemon-yellow study, to produce seed of new sweet sorghum populations and grain populations with potentially unique grain yield genes, 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 to produced hybrids.

Achievement of Activities Proposed in Work Plan

All activities proposed in the Work Plan were accomplished. For the U.S. the proposed activities included: evaluation of germplasm and populations already in the breeding program to determine reaction to important biotic and abiotic stresses; increase lines and exotic cultivars useful in developing new populations; evaluate and select segregating germplasm for resistance to selected biotic (disease: headsmut, downy mildew, anthracnose, rust, zonate, grain weathering) and abiotic (pre- and post-flowering drought) stress; evaluate advanced lines as hybrid parents for grain yield, biotic and abiotic stress resistance, and adaptation; develop new segregating populations based upon results of trials; distribute to collaborators replicated trials of advanced germplasm potentially useful in southern Africa cropping systems; utilize a Puerto Rico winter nursery to develop new breeding segregating populations, identify F1 plants, increase exotic cultivars and adapted lines, continue sterilization of potential new A-lines; distribute seed of released lines; 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 the proposed activities included: travel to the region to consult with collaborators and develop specific work plans; collaborate with regional scientists to evaluate sorghum for the traits (adaptation, grain yield, disease resistance, insect resistance, drought tolerance, grain quality and grain weathering) necessary for developing improved sorghum cultivars for local production systems; distribute trials of germplasm potentially useful in the indigenous cropping system(s); develop new segregating populations based on research findings; select germplasm for use

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

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

in local production systems; participate in graduate training for regional breeders as appropriate.

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

Networking Activities

Participated in the Sorghum/Millet Germplasm Committee meeting, ATSA Corn and Sorghum Research Conference, December 11, 2008, Chicago, IL.

Participated in the Texas Seed Trade Association Production and Research Conference, February 2-3, 2009, Dallas, TX

Participated in the INTSORMIL Technical Advisory Committee meeting, July 16-17, 2009, Lincoln, NE.

Participated in the SICNA/Great Plains Sorghum Conference August 11-12, 2009, Amarillo, TX

Travel to Botswana and Zambia, October 31 - November 12, 2008. In Botswana participated in the Alternative Cereal Processing Technologies Workshop held at the National Food Technology Research Center, Kanye. The workshop was attended by approximately 65 participants. Met with Botswana College of Agriculture collaborator. In Zambia met with representatives of the National Institute for Scientific and Industrial Research to evaluate their research activities and possible collaboration with INTSORMIL. Met with representatives of the University of Zambia School of Agricultural Sciences to discuss on-going collaboration. Met with the SABMiller Lusaksa Technical Director to discuss the continued progress of Eagle clear lager beer.

Travel to Mozambique, South Africa and Zambia, February 24 to March 13, 2009. In Mozambique met with entomology and breeding collaborators to evaluate development of their respective research programs 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 evaluation of sugarcane aphid resistant germplasm for disease resistance. Met with ARC collaborator to discuss progress in evaluation of germplasm for resistance to sugarcane aphid. In Zambia met with collaborators from the Zambia Agricultural Research Institute and review 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

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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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Dr. John Sanders, Economist, Dept. of Agricultural Economics, Purdue University, West Lafayette, IN, USA

Introduction and Justification

Throughout human history, as economies have grown and people have experienced greater wealth, consumption of animal products has increased. Poultry production is particularly well suited to a rapidly growing demand for animal products because of relatively low expenditures for facilities, equipment, and land area to enter into the industry. Additionally, the short production cycle (less than two months of age at slaughter for a broiler vs six months for a pig vs 18 months for a feedlot steer) and extreme efficiency of growth (feed to gain ratios of about two in a broiler vs three in a 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 2008-2009 fiscal year, we finalized 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 (Ph.D. student at Kansas State) spent the summer of 2008 in West Africa visiting each experiment station, deliver feed ingredients, and initiate the growth assays. During the summer of 2009, Joe Hancock visited each experiment station of the collaborating scientist to share the pooled results. Our next step is to use this experiment as the cornerstone of a Poultry Field Day to be held in Niger this coming summer. This project, and a similar experiment with our collaborators in Nicaragua, served as the core activities for the successfully completed Ph.D. programs of Carolina Feoli (of Costa Rica) and Salissou Issa (of Niger). Additional accomplishments for this INTSORMIL project during the 2008-2009 fiscal year included numerous presentations by three students at professional meetings in Texas, Quebec, and Iowa and lectures by Dr. Hancock in a Poultry Seminar held in Bamako, a Feed Manufacturing Short Course held in Costa Rica, various sorghum related presentations in China, Mexico, Cuba, 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:

- 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 during the next two fiscal years.
- 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 and Central America.
- 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 during the Sorghum for Poultry Conference held in Bamako.
- Collaboration with grain scientists (e.g., McKinney and Behnke) in the Feed Science Program at Kansas State University was used to establish best manufacturing practices for diets used in our experiments in West Africa and Nicaragua.
- Interaction with animal nutritionists (e.g., Issa, Traore, Hien, Sangare, Missohou, Rios, and Campabadahl) in West Africa, Central America, and Kansas was essential to diet formulation strategies and conduct of our chick-feeding experiments.

Specific sites targeted for our 2008-2009 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 2008-2009 fiscal year. Beginning with participation by Hancock the Sorghum for Poultry meeting in Bamako, our goal was to meet with as many collaborators as possible and especially those that were not part of previous INTSORMIL activities. Issa continued contact with collaborators form Burkina Faso, Mali, Niger, Senegal, and Nigeria to execute/finalize the common experiment used to address a region-wide concern among poultry producers as it relates to the use of sorghum grain. Also, Hancock visited each of these collaborators to share thoughts and plan the "next step" for joint activities. As for the Americas, Feoli finalized her project results with Francisco Vargus (of AMPROSOR, the National Sorghum Producers Association of Nicaragua) and Miguel Rios (at UNA) in regard to our demonstration projects at UNA in Managua. Finally, at Kansas State University Chad Paulk jointed our research team and initiated a M.S. degree.

Research Results

Specifically for the 2008-2009 fiscal year, we were able to summarize (into a dissertation) a truly regional project involving a common protocol replicated in Senegal (on-site supervisor was Dr. Ayao Missohou, Veterinary Medicine and Animal Nutrition, Department of Biological Sciences, School of Veterinary Medicine, Université Cheikh Anta Diop, Dakar), Mali (on-site supervisor was Dr. Bantieni Traore, Animal Nutrition and Production, Centre Régional de la Recherche Agronomique de Sotuba, Bamako), Burkina Faso (on-site coordinator was Dr. Ollo Hien, Nutrition and Production, Institut de l'Environnement et de Recherches Agricoles, Bobo-Dioulasso), Niger (on-site supervisor was Dr. Salissou Issa, Animal Nutrition and Husbandry, INRAN Rainfed Crops Program, Niamey), and Nigeria (on-site supervisor was Dr. Iro Nkama, Food Science and Cereal Chemistry, University of Maiduguri). Issa spend the summer of 2008 in West Africa visiting each experiment station (to deliver feed ingredients and initiate the growth assays) and personally supervising the project in Niamey, Niger. The objective of this project was to compare maize to locally produced sorghum grain that had been properly milled. For the experiment, 400 1-day-old broiler chicks were randomly allocated to 16 pens (4 treatments and 4 pens/treatment with 25 birds/pen). This allocation was repeated at 5 sites for a total of 2,000 birds used in the experiment. The control diet was corn-based with fishmeal, peanut meal, cotton seed meal, and soy bean meal as the primary protein supplements. Sorghum was used to replace the corn on a wt/wt basis so that treatments were corn- vs sorghum-based diets with the cereals ground through a 6.4 mm vs 2 mm screen. The birds were allowed to consume feed and water on an ad-libitum basis for 42 days with weights taken on day 0, 21, and 42. At the end of the experiment, 12 birds/pen were killed for carcass evaluation. Carcass measurements included weights of the live bird, carcass, gizzard, liver, mesenteric fat, and full/empty intestines. Additionally, gizzards were scored for lesions on a scale of 0 to 5. 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 core of Issa's Ph.D. dissertation that was successfully defended the last week of December, 2009. Issa returned to Niger in January and is making contacts in Planning for a Poultry Field Day to be held in the summer of 2010. His regional project and prior experiments with broilers and layers fed in West Africa will serve as the cornerstone of that field day. A key end-result of that field day will not only be 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 (Miguel Rios and Francisco Vargas) resulted in keystone research activities for Carolina Feoli. For the experiments, broiler chicks were used in growth assays to determine the nutritional value of imported corn, locally produced bronze sorghum (CB-8996), and white sorghum (Pinolero-1) in broilers. Additionally, processing technologies (traditional vs fine particle sizes) were evaluated. There was no effect of grain source on average daily gain among birds fed the different cereals. However, average daily feed intake was greater and gain to feed ratio was lower for chicks fed the corn-based diet compared to those fed the sorghum-based diets. Thus, we found that bronze and white sorghums produced in Nicaragua supported equal or greater growth performance compared to imported corn when fed to broiler chicks and when properly milled to fine particle sizes, the sorghums were of their utmost nutritional value.

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 were extensive during the 2008-2009 fiscal year. The on-site supervision (by Issa) of our regional feeding projects in West Africa resulted in the creation of a core research team set to meet the need for information among West African poultry farmers. Additionally, the constant communications and data analyses by Feoli, as related to our feeding experiments in Nicaragua, resulted in a similar team of scientists, industry personnel, and sorghum farmers being formed in Nicaragua. Hancock also was active in promoting sorghum with presentations and seminars given around the globe (e.g., China, Costa Rica, Cuba, the U.S., and Canada) and a keynote lecture at the Sorghum for Poultry Conference held in Bamako, Mali.

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Hancock, J.D. 2009. A chicken for every pot. KSU International Brown-Bag Luncheon, Nov 9.

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

Project OSU 101
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Introduction and Justification

Improving the income and food security of small-scale sorghum and millet farmers in Zambia and Tanzania through the identification of new market opportunities and related constraints in the supply chain is the focus of this INTSORMIL/CRSP project. Sorghum and millet are traditional food staples and are important producer and consumer goods in Tanzania and Zambia. In both countries, the productivity and profitability of these crops is low and so is the income of small farmers who produce them. 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 plan 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 of the improved seed value chain in Zambia and beginning studies of the feed concentrate industry and food processing chain in Tanzania, (4) continuing the collection of monthly retail, wholesale and farm price information, (5) Joseph Mgaya from Tanzania completed his coursework for M.S. at The OSU and has returned to Tanzania for field research work on the feed concentrate industry, (6) Bernadette Chimai from Zambia started her M.S. coursework at The OSU Autumn term 2009, and (7) Rebecca Lubinda from Zambia expected to begin 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 2009 because of delays in the start of the program. She will begin study at the University of Pretoria in March 2010. The project supported two M.S. students in agricultural economics at SUA and two senior research projects at UNZA.

The combined studies are designed to identify and quantify new and/or rapidly growing markets for sorghum and millet in value added processing for clear beer, food, and feed concentrate markets. These value added processors offer opportunities for smallholders to sell their crops to more secure and stable markets than those currently available. Improved linkages to these markets will enable smallholders to adopt improved technology to increase yields, production, and incomes.

Objectives and Implementation Sites

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

These activities are centered on INTSORMIL (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 to increase technology uptake. The value chain studies are the means to study new 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 but not yet accepted by refereed journals. Household surveys have been completed in low and high potential sorghum production areas in both countries and are currently being analyzed.

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

Improved seed value chain studies: The farm household surveys discussed above have established the fact that sorghum and millet yields in both countries are very low (about 300 to 400 kg/ hectare). Farmers identified a lack of high quality seed as one of the obstacles to increasing yields. An improved seed value chain study has been completed in Zambia and one been initiated in Tanzania.

Seasonal price variability studies: Many times farmers are forced to sell their crops at harvest time when crop prices are frequently at the lowest level. Crop prices may increase substantially during the remainder of the marketing year. Data collection of the monthly price changes, costs of storage and household seasonal cash flows continued in 2009. Price analysis to identify ways for farmers to sell at higher prices in the post-harvest season has begun.

Description of Interdisciplinary Team

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

Research Results: Tanzania

In Tanzania, the project activities for July 1, 2008 to September 29, 2009 were to: (1) To initiate a study of improved seed value chain, (2) To initiate study of feed concentrate value chain, (3) To initiate and complete 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, will contribute to this study. The title of her M.Sc. is Economic Analysis of Seed Value Chain in Tanzania: A Case study of Millet and Sorghum in Singida. 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. This student will begin data collection in October, 2009 and is expected to complete the study by September, 2010.

Study on Feed Concentrate Value Chain

The feed concentrate study will be conducted by Mr. Joseph Mgaya who is sponsored by the project to undertake his M.Sc. in Agricultural Economics at The OSU. The candidate has completed his coursework on-time, developed his research proposal, and returned to Tanzania. . He will begin data collection in Mid-October, 2009.

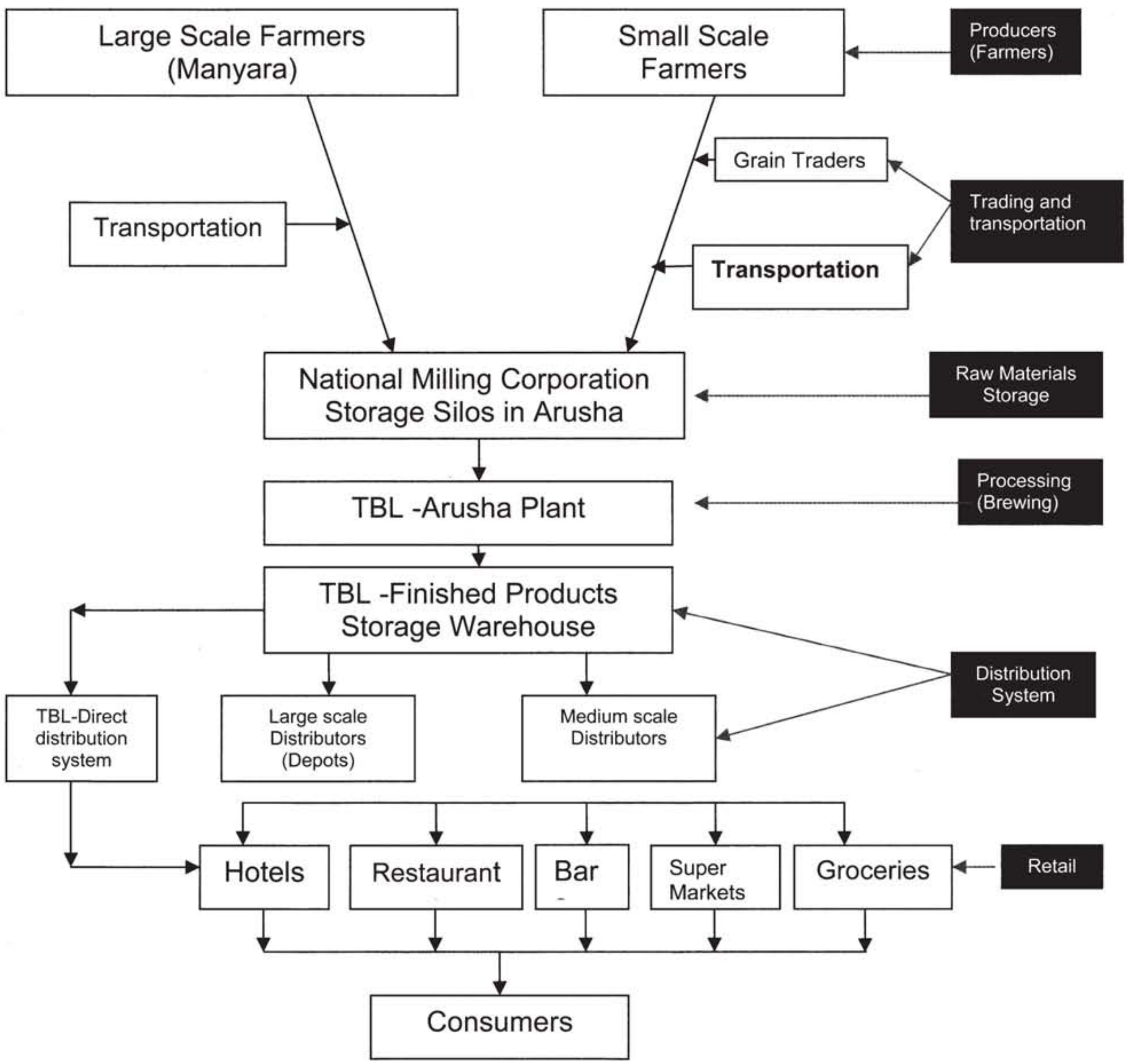
Study of Fortified Food Value Chain

Freddy Kilima and Emmanuel Mbiha, SUA faculty and INTSORMIL collaborators, will lead the fortified food value chain study. The main objective of this study is 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 are to: (i) identify actors in fortified food value chain; (ii) identify constraints to increased utilization of sorghum and millet in fortified foods; (ii) estimate prospect for increased utilization of sorghum and millet in fortified foods and; (ii) examine strategies to increase returns and reduce risks for farmers in the sorghum and millet value chain. To achieve these objective, a preliminary survey study was conducted in Arusha regions, which is one of the major markets for sorghum and millets grown in Tanzania. In total, six sorghum and millet fortified food processors were interviewed. These processors were purposefully selected to accommodate variation in scales of operations. These interviews were conducted field assistants and project collaborators between June and early August, 2009. A similar survey for Dar Es Salaam based firms is planned to start in September, 2009.

A preliminary assessment of country capacity for food fortification revealed that there are many small hammer and plate mills both in sorghum growing areas and major consumption centers. There is a good prospect to enhance the fortification of sorghum and millet products if appropriate technologies (e.g. batch mixing of fortifiers) are identified and promoted. However, this endeavor should mainly focus on small to medium scale operations because a rapid transition to large scale operations could not be supported by the current highly variable supply of grain. The predominantly small scale production of sorghum and millet can not guarantee adequate supply of high quality grains needed for commercial milling.

There is little incentive to invest heavily in value addition processing as effective demand for fortified foods is mainly in specific niche markets (e.g. for infants as weaning foods). Thus building up and supporting local capacity for fortification might encourage investment in fortification practices in the food processing industry. Despite Tanzania's planned launch of a National Fortification Alliance (NFA) to steer the fortification agenda, mandatory for-

Figure 1. Sorghum based clear beer value chain in Tanzania.



tification has only been implemented for wheat flour but not for maize and other major grains including sorghum and millet.

Most commercial millers or food processing firms were willing to fortify the foods they process, though they lack the appropriate equipment and technology or experience in fortification. Also these processors were uncertain about what fortification entailed, what nutrients need to be added and what was required to mount a fortification process.

Acceptability of sorghum and millet based foods in societies where they are perceived as poor people's food could be enhanced if these products are incorporated into familiar products/dish, especially as ingredients in popular food or products (e.g. through blending). Increasing precision in labeling as well as describing the contents and utilities of all ingredients in these products coupled with effective market promotion are ideal strategies to improve the market value of sorghum and millet products in places where they are rarely eaten, sold or exchanged.

Examine the Supply Chain for Sorghum-Based Clear Beer

Jeremia Makindara, a faculty member and Ph.D. candidate at SUA is conducting the sorghum-based clear beer supply chain analysis. The objective of the study is to assess the emerging market for the sorghum-based clear beer value chain as a new market opportunity for small holder sorghum producers. The study includes interviews with farm households (107), with traders (60), transporters (60), distributors and warehouse owners in the Arusha region have been completed and are being tabulated.

The sorghum value chain starts with smallholder producers who then sell their produce to village buyers (Figure 1). Some village buyers are agents of grain traders from urban centres who may sell produce to large scale industrial users such as Tanzania Breweries Limited (TBL) or Dar Brew Limited. Village buyers also sell to urban wholesalers. Some larger scale commercial sorghum farmers enter into contracts and sell directly to industrial users such as TBL or Dar Brew.

Tanzania Breweries Limited (TBL), a subsidiary of SAB Miller, introduced sorghum based clear beer (Eagle lager) in Tanzania in 2007. TBL's principal activities are the production, distribution and sale of malt beer and alcoholic fruit beverages in Tanzania (TBL Annual report, 2009). TBL operates breweries in Dar es Salaam, Arusha, Mwanza and is building a new one in Mbeya targeted to start production in November 2009. The company also operates a malting plant in Moshi. TBL also co-owns and manages Tanzania Distilleries Limited (TDL) a spirits liquor company in Dar es Salaam. The popular TBL brands are Safari Lager, Kilimanjaro Premium Lager and Konyagi. TBL sales in 2009 amounted to 464,199 million TAS (21 % sales revenue growth) resulting in a profit after tax of 80,797 million TAS (11% operating profit growth). The Board of Directors considers this result satisfactory; while the future prospects for the company are also very promising (TBL Annual report, 2009).

TBL through its Arusha Brewery plant started to produce sorghum based clear beer in 2007. The initial sorghum used to produce Eagle was first produced by a contract farming arrangement. Under the contract arrangements, TBL procured sorghum for about 200 TAS per kg and also subsidized transport for about 45 TAS per kg shipped. However, the future plan is to procure sorghum from small holder farmers who will sell through their agricultural produce co-operatives. TBL wants to market Eagle Larger beyond the large city market centres and develop rural markets to be served by low cost products (SABMiller, 2005).

At the National Milling Corporation (NMC) warehouse in Arusha, the sorghum is tested for moisture, weighed, cleaned and reweighed. The cleaned sorghum is then stored and ready to be transported to TBL –Arusha plant fọr brewing. Based on the TBL-Arusha plant production schedule, about 24 tons of sorghum is processed every week1[1] .

The sorghum beer brewing involves the use of unmalted sorghum grains and food-grade enzymes to produce Eagle lager. In addition to the lager beer, two valuable by-products of the process are spent grains and yeast which are normally used as animal feeds and as a raw material for animal feed processing respectively. The beer is bottled in either 300 or 500 ml bottles and packed in 25 bottles per container and stored in a warehouse ready for distribution. The ingredients of the Eagle Larger are water, sorghum, malt, sugar and hops. The alcohol content is 5.8% by volume.

Eagle lager beer consumption varies from one retail outlet to another depending on the location and the 'popularity' of the outlet. Some outlets, especially bars are more popular than others and sell more beers to their customers. In addition, the sale of the roasted goat and beef meat, popularly known as "nyama choma", also influences the nature and number of the customers visiting the outlet. Based on the type of the outlet, this study identified three types of outlets 'High Class', 'Middle Class' and the 'Popular'. From this classification, the study finds that sorghum beer in Arusha Urban has no market share in the 'High Class' outlets when compared to other locally produced brands such as Kilimanjaro, Tusker, Serengeti and imported Heineken. In the 'Middle Class', the study finds that sorghum beer has a market share of 3.4% while in the 'Popular' Outlets the market share is 4%. (Researcher's observations, 2009)2[2] . Thus, Eagle lager has increased from no market share in 2007 to 4% market share two years later. This is acceptable considering the stiff competition between the two beer brewing companies as well as competition from local home brews, imported beers and wines and spirits.

Increased opportunities for sorghum market development in the brewing industry will be possible if more clear beers will include sorghum in their processing or in developing new products. In addition, if the sorghum beer producers change their marketing strategy, sorghum consumption in the industry will also increase. Long term sustainability of a value chain depends upon potential demand of the buyers; consistent and high quality supplies from producers; as well as adequate transportation and storage infrastructure, profitability for all chain members, trust and contract enforcement mechanisms.

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 the next four years (2008-2011). To initiate this process the Tanzanian collaborators at SUA developed a protocol for data collection to undertake the following:

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

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

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

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

The project is supporting M.S. degree study at The OSU in agricultural economics for Joseph Mgaya from Tanzania who began his graduate study in autumn of 2008. The OSU provides a cost share tuition award for this student. Joseph completed his coursework (July 2009) and returned to Tanzania to conduct his field research on sorghum use in the feed concentrate industry.

1. The production schedule also depends on market requirements from the marketing department.

2. Due to the rivalry in the Industry, the source of information is withheld.

Research Results: Zambia

In Zambia, the project activities for July 1, 2008 to September 29, 2009 were to: (1) complete study of improved seed value chain, (2) complete study of clear beer value chain, (3) analyze farm household interviews in 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 for the PhD program in agricultural economics located at Bunda College (RUFORUM).

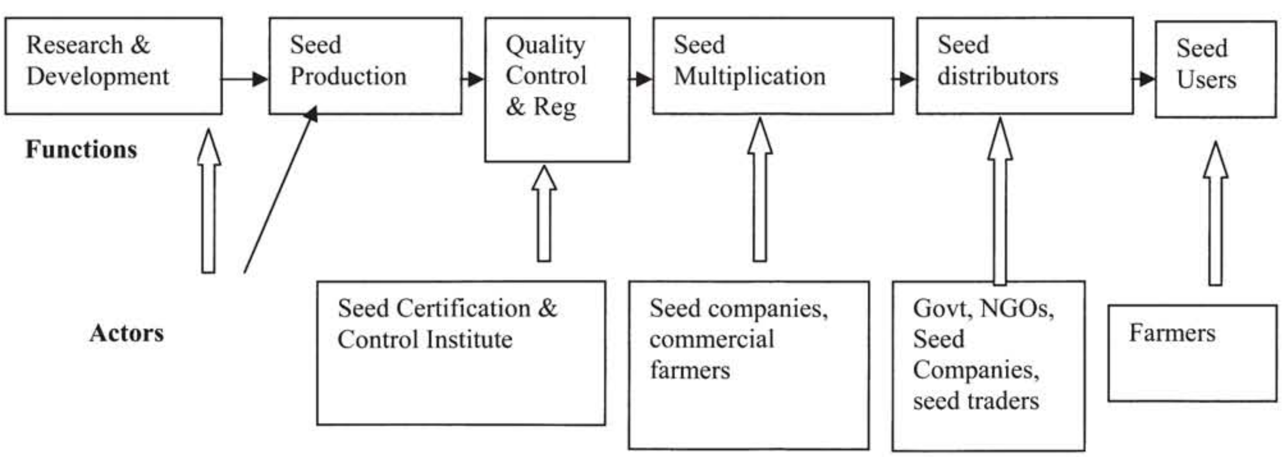
Complete Study of Improved Seed Value Chain

Priscilla Hamukwala, a UNZA faculty member and INTSORMIL collaborator, studied the improved seed value chain for sorghum, millet and maize in Zambia. The study began by mapping the seed chain functions, actors and identifying key informants at critical points (such as production, distribution, consumption) in the value chain (Figure 2). The value chain has three interlinked components; namely the value chain actors, enabling environment (policies and institutions and that shape the market environment) and service providers (business services that support the value chain's operations). Both primary and secondary data were used in the study. Primary data were collected using checklists and structured questionnaires. Site visits of the study area (Siavonga & Lusaka) particularly the input and output market facilities were made and in-depth interviews were held with key informants. A total of 130 farming households, 57 seed dealers, five seed companies, and two research and development institutions were interviewed. Secondary data on crop yields, the level of improved seed and fertilizer use in Zambia by farming households since 1990 were collected from Central Statistics Office.

The key value chain actors in the public sector are agencies such as ZARI, SCCI, UNZA, and the Ministry of Agriculture and Cooperatives. They play key roles in varietal development, inspection and certification, and in providing extension services. From the private sector, there are five seed companies who mainly deal in maize hybrid seed and three of these companies sell sorghum and millet seed. Most of these companies perform multiple functions which include, varietal development, seed production, seed processing and distribution. Farmers' organizations, NGOs and faith based organizations also work in close collaboration with the government departments and seed companies in seed distribution and extension services. The seed end users are primarily small scale subsistence farmers (1-5 hectares). Farmers rated access to facilities relevant for agricultural development as poor. These included access to agricultural information, inputs and produce markets. The challenges faced included poor extension services, poor quality of seed, lack of processing technologies and lack of stable markets.

The formal channels distribute mainly improved maize hybrid seed while both the formal and informal channels distribute sorghum and millet and OPV maize seed. Millet particularly is largely distributed through informal channels and mainly between farming households. The study also found out that formal seed companies viewed investment in sorghum and millet as unprofitable due to lack of a stable markets and low demand for the seed. The rate of seed replacement in sorghum and millet among seed users is very low compared to research recommendations. There is a heavy dependence on recycled seed (average of 13 years) and thus a very small proportion can be considered to be improved seed. Based on the household surveys, the reasons for low farmer adoption of improved varieties are attributable to lack of access to improved seed, poor linkages to supporting organizations like extension, poor access to markets and lack of market demand. There is lack of awareness and understanding of consumer preferences and market demand among chain actors particularly farmers. This has resulted in the inability to successfully market sorghum as well

Figure 2. Improved Seed Value Chain Actors & Their Functions, Zambia 2008



Source: Survey data 2008

as the inability to take advantage of market opportunities that exist in the sorghum markets.

Seed dealers ranged from farmers selling surplus seed to seed companies selling through their agents. The places of operation for the seed dealers included owned stalls, roadside stands and door-to-door sales. Typically, seed dealers who own stalls stocked other merchandize along with seed. Because the amount of purchased seed is low, seed traders stock small quantities. Most traders advised seed buyers on the suitability of seed and how seed of specific varieties should be planted. According to seed traders, the most serious constraints to selling improved seed in the area were low quantities of seed purchased, delayed payments by farmers and stiff competition among the seed traders.

Formal seed producers were mainly private seed companies. Their core business is hybrid maize seed. The seed is sold through their regional distributors, the majority of whom have outlets in almost all farming communities. Most of the seed companies have their own breeding programs, and do their own seed multiplication on-farms largely through contracting with commercial farmers. Seed producers also get basic and pre-basic seed from government sources in addition to their own production. The major constraints they face in sorghum and millet seed production is low quantities of seed demanded and lack of stable markets. Major buyers of seed from seed companies for sorghum and millet are government and NGOs who only buy in years when they anticipate drought.

Factors affecting the competitiveness of the chain include the enabling environment such as the crop diversification policy, and changes in market trends which may have a positive impact on sorghum and millet use. Other factors such as the fertilizer and price subsidy programs for maize adversely impact the competitiveness of the sorghum and millet seed chain. In Zambia, the largest outlay of government agricultural expenditures was for fertilizer subsidies for large scale farmers (Eicher, 2009).

This study found that adoption of improved practices particularly the use of improved seed and fertilizer is very low. The result is low yields for sorghum and millet (national average about 500 kg/ha) with no increasing trend in yield (productivity) since 1990. Yet, sorghum breeders have varieties on the shelf that yield 3-6 tons/ha on experiment station farms. The low rate of adoption raises questions of whether the goals of research and development of new technology are being met.

Technology adoption is not well documented by public institutions for crops like sorghum and millet. This lack of documentation of improved production practices prevents tracking the exact trends in the use of improved practices. The responsible institutions should make it a priority to collect data on improved practices along with other data so as to make conclusive recommendations on the results of research.

Sorghum-Based Clear Beer Supply Chain Study

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

Eagle lager, a product made from locally produced sorghum, was introduced in the Zambian clear beer market in 2005 and offers an alternative to the traditional maize-based clear beer. It entered the market at a much lower price than its close competitors, Mosi and Castle lagers. Most importantly its introduction has created new value chain relationships involving farmers, traders, transporters, wholesalers and retailers. For the farmers, the beer provides a stable market at a known price for their sorghum. The distributors and retailers are provided with more service-provision activities making it possible for them to expand their businesses.

Previous studies have identified the main players in the clear beer supply chain and have provided useful insight into the activities of the chain and how the different chain members are interrelated. To the best of our knowledge, no study has assessed the performance of Eagle lager and the opportunities and challenges it presents to smallholder farmers in Zambia. As a major player in the chain, it is necessary to assess the performance of Eagle lager since its introduction as well as estimate future market opportunities that it may present.

In the past, sorghum was considered a traditional crop with limited industrial uses such that most of it was used for household consumption. However, in recent years, the crop has been identified as a possible substitute for maize. Research and transformations in consumer tastes and preferences have led to the development of new uses for sorghum. In particular, four major industrial uses of sorghum have thus far been identified, including food processing, beer brewing, feed concentrates and energy production. Beer brewing presents by far the largest industrial market for sorghum, whereas the sorghum-based bioenergy industry is yet to be developed though equally presenting great potential owing to persistently high world energy prices (Larson et al., 2006).

Sorghum is used in combination with maize, and sometimes millet, in both home and commercial beer brewing. Initially, it was only used in opaque beers made by a few breweries. The commercial opaque beer brewing industry has been growing steadily providing an affordable beer that is more hygienic than that from home breweries. This industry has evolved from a few firms offering bulk chibuku to quite a number selling their products both in bulk and one-liter tetra packs. National Breweries has taken a step further to import already malted sorghum from South Africa. So far, only National Breweries is importing malted sorghum. Though this has a possible implication of reducing market opportunities for locally produced sorghum, this market has been, to some extent, filled by a number of small breweries. Eagle lager was introduced onto the clear beer market in 2005 by Zambian Breweries, creating new supply chain linkages with other business organizations.

Initially, Zambian Breweries used the Cooperative League for the USA (CLUSA), a USAID-funded NGO, to sensitize up to 4,000 local farmers to produce sorghum required for brewing by providing technical advice and loans for production inputs. Purchase arrangements were signed between farmers and Zambian Breweries at time of planting to guarantee a ready market at a reasonable price range, with final price determined at harvest time (Inspiris, 2006). Importantly, Zambian Breweries advances no credit to farmers. At the time of this review, Zambian Breweries (ZB) was obtaining all its sorghum supplies from a local commodity broker, CHC Commodities. The broker entered into an agreement with ZB to be its only supplier of sorghum. CHC Commodities purchases sorghum from smallholder farmers, small traders, and large-scale farmers. However, the contribution by large-scale farmers has been declining such that in 2008 all the sorghum was sourced from smallholder farmers.

Processing of Eagle lager is done by Northern Breweries, a subsidiary of Zambian Breweries, in Ndola. The company produces 4 to 6 brews in a week with each brew yielding 30,000 liters of beer from 3.8 metric tons of sorghum. The beer is bottled in 300 and 375 milliliter glass bottles and packaged in crates of 24 bottles. These are then distributed to the main Zambian breweries depots around the country. It is from these depots that the beer is redistributed to retailers through registered distributors. In order to market its product, Zambian breweries advertises eagle in print media, promotion and road shows. Another key marketing strategy used for Eagle lager is sponsoring traditional ceremonies like the kuomboka ceremony of the Lozi people. The ceremonies are also used as a platform for further advertisements through t-shirts and posters. They offer-point-of-sale support materials like refrigerators, posters and recommended price charts. Sales representatives act as observers for the company and ensure that retailers are complying with the company's selling standards. Bi-annual surveys are also conducted in areas along the line of rail to provide useful information on customer preferences and complaints.

Eagle lager enjoys 15-17 percent clear beer market share, and is reportedly growing at 5-10 percent per annum. Such a growth rate is likely to encourage increased production but also presents a challenge on the existing plant size at Northern Breweries. To cope with the increasing demand, it is estimated that the existing processing plant needs to be expanded at least fourfold. Also, there is an increasing need for research in improving the efficiency of sorghum in terms of yields per kg. Zambian Breweries recognizes the need for such research and are currently looking at the possibility of providing support for research in this area.

Survey of Sorghum And Millet Farmers in Luanshya- a High Potential Area

A survey of sorghum and millet farmers in a high potential area was conducted in two blocks of Luanshya district north of Lusaka. Luanshya is considered 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 is now grown there. Maize is the major crop now grown in the Mumbwa area. The change to maize is due in part to large government subsidies (60%) on maize seed and fertilizer prices.

In the Luanshya survey, 170 households were visited, of which 169 complete interviews were covering the two target agricultural bocks, Kafubu and Chilabula. The choice of the two blocks was further informed by consultations with the District Agricultural Coordinators' (DACO) offices in Luanshya and Masaiti. Because there were not many households that grew sorghum and/or millet in the 2007/08 agricultural season, an attempt was made to interview every household that had grown the two crops.

Progress toward indicators such as income growth, yield increases, and production increases will be measured against this baseline information in the high potential area. Sorghum breeders at the Golden Valley Research Station plan to introduce an improved sorghum variety (WP-13) to farmers in the area with assistance from CARE in 2008-09.

The data from the baseline survey have since been entered, cleaned and analyzed. For ease of manipulation, and in recognition of the fact that different modules in the questionnaire presented data at different levels, the SPSS dataset was organized into 11 files. A draft baseline report has been prepared.

Price Variability Study

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

Select a Student From Zambia for M.S. Study at OSU and for Ph.D. at Bunda College (RUFORUM)

Bernadette Chimai, a recent UNZA graduate in agricultural economics, has begun her MS studies at The OSU in autumn 2009. Rebecca Lubinda, a faculty member in the Department of Agricultural Economics and Extension Education at UNZA, has decided to begin PhD studies at the University of Pretoria in March 2010.

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. 2009. "An Evaluation of New Market Development and Marketing Strategies on Sorghum and Millet Farmers' Income in Tanzania and Zambia." INTSORMIL Annual Report 2008. USAID/INTSORMIL Grant. University of Nebraska. Lincoln, Nebraska. Pp. 79-84.

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

Project PRF 102
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Introduction and Justification

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

In the past year, we have been involved in three activities: 1) incorporation of the high digestibility/high-lysine mutant sorghum in composite bread, 2) establishment of a functioning incubation center at INRAN in Niger, and 3) involvement in the processing part of the large USAID Mali mission-funded project "Transfer of Sorghum, Millet Production, Processing and Marketing Technologies in Mali" aimed to increase farmer's incomes through expanded markets by processed products. During this period, the PI traveled three times to West Africa for a training workshop with team members Y. Koreissi (IER scientist) and M. Diouf (consultant), a site visit at INRAN Niger and a planning session with INTSORMIL West Africa Regional Program coordinators, and to attend a USAID Mali workshop for funded agricultural projects and for a site visit to University of Maiduguri, Nigeria.

Based on previous work showing that isolated maize and sorghum storage proteins (zein and kafirin) can be functionalized to participate in dough structures and bread making, work continued in 2009 to both understand how the proteins in our high digestibility/high-lysine mutant sorghum can be made to better act in this process and to work towards a better formulation for optimizing high incorporation sorghum composite bread. This is a collaborative project with A. N'Doye and I. M'Baye at ITA in Dakar. In August, a senior undergraduate student, M. Goodall, who has worked on this project for three years, traveled to Dakar to work towards composite bread optimization. These studies are continuing and it is our expectation that a high ratio sorghum composite bread can be made and tested in the Dakar market.

In Niger, a fully functioning incubation center was realized through hard work on the part of INRAN collaborators led by M. Moussa. This processing unit housed at INRAN is set up to process high quality milled products (flour, semolina, grits) and second level agglomerated products (two types of couscous, degue and others). In 2009, ten women entrepreneur processor groups used the facility on a rotating basis to produce products, pay a fee to the unit, and sell them in the marketplace. This incubation activity has resulted in training about 50 women to process high quality, competitive products that sell well in the marketplace. Because of this arrangement and the technical support provided by INRAN technologists, a local NGO has provided a loan to one of the women's groups to build and outfit their own processing facility and has financed a local fabricator to build the agglomerator (originally designed at CIRAD, France).

In Mali, a the processing component of a large project "Transfer of Sorghum, Millet Production, Processing and Marketing Technologies in Mali" funded by the USAID Mali Mission was continued. Primary processing equipment was installed in six units of previously identified entrepreneur partners in the Mopti/Gao area, and at IER/LTA Sotuba to establish an incubation center for Bamako area partners. A training workshop was held in June.

Objectives and Implementation Sites

Collaboration sites West Africa are associated with 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, Seydou Malle, 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

- In collaboration with A. N'Doye and I. M'Baye of ITA in Dakar, and with G. Ejeta, continue basic and applied work towards the goal of enhancing wheat-like properties of sorghum grains for high incorporation of sorghum (high digestibility/high lysine mutant lines) into baked products (mainly bread),
- Through the Marketing and Processing project funded through the Mali USAID mission, work to create successful processing enterprises in the Mopti and Gao regions of northern Mali and an incubation center at IER/Sotuba (Bamako) to bring new technologies and training to urban entrepreneurs in establishing millet and/or sorghum processing units,
- Facilitate the optimization of products and processes through a partnership approach between West African NARS food technologists and entrepreneurs,
- Further develop, refine, and transfer technologies to appropriate West African NARS food technology laboratories to make high quality sorghum and millet processed foods (e.g., pregelatinized "instant" sorghum, agglomerated products, and millet flours for thin and thick porridges),
- Understand the role of sorghum and millet-based thick porridges in providing extended satiety and energy levels to consumers,
- 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

Senegal: Continue current collaborative work with A. N'Doye on product optimization and testing work on the wheat-like properties of sorghum proteins and incorporation of the high digestibility/high lysine sorghum mutant into composite flour baked products. We hope to extend our current baking optimization trials and work towards field trials in the private sector. Other collaborative work assists the further development and testing of a new technology developed by ITA to process couscous directly as grits. Project beginning date – October 2007, ending date – September 2011.

Niger: (1) Our overall aim has been to achieve commercial processing of high quality sorghum- and millet-based products (agglomerated - two sizes of couscous products and degue) and flours. Moustapha Moussa obtained his M.S. from Purdue in May 2007 and returned to Niger to become a scientist at INRAN. Our strategy has been to develop an incubation center at INRAN for local entrepreneurs to be trained and use to test the marketplace and begin to grow consumer sales. Work now focuses on further development of pregelatinized flours and agglomerated products for urban markets and assisting in gaining loans for an entrepreneurial units. This processed product marketing objective is linked to the hybrid development program of I. Kapran. Project beginning date – October 2007, ending date – September 2010.

Mali: Through Mali USAID mission support of the project "Transfer of Sorghum, Millet Production, Processing and Marketing Technologies in Mali", a entrepreneurial-based processing project was launched in 2008 in Mopti (team consisting of consultant Mamadou Diouf of ITA/Dakar, Y. Koureissi of IER/Mali, B. Hamaker). Milling and decortications equipment has been placed in six entrepreneur units in the Mopti/Gao region. Structures were funded and build to specifications by entrepreneurs and a training workshop was held. Future activities will involve further assisting entrepreneur(s) with technology expertise (training workshops), basic equipment procurement, and linkage with the grain contracting project of J. Sanders and O. Botouru. Project beginning date – October 2007, ending date – September 2012.

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. Thesis plans include 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 on millet processing and millet varietal differences suitable for specific processes; expand focus from screening of varieties to commercial products. Work through the regional West Africa program. Project beginning date – October 2007, ending date – September 2011.

U.S.: 1) Continue research to functionalize sorghum (and perhaps millet) grain storage proteins to behave similar to wheat gluten to increase their proportion in composite flour breads and other leavened products. These studies are funded by INTSORMIL, as well as fundamental studies funded by USDA on improving non-wheat cereal storage protein functionality. Obtain a new graduate student to work on the bread making project. Project beginning date October 2007 –, ending date – September 2011. 2) New graduate student, Fatima Cisse from Mali, will begin January 2010 and will work on instant flours for thin and thick porridges and study the role of thick porridges of differing consistencies in delayed energy release and satiety. Project beginning date –August 2010, ending date – May 2012. 3) Continue to work with G. Ejeta toward further improving grain quality of high protein digestibility (and possibly wheat-like property) sorghum. Project beginning date – October 2007, ending date – September 2011.

Research Results

Sorghum/Wheat Composite Bread

Work continued on the functionalizing of sorghum proteins to participate in dough and bread making. Our objective for this project is to produce high sorghum-containing composite flour breads and other leavened products using a technique developed in our Purdue laboratory and using the high digestibility/high-lysine sorghum mutant developed through INTSORMIL at Purdue. The hypothesis pursued in this project is based on previous work in our laboratory showing that maize zein protein can be made functional to behave similar to wheat gluten, and to form a viscoelastic dough that can make a leavened bread product. Sorghum grain has analogous proteins to zeins called kafirins, however both zeins and kafirins are normally restricted from forming functional structures in dough due to their encapsulation in discrete protein bodies. In the case of the high digestibility/high-lysine mutant, the protein bodies are disrupted when synthesized and partially fused during seed development. This was shown in experiments to allow for the kafirins to participate in viscoelastic fibril formation during the dough process (Figure 1). This translates, as shown in last year's report, to a bread structure with acceptable properties at 60% sorghum incorporation. However, we are still in the process of understanding how this high incorporation can be optimally done. In August 2009, an undergraduate student, M. Goodall, who has participated on this project for three years was sent to ITA in Dakar to work with collaborators I. M'Baye and A. N'Doye. ITA has a good functioning baking laboratory with baking expertise. Various formulations were tested with further positive results showing the potential of the high digestibility/high-lysine mutant in high ratio composite breads, as well as limitations in the current process. Further studies are now in process at Purdue, for example, to strengthen high ratio doughs further to prevent loss in loaf volume following proofing. Our goal is to increase the amount of sorghum flour that can be incorporated into composite breads and associated products both to increase market opportunities for local sorghum farmers and to reduce need for imported and often high priced wheat.

Functioning Incubation Center at INRAN, Niger

In the late 1990's, collaboration between INRAN and this project resulted in the setting up a agglomerated product (couscous and other precooked, agglomerated products) processing unit. The purpose was to have a complete processing unit to do technology development work, and also for it to act as an incubation center for demonstration and training to local entrepreneurs and to provide them a way to test the marketplace with improved products. This has been reported in past INTSORMIL annual reports. In 2009, notable progress has been made regarding the incubation center concept. This is chiefly due to the organizing skills and persistence of M. Moussa who obtained his M.S. from Purdue in 2007 through the INTSORMIL program. In August 2009, 10 entrepreneur women's groups were using the processing facility on a scheduled basis with produced products (flours, grits, 2 couscous products, degue) distributed to all groups equally for sale in the Niamey marketplace with payment made to the Center based on units distributed (Figure 2 left). This has facilitated a growing market for these quality and competitive products and products sell quickly in stores in Niamey. One of the groups was given a loan by a local NGO to build a processing unit (Figure 2 right), and a local fabricator was provided a loan to build agglomerators, the critical and most technologically advanced part of the processing unit (this agglomerator was designed by J. Faure, CIRAD, France). These encouraging activities show that this strategy and use of an incubation center functions in this environment. The ability to back up local entrepreneurs with technical expertise and support was the reason given by the NGO for their backing of the processor and fabricator (equivalent to ~$120,000).

All processing projects at INRAN are done in integration with the breeding group to meet the overall objective of promoting new high quality hybrids and expanding markets for farmers.

Mali Marketing-Processing Project

In 2009, our processing component of the Mali USAID INTSORMIL project "Transfer of Sorghum, Millet Production, Processing and Marketing Technologies in Mali" continued with placement of a commercial-scale decorticator, hammer mill, and abrasive disk mill in each of six entrepreneur partners in the Mopti/Gao region who were previously identified to participate in the project (Figure 3). Each partner built and prepared by specifications of the project a structure to house the equipment, and processors will repay a portion of the equipment costs. Identical equipment were purchased and installed at the IER/LTA Sotuba unit in a building now designated for formation of an incubation center for demonstration, training, and market testing for Bamako area processors. Other equipment will be added in 2010. A four-day training workshop was held in June in Mopti with three participants from each unit, as well as staff from IER, mechanics, and our project team (Y. Koreissi, M. Diouf (consultant), S. Malle, B. Hamaker). The workshop trained participants on equipment usage, maintenance, and processing sorghum and millet to high quality milled products. The goal of the project is to increase farmer's incomes through activities concentrated on expanding markets for sorghum and millet.

Plans for 2010 activities include making final adjustments and mechanical alterations to equipment, a second training workshop in Mopti in March on processing, product quality, grain sourcing and contracting, and marketing; a training workshop at IER/LTA Sotuba for Bamako area processors, and a third training session for entrepreneur partners on advanced cereal processing techniques.

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 for thesis research planning including a future training period at Purdue University. Fatima Cisse from IER, Mali began English training in the US prior to her M.S. program to begin at Purdue in January 2010.

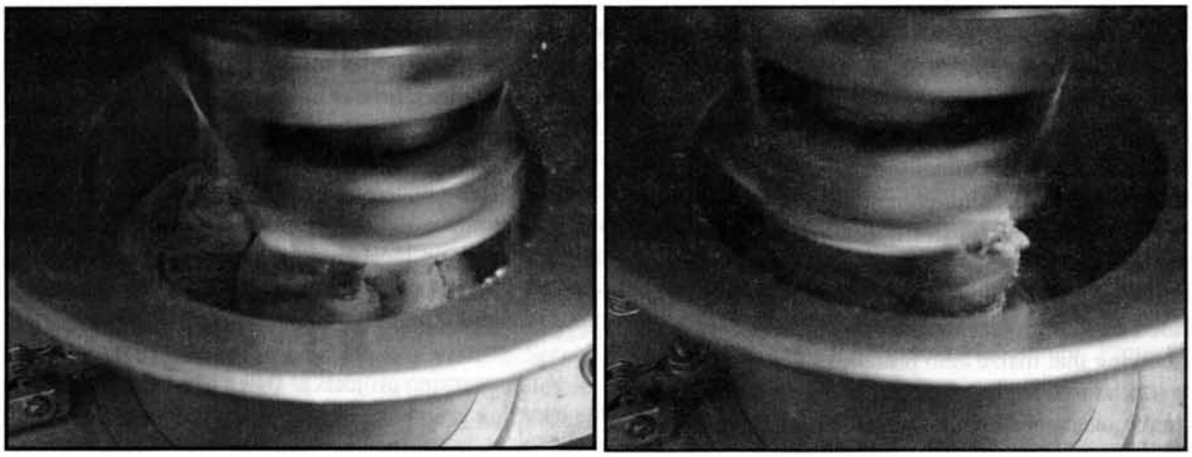

Figure 1: (left) shows lack of viscoelasticity in a 60% normal sorghum/40% wheat flour dough compared to (right) a viscoelastic dough made from a 60% high digestibility, high-lysine sorghum mutant/40% wheat flour composite using an pre-incubation step and sonication. This demonstrates that proteins made available from the mutant flour protein bodies, which are abnormal and in a folded structure, participate in the dough making process.

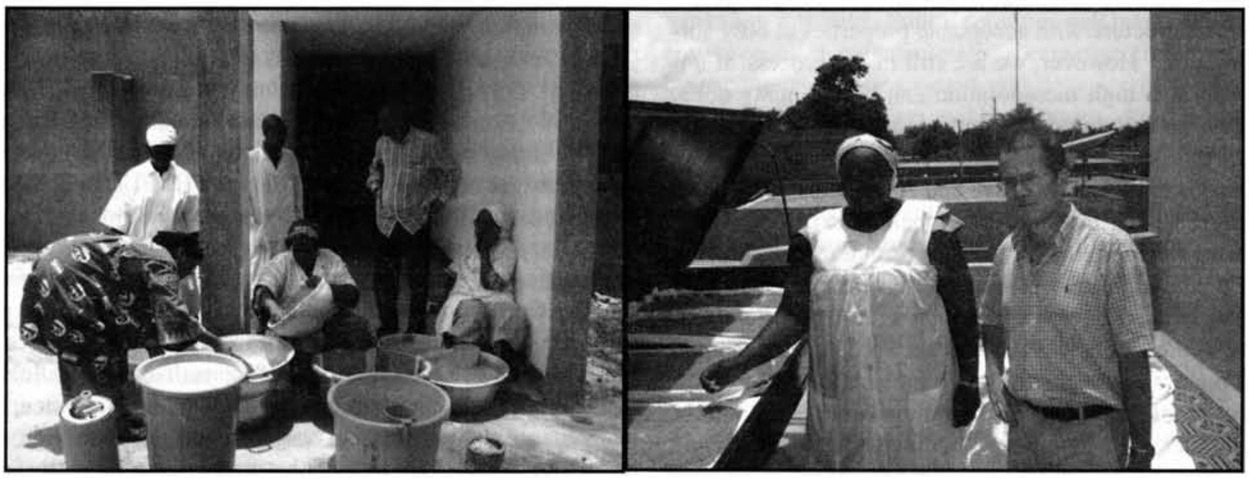

Figure 2: (left) shows an entrepreneur women's group outside of the INRAN incubation center. Entrepreneur groups are trained and use the facility to produce and sell high quality, market competitive sorghum and millet products. On the right, Mme. Liman, the head of one of the entrepreneur groups, and B. Hamaker tour their new processing facility financed by a local NGO.

Figure 3: Inspection by team members Y. Koreissi and M. Diouf of processing equipment in Mopti entrepreneur partner unit.

Networking Activities

B. Hamaker made three trips to West Africa in 2009: 1) to participate in a training workshop with entrepreneur partners in the Mopti/Gao region of Mali, June, 2) a site visit to INRAN, Niamey, Niger followed by a West Africa Regional Program coordinators meeting in Bamako, August, and 3) to participate in a USAID Mali workshop for those funded by the mission in agricultural projects followed by a site visit to University of Maiduguri, Nigeria, December.

Publications and Presentations

Journal Articles

Matalanis, A.M., Campanella, O.H., and Hamaker, B.R. Storage retrogradation behavior of sorghum, maize and rice starch pastes related to amylopectin fine structure. J. Cereal Sci. 50:74-81.

Presentations

Hamaker, B.R., Mejia, C.D., Goodall, M.A., and Bugusu, B.A. 2009. Texture and cereal protein functionality, American Association of Cereal Chemists International annual meeting, Baltimore,

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

Project PRF 103

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Introduction and Justification

The major activity in 2009 was to expand the area and farmer participation in the technology-marketing strategy-institutional development of farmers' associations in the three Sahelian countries of Mali, Niger, and Senegal. In the summer of 2009 there were almost 1,000 ha and approximately that many farmers in Mali alone and over 1700 of both area and farmers when Niger and Senegal are also included. We are facilitating the development of new markets (Objective 1) of processed food for millet and chicken feed for Mali by increasing yields, making marketing contacts, and doing market studies.

Our project functions by creating broad networks (Objective 7)of agricultural researchers, extension /development organizations, processers of cereals for food and feed, and the new farmers' associations. First, we define with the agricultural research institutions of the three countries the technologies. We implement the on-farm work with monitoring from the national extension service or NGOs such as Sasakawa 2000 and AMEDD. We develop links to the millet food processors in the urban areas as buyers of the increased millet production of our farmers' associations. Similar links are forged with feed mixers and intensive chicken producers as a residual market for good and even normal rainfall years for sorghum. We engage training programs to develop the farmers' associations into more effectivel [1] marketing coops. Seventeen farmers' associations have been developed often beginning from another organizational base.

Our focus has been on developing a pilot project that others could scale up all or components of the whole project. So we try to resolve specific farm and region level problems and then present and publish the results. Over time we are developing new activities such as training our own seed producers in 2009. Now donors and collaborators (USAID in Mali and INRAN in Niger) are pushing us to scale up our own activities more rapidly. So in 2009 with IICEM help we made contact with two Malian savings and loan associations, Kafo Jiginew and Kondo Jigima. We explained our program to their Directors in Bamako and will be making more direct requests to their regional offices for input credits for new farmers' associations in the regions where we have had success with our new cultivars and associated technologies. Tthis scaling up could enable a substantial expansion in area coverage in 2010.

Objectives and Implementation Sites

We have very specific objectives that lead to the broader INTSORMIL objectives of farmer income increases and the development of new networks to move technologies out of the experiment stations onto farmers' fields. Our specific objectives are for mean yields in the farmers' associations to reach 2 t/ha for sorghum and 1.8 t/ha for millet. As of 2009 we have regularly 1.5 t/ha for sorghum in our farmers' asssociations with best farmers getting over 2 t/ha.

An objective for our marketing strategies is to raise prices by at least 50% for farmer participants. Sales of the farmers' association and some of the better farmers are already attaining average prices 30 to 50% higher than farmers not in the program.The big hurdles now are good storage facilities, good storage practices, and obtaining farmer confidence in the farmers' associations intent[2] to share profits with their members. If these factors are adequately handled, the farmers will be willing to let the association sell more of their output than the grain reimbursed to the farmers' association in payment for the input credits.

Farmers' incomes have already been substantially improved by attaining these intermediate goals of yield and price increases. Given the low soil fertility pressures there is no alternative to the increased inorganic fertilization. Our combined practices insure the profitability of the increased input use in most years. Once the

1. Effective is defined as able to buy inputs in quantity at a price discount, to store the cereal and to sell strategically. The latter would involve waiting for the price recovery, selling in quantity and identifying the buyers such as food processors willing to pay a quality price premium.

2. The farmers' associations especially those already in operation before our intervention often follow the French paternalistic tradition of believing that they know what is best for their membership so they make the allocation of profits decisions on items such as their office facilities or other investments that they choose. With training courses we attempt to inculcate the importance of incentives and farmer confidence for the successful expansion of these farmers' associations.

Table 1. Area in New Technology in the Production-Marketing Project of INTSORMIL for the 2007-2009 Crop Years

	2007	2008	2009	Village Site
Senegal				
Millet	200 ha	250[1]	250	Thiare
Sorghum	25	35	70	Nganda
Total	225	285	320	
Niger				
Sorghum	140	140	140	Gabi
Sorghum	90	114	100[2]	Maraka
Sorghum	30	28	30	Safo
Sorghum	20	54	70	Angolua Mata
Sorghum	20	20	20	Dan Arao
Millet	40	50	60	Dogondoutche
Total	340	406	420	
Mali				
Sorghum	78	100	100	Kafara
Sorghum	50	100	150	Diola
Sorghum	50	50	59	Kaniko
Sorghum	--	50	150	Garasso
Sorghum	--	--	50	Zanzino
Sorghum	--	50	110	Kolokani
Millet	150	150	150	Tingoni
Millet	--	--	60	Bankass/Pissa
Millet	--	--	60	Doutenza/Wakoro
Sorghum	--	--	75	Diankounte Camara
Total	328	500	964	
Overall Total	893	1191	1704	

Source: Unpublished data from the field trips visiting the farmers' associations in the various regions.

1 Increase of 25 ha paid by the Production-Marketing program and 25 ha financed by the farmers' association of Thiare.
2 The farmers' association reduced participation to 80 ha to get fertilizer levels back up. There was decapitalization of the rotating fund from the bad rainfall year of 2007. Then we agreed to finance another 20 ha in 2009.

above goals of 2 t/ha for sorghum and 1.8 t/ha for millet[3] are attained, we expect much more interest of the financial institutions. Moreover, when we get to 2 t/ha averages for sorghum in our farmers' associations, we will identify regionally adapted hybrids to be introduced.

Another objective is to create 20 to 30 mature farmers' associations in each country, ie Mali, Niger, and Burkina Faso. A mature farmers' associations has at least 150 ha and that many members, has a bank account, adequate storage facilities and serves as a marketing coop for its members. We presently have ten farmers' associations in Mali, five in Niger, and two in Senegal. Only about one third of these would presently pass this definition as mature. But we are learning how to accelerate this process and to develop the functions they need to do to be successful.

In 2009 the main emphasis of our fieldwork was to expand the Mali program in the cotton zone and in the Mopti region (Table 1). In the cotton zone the new cultivar, Grinkan, is especially appreciated by farmers. So we attempted to expand to 150 ha in the Koutiala region (Garasso, Kaniko and Zanzoni). Unfortunately, we had seed availability problems . The Kaniko farmers' association seed sold to Zanzoni was the local tall cultivar as farmers kept their Grinkan or sold it for a higher price. In contrast Garasso did extemely well with raising Grinkan and with seed production of the four farmers specializing in seed production (Picture 1).

The USAID-Mali project has been emphasizing expansion in the north of Mali. For the Production-Marketing project there was a 120 ha expansion in two villages in the greater Mopti region in 2009. Here the millet cultivar Toroniou was introduced with moderate fertilization, water harvesting, and improved agronomy. Farmers were very happy with the fertilization as there was substantial rain after a late, irregular start for the rains. Farmers were not happy with the seed quality.We need to find a better source for the Toroniou seed.

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. The project and then the farm-

3. Millet is grown on poorer soils often with lower rainfall. We now regularly get 1.3 t/ha of mean yields in the farmers' association in Tingoni and best farmers are above 1.8 t/ha. Millet has the advantage of being preferred by the food processors, who are expanding rapidly in the urban Sahel.

Picture 1. The Director of AMEDD, Bougouna Sogoba, gave an interview to the press during the field day, Oct 23, 2009 focusing on the collaboration between AMEDD, IER, and INTSORMIL to diffuse Grinkan rapidly in the Koutiala region. (Picture Courtesy of M. Diourte)

ers' association take away most of the risk by providing the input credit. If the farmer does not repay, he is out of the association but he does not lose his land or animals. There is no collateral requirement. As we move to bank financing these institutions will look for some guarantees. So we will only move to bank financing when we have shown high profits on the farm and have high quality seed.

There are two research components to this project. 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.

The second component is the field research done on research questions related to our extension program and to the development of new markets. For example, in 2009 Felix Baquedano analyzed income alternatives in the Malian cotton zone including our cereal technology as well as various technological and policy alternatives for cotton (see publications).

Research Results

Evaluating the impact of the Production-Marketing project in an adverse rainfall year:

2007 was a bad rainfall year in the Sahel. The rainfall was irregular and insufficient at the beginning and the end of the season. In the middle of the season there was excessive rainfall and flooding. The flooding was the most serious problem for sorghum as it is often planted in low lying, alluvial soils near the rivers. Millet soils tend to be more sandy and porous hence the flooding would have less effect. But the rainfall levels and variability at the beginning and end of the season also were expected to reduce millet yields

Table 2 shows the sorghum yield gains in the Dioila region with the Wakoro region being more subject to flooding. The harvest price was 85 CFA and the cooperative, ULPC, paid a price premium of 15 CFA. But in this adverse year the price advance seasonally was to over 150 CFA and the ULPC was the principal beneficiary and did not share these profits from the seasonal price increase with its members.[4] The price the ULCP received for the sorghum was 47% higher than the market price while the farm level price was only 17% higher than the harvest price. As a result of the lack of benefits to farmers from the seasonally higher price, the marketing strategy only covered half of the additional technology costs in the village of Wakoro. Nevertheless, there was 99% reimbursement of the input credits in the Dioila region. Farmers were firmly convinced of the benefits of inorganic fertilizer and committed to the program even when they lost money in this year.

Tingoni millet yields were also decreased in this deficit-excess rainfall year with only a 32% yield increase over farmers following traditional practices (Table 3a). The price at harvest was only 75 CFA/kg and the farmers' association paid a quality premium of 25 CFA/kg. The farmers' association only sold for 121 CFA/kg.[5] Moreover, the farmers did not receive any benefits from this seasonal price increase. The gains to farmers from the additional yields, from the quality premium of 25 CFA and from own storage only covered 72% of the additional input costs. However, if farmers had shared in the profits from selling at 121 CFA/kg a substantial profit would have been made. Ignoring the time factor a 225% of the cost of inputs implies a return of 2.25 for each one unit of investment, a very nice return (Table 3b).

4. With most farmers' associations they pay back for the input credit in kind at harvest and then the decision with regard to the rest of the harvest is theirs. The ULPC, like several other organizations puts pressure on its members

5. The association needs to sell before or during May to have time to purchase inputs but one big farmer reported to me that he sold ten tons in Bamako for 150 CFA. With rapidly rising fertilizer prices in the spring of 2007, the association was nervous about waiting to sell until May.

Table 2. Yield Effects of New Cultivars and Associated Technologies in Two Communities and Four Villages of Dioila, Mali 2007.

	Soumba and associated technologies	Traditional	Difference
	Kg/Ha		%
Community of Nangola	1,182	830	42
Village of Magnambougou	1,293	575	125
Village Kenie	1,096	1,029	7
	-		
Community of Wakoro	725	641	13
Village of Wakoro	761	738	3
Village of Tonga	689	545	26

Source: Baquedano, F., M. Diarra, and Aly Ahmoudou, 2009, p. 4.

Table 3a. Crop cuts and actual millet yields for farmers in the INTSORMIL program in Tingoli' 2007/08

Yields	Program Millet	Traditional Millet	Difference
	Kg/Ha		%
Actual	1,333	993	34
Crop Cuts	1075	660	63

Source: Baquedano, F. ,M. Diarra, and Aly Ahmoudou, 2009, p.14.
No of farms- Actual (n=32); Crop Cuts (n=68).

Table 3b. Monetary Gains from Increased Yields and Marketing (per ha)by Farmers and the Cooperative of Tingoni in 2007/08.

Yield Gain	Gain from Increased Yield	Gains from Sales at Harvest with a 25 FCFA/Kg Quality Premium	Gains from Own Storage	Cleaning Cost	Gains from Marketing by the Cooperative	Total Gains	(%) of Technology Cost Covered by Total Gains
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Kg/Ha			FCFA/Ha				
341	25,551	11,250	7,846	13,333	39,866	97,846	226

Source: Baquedano, F., M. Diarra, and A. Ahmoudou, 2009, p. 20. Column (1) Yield Gain is the difference between farmers' yields using their traditional variety and farmers' yields using Toroniou and 150 Kg/Ha of fertilizer; (2) The yield gains in (1) were multiplied by the harvest price of 75 FCFA/Kg.; (3) Gains from the quality premium is the product of the multiplication of the amount of grain given to the cooperative for reimbursement times the quality premium of 25 CFA ; (4) Gains from storage are the average amount stored and sold by farmers using their own storage times the reported price difference between harvest and period of grain sold; (5) Cleaning cost is the yield with Toroniou times the cleaning charge of 10 FCFA/Kg.

The problem of sharing profits is that farmers associations in the French tradition often have a paternalistic orientation towards their membership. Farmer association officials often feel that they know best what to do with profits and act like "commercants." They neglect incentives and are surprised when farmers are not interested in letting the association sell more of their millet besides the repayment of the input credits.

Sharing profits from the marketing strategies is critical to the long run success of these farmers associations. In poor rainfall

Table 3c. Utilization (per ha) of Millet by Farmers in Tingoni. 2007/08.

	Yield	Reimbursement	Individual Sales	Consumed
			Kg/Ha	
Average	1,333	450	238	646
(% of Yield)		34	18	48

Source: Source: Baquedano, F., M. Diarra, and A. Ahmoudou, 2009, p.16. Survey data (n=32).

years the production package yield increase often does not cover the increased input expenditures. Hence, the marketing strategies are especially important to offset or decrease potential losses during these years. In good and normal years substantial profits are made with the yield increases.[6]

Poor rainfall years occur approximately one-third of the time in Dioila. In these adverse rainfall years the seasonal price increase is the much larger than in good and normal rainfall years and is needed to offset the negative effects of climate on yield. The five part marketing strategy is designed mainly to benefit farmers and thereby increase the incentives to do the intensive agronomical practices and to take the risks associated with rainfall variability and fertilization. When the ULPC uses these profits for expanding their office sites, they risk the future program development. Farmer response can be non- participation or not undertaking the labor intensive operations needed for high yields (replanting, thinning, two to three weedings, constructing ridges for water harvesting), or not providing their surplus for sale by the ULPC.

The utilization (Table 3c) indicates that average farmers do not allow the association to sell any of their own production beyond the necessary reimbursement. Their individual sales are complicated by their poorer storage conditions and inability to get as high a price on smaller quantities than the association sells. They also would not be able to invest as much in price search. So the paternalistic orientation of the association has a high cost to individual farmers as well as to the evolution of the association to being able to sell larger quantities voluntarily offered by the farmers. The process of increasing the quantity that the association can sell of the farmers' surplus will be facilitated when the association can get inventory credit for the farmers as most farmers have large cash requirement for expenditures at harvest. Inventory credit responds to that need and also facilitates farmers selling later in the season and taking advantage of the price recovery.

In technology evaluation the bottom line is whether the technology is profitable enough and a good fit in the farmers' systems and whether it can compete with the other alternatives available to the farmer. With a farm model based on many other field studies of small farmer decision making Felix Baquedano evaluated the alternatives available to sorghum producers now and potentially available to cotton producers in the next five years. These alternatives include the U.S. reducing its subsidies on cotton exports and the development and introduction of Bt cotton varieties.

6. Conversely in these years harvest prices generally start lower and do not increase as much seasonally as in low rainfall years. There is a much lower return from waiting for the price recovery in low rainfall years.

An improved sorghum cultivar with fertilizer has only a small effect on increasing income (3.2 % increase) (Table 4). But it had a large effect in improving food consumption and reducing the requirements for purchasing cereal. Cereal grain consumption was increased 23% and the value of expected food purchases was reduced by 56%. Note also the very large consumption effect in bad rainfall years. Combining improved, fertilized sorghum with improved marketing strategies increased incomes by almost 11%, and decreased the value of cereal grain purchases by 60%. Fertilized Bt cotton raised income more (15%) but had much less effect on cereal consumption (+9%) and on reducing the cereal grain purchases (-19%).

The above technologies are not an either-or case. Combining the improved sorghum and cotton activities increases farm income by 24%. Also adding in the world price effect of removing US subsidies to cotton exports doubles the income effect when combining it with the two improved activities above. So the important effects of multiple technologies, marketing and policy strategies are apparent here.

Networking Activities

Program implementation through networking: We use technical help from INTSORMIL and national scientists as we proceed with program implementation. In 2009 Bonnie Pendleton and Niamoye Yaro Diarisso traveled to our sites and provided training on storage pests to the farmers' associations. They have recently finished a circular for the farmers' associations on storage pests and this will be translated into Bambara and made available to the farmers' associations.

Workshop for Intensive Chicken Producers: In September 2009 we held a workshop for approximately 65 intensive producers of chicken in Bamako. Joe Hancock presented a talk on nutritional issues of substituting sorghum for maize in chicken feed. He also covered technologies to respond to the heat problems, which are especially important from March until the first rains in the Sahelian countries. After the workshop Ouendeba, Sanders, Hancock, Saliou N'Diaye and Mme. Sanogo Diarrata, the head of the Malian association of chicken producers, spent four days visiting intensive chicken producers in the Bamako region. Saliou produced a detailed report on these field visits.

Farmer group training: As part of the Production-Marketing project Ouendeba, Sanders and the IER delegate scientist (formerly M. Diourte) Niaba Teme visited the farmers' associations in the

Table 4. The Effects of Improved Activities of Cotton and Sorghum and of the Elimination of US Cotton Subsidies on Farmers' Incomes, Cereal and Cereal Purchases in Mali.

Technology Package	Harvest Revenue State of Nature				Post Harvest Revenue State of Nature				Value of Cereal Grain Purchases State of Nature				Value of Cereal Grain Consumption State of Nature				Total Household Income State of Nature			
	Bad (1)	Normal (2)	Good (3)	Expected (4)	Bad (5)	Normal (6)	Good (7)	Expected (8)	Bad (9)	Normal (10)	Good (11)	Expected (12)	Bad (13)	Normal (14)	Good (15)	Expected (16)	Bad (17)	Normal (18)	Good (19)	Expected (20)
											US$									
Traditional Technology	1,204.8	1,455.8	2,257.2	1,643.5	-	-	-	-	2,736.5	805.7	-	969.5	522.8	1,718.0	2,154.3	1,597.9	2,696.9	3,055.9	2,743.7	2,886.8
15% World Cotton Price Increase																				
58% Price Transmission	1,204.8	1,850.1	2,848.6	2,014.1	-	-	-	-	2,139.7	836.0	-	859.0	964.4	1,706.8	2,183.7	1,693.9	2,321.0	3,248.4	3,143.8	3,022.3
(% Change from Tradional Technology)				22.5								-11.4				6.0				4.7
80% Price Transmission	1,204.8	1,986.8	2,980.2	2,120.6	-	-	-	-	1,977.2	910.7	-	861.5	1,077.0	1,651.0	2,222.8	1,702.0	2,271.0	3,404.1	3,314.4	3,139.3
(% Change from Tradional Technology)				29.0								-11.1				6.5				8.7
Bt Cotton with Increased Fertilization	1,265.7	2,169.8	3,328.3	2,327.5	-	-	-	-	1,835.0	823.8	-	789.0	1,187.1	1,711.3	2,171.8	1,739.4	2,299.9	3,560.5	3,611.5	3,311.1
(% Change from Tradional Technology)				41.6								-18.6				8.9				14.7
Improved Sorghum and Increased Fertilization	1,204.8	1,455.8	2,257.2	1,643.5	-	-	341.6	102.5	1,982.7	26.1	-	429.2	1041.628	2261.669	2116.466	1,961.9	2546.753	3053.897	3163.683	2,980.3
(% Change from Tradional Technology)				-								-55.7				22.8				3.2
Improved Sorghum, Increased Fertilization, and Better Marketing	1204.819	1455.823	2175.719	1,619.1	-	-	571.8	171.5	1,831.9	-	-	384.7	1,149.3	2,253.0	2,116.5	1,980.3	2650.629	3215.774	3542.353	3,195.1
(% Change from Tradional Technology)				(1.5)								-60.3				23.9				10.7
Improved Sorghum, Increased Fertilization, and Better Marketing and Bt Cotton with Increased Fertilization	1296.845	2223.163	3334.744	2,362.1	-	-	-	-	1032.289	0	0	216.8	1720.482	2253.012	2116.466	2,100.2	2205.057	3673.986	4392.25	3,581.0
(% Change from Tradional Technology)				43.7								-77.6				31.4				24.0
Improved Sorghum, Increased Fertilization, and Better Marketing and Bt Cotton with Increased Fertilization and a 15% World Cotton Price Increase																				
58% Price Transmission	1859.494	3187.704	4794.003	3,390.7	-	-	-	-	1,507.2	618.3	-	619.5	1383.2	1816.0	2116.5	1,815.3	2761.897	4676.408	5220.71	4,437.7
(% Change from Tradional Technology)				106.3								-36.1				13.6				53.7
80% Price Transmission	1949.288	3341.636	5012.454	3,550.5	-	-	-	-	1,519.2	633.6	-	629.5	1,374.8	1,805.6	2,125.1	1,811.0	2,855.4	4,835.3	5,447.8	4,603.2
(% Change from Tradional Technology)				116.0								-35.1				13.3				59.5

Source: Baquedano, F.G., J.H.Sanders, and J.Vitale, 2009.

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 once the crop season starts to review the performance over time. These repeated field visits are also useful to make sure that the inputs arrive on time and that the agronomy recommendations are followed.

Publications and Presentations

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Baquedano, F., J.H.Sanders, and J.Vitale, 2009. "Increasing Incomes of Malian Farmers: Is Elimination of U.S. Subsidies the Only Solution?" Mimeo, 40 pages.

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

Project TAM 103

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Introduction and Justification

This project's major activities relate to objectives 1 and 2 on supply chain management and development of super healthy foods from sorghum. It provides for education of students on new, more effective ways of processing sorghum / millet into profitable food products. Extensive breeding and analysis of sorghums for flavanoids is ongoing. Additional effort was made to measure in vitro and in vivo indices of health contributions by special sorghums.

Major activities include utilization of El Salvador 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.

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. Ms. C. Chiremba of the Agriculture Research Council (ARC) in South Africa is participating in this program.

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

Objectives and Implementation Sites

We have focused our efforts on improving the utilization of sorghum in Central America and Southern Africa. Key targets are El Salvador and South Africa. We are working with Ms. Calderon, Texas A&M graduate who leads efforts to utilize sorghum in food systems in El Salvador. We are using her expertise to assist Ms. Palacio in Nicaragua (INTA).

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

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

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

pearl millet to enhance their marketability and image as grains that promote healthy wholesome convenience foods.
- Contribute to host-country institutional human capital development by providing short-term and long-term educational opportunities. Non-degree (short-term) training will include research methodology and conferences or hands-on training workshops; degree (long-term) training includes M.S. and Ph.D. programs.
- Provide practical technical assistance and information on supply chain management, processing technologies and related matters.

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

Research Methodology 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 involved. For example, Dr. Kebakile completed his Ph.D. at University of Pretoria and conducts processing research on sorghum and millet in the Botswana Food Processing Center in Kanye. He organized an excellent workshop in Botswana in November 2009 for Southern Africa. He will provide excellent leadership in the Botswana Food Research Center.

Research Results

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

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

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

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

Our research on these special sorghums has stimulated 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 the image of sorghum 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 high levels of these phenolics.

Highly Digestible Sorghums: Progress was made in developing improved mold resistance in sorghums that have genes for improved protein digestibility. The original highly digestible types developed at Purdue University were quite susceptible to molds. The new lines developed at TAMU appear to have increased resistance to molding and were tested for use in malting and brewing and ethanol production. Dr. Hays has demonstrated that they produce significantly higher levels of alcohol (up to 15%) with improved nutritional value of their dry distiller solubles.

Increased levels of free amino nitrogen (FAN) would be highly useful for sorghums used in brewing. However, L Mugode (MS thesis, U. of Pretoria) found that they produced only slightly higher levels of free amino nitrogen during malting and mashing. However, these highly digestible types also have extra lysine. They may be adapted for production in areas where the grain matures during very hot, dry conditions. They might be used in the Sudan, Ethiopia and similar places. In more humid areas during grain maturation, there must be improvement in resistance to molds or they can not be grown.

Outreach Activities

Participated in workshops (seminars) in Southern Africa (Botswana, Zambia) and El Salvador. Conferred with University of Zambia food scientists.

Presented information at Institute of Food Technologists (IFT) and American Association of Cereal Chemistry International (AACCi) conferences. Several Students participated in Conferences to present 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 brans added to wheat flour produced excellent naturally dark colored flour tortillas with improved nutritional values. Sorghum tannin bran made excellent baked products with enhanced levels of antioxidants and dietary fiber.

Training (Degree and Non-Degree)

Two Ph.D. and two M.S. degrees were awarded to students working on sorghum. In addition, L. Rooney collaborated with Professor Taylor, University of Pretoria, South Africa, on an M.S. thesis which was completed. Two Ph.D.'s are in the pipeline at the University of Pretoria.

These "sandwich" degree programs reduce the costs to enable education of more students while providing them exposure to US universities and related technologies. Ms. Constance Chiremba, Ph.D. student, University of Pretoria, was selected for short-term training at Texas A&M University. She is a technician in charge of summer grain quality evaluations at Ag Research Corporation (ARC) in South Africa.

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

Mr. Luke Mugode, Zambian National Institute for Scientific and Industrial Research, completed his M.S. degree on protein hydrolysis during brewing of sorghum. He evaluated the FAN production of highly digestible sorghum cultivars developed and increased by Dr. Hays at Texas A&M University. Unfortunately the highly digestible types did not give a significant boost to Free Amino Nitrogen production during brewing.

Short Courses

L. Rooney assisted Ms. V. Calderon/ 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.

More than 25 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, Ms. Alicia Rodriguez, from El Salvador who was a senior at Escuela Agricola Panamericana (EAP), Zamorano, Honduras.

Central America/Mexico: After the successful use of the first Omega VI grinder, INTSORMIL purchased four additional Omega VI grinders from Compatible Technology International. They were distributed to small processors in El Salvador who use sorghums in food systems, but needed improved grinders. One grinder was presented to INTA in Nicaragua.

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

Sorghum in Central American Foods: 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 produced in Salvador. 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.

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

The intense interest of a large number of people/companies led to Ms. L. Taylor, from CTI, presenting blue prints and a seminar on how to build wooden grinders or assembling metal Omega VI grinders made locally. The workshop was well attended and subsequently local groups became interested in producing the grinder to reduce its cost and availability in Salvador and possibly other areas. The grinder has many applications and has proven effective in a wide array of applications. It is sturdy with few maintenance problems. A WINROCK farmer-to-farmer proposal to fund a volunteer for two months to promote the use and development of Omega VI grinders was approved.

A large commercial mill has been built to produce sorghum flour. It greatly increased the potential use of sorghum flour; but, will also challenge sorghum producers to meet the need for larger amounts of grain. A supply chain will be necessary.

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 is less expensive.

Interaction with Escuela Agricola Panamericana (EAP) in Honduras continues with short- training programs conducted each spring for EAP students. 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.

Supply chain management allows farmers to invest in new varieties, fertilizer and other inputs because of higher earnings and more reliable markets. Thus, there are increasing opportunities for small farmers to participate in new markets and generate income.

Other examples exist across Southern and East Africa where South African Breweries (SAB) is using supply chain management to secure sorghum for brewing.

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

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 that use 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. Many special sorghums are high in anti-inflammatory and bioactive components that are of increasing importance as we document their health benefits.

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 interests in these materials with some new sources of supply under development.

Dr. Awika, a food chemist/ technologist, joined the Cereal Lab in 2008 and has developed a research program on in vitro evaluation of sorghums' anti-cancer activities using cell cultures. One of his students found that the black and tannin types of sorghum clearly had anti-cancer activities against esophageal cancer cells. Dr. Turner's nutrition research has demonstrated that black and tannin sorghum brans significantly reduce the development of cancer in rats that were treated to induce colon cancer. These studies have been conducted for several years and agree with other findings that special sorghum brans protect against colon cancer.

The sorghum brans are high in insoluble dietary fiber and antioxidant levels. Those with condensed tannins are more slowly digested because they 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.

Efforts continue to breed sorghums with high levels of these components including condensed tannins, high 3-deoxanthocyanins, flavanones and flavones. We believe sorghum is a treasure trove of healthy components with significant variation among varieties.

Publications

Journal Articles

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

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

During the past year we have made progress in all three areas: a) maintenance of a business development and technical support network, b) sharing the business development educational materials and program success with others in East Africa and, and finally c) Continuing the academic and research training of 1 M.S. student (from Tanzania) and 1 Ph.D. student (from Zambia) that emphasizes Sorghum/Millet grain quality, food product development, and entrepreneurship, for East African University faculty members. Specifically, we have:

- Continued operation of the entrepreneurial assistance program in Tanzania with existing clients.
- Identified new potential clients in Dar es Salaam and Dodoma and conducted initial training workshops.
- Worked with new clients to develop their initial business plans.
- Strengthened workshop offerings for food processing entrepreneurs and educational programs for farmers.
- Conducted a new farmer training workshop for producers in Mazae, Mpwapwa
- Identified approach for a regional sorghum workshop in collaboration with the Southern Region.
- Continued a Ph.D. academic program for a faculty member from the University of Zambia at the University of Nebraska's Department of Food Science & Technology.
- Continued a M.S. program a non-research MS degree holder from Tanzania.

Objectives and Implementation Sites

Our specific objectives during year 3 of this project were to:

- Continue operation of entrepreneurial assistance program in Tanzania with existing clients, identify new potential entrepreneurs in current and new regions within Tanzania, conduct introductory workshop for potential new clients.
- Strengthen workshop offerings and/or educational programs to farmers.
- Begin planning of regional entrepreneurial assistance education workshop that would demonstrate program and distribute educational materials.
- Continue educational and research programs of study for two advanced degree students in Food Science & Technology and the University of Nebraska-Lincoln related to sorghum.

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

These objectives were to be implemented at the following sites:

As we have a strong partnership with Sokoine University of Agriculture, our regional efforts are coordinated from Tanzania. As funding is limited, the Food entrepreneur workshops and farmer education activities will continued to be offered in Tanzania. Minimal technical support related to sorghum has been provided both by UNL and SUA to the University of Zambia in Lusaka.

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

Research Methodology and Strategy

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

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

Research Results

Ongoing activities are characterized in the following table.
(Planned Target/Activities)

Networking Activities

Various governmental agencies and university departments as noted in this report.

Publications and Presentations

Students have presented informal poster presentations at a sorghum meeting in Texas. It is anticipated that students will present formal posters at the annual meeting of AACC International during the Fall of 2010.

Objective (Planned Target/Activities)	Status of implementation	Problems encountered	Corrective measures
Continue operation of entrepreneurial assistance program in Tanzania with existing clients, identify new potential entrepreneurs in current and new regions within Tanzania, conduct introductory workshop for potential new clients.	**Site Visits to Current and New Clients:** Sorghum processors in Dar es Salaam were visited one-on-one to assess their progress and hence advise them accordingly. A total of 10 groups (6 ongoing groups and 4 new groups) were visited. This activity was conducted in April 2009 and involved a team of 5 SUA researchers and 2 Principal Agricultural Field Officers (PAFO) from Ilala Municipal Council. New and prospective sorghum processors were identified following the suggestion/recommendation of the Municipal Councils in Ilala and Temeke districts of Dar es Salaam region. A total of 4 processors (groups) were identified and visited at their premises. Relevant information on each group was gathered that will enable the research team to make a rational decision on whether to work with that group or not. **Processor Workshops:** ***May 20-21, 2009*** A two day workshop (20 – 21 May 2009) involving 24 stakeholders (sorghum processors, farmers, non-SUA researchers and extension officers). The participants were drawn from Ilala, Temeke and Kinondoni Municipalities. The training Workshop covered such aspects as; an overview of Sokoine University of Agriculture (SUA) and in particular the Department of Food Science and Technology where this Project is hosted, Marketing research, new product development, business development and improvement, legal and regulatory requirements for food processing, food safety and quality assurance, product brand names, sales and distribution of food products, and the way forward following the Workshop. In addition to theoretical training, participants had hands on experience in preparation of different sorghum based products with the assistance and guidance of technicians from SUA. Also, existing groups which are already involved in sorghum processing shared experience with the new clients on the challenges and opportunities. ***September 29-30, 2009*** This workshop followed the same format as outlined above, but the participants were drawn from Dodoma and Singida Municipalities except for the 5 SUA researchers and one researcher from Ilonga Agricultural Research Institute (ARI Ilonga). This workshop involved 30 stakeholders.	None	None
Educational activities for processors (continued).	**Business Plan Development:** This activity was done one-on-one by visiting the newly identified sorghum processors at their places of work. This activity was accomplished by a team of 2 SUA researchers after the identified processors had attended a two day training Workshop in Dar es Salaam. Each group was accorded enough time to allow the research team to get a clear understanding of the business the group envisioned. A total of 5 prospective groups have been assisted by this focused activity this year. **Nane Nane Zonal Farmers Show** This is an annual event that takes place every year. The shows avail an opportunity for farmers and other stakeholders (like food processors) to display their products		

Objective (Planned Target/Activities)	Status of implementation	Problems encountered	Corrective measures
	and hence expose their products and produce to a wider audience. The shows also are an ideal forum for linkages of different stakeholders in the agricultural sector. Two groups (Ongoma Foods and Miracle Foods) were facilitated by the Project to attend the 8 days shows (1 – 8 August 2009). The two groups established important links with new clients and hence opened up new markets.		
Conduct and Strengthen workshop offerings and/or educational programs to farmers.	This training Workshop (Sept. 2009) involved 30 stakeholders, the majority of who were farmers from Mazae village in Mpwapwa district. The Workshop was conducted at Mazae Primary School. Five SUA researchers and 1 non-SUA researcher facilitated the Workshop. The goal of the Workshop was to train farmers on the best post harvest practices suitable for handling and processing sorghum. The aspects addressed included; an overview of Sokoine University of Agriculture (SUA) and in particular the Department of Food Science and Technology where this Project is hosted, sorghum agronomy and its nutritional quality, sorghum harvesting, post harvest handling and value addition, sorghum products and brands, entrepreneurship record keeping and sorghum marketing, farmers, researchers and other stakeholders linkages, and practical preparation of sorghum based food products.	None	None
Begin planning of regional entrepreneurial assistance educational workshop that would demonstrate program and distribute educational materials.	Workshop is scheduled to run in conjunction with Southern Region workshop in early November 2010.	During the planning process we quickly realized that the economics for running the workshop *and* making certain African participants could attend was not favorable.	Workshop is now planned in conjunction with a malting workshop; there is now potential for corporate co-sponsorship.
Continue educational and research programs of study for two advanced degree students in Food Science & Technology and the University of Nebraska-Lincoln related to sorghum	M.S. and Ph.D. students are making adequate progress towards degrees.		

Figure 1. Nzasa Women Group (Mbagala)
This group was visited on Wednesday, April 29, 2009.
The group reported a slight increase in their activities since our last visit. They also reported that their first priority at the moment was to get registered by the Tanzania Food and Drug Authority (TFDA) and later with the Tanzania Bureau of Standards (TBS). They were thus currently working very hard to achieve that goal.

Members of Nzasa Women Group who attended the meeting.

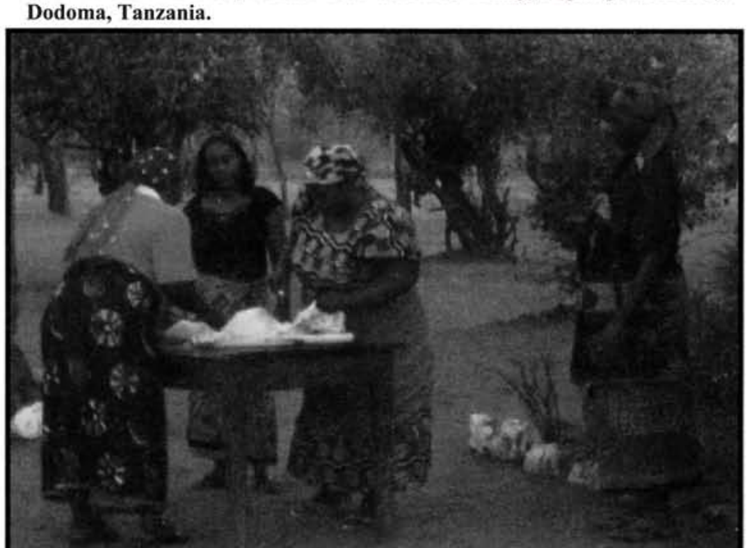
Figure 2. Participants to the Entrepreneurship Seminar Held From 20 – 21 May, 2009 in Dar Es Salaam.

Figure 3. Participants to the entrepreneurship seminar held at Mikocheni Agricultural Research Institute in Dar es Salaam, 20 – 21 May, 2009.

Figure 4. Some of the products that were displayed by the participants.

Figure 5. Food Processing and Entrepreneurship Workshop Conducted by INTSORMIL from on 29th to 30th September, 2009 at VETA Conference Hall– Dodoma.

Figure 6. Sorghum Post Harvest Processes, Handling and Entrepreneurship Conducted by INTSORMIL in September 2009 at Mazae Village, Mpwapwa District, Dodoma, Tanzania.



Host Country Program Enhancement

INTSORMIL

Central America (El Salvador, Nicaragua)

William Rooney
Texas A&M University

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Collaborative Program (Regional Program Description)

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

Institutions

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

Organization and Management

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

Financial Inputs

Primary financial support for the program is from the INTSORMIL Central America Regional Program budget, which totaled $40,000 in 2008-2009 which is a significant reduction in budget compared earlier years (which averaged ~$120,000). This drop has obviously had an effect on the scope and depth of the Central American program. These funds were allocated to individual projects within both the Nicaraguan and El Salvadoran research programs. In addition, these funds are used for short-term training, equipment purchases and administrative travel.

Sorghum/Millet Constraints Researched

Collaboration

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

Sorghum Production/Utilization Constraints

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

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

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

Research Projects and Results

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 2008 (May – December 2008).

Plant Breeding

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

Figure 1.

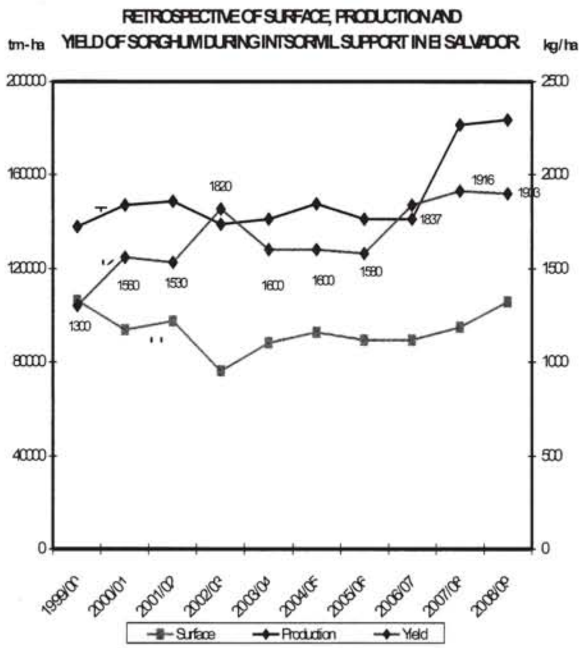

Table 1. Results of the PCCMCA sorghum trial, combined across seven locations in Central America.

HIBRIDO	Rendimiento grano. (tn ha^{-1})	Días floración	Altura planta (cm)	Largo Panoja (cm)	Exer-sión (cm)	Enferm. Foliares (1-5)	Color grano
MSG 540	6.08a	68	161	28.1	17.0	2.60	Rojo
MSG 541	5.76ab	67	152	28.6	14.8	2.40	Rojo
SR-340	5.46 bc	66	153	29.1	18.9	2.43	Rojo
AMBAR (TC)	5.38 bcd	66	147	27.4	14.7	2.67	Rojo
SR-360	5.34 bcd	66	151	29.3	18.6	2.58	Rojo
ESHG-3	5.19 bcde	68	137	30.7	19.9	1.85	Blanco
CBH-8078	4.97 cdef	65	145	28.5	17.9	2.60	Rojo
CBH-8076	4.95 cdef	68	150	26.8	18.4	2.55	Rojo
BORA	4.83 defg	65	122	27.5	18.4	2.72	Rojo
CBH-8075	4.73 efg	63	147	31.0	17.6	3.10	Rojo
CBH-8077	4.43 fg	64	118	32.7	14.6	3.67	Rojo
81T91	4.27 g	65	149	25.3	18.3	3.08	Rojo
X	5.12	66	145	28.6	17.2	2.66	
Significancia	**						
DMS	0.61						
CV(%)	16.95						

and selections were made at this site. Of special emphasis is the development of dual purpose sorghums with high forage yield and grain yield. In these populations, both the bmr and tannin trait are segregating; while all combinations are being selected, the types that are both brown midrib (bmr) and possess tannins are or primary interest. The target market for this material is the forage industry and they desired brown midrib for increased forage quality; the presence of tannins in the grain minimized the loss of grain to birds. All of these selections will be advanced for further evaluation next year. The most advanced selections are now at the F5 and are ready for replicated testing.

In hybrid testing, the PCCMCA was coordinated by Rene Clara. A total of 8 locations were planted and grown throughout Central America. In El Salvador and Nicaragua, INTSORMIL collaborators conducted these PCCMCA trials. In 2008, the trial had 13 entries with 10 of these entries coming from private industry and the remainder from INTSORMIL supported breeding activities (Table 1). In these trials, the hybrid ESHG3 (CENTA hybrid with INTSORMIL developed parentage) produced the highest yields in both 2005 and 2006.

Seed Production optimization for ESHG3 was evaluated in both El Salvador and Nicaragua. To determine optimum seed production the trial were designed as randomized blocks in a 3x2 factorial; the female:male ratios evaluated were: 3:1 and 4:1 (ICSA613 female: male 86EO361), and three planting dates 0x0 (simultaneous planting), 5x0 (female planted 5 days after the male), and 0x5 (male planted 5 days after the female). In both Nicaragua and El Salvador, differences in planting date did not affect seed yield,

Table 2. Data obtained from seed production trials of the grain sorghum hybrid, ESHG-3 in Santa Cruz Porrillo, El Salvador 2007.

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

Table 3. The effect of nitrogen rate on biomass yield and plant height in multiple cuts of the INTA forage hybrid in Managua, Nicaragua.

Nitrogen Rate	Biomass Yield (Kg/ha) Primary Cut	Height (cm.) Primary Cut	Biomass Yield (Kg/ha) Second Cut	Height (cm.) Second Cut
65 Kg/ha	8405	184.88	3531	128.25
130 Kg/ha	9118	194.25	4727	134.69
195 Kg/ha	12571	196.81	5612	143.94
0 Kg/ha	5269	125.25	1979	108.69

indicating that these parents have a good nick. Significant differences were detected for the ratio of female to male row numbers. Higher seed yields were produced in the R = 3:1 ratio (Table 2). This trial was repeated in 2008; while not shown the trends were exactly the same and the recommendations are that the male and female lines be planted simultaneously with a 3:1 ratio for maximum productivity.

Agronomy

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

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

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

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

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

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

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

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

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

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

The effect of planting density and fertilization on forage yield sorghum forage variety INTA: In 2007, four populations of the Forage Variety INTA were evaluated (266,000, 332,500, 399,000 and 465,500 plants per hectare). Each population was tested at four nitrogen levels (0, 65, 130 and 195 kg/ha).

No interactions were detected between population density and N level and there was no statistical difference in biomass yield based on population density. Nitrogen was a significant effect and with the best yields produced both the 130 and 195 kg/ha N rates. Because there was no statistical difference between these rates, use of the lower N rate was more cost effective, producing 55.6 and 21.8 Mg/ha fresh and dry weight, respectively. The N rate study was repeated in 2008 with an essentially linear response to N being observed (Table 3).

Grain Utilization – Food Use

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

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

As a result of trainings, big bakeries like Santa Eduviges, Pan Rey, and Monico located in San Salvador and surrounding areas, and many small and medium bakeries and productive groups from rural areas begin conducting trials with sorghum flour and actually they are using it to produce many of their products. "Pan Rey" a medium bakery located in Apopa, San Salvador, is producing its own flour, but is limited in their production by the limited supply of high quality sorghum grain. CENTA, through the INTSORMIL program is assisting them by identifying which hybrids they should buy. This has helped, but consistent supplies of good quality grain are difficult to find. They are using sorghum flour in a diversity of their products they are currently conducting trials right now with French bread formulation using 20% and 25% of sorghum flour. Consumer acceptance of their baked products with sorghum is good.

Sorghum milling capacity is slowly but consistently increasing. In 2007 two Omega VI mills were purchased by INTSORMIL and our currently being used in El Salvador to produce sorghum flour. A small producer (Kris Duville) and CENTA's food lab are now providing this flour in a small scale. The Omega VI mill has a capacity of 2 pounds per minute. To get good particle size (flour pass through a mesh of 80) the flour must pass through the Omega VI at least four times but this is less than seven (what was required in a nixtamal mill). These mills, located in strategic points, will likely be more effective to supply sorghum flour than a large milling company in a single location, primarily because of transportation costs and logistics. 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.

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

Table 4. 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

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 4). 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.

Technology Transfer

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

This project is conducted to increase seed of improved varieties of sorghum INTA RCV and INTA SR-16, INTA-Forrajero and release the seed to market as commercial varieties.

On April 29 two varieties (INTA RCV and INTA SR-16) were released by INTA. For each variety, phenotypic descriptors and seed (40 qq INTA RCV and 30 qq of INTA SR-16) were produced. This seed will be distributed to the Pacific zone of Nicaragua where the use of the grain is primarily for animal feeding. Each producer will be provided with approximately 20 lb of seed. The distribution should provide seed to approximately 3500 farmers to plant about 65,000 manzanas. This distribution should allow producers across the región to learn the new varieties. In addition, in 2008, seed of the variety 'Soberano" was increased by four farmer groups for sale/distribution to local farmers in El Salvador. From these growouts, overseen by INTSORMIL funded scientists, almost 100 hectares of seed were grown, producing approximately 475 metric tons of seed (Table 5).

Production and Transfer of Improved Sorghums to Small Producers in El Salvador

The objective of the Project is to improve the productivity and profitability of small producers in NE El Salvador. During the first year seed was produced for eight varieties (85SCP805, 790, 226, Soberano, RCV, CENTA S-2, CENTA S-3 and Jocoro). Extension training to use these varieties was in the New Conception area. Seed of these varieties was provided to establish 321 plots and 227 varieties insensitive sorghums, making a total 548 plots, using 10 pounds per plot. Yield and productivity was measured and summarize for 211 plots. Seed was also provided to small producers specifically to produce additional seed for sale. A total of 260.50 quintals of sorghum seeds were produced for use in extension agencies that have areas of influence in the northeastern part of the departments of Chalatenango, Cabanas, Cuscatlan, Morazán, San Miguel and Union.

Table 5. Seed production of the sorghum variety 'Soberano' in El Salvador in 2008.

Farmer Group	Hectares	Production (tons)
ADISA	56	280
ACOPAI	12	55
FECASAL	14	70
FORO AGRO	14	70
Total	96	475

Sorghum Utilization

Since March 2008, sorghum utilization experts at CENTA have conducted 26 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.

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 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.

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. The original Sorghum/Millet CRSP Grant program was closed after 27 years and the new Sorghum and Millet and Other Grains CRSP was initiated on September 29, 2006. As the Horn of Africa Regional Program goes forward, the planning workshop participants determined that we need take what has been 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 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 3 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.

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

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Regional Program Description

The Southern Africa regional program is composed of 12 research projects directed by 14 scientists representing 8 agencies in 4 countries. Eight U.S. based principal investigators collaborate with the regional scientists. Countries and agencies represented are the Botswana College of Agriculture; the Mozambique National Agrarian Research Institute; in South Africa the University of the Free State, the ARC-GCI (pending acceptance of MOU), the University of Pretoria, and the Medical Research Council, and in Zambia the Zambia Agricultural Research Institute and the University of Zambia. The scientists represent the disciplines of agronomy (1), breeding (3), socio-economics (2), entomology (3), food science (1), and pathology (1). 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 were selected for the 2006-2011 program with the expectation each has expertise to contribute to achieving the goal of improving sorghum and millet for the regions farmers and end-users. Individual work plans are developed using a format similar to that for U.S. investigators. Each scientist is expected to specify where activities fall within the regional plan and to provide performance indicators and outputs. Progress listed in the individual annual reports should be used to evaluate progress and performance. Each collaborating scientist brings to INTSORMIL individual collaborators including Future Harvest Centers, NGOs, and other governmental or private organizations. Each also has other grant funds - other donors, grants and commodity organizations - that provide reciprocal leveraging of resources. 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 food crops in the Southern Africa region. Sorghum is also used to make opaque beer and as a livestock feed. Sorghum is the major cereal in Botswana and parts of Zambia and Mozambique while pearl millet is the major cereal in Namibia and parts of Mozambique, Zambia, and Zimbabwe. In many areas the stalks are used as forage for animal feed, 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, and poor distribution and market structures. Policy constraints can place sorghum and pearl millet at a disadvantage relative to other commodities. 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. Improved crop genetics combined with better disease or insect management can economically address some constraints by increasing grain yield potential and stress resistance and by improving grain quality to meet end-use requirements. To increase end-use beyond the farm gate market channels should be improved as sorghum grain with the required quality to meet commercial requirements frequently has inconsistent production and supply. The inconsistent supply of quality grain is frequently cited as a major factor in deciding to use maize as opposed to sorghum. A major constraint to increased farmer production and productivity is the lack of adequate seed systems to distribute improved varieties. The adoption rate of improved varieties is largely unknown due to inadequacies of the seed system. Consequently farmers continue to use their local varieties which have low productivity potentials. Availability of a consistent supply of improved quality sorghum and pearl millet for processing into value added urban products is a major constraint limiting utilization. Food companies will use but cannot consistently acquire sufficient quantities of high quality sorghums for processing. A system of identity preservation for production, marketing, and processing is urgently needed.

New varieties and hybrids with increased grain yield potential, improved environmental adaptation, increased resistance to abiotic (drought tolerance) or biotic (disease and insect) stress, improved end-use traits (for food, feed and forage), and other desirable traits are in development by national programs. Reduced stored grain loss, with some estimates of a 30 - 50% loss annually, will increase the availability of high quality grain. Exotic sorghums and pearl millets are continually introduced into the region as sources of needed traits. Identification of regionally adapted sorghum or pearl millet cultivars or hybrids with stable grain yield and multiple stress resistance will assist the NARS teams in developing lines, varieties, and hybrids for the diverse environments and production systems in each country and in similar environments. Research is on-going to improve disease and insect pest management and to improve sorghum and pearl millet processing techniques to improve use in value added foods.

Institution Building and Networking

Networking

Workshops and Meetings

A database of sorghum and millet food scientists and technologists in sub-Saharan Africa with their specific areas of expertise was developed and posted on the INTSORMIL website.

A three-day workshop entitled "Alternative Cereal Processing Technologies" for existing and potential sorghum food processors was held in Lobatse, Botswana in November 2008. The workshop was jointly organized by the Botswana National Food Technology Research Centre, INTSORMIL and Cereal Science and Technology-SA. There were some 60 participants representing all players in sorghum value-chain in Botswana. In addition to lectures there was hands-on training in sorghum end-use quality evaluation, demonstration of sorghum processing technologies and product making, and technical visits.

Joaquim Mutaliano (IIAM) participated in a workshop sponsored by AGRA on the Program for Africa's Seed Systems held in Bamako, Mali.

Research Investigator Exchanges

John Leslie visited Mozambique and South Africa October 27-November8, 2008. The objectives in Mozambique were to help establish better Kansas State linkages in the country and to explore a larger education program for Mozambiquan agricultural scientists. At Cape Town, was an invited speaker at the PAEMS meeting organized by PROMEC, presented at one-day scientific writing seminar, discussed collaborative research projects, and recruited a new (non-INTSORMIL supported) student. Visited the Univ. of the Free State and Univ. of Pretoria to discuss collaborative projects and present a scientific writing workshop.

David Jackson (Nebraska), Don Larson (Ohio State), Lloyd Rooney and Gary Peterson (Texas A&M) participated in the Alternative Cereal Processing Technologies workshop at Lobatse, Botswana, November 2008.

Don Larson, Lloyd Rooney and Gary Peterson reviewed the status of current activity in Zambia and the potential for expanded collaboration. Evaluated on-going research at Golden Valley and the University of Zambia, and the potential for collaboration with representatives of the National Institute for Scientific and Industrial Research, and SABMiller, November, 2008.

Gary Peterson traveled to Mozambique, South Africa and Zambia, February 24 to March 13, 2009. In Mozambique met with entomology and breeding collaborators to evaluate development of their respective research programs 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 evaluation of sugarcane aphid resistant germplasm. Met with ARC collaborator to discuss re-starting the germplasm evaluation program for resistance to sugarcane aphid. In Zambia met with collaborators from the Zambia Agricultural Research Institute and reviewed status of the regional program.

Bonnie Pendleton (West Texas A&M Univ) visited with collaborators in Botswana and Mozambique April 16-28, 2009. The status of on-going activity in entomology, breeding and on-farm seed multiplication was reviewed.

Don Larson and Mark Erbaugh visited Zambia April 27 - May 2, 2009 to meet with UNZA collaborators and discuss progress in the research activities. Discussions were held to discuss progress in studies on improved seed value chain, price data collection, and clear-beer chain; interview students for additional training opportunities, and plan future training activities.

Lloyd Rooney discussed research activity with Prof J. Taylor at the AACC meeting, Baltimore, MD, September, 2009.

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.

Germplasm Conservation and Distribution

The Zambia national program continued to produce seed with the revolving fund at Nanga in collaboration with the Food Crop Diversification (FODIS) project supported by JICA. Seed of Kuyuma (1.0 ton), Sima (1.0 ton), ZSV-15 (0.8 ton) and [Fram x SDS 3845]16 – 2 – 2 (1.5 tons) were produced. This seed will be distributed in Shangombo, Sinazongwe, Siavonga, Rufunsa and Luangwa districts. It is expected that about 1,300 smallholder farmers will benefit from the seed distribution program this coming season. It is also projected that 700 hectares will be planted to improved seed from this effort. Not enough seed of WP-13 was increased and the demand remains high among smallholder farmers in region III.

The Zambia national program assists with seed production at the Foundation or Basic seed level collaboration with NGOs such as CARE International, Harvest Help and FODIS. The program offers technical expertise and the NGOs the financial resources to produce the seed.

In Mozambique seed of Macia and Sima was planted for increase at 7 research stations and 5 on-farm sites. The on-station increases produced a total of 35.5 tons (combined) and the on-farm sites produced 11.35 tons. Seed from the on-station production was sold and will represent a planted area of 3,550 hectares of certified seed in the 2009-10 growing season. Seed from the on-farm increases will be planted in the districts where it was produced. It is anticipated that the seed will plant 1,100 ha with an expected production of 3,300 tons.

The Mozambique national program is collaborating with several partners including ICRISAT-Mali, the Zambia Agricultural Research Institue, IER-Mali and Texas A&M University on genetic resources exchange.

The Mozambique national program carried out local landrace collection and mass selection for varietal improvement in the provinces of Nampula and Cabo Delgado which covered seven districts (Montepuez, Namuno, Ancuabe, Balama, Chiure, Ribaue and Malema). A total of 12 local landraces were collected. The landraces were found to be similar to those of West Africa guinea type sorghums.

Spreading Research Results

Prof John Taylor participates in the South African Sorghum Forum (sorghum stakeholders group) and in August 2009 gave a talk to their sorghum producers group on "Food, feed and industrial opportunities for sorghum".

Prof John Taylor and Dr Janet Taylor delivered papers on sorghum brewing related research and development work at the Institute of Brewing and Distilling convention in South Africa in March 2009.

The Zambia national program participated in on-station field days at GART, Manza, Lusitu, Mt. Makulu and Mponge, and on-farm field days in Rufunsa and Shikabeta. All the field days were well attended and the interest from farmers on seed availability and markets was high.

The Zambia national program distributed 1,200 booklets on sorghum and pearl millet production.

The Zambia national program collaborated with World Vision, CARE International, PAM and Oxfam on seed distribution and sorghum/millet production.

The Mozambique national program collaborates with Helvetas, Aghakan, FHI-USAID Mozambique and Oxfam-Belgica on farmer seed production promotion training and capacity building at the village level.

The Mozambique national program collaborates each growing season with NGO's IKURU and CLUSA on seed production with IIAM being responsible to produce and supply seed with good quality and improved yield performance for each agro-ecological zone.

F.P. Muuka trained nearly 40 agricultural extension staff and lead farmers based in southwestern Zambia on how to improve the productivity and production of both pearl millet and sorghum grain as well as potential ways to add value to the grain and generate income.

The Zambia national program distributed to nearly 2,000 farmers 1 kg seed packets of improved varieties. Distribution was in the least developed and difficult part of Zambia to access due to sandy terrain, rivers, and no road infrastructure.

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 2009, more than 30 persons from the industry in southern Africa are taking the course.

Rebecca Lubinda, a faculty member in the Department of Agricultural Economics and Extension Education at UNZA, was not able to begin PhD studies in agricultural economics this fall through the RUFORUM program located at Bunda College in Malawi. The Bunda College program has been delayed. She will most likely begin studies at the University of Pretoria in early 2010. Her studies will be partially supported by the INTSORMIL/Zambia project.

Gloria Musaba, a final-year student in the Department of Agricultural Economics and Extension Education, University of Zambia, is using the price study from the University of Zambia/INTSORMIL (Ohio State) project as her senior thesis project. INTSORMIL supported her senior thesis research work.

Lloyd Mbulwe has returned to the Zambian breeding program after completing an M.Sc. program at Nottingham University in the UK.

INTSORMIL supported students, and students affiliated with INTSORMIL collaborators, at the University of the Free State receive training in interdisciplinary research including plant pathology and breeding.

Research Accomplishments

Entomology

Mozambique

Three primary studies were initiated or conducted. An on-station push-pull study in grain sorghum was initiated. Napier grass (variety 'Banna') was planted around an experimental site. Desmodium will be planted in the experimental site. Sorghum will be sown between the desmodium rows. The objective of the experiment is to study whether stem borer moth will prefer Napier grass over sorghum.

The response of entries in two trials (25 and 17 varieties, respectively). for stem borer damage was evaluated. Significant differences among varieties for resistance were identified in both trials. In the 25 entry trial the varieties 104GRD, ICSB654, ENT#64DTN and SPV111 sustained less damage than other varieties while ICSR 93034, ICSV 700, E36-1 and ICSB 324 sustained high damage. In the 17 variety trial 04CS-452-4-1, 04CS-573-3-1, 02CS-30932, and 02CS-30445 exhibited less damage while 03CM-1104-BK, 04CS-798-7-1, and 03CM-15012-BK exhibited higher damage.

Twelve varieties were evaluated for response yellow sugarcane aphid. Generally aphid population density was low due to moist conditions during the growing season. The varieties SDS-3047/722E-8, Sima, GVSIMS710E-2 and SDSs-1958-1-3-2/724E-5 exhibited less damage with the varieties ICSV-93010-1/708E-9, Macia, ZSV15-4/723E-3 and (SDS-5006*USV-187) sustained high damage.

Botswana and South Africa

Primary research activity is directed to developing 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 in South Africa 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 of 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 over the years and could now be included in on-farm trials with the aim of release for use by the small-scale farmer market.

Sugarcane aphid screening/yield trials with 24 entries each were planted at Cedara Research Station (Table 1). The trial consisted of 16 entries from the 2008/09 sugarcane aphid trial, six entries from the 2008/09 sugarcane aphid yield trial and two local hybrid checks. The entries were selected to be evaluated for sugarcane aphid resistance and along with additional entries for resistance to grain mold. Severity of infestation was evaluated when the majority of entries grain was in the milk stage. Severity of infestation was evaluated on a 1 to 5 scale, where 1 = no aphids present on plants, 2 = light infestation with aphids present on a few leaves (no dead leaves), 3 = moderate infestation with aphids present on two to three leaves (one or two dead leaves may be present), 4 = high infestation with aphids on nearly all leaves (many dead leaves) and 5 = majority of plants in plot dying. Plants with a rating of 1 or 2 were considered resistant, while a rating of 3 indicated an intermediate level of resistance. Plants with a rating of 4 and 5 were considered susceptible.

Results indicated that 42 % of the entries rated 1 on a scale of 1 to 5, indicating none to very little damage. Ratings of 2 were scored for 33 % and ratings of 3 were scored for 17 % of the entries. Eight percent of the entries were highly susceptible to aphids with a rating of 4. Aphid damage ratings therefore ranged between

Table 1. Evaluation of sorghum lines for disease resistance, sugarcane aphid resistance and grain yield.

Pedigree/Designation	Sooty stripe†	Leaf blight†	Anthracnose†	Grain molds‡	Sugarcane aphid damage§	Grain Yield t/ha
(Segaolane*WM#322)-LG2-LG2-(03)BG1-LG1-LBK	1.25	0.75	0.25	2.25	1	4.46
(Macia*TAM428)-LL2	1.00	1.25	2.75	3.75	1	3.59
CE151	0.00	2.00	2.00	2.00	4	3.52
(6BRON161/(7EO366*Tx2783)*CE151)-LG5-CG2-(03)BG1-BG2-LBK	2.25	0.00	1.00	3.50	1	3.17
(Macia*TAM428)-LL9	1.25	1.50	0.00	2.25	1	3.15
Tegemeo	1.00	1.50	0.00	3.25	2	2.73
(9MLT176/(MR112B-92M2*Tx2880)*A964)-CA3-CABK-CCBK-CABK	1.25	1.25	0.00	3.00	3	2.36
(LG35*WM#322)-BE40-LG1-CA1-LGBK-CABK	2.50	1.00	0.00	3.25	2	2.14
(9MLT176/(MR112B-92M2*Tx2880)*A964)-LG8-CABK-LGBK-LGBK	1.25	0.50	2.50	2.50	2	2.06
TAM428	0.75	2.25	2.75	2.75	2	1.90
(5BRON151/(7EO366*GR107B-90M16)*Tegemeo)-HG7-CC2-CABK	1.25	1.50	0.00	3.25	2	1.85
Segaolane	2.25	2.50	0.00	2.75	3	1.66
(Dorado*Tegemeo)-HW13-CA1-CC2-LGBK	1.25	0.75	0.25	2.25	2	1.54
(5BRON151/(7EO366*GR107B-90M16)*Tegemeo)-HG1-LGBK-CABK	1.25	0.50	0.00	2.00	2	1.43
(Kuyuma*5BRON155)-CA5-CC1-CABK	0.50	1.25	1.50	2.50	1	1.43
Kuyuma	1.00	1.25	1.75	2.50	1	1.42
(A964*P850029)-HW6-CA1-CC1-LGBK	0.25	0.00	2.25	3.25	2	1.42
(Dorado*Tegemeo)-HW14-CA1-CC2-CABK	1.00	1.25	0.25	1.50	3	1.38
SRN39	1.00	2.00	0.00	3.25	4	1.31
Ent62/SADC	1.50	2.00	2.00	2.75	1	1.22
(Dorado*Tegemeo)-HW15-CA1-CC2-LG1	1.50	1.75	0.00	2.00	2	0.94
Macia	0.25	1.25	0.75	3.00		
(SV1*Sima/IS23250)-LG15-CG1-BG2-(03)BGBK-LBK	1.00	1.50	2.25	2.25		
(Macia*TAM428)-LL9	0.50	0.00	0.50	2.50		
(6BRON168/6OB172/(88CC445*Tx2862*Tegemeo)/HG5-CC2-LGBK	1.00	1.00	0.00	2.00		
(Town*EPSON2 – 40/E#15/SADC) – CG2 – BGBK	0.00	1.50	0.50	1.50		
BTx635	1.00	1.00	1.00	3.00		
Ent.62/SADC	0.00	1.00	0.50	3.50		
((ISCV401*S34)*R9204)-CS7–CS1-BE1	0.00	1.50	0.00	2.50		
Tx2957	0.00	1.00	0.00	2.00		
(SRN39*87ED366)-L039-BEI	1.00	2.00	0.00	2.00		
Sureno	1.50	1.00	1.50	3.50		

Table 1 cont'd: Evaluation of sorghum lines for disease resistance, sugarcane aphid resistance and grain yield.

86EON361	1.00	2.00	0.00	3.00
Macia*Sureno	1.50	1.50	0.00	2.50
Macia	2.00	1.25	0.00	2.50
EPSON2 – 40/E#15/SDAC*A964) – CG3 – BGBK	1.00	1.50	0.00	1.50
(Dorado*Tegemeo)-HW13-CA1-CC2-LGBK	2.50	1.00	1.50	2.00
Tegemeo	1.50	2.50	0.00	2.50
Malisor 84-7	0.00	2.00	0.50	3.00
LSD (P>0.05)	0.92	1.2	0.3	1.4

†Rated on a scale of 0 = no damage to 5 = plant necrosis.
‡Rated on a scale of 0 = no grain mold to 5 = grain deteriorattion due to molds.
§Rated on a scale of 1 = no aphids present on plants, 2 = light infestation with aphids present on a few leaves (no dead plants), 3 = moderate infestation with aphids present on 2 or 3 leaves (one or two dead leaves may be present), 4 = high infestation with aphids on nearly all leaves (many dead leaves) and 5 = majority of plants in plot dying.

1 and 4, which indicate the presence of low, intermediate to susceptible levels of resistance.

Yield of the entries at varied between 0.94 and 4.5 tons/ha. Five genotypes yielded significantly better than the standard check, PAN 8240 and only one genotype yielded significantly better than both the standard checks, viz PAN 6848 and PAN 8240. Promising white genotypes should be included in on-farm trials with the aim of release for use by the small-scale farmer market.

Studies at the Botswana College of Agriculture showed that sugarcane aphids and sorghum stem borers were the most destructive field pests during the 2008-09 cropping season. Results from studies on the sugarcane aphid led to the conclusion that abundance of the pest increases with plant age. The lines (Macia*TAM429)-LL9, TAM428, (6BRON161*CE151)-LG5-CG2-(03)BG1-BG1, and (Segaolane*WM#322)-LG2-LG2-(03)BG1-LG1-LBK had low levels of aphid abundance and should have higher levels of resistance and should be further investigated. The abundance of coccinellid predators also increase with the age of the plants. Overall abundance of coccinellid predators increased by 8.8x from about 4.5 on 40-47 day old plants to 39.8% on 74 day old plants. The findings indicate that the indigenous predators can play an important role in the management of the sugarcane aphid. Analysis of results on relative susceptibility of Texas bred lines to stem borers has not been completed.

At the Botswana College of Agriculture experiments were conducted on two sets of lines from the Texas A&M sorghum program. An advanced trial was composed of 22 lines previously identified with resistance to sugarcane aphid and acceptable adaptation. The advance trial was evaluated for incidence and abundance of major pests (panicle pests, aphids, shoot flies and stem borers) under field conditions and in field cages. Genotype and plant age significantly affected the average abundance of the corn leaf aphid (Rhopalsiphum maidis Fitch). Corn leaf aphid appeared to be an early season pest with the greatest overall average proportion of infested plants (33.2% per plot) found on 40 day old plants while the smallest (1.3%) was on 54 day old plants. The entry (Dorado*Tegemeo)-HW14-CA1-CC2-CABK-CABK had the greatest portion of infest plants per plot (29.2%) while (Macia*TAM428)-LL9 had the lowest proportion (1.3%). The majority of Texas lines were moderately resistant to the corn leaf aphid, and (Macia*TAM428)-LL9 would be an excellent line to use in an IPM program against the pest.

For sugarcane aphid, overall date averages show that the level of sugarcane aphid infestation increases with plant age. This indicates a rapid spread of the pest once initial infestation has occurred. The implications are that the sugarcane aphid becomes more abundant later in the season coinciding with the grain filling and grain maturation plant growth stages. The lines with the lowest abundance and thus least suitable for aphid were (Macia*TAM428)-LL9, (6BRON161*CE151)-LG5-CG2-(03) BG1-BG1, and (Segaolane*WM#177)-LG2-LG2-(03)BG1-LG1-LBK. These lines should be considered relatively more resistant than those with significantly higher proportions of infested plants per plot. The overall abundance of coccinellid beetles did not vary significantly but was significantly influence by the age of the plants. The increase in predator abundance corresponded to an increase in abundance of sugarcane aphid infestation per plot, suggesting that the predators responded positively to the increasing number of aphids. There did not appear to be a relationship between corn leaf aphid abundance and coccinellid predator abundance. This suggests that sugarcane aphid is a more important prey of coccinellid and enhances abundance and spread of coccinellid. An additional forty-five lines were subjected to an initial evaluation for resistance to sugarcane (Table 2). No significant differences were identified in the average abundance of sorghum plants attached. Damage rating ranged from 1 (resistant) to 3 (moderately resistant). Six experimental entries – (9MLT176*Dorado)-CA4-CA1-CC2-CABK-LGBK, (9MLT176*A964)-CA3-CABK-CCBK-CABK-CA2, (5BRON154*Macia)-HG10-CA1-LG2, (Tegemeo*WM#322)-CA1-CC1-CABK-CA2, (Tegemeo*ICSB12)-CA12-CC1-LG1-LG1, and (5BRON139*Tegemeo)-HG7-LG1-LG2 showed relatively low sugarcane aphid damage per plant and displayed some level of resistance to the pest. The six entries should be subjected to additional evaluation in developing cultivars resistant to sugarcane aphid.

Food Science

Four major activities were undertaken: 1) Dissemination of technology know-how between scientists and industrial end-users in southern Africa; 2) Create and maintain a database for scientists and processors on the end-use quality attributes of the major sor-

Table 2. Abundance of sugarcane aphid and coccinelid predators on 45 Texas bred sorghum lines during the 2008-2009 cropping season at the Botswana College of Agriculture.

Source Code	Pedigree/Designation	% Plants with Sugarcan e aphids	Sugarcane aphid damage rating†	% Plants with Coccinellids	% Plants with Sugarcane aphids	Sugarcane aphid damage rating†	% Plants with Coccinellids
		47 Days After Emergence			74 Days After Emergence		
07LI 35536-BK	TAM428	33.3	2.0	0.0	3.7	1.0	0.0
07LI 3557	Segaolane	32.4	2.0	29.8	43.8	2.0	24.3
07LI3538-BK	Kuyuma	25.7	2.0	31.6	29.2	2.0	17.5
07LI 3535-BK	CE151	4.4	1.0	0.0	3.7	1.0	7.9
07LI 3537-BK	Macia	2.1	1.0	0.0	4.2	1.0	0.0
07LI 3542-BK	Tegemeo	19.0	1.0	4.7	27.8	2.0	6.7
07LI 3543-BK	WM#177	4.7	1.0	1.6	16.7	1.0	7.6
07LI 3541-BK	SRN39	15.2	1.0	3.0	14.3	1.0	4.2
07LI 3545-BK	Ent62/SADC	2.2	1.0	4.4	11.7	1.0	12.8
08LI 10311	(Dorado*Tegemeo)-HW13-CA1-CC2-LGBK-CABK	17.9	1.0	36.1	28.7	2.0	28.1
08LI 10317	(A964*P850029)-HW6-CA1-CC1-LGBK-CABK	27.5	2.0	43.1	32.3	2.0	32.6
08LI 10320	(R.88B928*Tegemeo)-HW1-CA1-LGBK-CABK-CABK	50.0	2.5	8.3	27.5	2.0	4.2
08LI 10324	(Kuyuma*5BRON155)-CA5-CC1-CABK-CABK	40.5	2.0	6.2	32.4	2.0	22.8
08LI 10331	(5BRON151/(7EO366*GR107B-90M16)*Tegemeo)-HG1-LGBK-CA-CABK	42.2	2.0	29.2	34.8	2.0	19.0
08LI 10332	(5BRON151/(7EO366*GR107B-90M16)*Tegemeo)-HG7-CC2-CAB-CABK	38.2	2.0	23.9	20.1	1.0	8.3
08CA 6-BK	(Malisor84-7*(6OB172/88CC445*Tx2862))-LG19-CG1-CA1-CABK-CC1-CABK-CA1	28.5	2.0	1.9	23.9	1.0	15.5
08CA 28-BK	(Segaolane*KS115)-HW3-CA3-LD1-CABK-CA2	33.3	2.0	20.9	44.3	2.0	23.1
08LG 6028-BK	(9MLT176/(MR112B-92M2*Tx2880)*Segaolane)-CG1-LG1-CA1-CC2-CA2-CA2	36.1	2.0	16.7	0.0	1.0	38.9
08CA 39-BK	(9MLT176/(MR112B-92M2*Tx2880)*Dorado)-BE1-CA1-CA2-CC2-LGBK-CA1	45.0	2.0	14.4	62.5	2.7	50.0
08LG 6038-BK	(9MLT176/(MR112B-92M2*Tx2880)*Dorado)-BE9-CA1-CA2-LGBK-CABK-CA2	34.9	2.0	13.5	22.6	1.0	5.5
08LG 6041-BK	(9MLT176/(MR112B-92M2*Tx2880)*Dorado)-CA4-CA1-CC2-CABK-CABK	51.2	2.8	24.5	70.0	3.0	70.0
08CA 49-BK	(9MLT176/(MR112B-92M2*Tx2880)*Dorado)-CA4-CA1-CC2-CABK-LGBK	7.5	1.0	33.3	0.0	1.0	27.8
08CA 6045-BK	(9MLT176/(MR112B-92M2*Tx2880)*A964)-CA3-CABK-CCBK-CABK-CA2	12.1	1.0	3.0	0.0	1.0	41.7
08CA 6061-BK	(CE151*Tx430)-HW2-CA1-CG1-LDBK-CA1	69.0	3.0	50.0	75.0	3.0	41.7
08LG 6060-BK	(CE151*Tx430)-BE3-CA1-LGBK-CABK-CA2	17.9	1.0	2.6	38.9	2.0	36.1
08CA 70-BK	(Kuyuma*LG35)-CA6-CC2-CABK-CABK	39.8	2.0	11.1	34.1	2.0	22.5
08CA 74-BK	(Kuyuma*LG35)-CA10-LGBK-CABK-LG1	36.5	2.0	34.9	15.8	1.0	18.8
08CA 80-BK	(Kuyuma*5BRON155)-CA5-CC1-CABK-CA1	27.5	2.0	17.0	37.9	2.0	17.9
08LG 6074-BK	(5BRON139/(6EO361*GR107-)*Kuyuma)-HG3-LD2-CABK-CA1	51.2	3.0	14.4	30.0	2.0	6.7

Table 2 cont'd: Abundance of sugarcane aphid and coccinelid predators on 45 Texas bred sorghum lines during the 2008-2009 cropping season at the Botswana College of Agriculture.

Source Code	Pedigree/Designation	% Plants with Sugarcane aphids	Sugarcane aphid damage rating†	% Plants with Coccinellids	% Plants with Sugarcane aphids	Sugarcane aphid damage rating†	% Plants with Coccinellids
08LG 6076-BK	(5BRON139/(6EO361*GR107-)*Kuyuma)-H17-CG2-LDBK-CA1	33.3	2.0	16.7	45.9	2.4	3.2
08LG 6079-BK	(5BRON154/(87BH8606-4*GR127-90M46)-HG10-LG1-LG3-CGBK*Macia)-HG3-CA1	45.1	2.5	13.1	45.9	2.4	3.2
08LG 6082-BK	(5BRON154/(87BH8606-4*GR127-90M46)-HG10-LG1-LG3-CGBK*Macia)-HG10-CA1-LG2	6.7	1.0	0.0	9.5	1.0	17.9
08CA 101-BK	(99GWO92*ZSV15)F3-H55-HW1-HW1-LG1	49.0	2.5	9.0	49.0	2.4	8.4
08LG 6095-BK	(R.88B928*Tegemeo)-HW1-CA1-LGBK-CABK-CA1	48.3	2.5	13.9	42.2	2.0	24.4
08CA 112-BK	(Tegemeo*WM#322)-CA1-CC1-CABK-CA2	14.3	1.0	7.1	10.0	1.0	10.0
08LG 6106-BK	(Tegemeo*WM#322)-CA2-CC2-CABK-CA2	0.0	1.0	45.6	16.7	1.0	12.8
08LG 6109-BK	(Tegemeo*ICSR-939)-CA7-CC1-CABK-CA1	43.2	2.0	16.7	27.8	2.0	13.8
08LG 6114-BK	(Tegemeo*ICSB12)-CA2-CC1-CABK-CA2	21.1	2.0	29.4	26.9	2.0	25.9
08LG 6119-BK	(Tegemeo*ICSB12)-CA12-CC1-LG1-LG1	9.4	1.0	19.7	18.2	1.0	16.4
08LG 6125-BK	(5BRON151/(7EO366*GR107B-90M16)*Tegemeo)-HG7-CC2-CABK-LG1	7.2	1.0	2.2	26.4	2.0	13.4
08LG 6134-BK	(Dorado*Tegemeo)-HW13-CA1-CC2-LGBK-CABK	42.9	2.0	21.9	23.8	1.0	8.5
08LG 6136-BK	(Dorado*Tegemeo)-HW15-CA1-CC2-LG1-LGBK	27.5	2.0	4.8	57.1	2.6	21.4
08LG 6183-BK	(5BRON139/(6EO361*GR107-)*Tegemeo)-HG7-CA1-LG1	24.8	2.0	8.3	16.7	1.0	13.3
08LG 6186-BK	(5BRON139/(6EO361*GR107-)*Tegemeo)-HG7-LG1-LG	10.9	1.0	0.0	18.2	1.0	8.9
08LG 6306-BK	(Sureno*LG70)-HW5-CA1-CC2-CA1-LG1	38.8	2.0	33.3	5.6	1.0	5.6

†Rated on a scale of 1 = 0-20% damaged leaves, 2 = 21-40%, 3 = 41-60%, 4=61-80%, and 5=81-100%.

ghum and millet varieties in southern Africa; 3) Promote sorghum within the health food niche market; and 4) Improve the viability of sorghum as a lager/stout brewing raw material.

There is a reasonable-sized corps of food scientists and technologists in sub-Saharan Africa who are highly knowledgeable about sorghum and millet science and processing technologies. However, their know-how is currently poorly transferred to existing and potential processors of these grains. 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. Further, there is often a mismatch between the varieties that the farmers produce and hence are available and their suitability for processing into different food and beverage products. For example, in one particular country a company wants to build a sorghum maltings in order to malt local produced sorghum for commercial beer brewing. However, at present there is essentially no production of suitable sorghum cultivars in that country. 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 are products that exploit sorghum's health-promoting properties. The SABMiller Africa company, which is the major beer brewer in almost all countries in southern Africa, has committed itself to source locally produced brewing materials in each of the countries it brews in with an activity called the "Enterprise Development Project". Major among the raw materials targeted in the Enterprise Development Project is sorghum for lager beer brewing. There are, however, several sorghum-related technical aspects that require research and development work in order to improve the economic viability of sorghum lager beer brewing.

Data on the general physical characteristics of available and potentially available sorghum cultivars is being collated. Limited research work to determine malting and brewing qualities of some of these cultivars is being undertaken. Progress on the database of sorghum varieties has been slow because of human resource issues, and work on the database is neither education nor scientific research. With specific commercial industry interest in the database progress in creating the database should be more rapid. Simple technology to produce good quality cookies from 100% sorghum has been developed. The antioxidant activities of the cookies produced from different types of South African sorghums has been determined. A sensory evaluation trial of the whole sorghum cookies and soya protein enriched sorghum cookies has been undertaken at a primary school in Mamelodi near Pretoria. A short training course was given for mothers of the children on how to make these cookies. Research has been undertaken to try to improve the free amino nitrogen (FAN) content of sorghum worts. FAN is an essential nutrient for yeast fermentation in brewing and similar bioethanol processes. However, in sorghum FAN can be limiting, which inhibits fermentation efficiency. Various methods to improve FAN were investigated, including malting the sorghum, addition of commercial proteases, use of "high protein digestibility" sorghum cultivars and chemical treatments.

As was believed, it appears that white, tan-plant type sorghums give the highest hot water extract (yield of beer) in lager brewing. Also, it was found that there is an inverse relationship between grain protein content and hot water extract. Protein content could therefore serve as simple indicator of the potential brewing quality of a batch of sorghum. Cookies made from tannin sorghum had the highest antioxidant activity, but were sensorially poor. Those made from red, non-tannin sorghum had lower antioxidant but better sensorial characteristics. Sensory evaluation of these and the sorghum-soya by primary school children revealed that within a short period of time the children adjusted to the taste of sorghum cookies and liked them just as much as cookies made with wheat flour. This is a very promising finding with respect to using sorghum and sorghum-soya cookies in school feeding schemes. Malting sorghum was found to be the most effective way of improving sorghum wort FAN levels. Some improvement in wort FAN was obtained by the addition of potassium metabisulfite (KMS) in conjunction with certain commercial protease enzymes. This later process is now being implemented in commercial sorghum brewing through a major international enzyme company.

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 major achievements in the past year were completion of the project activities as specified in the work plan. These include 1) a study of the sorghum based clear beer value chain, 2) analyzing the baseline farm household surveys in high potential areas, 3) completing a study of the improved seed value chain in Zambia and beginning studies of the feed concentrate industry and food processing chain in Tanzania, 4) continuing the collection of monthly retail, wholesale and farm price information, and 5) Initiation of M.S. course work at The Ohio State Univ. by Bernadette Chimai (Zambia), autumn term 2009.

In the past, sorghum was considered a traditional crop with limited industrial uses such that most of it was used for household consumption. However, in recent years, the crop has been identified as a possible substitute for maize. Research and transformations in consumer tastes and preferences have led to the development of new uses for sorghum. In particular, four major industrial uses of sorghum have thus far been identified, including food processing, beer brewing, feed concentrates and energy production. Previous studies identified the main players in the clear beer supply chain and provided useful insight into the activities of the chain and how the different chain members are inter-related. No study is available that has assessed the performance of Eagle Lager and the opportunities and challenges it presents to smallholder farmers in Zambia. As a major player in the chain, it is necessary to assess the performance of Eagle Lager since its introduction as well as estimate future market opportunities that it may present.

Zambian Breweries (owned by SABMiller) introduced Eagle Lager; sorghum based clear beer to the market in 2005. Eagle Lager offers an alternative to the traditional maize-based clear beer; it entered the market at a much lower price than its close competitors, Mosi and Castle Lagers. Eagle Lager has become an important new market for sorghum in Zambia. Eagle Lager enjoys a 15-17 percent clear beer market share, and is reportedly growing at 5-10 percent per annum. Such a market growth rate will very likely encourage increased brewer demand for sorghum production. To cope with the increasing demand, it is estimated that the existing processing plant in Ndola needs to be expanded at least fourfold. Most importantly the introduction of Eagle Lager has created new value chain relationships involving farmers, traders, transporters, wholesalers and retailers. For the farmers, the beer provides a stable market at a known price for their sorghum. The distributors and retailers are provided with more service-provision activities making it possible for them to expand their businesses.

Initially, Zambia Breweries (ZB) used the Cooperative League for the USA (CLUSA), a USAID-funded NGO, to sensitize up to 4,000 local farmers to produce the sorghum required for brewing by providing technical advice and loans for production inputs. Purchase arrangements were signed between farmers and Zambia Breweries in advance to guarantee a ready market for the farmer's crop at a price considerably higher than the market rate. The CLUSA project no longer has this USAID funded program. Recently, Zambia Breweries has obtained all its sorghum supplies from a local commodity broker, CHC Commodities. The broker entered into an agreement with Zambia Breweries to be its only supplier of sorghum. CHC Commodities purchases sorghum from smallholder farmers, small traders, and large-scale farmers. However, the contribution by large-scale farmers has been declining such that in 2008 all the sorghum was sourced from smallholder farmers. The new value chain is increasing employment, smallholder incomes and promoting local development.

An improved seed value chain study has been completed. The study began by mapping the seed chain functions, actors and identifying key informants at critical points (such as production, distribution, consumption) in the value chain. The value chain has three interlinked components; namely the value chain actors, enabling environment (policies and institutions and that shape the market environment) and service providers (business services that support the value chain's operations). Factors affecting the competitiveness of the chain include the enabling environment such as the crop diversification policy, and changes in market trends which may have a positive impact on sorghum and millet use. Other factors such as the fertilizer and price subsidy programs for maize adversely impact the competitiveness of the sorghum and millet seed chain.

This study found that smallholder adoption of improved practices particularly the use of improved seed and fertilizer is very low. The result is low yields for sorghum and millet (national average about 500 kg/ha) with no increasing trend in yield (productivity) since 1990. Yet, sorghum breeders have varieties on the shelf that yield 3-6 tons/ha on experiment station farms. The low rate of adoption raises questions of whether the goals of research and development of new technology are being met.

A procedure is established to collect monthly price data for sorghum and millet for 2008 to 2011 to permit analysis of monthly price variability and opportunities to store grain on-farms to sell at higher farm prices in the post-harvest period.

Pearl Millet Breeding

Zambia

Experimental protogyny population hybrids based on intervarietal crosses and top-cross hybrids based on the male-sterility systems are being developed. It is envisaged that appropriate hybrids will generate interest to solve the persistent seed issues and problems being experienced. During this research year nearly 46 experimental population hybrids were made through hand crossing using the varieties Lubasi, Dola and SOSAT-C88 as seed parents and several other varieties from Zambia, Southern Africa, Western Africa, India and the USA as pollinators. The hybrids will be evaluated during the 2009/10 season to establish their potential. The three seed parents were carefully selected: Lubasi is a very popular improved variety; Dola is an improved and popular variety in the public and private sectors of Zambia and other Southern Africa countries due to its bristled characteristic which protects grain from damage by birds in the fields; SOSAT-C88 originated from West Africa has good combining ability. Fifteen other varieties were selected for development of genotypes having light colour of the grain to address the problem of food colour preferences (other than gray) and improve acceptability among consumers.

Sorghum Breeding

Zambia

In general, 2008/2009 was yet another wet season characterized by late and heavy rains. Local landraces of sorghum on farmers' fields that normally fail benefited from these late rains. Multi – location trials were reduced due to insufficient funds from government. Trials at Mpongwe, Mansa, Lusitu and Golden Valley performed well and valuable data was collected.

The program is largely collaborative involving disciplines in breeding, pathology, entomology and food quality. Expertise drawn from these disciplines is critical in the development of varieties that are useful to both farmers and end–users. Local germplasm is used in hybridization followed by evaluation and selection in subsequent generations. Several crosses were made between WP-13, Malisor 84-7 and other elite lines. The progeny of these crosses is being evaluated at Golden Valley and Mansa. Work on understanding the gene action conferring acid tolerance in sorghum and on transferring the same through backcrossing was initiated several years ago. Several crosses have been made and selections to identify and evaluate the crosses are being made in Mansa. The use of biotechnology (Random Amplification of polymorphic DNA – RAPDS) is another option that the program is contemplating in identifying potentially successful varieties for the region.

There were 20 entries in the Sorghum Advanced Variety Trial for region III evaluated at Mansa and Mpongwe. Results from Mpongwe are yet to be received. The trial at Mansa showed significant differences among entries but had a high CV (Table 3). This is expected as different varieties react differently to low pH conditions. The checks ZSV-12 and WP-13 had lower yields than the highest yielder SDS 4378–1-1-1. Several other entries

Table 3. Sorghum Advanced Variety Trial – III in 2008 – 2009 season at Mansa, Zambia

Designation	Days to 50% flower	Plant height	Harvested rows	Grain Yield kg/ha
SDS89426	80	138	56	1703
PRGC/E3#69414	82	180	50	1078
ICSV1089BF	88	139	45	939
MACIA x DORADO	80	94	50	1131
ZSV-18	85	114	45	1294
ZSV-30	79	160	49	1872
ZSV-31	78	155	42	1233
SDS4378-1-1-1	71	128	49	2519
SDS1023-10-2-4-1-3-2	80	109	38	1372
SDS876-3432(OT)8-2-1	83	141	47	914
[SDS3845 x SDS4548]F6-10-2	78	159	42	2161
[SDS3845 x SDS4548]F6-10-3-2	84	169	39	1292
[SDS2690-2 x M91057]8-2-1-1	65	94	38	1275
SDS2690-2-3-5-1	82	146	46	789
KSV-7	73	116	31	969
KSV-10	79	199	49	1300
KSV-4	77	220	58	1619
SDS4380-S7	71	134	49	1592
ZSV-12	78	108	45	850
WP-13	81	154	41	1814
MEAN	79	143	45	1386
LSD	14.5	39.4	14.1	989
CV %	6.9	23.3	13.9	33

had higher mean yield than the trial mean ([SDS3845 x SDS4548] F6-10-2, ZSV-30, SDS89426). These entries also showed high agronomic scores.

The sorghum research programme has released a number of varieties for the three agro – ecological regions. Varieties Kuyuma, Sima, ZSV-15 and hybrids MMSH-1257, MMSH-1324 are popular with farmers in region I and II. The acceptance and adoption rates of these varieties are good and fairly high. However varieties released for region III have not had the same success. The varieties needed for this region need to be late maturity (photoperiod sensitive) and withstand low pH. The programme has released two varieties ZSV – 12 and WP – 13 for region III. The adoption rates of these varieties is low largely on account of poor grain quality (soft endosperm) and non – availability of seed.

The development of sorghum varieties with improved grain quality that can withstand low pH should see high adoption rates in region III. Increased sorghum production in region III will also increase commercialization by smallholder farmers as the market (Zambia Breweries plant) is located in the region. It will be cheaper to source the grain in region III than from region I and II. Seed availability and limited markets remain a big challenge to the adoption and utilization of improved sorghum varieties.

There is a growing interest in identifying sweet sorghum varieties for silage and biofuels. The current focus is on dual purpose varieties. Most of the varieties are photoperiod sensitive and this work has to be done in Mansa.

Mozambique

Research methods include pedigree selection, mass selection for local collections and germplasm characterization. Macia and Sima sorghum improved varieties are produced in the country and farmers are becoming familiar with growing improved sorghums. Nine introductions from Texas germplasm were selected for potential use based on tolerance to drought, midge, and grain quality. Exotic germplasm from Zambia and Mali sorghum breeding programs was introduced to enhance the germplasm base of the national program.

Collection, conservation and use of local landrace varieties important in developing the national sorghum breeding program. In present year 12 local landraces were collected. This represents an increase of 33% of local germplasm collected and characterized. The collected materials are showing good performance and resistance to bird and insect damage, and because of hard endosperm appear to exhibit some resistance to stored grain insects.

Multi-location National Performance Variety trials with the following germplasm were conducted:

- 12 early maturing genotypes,
- 17 early maturing genotypes resistant to midge, down mildew, Head smut, Ergot and drought; this materials were selected from Texas (ADIN, DLT, MLT, and UHSN nurseries) introductions;
- 25 open pollinated sorghums trial in central and north Mozambique. The varieties have multiple uses (food, feed and bio-ethanol).

- 5 sweet sorghum hybrids for planting date trial

Eighteen inbreed lines were selected from 70 segregating populations for stability and uniformity after six years of selection. This represents an 11% increase of improved sorghum varieties in Mozambique over the two most popular varieties Macia and Sima. The sorghum market in Mozambique is gaining space and present demand is growing. Seed companies such as LONZAN, PANNAR and SEMOC-Mozambique are requesting huge quantities of Sima and Macia improved sorghum varieties. In the next two years production area is expected to increase by 25%.

A replicated yield trial composed of 15 introductions form the Texas A&M program along with two local checks (Sima and Macia) was grown at four locations (Table 4). At each location entries were identified with grain yield at least equal to the standard checks. Under low rainfall conditions, the introductions demonstrated good yield performance with an average grain yield of 2,950 kg/ha. The represents a yield increase of 20.33% over local landraces. The trials will be repeated to confirm this years results and identify potential new varieties with the characteristics needed for increased production in Mozambique.

Plant Pathology

Root efficiency remains a critical component of low input agriculture and is essential in ensuring that limited soil moisture and nutrients are used optimally so as to ensure sustainable crop production. Twenty-six sorghum hybrids from the current and previous National Cultivar Trials were planted at Cedara for root rot evaluation. Root health is important for optimal water and nutrient uptake by plants and previous studies have indicated that subtle losses of up to 25% may occur due to the disease complex. Evaluations were conducted using a root efficiency index based on visible root infection severity and root volume. Analyses of the data indicated a limited range of disease severities with all cultivars showing relatively high levels of infection (lowest = 29.42 and highest= 45.60). However, when root rot severity was combined with root volume to determine effective root volume, the latter ranged from 14.42 ml per plant to 2.72. Root rot severity is not directly correlated with plant growth reductions and the effect of root rot on the host plant is dependent on the initial/inherent root volume. Regression analyses using the reduction in root volume vs plant height as an indicator of plant vigour indicated a tendency for reduced plant vigour although the R^2-value was not significant.

The relationship between host structural and biochemical characteristics and root diseases are being evaluated. The degree of root exodermis lignification, as indicated by root cross sections and microscopic examination after staining with phloroglucinol, in relation to root rot resistance was evaluated in four resistant and six susceptible lines. Anatomical studies of roots indicated a significant relationship between the degree of exodermis lignification and root rot resistance. Data suggest that genotypes with resistance to root colonization also have a greater structural barrier to infection. Susceptible roots do not possess a significantly thickened exodermis.

Forty advanced selections from the Texas A&M program were evaluated for response to the diseases of sooty stripe, leaf

Table 4. Mozambique elite sorghum variety trial of germplasm introduced from Texas A&M University.

Designation	Source Code	Namialo	Namapa	Mapupulo	Sussundenga	Average
		t/ha	t/ha	t/ha	t/ha	t/ha
Sureño	03CS-GWT 115	3.50	2.30	3.00	3.09	3.02
Sima		3.30	1.73	2.90	3.14	2.79
(ICSV-LM-88511*R9120)-F1-CS	04CS-884-5-1	2.40	2.80	2.20	3.16	2.66
((Sepon82*87eon366)-H38/Jocoro)-CSF1-CS	04CS-452-4-1	1.80	2.20	3.10	3.34	2.64
(R01125/CE151*Macia)-LD3)-CSF1-CS	04CS-523-2-1	1.00	2.53	3.80	3.06	2.64
Macia	02CS-30932	2.30	2.41	2.90	2.51	2.54
(Tx2880*(Tx2880*(Tx2864*(Tx436*(Tx2864*PI50607)))))DER	03CM-1104-BK	6.10	0.68	1.40	1.74	2.51
Macia		2.60	2.07	2.40	2.72	2.48
(87BH8606-6*RTx430)-CS-CA	02CS-30445	1.70	2.40	2.50	3.05	2.44
B.HF8/(BTx643*BTx635)	02CS-5067	2.40	2.14	2.50	2.20	2.34
(Tx2880*(Tx2880*(Tx2864*(Tx436*(Tx2864*PI550607)))))DER	03CM-15067-BK	2.20	1.72	2.10	3.13	2.30
(05OG4300-5*Tx2782)DER	03CM-15012-BK	3.30	1.78	2.00	2.00	2.28
(RTx2917*Tegemeo)-CSF1-WFF2-CS	04CS-573-3-1	3.00	1.64	2.00	2.36	2.27
B409/(B1*B9501)	02CS-30331	2.40	1.86	2.10	2.26	2.18
(91BE7414*R01160)-CSF1-CS	04CS-798-7-1	2.00	1.97	1.80	1.62	1.86
(R01165*R0036)-CEF1-CS	04CS-608-6-1	2.00	1.69	1.51	1.35	1.64
	02CM-19225	1.90	0.84	0.84	1.10	1.19
Mean		2.60	1.87	2.33	2.45	2.34
LSD .05		1.62	1.07	1.34	0.74	
CV		37.0	34.5	34.6	18.0	

blight, anthracnose and grain mold (Table 1). For each disease the response ranged from no infection (rating = 0.0) to a moderate to high level of susceptibility. For the foliar diseases several entries exhibited very good resistance to each disease. Several of the entries produced excellent grain yield. The entries were mostly moderately susceptible, at least, to grain molds. Research is ongoing to improve the grain mold resistance in potential varieties but this is a slow process. No entries had excellent resistance to each disease. These are primarily white-tan selections aimed at the development of white grained genotypes with acceptably grain characteristics. Analyses of multi-seasonal data from line and cultivar trials are being conducted to determine the stability of genotype response to diseases over changing environments. These will be conducted using AMMI analyses.

Sorghum panicles were inoculated with five fungi frequently isolated from sorghum grain to determine the relationship between fungal pathogenicity and host genetic resistance. A collection of 11 sorghum genotypes from Southern Africa regional trials supported by the International Sorghum and Millets Collaborative Research Support Program (INTSORMIL CRSP) was used. Panicles of selected genotypes were inoculated at anthesis with Fusarium graminearum, Fusarium thapsinum, Curvularia lunata, Phoma sorghina and Alternaria alternata spores. There were highly significant differences in the levels of fungal pathogenicity on the different sorghum genotypes. These differences accounted for 58.4% of observed variation in ergosterol concentration. Genotype by pathogen (G x P) interactions accounted for 33.5% of the observed ergosterol concentration variation. The implication is that different genotypes reacted differently to different fungi. The genotypic reactions of the hosts accounted for 8.1% of the observed ergosterol concentration variation. Overall, fungal pathogenicity is the most important factor to consider in the evaluation of germplasm for grain mould resistance. However, fungal pathogenicity also depends on host genetics. Individual host genes associated with resistance to individual grain mould fungi need to be identified and manipulated into sorghum hybrids and cultivars. Possible sources of resistance could be identified by use of biplot analysis of G x P interactions. Visual scoring for grain mould is insufficient without identifying causal fungi. A multiple regression model involving all the fungal species accounted for 67% of the variation in the final visual grain mould damage rating. Alternaria alternata accounted for 52% of the final visual grain mould damage rating. However, Fusarium thapsinum and Phoma sorghina were the most abundant fungi across all genotypes. Thus, it should be possible to identify individual host resistance genes and pyramid them in order to get a broad sense resistance mechanism that will hold against all important fungi across environments and seasons.

Gene action and heritability for grain mould resistance in sorghum were investigated using a selection of specific parental lines. The combining ability of 9 random pollen parents with varying levels of grain mould resistance to a different set of three random seed parents was evaluated. The combined analysis of variance showed no genotypic variance for grain mould resistance. The expression of grain mould resistance was also not stable with significant genotype x location interactions. Additive genetic variance was greater than dominance variance for all traits except grain mould resistance. A significant heterosis of -20.15% was observed for grain mould resistance indicating the importance of use of hybrid seed. Due to very high environmental variance, grain mould heritability could not be detected. The variation in genotype performance for grain mould resistance was studied using the same parents to assess significance and nature of genotype by environmental interactions in the expression of grain mould resistance. Differences in ergosterol concentration in mature grain were evaluated and used as the primary measure of the level of grain colonization in genotypes. Significant G x E interaction effects on ergosterol were detected. Single site analysis was conducted to better explain the nature of the G x E interaction.

The Medical Research Council PROMEC Unit studies 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 and moniliformin, which have been shown to have negative health effects or implications on both humans and animals that consume agricultural crops that are infected by them.

The current research project concentrated on the determining the fumonisin (FUM) and moniliformin (MON) profiles of 20 Fusarium strains previously isolated from maize, millet and sorghum patty media in the laboratory. In order to achieve this, millet patty cultures were developed, and the results compared to those of the same fungi grown on maize and sorghum patties. A total of 92 cultures were successfully grown on maize, sorghum and millet patty cultures and will be chemically analyzed for both, fumonisin and moniliformin mycotoxins in 2010 (total of 184 analyses).

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, both maize and sorghum grains can potentially harbor high fumonisin producing Fusarium species, and that the unidentified new Fusarium species isolated from sorghum and millet needed to be further investigated and their toxin profiles determined. This part of the research plans to confirm that the fungi isolated from maize, sorghum and millet, do have the ability to produce mycotoxins in in vitro cultures.

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

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Regional Program Description

Multi-agency, multi-disciplinary teams of agronomists, entomologists, food scientists, plant breeders, plant pathologists, poultry scientists, extension educators, and others from Burkina Faso, Mali, Niger, Nigeria, and Senegal are developing, evaluating, and transferring technologies to improve production and marketing of sorghum and pearl millet and manage *Striga* in West Africa. The West Africa regional program with collaboration among scientists at Institut D'Economie Rurale in Mali, Institut National de la Recherche Agronomique du Niger, INERA and IRSAT in Burkina Faso, Institut Sénégalais de Recherches Agricoles and ITA in Senegal, University of Maiduguri in Nigeria, universities in the US, volunteer organizations, and private industries is contributing to INTSORMIL objectives to facilitate markets; improve food and nutritional quality to enhance marketability and consumer health; increase stability and yield through crop and natural resources management; develop and disseminate information on stresses to increase yield and quality; enhance stability and yield through genetic technologies; and better the lives of people dependent on sorghum and pearl millet.

Hamidou Traoré from Burkina Faso coordinated the "Integrated *Striga* and nutrient management for sorghum and pearl millet" project. Involved are Mountaga Kayentao from Mali, Nouri Maman and Souley Soumana from Niger, and Moctar Wade from Senegal. The goals were to identify and characterize *Striga*-resistant sorghum and millet; characterize and implement integrated *Striga* management systems for millet that incorporate fertilizer, rotation or intercropping millet and cowpea; characterize and implement integrated *Striga* management systems for sorghum rotated with cotton; assess effects of herbicidal seed treatments on crop performance and *Striga* management; evaluate ALS-resistant genotypes; and transfer *Striga* control methods as technology packages to increase yield of sorghum and millet and the incomes of farmers throughout West Africa.

Mamourou Diourté from Mali coordinated the production component of the "Increasing farmers' and processors' incomes via improvement in sorghum, pearl millet, and other grain production, processing, and marketing systems" project. This 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; plant pathologist 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 with the goal of disseminating the best cultivars in combination with fertilizer and other crop management options such as legumes in crop rotations and crop protection options. They also are identifying storage disease and insect pests and control measures to manage grain harvesting and storage practices. They are developing base populations of cultivars of sorghum and millet with known adaptation, stability, and acceptability through multi-environment experiments and resistance to pests and drought. They are using conventional and/or marker-assisted recurrent selection to generate adapted dual-purpose varieties, open-pollinated varieties, and hybrid parental lines for targeted environments.

Ababacar N'Doye from Senegal coordinated the processing and marketing systems component of the project "Increasing farmers' and processors' incomes via improvement in sorghum, pearl millet, and other grain production, processing, and marketing systems." The processing and marketing sub-project involves food scientists Boniface Bougouma from Burkina Faso, Moussa Moustapha from Niger, and Iro Nkama from Nigeria, and poultry scientist Salissou Issa from Niger. The project focuses on processed food and animal-feed markets and their expansion through development of good-quality, competitive millet- and sorghum-processed products and greater use of sorghum in poultry feed. The overall goal is to enhance urban markets for improved and hybrid sorghum and millet cultivars for farmers to sell surplus grain with emphasis on development and transfer of food technologies to farmers, NGOs, food processing and marketing entrepreneurs, and consumers. Activities were focused on processed products that contribute to development of markets for sorghum, millet, and fonio by development and transfer of technologies to entrepreneurs. Technologies for production of breads and other products based on sorghum, millet, and fonio were transferred; local processing groups were assisted to disseminate new processing technologies and initiate businesses; and sorghum, millet, and fonio are being characterized as "functional foods" for health. The goal was to have competitive composite flour and other products in the marketplace. For animal feed, use of sorghum in poultry feed in West Africa is being validated and education provided on availability of low-tannin varieties and aflatoxin-free grain, with the goal to increase the use of sorghum for poultry.

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 manage *Striga* and improve production and marketing of sorghum and millet. Sorghum and pearl millet, the staple foods of people in Sub-Saharan Africa, suffer significant yield losses 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. Losses of 10-100% occur and result in abandonment of arable land. In addition to *Striga*, major pests of sorghum and millet in fields in West Africa include anthracnose and other diseases, millet head miner, sorghum midge, and stalk borers. Colletotrichum, *Curvularia*, *Aspergillus*, and *Fusarium* that cause human cancers, lymphatic diseases, and gastritis and insect pests such as beetles and moths cause loss of grain quality and weight within only a few months in storage. Pest-resistant cultivars and packages of improved crop, soil, water, and pest management technologies would 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 known adaptation, stability, and acceptability and resistance to drought and pests in multiple environments are being identified and developed. Agronomic and pest management technologies that include the use of resistant cultivars, crop rotation, intercropping, fertilizer, and herbicides are being developed to manage diseases, insects, and *Striga* in the field. Pests are being identified and control measures developed and transferred to manage grain harvesting and storage practices. Development and adoption of high-yielding, quality sorghum and millet with increased nutritional value would improve human nutrition and health. Enhanced urban markets are needed for farmers to sell surplus grain of improved sorghum and millet. Processed products such as competitive composite flour would contribute to development of markets for sorghum, millet, and fonio through transfer of the technologies to entrepreneurs to initiate businesses. Use of sorghum in poultry feed in West Africa needs to be validated and education provided on availability of low-tannin varieties and aflatoxin-free grain. Partnerships among host-country scientists, NGOs, international agencies, extension, and farmers are needed to ensure transfer of technologies for improved agricultural production and marketing. Greater, more stable yields and enhanced markets will better the livelihood of people dependent on sorghum and millet and help end hunger in West Africa by increasing farm incomes and agricultural development.

Institution Building

A prototype baking oven and groundnut roaster were constructed and tested in Nigeria. A dehulling machine for sorghum and millet was purchased and installed for testing in Nigeria. A project on implementation of a couscous line for millet/maize couscous preparation was supported by a regional World Bank program called "West African Agricultural Productivity Programme' that allocated to ITA 17 000 000 CFA F to complete the couscous line using the agglomerator developed by ITA in Senegal. A color brochure in French entitled "Les insectes nuisibles du sorgho stocke et la gestion integree des insectes nuisibles des stocks" was given out when discussing with 199 farmers how to manage insect pests of stored grain at seven villages in Mali in March 2009.

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.

One Ph.D., 2 M.S., and more than 15 undergraduate students from Nigeria assisted through the INTSORMIL grant in 2008-2009. The Ph.D. program of Mohammed Diarra from Mali started in January 2009 in Food Science and Technology at the University of Maiduguri, Nigeria was supported by INTSORMIL under the collaborative supervision of Professors Iro Nkama (Nigeria) and Bruce Hamaker (Purdue University). The student completed most coursework. Research is expected to begin after the student's examinations which were delayed by an industrial dispute at Nigerian universities. Tuition, fees, and research costs of the Ph.D. program of Amina Jato, staff of the Department of Food Science and Technology, University of Maiduguri, have been paid from INTSORMIL funds for the past 3 years. She started research to improve the nutritional quality of millet/sorghum-based sinasin (injera-like food) through supplementation with grain legumes (cowpea).

Hame Abdou Kadi Kadi in Niger collaborated with Dr. Kadri Aboubacar, Faculté d'Agronomie, Université Abdou Moumouni de Niamey, to supervise internship activities of five students for practical field training, writing reports, and defense committees in 2008. In 2009, Mr. Kadi Kadi worked with two interns at Tahoua, Niger. One intern assessed evaluation and adoption of SSD-35 sorghum at Doguéraoua (Birni N'Konni) and the second intern was posted at Madaoua to survey farmers' knowledge about insect pests of sorghum.

Networking

Workshops and Meetings

The pilot plant of the research institute DTA Technopol and bakeries and breweries in Burkina Faso were used to teach new technologies for bread, biscuits, and dolo. Two sessions from 23-28 February and 13-22 July taught new technologies for dolo based on a gas-improved fire box and optimized brewing process. Twenty females who are members of the Association des Dolotières et Revendeuses du Kadiogo and two men were trained to use the new technology, with collaboration from a Sodigaz project.

Research Investigator Exchanges

In addition to visits by various PIs involved with INTSORMIL, the West Africa coordinators met in August 2009 at Bamako, Mali, to prepare annual sorghum and millet production, marketing, and Striga-management workplans and budgets.

Research Information Exchange

Entomologists Niamoye Yaro Diarisso in Mali, Hame Abdou Kadi Kadi in Niger, Alain Ratnadass with CIRAD/ICRISAT in Niger, and Bonnie Pendleton discussed in October 2008 collaborative research for the "Cereals for the Drylands" proposal to the Gates Foundation. A color brochure translated into French was given out when discussing with 199 farmers how to manage pests of stored grain in March 2009 in Mali. Sorghum midge-resistant SSD-35 developed at INRAN was evaluated by 48 farmers and produced by 184 farmers in Niger. In six villages, 171 farmers adopted SSD-35 and Mota Maradi. Technologies for danwake (sorghum/cowpea-based dumpling), biscuits, dakuwa, sorghum and millet grits and flour and couscous developed through INTSORMIL were transferred to entrepreneur Al-Muneer, Nigeria Limited in Maiduguri. Products are being analyzed to enable the company to obtain National Agency for Food and Drug Administration registration numbers and begin full operation. Based on results from INTSORMIL projects on sorghum and millet, a proposal for training and establishing two small-scale value-added product enterprises in Tikau (Nengere government area) and Jimbam (Tarmuwa government area) in Nigeria was submitted to the Community Based Agricultural and Rural Development Programme, Yobe State in Partnership with Intellectual Property and Technology Transfer Office of the University, coordinated by Iro Nkama. Products to be processed include weaning foods, biscuits, couscous, and dakuwa (snack food like chocolate). The MOU has been signed and the partner is seeking a No Objection Letter from the sponsors so the project can begin.

Germplasm Distribution

Twenty early-, 10 medium-, and seven late-maturing sorghum breeding lines developed by IER in Mali were transferred to farmers to compare with local checks. Nine extension agents, 28 farmers, and an organization of 80 farmers multiplied seed of sorghum midge-resistant SSD-35 on 3.5 hectares in Niger. SSD-35 was evaluated by 48 farmers and produced by 184 farmers on 67 hectares. In six villages, 171 farmers adopted SSD-35 and Mota Maradi planted on 40 hectares. Seeds of SSD-35 and Mota Maradi were multiplied on 55 hectares by 92 farmers from eight villages. Bagged grain of SSD-35 is being sold by the private "Semences Améliorées ALHERI" seed company in Niger. Three millet head miner-resistant millets developed by INRAN were transferred to farms in Niger.

Research Accomplishments

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

Weed scientist Hamidou Traoré used an agar gel assay method for in vitro evaluation of 15 landraces of sorghum (five from INERA Burkina Faso, four from IER Mali, one from ICRISAT-Samanko, three from INRAN Niger, and two from ISRA Senegal) for resistance to *Striga* from Burkina Faso, Mali, and Niger in a laboratory at Kamboinsé research station in Burkina Faso. The 15 landraces of sorghum were evaluated to confirm resistance to *Striga* in fields at Kouaré and Farako-ba research stations in Burkina Faso, Sotuba and Samanko research stations in Mali, Konni research station in Niger, and Bambey research station in Sénégal. At Kouaré, seeds of the landraces were sown on 17 July, while seeds were sown on 24 July 2009 at Farako-ba. Data were collected on the number of plants per plot, date of flowering of sorghum, sorghum height (21 days after sowing and at harvest), days until emergence of the first Striga, and numbers of *Striga* 60 and 90 days after sowing. At Kouaré, few *Striga* plants were recorded at 60 days after sowing (0 to 27 per plot), but at 90 days, *Striga* plants ranged from 6 to 289 per plot. The sorghum is not yet ready to harvest.

Integrated sorghum management systems that include water management, improved variety, improved fertility, and non-target hosts for sorghum in Burkina Faso were evaluated starting in 2008. Treatments included: 1) improved sorghum variety, 2) improved sorghum variety with 2 to 5 tons of manure per hectare, 3) improved sorghum variety with 2 to 5 tons of manure and inorganic fertilizer per hectare, 4) improved sorghum variety with 2 to 5 tons of manure and inorganic fertilizer per hectare and weeding 60-65 days after planting, and 5) improved sorghum variety in rotation with cowpea in 2008 and sorghum in 2009. Four experiments were done on farms in eastern Burkina Faso, each farm representing a replication. In each experiment at each location, days to first emergence of Striga, numbers of Striga at 60 and 90 days, plant height, days to flowering, and plants per plot will be recorded. Plots were not yet harvested; yield will be determined at harvest.

Mountaga Kayentao in Mali evaluated sorghum varieties for resistance to *Striga* and used herbicide to control *Striga* under artificial infestation of the parasite. Three experiments were done at Sotuba and Cinzana with the objectives to 1) verify the effectiveness of herbicide doses in treating sorghum seed to control *Striga* and 2) develop and transfer an integrated approach to control *Striga* throughout the Sudanese and Sahelian zones of West Africa. The first experiment used three sorghum genotypes treated with three doses of herbicide and one nontreated check planted on 15 July at Sotuba and 17 July at Cinzana with three replications at both locations. The second experiment involved 14 entries from Burkina Faso, Mali, Niger, and Senegal planted on 15 July at Sotuba. The experiment was done for the second year in the four countries. Data on *Striga* rating and yield will be available at harvest.

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

Agronomist Abdoul Wahab Touré evaluated optimal plant population for newly released tan sorghum varieties to express their full yield potential at Sotuba; Mali. A strip-plot design with four blocks was used. The treatments were six populations of 0.75 x 0.50 m with 2 plants per hill (53,333 plants per hectare), 0.75 x 0.50 m with 3 plants per hill (79,999 plants per hectare), 0.75 x 0.25 m with 2 plants per hill (106,666 plants per hectare), 0.50 x 0.40 m with 1 plant per hill (50,000 plants per hectare), 0.50 x 0.40 m with 2 plants per hill (100,000 plants per hectare), and 0.50 x 0.40 m with 3 plants per hill (150,000 plants per hectare) in combination with the four sorghum varieties of CSM388 (check), Séguifa, Tiandougou, and Niatichama, for 24 treatment combinations in each block. One hundred kilograms per hectare of d-iammoniac phosphate were applied at planting and 50 kg/ha of urea 30-40 days after planting. Table 1

Harvested plant population fluctuated between 80 and 114% of recommended but should have been 90-283%. Compared to expected, the harvested plant population fluctuated between 36 and 80%. Harvested plants averaged 46,365 per hectare; the most was 64,684 and least 21,111 plants per hectare. No differences among varieties were observed. Compared to the recommended 53,333 plants per hectare, plant populations of CSM388 (local), Séguifa, and Tiandougou were 101, 93, and 76%, with 53,889, 49,537, and 40,663 plants per hectare, respectively. Tiandougou and Niatichama had less than 50,000 plants per hectare (-24 and -22 %). Tiandougou yielded 2,000, while Niatichama yielded 1,700 kg per hectare. Two classes were distinguished based on grain yield: yield less than 2,000 kg and plant population less than 50,000 per hectare and yield greater than 2,000 kg, with plant population more than 50,000 plants per hectare. Regression analysis of harvested plants on grain yield led to the equation: grain yield (kg/ha) = 0.02295 * number of stalks + 937.49 (R2 = 31.8). A change of 10,000 plants would result in 230 kg/ha more grain. Table 2

Abdoul Wahab Touré compared new tan sorghum varieties Niatichama and Tiandougou at 100,000 plants per hectare with CSM388 (check) at the normal 50,000 plants per hectare to assess response to fertilizer rates and use efficiency at Sotuba, Mali. A split-plot design was used with three blocks. Six amounts of fertilizer were main plots and sorghum varieties were subplots. Data collected will be germinated hills before thinning, plant population after thinning and at harvest, biomass at flowering and physiological maturity, and panicle and grain weights at physiological maturity. Table 3

Niatichama and Tiandougou sorghum varieties at 100,000 plants per hectare were compared to CSM388 at 50,000 plants per hectare for early (27 June), intermediate (8 July), and late (18 July) planting dates. Data to be collected at harvest in November are biomass, panicle, and grain weights per variety per date at flowering and physiological maturity.

Plant breeders Abocar O. Toure, Adoulaye G. Diallo, and Niaba Teme made new crosses at IER during the rainy season to assure improvement of breeding stocks through recombination of the best materials. From multi-location evaluation of 30 F2 families, they made single-plant selections to advance by pedigree method. One hundred fourteen F3 and 466 F5 generations were planted and will be evaluated according to maturity group. The early 140 F5 progenies were at Béma and Cinzana. The intermediate 202 F5 progenies were at Sotuba and Kolombada. The late 124 F5 progenies were at Farako and Kita. Thirty F2, 114 F3, and 466 F5 progeny lines were evaluated.

The plant breeders at IER evaluated 35 advanced elite early-maturing varieties in a randomized complete block design at Bema and Cinzana stations in Mali. Each plot was 4 rows 0.75 m apart and 5 m long. Farmers were selected to compare their local checks with 20 early-maturing breeding lines in plots 500 m2 with rows

Table 1.

Variety	Pedigree of variety	Year obtained	Plant height (m)	Range (m)	Cycle (days)	Sensibility to photoperiodism	Yield (kg/ha)	1,000-grain weight (g)
Niatichama	97-SB-F5-DT-150	1997	1.75	1.75-2	110-120	LS	2000	23
Tiandougou	98-SB-F2-78	1998	1.75	1.75-2	120	NS	3000	21
Séguifa	MLS-92-1	1992	2	1.75-2	100	NS	3000	30
Jigiseme	CSM388	1984	3.7	3-4	120-125	S	2500	25

Table 2.

Treatment	Expected plant population per hectare	Harvested plants per hectare	Harvested plant population in % of expected	% of recommended plant population	Grain yield (kg/ha)	% of 0.75 x 0.50 m 2 plants per hill
Density of population (DP)						
0.75 m x 0.50 m 2 plants/hill	53333	42639	80	80	2021	100
0.75 m x 0.50 m 3 plants/hill	79999	60694	76	114	2375	118
0.75 m x 0.25 m 2 plants/hill	106666	56667	53	106	2035	101
0.50 m x 0.40 m 1 plants/hill	50000	21111	42	40	1774	88
0.50 m x 0.40 m 2 plants/hill	100000	42639	43	80	1875	93
0.50 m x 0.40 m 3 plants/hill	150000	54445	36	102	1930	95
Mean		46365.66			2002	
s (ddl = 15)		16469 **			875	
CV		35.51			44	
Variety (V)						
CSM388		53889		101	2611	
Séguifa		49537		93	1644	
Tiandougou		40463		76	2067	
Niatichama		41574		78	1685	
Mean		46366			2002	
s (df = 9)		19054 **			1415	
CV		41			71	
Interaction (DP x V)						
S		8780.26 ns			472	
CV		18.93			23.58	

Table 3.

		PNT	Dolomite		Urea	Potassium sulfate	
		kg/ha	kg/ha	kg/ha	kg/ha	kg/ha	kg/ha
		P2O5	MgO	CaO	N	K2O	S
F1	No fertilizer				0	0	0
F2	200 kg/ha of tricalcic phosphate	54			0	0	0
F3	F2 + 43.5 kg/ha of urea + 300 kg/ha dolomite	54	60	90	20	0	0
F4	F2 + 87 kg/ha of urea + 300 kg/ha dolomite	54	60	90	40	0	0
F5	F2 + 130 kg/ha of urea + 300 kg/ha dolomite	54	60	90	60	0	0
F6	F2 + 87 kg/ha of urea + 300 kg/ha dolomite	54	60	90	40	15	5.4

0.75 m apart and 5 m long. At harvest, the varieties will be evaluated for maturity, yield, agronomic desirability, and food quality..

Agronomically elite medium-maturing varieties and a local check were planted in a randomized complete block design at three locations in the Sudan Zone of Mali. Each plot was 4 rows 0.75 m apart and 5 m long. There were 25 GI and 25 GII entries. Ten medium-maturing breeding lines were compared to a local check used by farmers in plots of six rows 0.75 m apart and 5 m long at Bancoumana, Kafara, and Katibougou. At harvest, maturity, yield, agronomic desirability, and food quality will be evaluated.

Abocar O. Toure, Adoulaye G. Diallo, and Niaba Teme tested agronomically elite late-maturing varieties and local checks in a randomized complete block design at three locations on stations in the North-Guinea Zone of Mali. Each plot was 4 rows 0.75 m apart and 5 m long. Twenty-three breeding lines were compared with three local checks for GI, and 20 breeding lines for GII were compared to two local checks. Seven late-maturing lines were compared to a local check of a farmer at Kita. Each plot had rows 0.75 m apart and 5 m long. At harvest, the cultivars will be evaluated for maturity, yield, agronomic desirability, and food quality.

The plant breeders at IER crossed sorghums to maintain A/B lines and R to A lines for the sorghum hybrid program in Mali. Sewa, Fadda, 97-SB-F5DT-150A*Grinkan, O2-SB-F5DT-12A*02-SB-F4DT-298, and 97-SB-F5DT-150A/B hybrids were grown in isolation on farms at Kirina, Faraba, Samanko, and Sabalibougou to produce seed for testing in the region. The parent sorghums were grown on 1 hectare.

Plant pathologist Mamourou Diourté identified fungal pathogens on stored sorghum grain at three locations in Mali. Sorghum grain stored in November 2008 at Kaniko, Garasso, and Dioila was sampled in February-March 2009. A minimum of 20 samples each of 5 kg per storage facility was taken. One hundred seeds per sample were randomly selected and disinfected with 2% sodium hypochlorite for 15 minutes and rinsed in sterile distilled water. The seeds were spread on PDA and cultures were incubated at 25°C at a photoperiod of 12 hours. After incubation for 48 hours, the mono-emerged colonies were re-isolated and grown on new

Table 4.

Morphological characteristics of fungal species from stored grain of sorghum varieties at three locations in Mali			
Location	**Variety**	**Fungi isolated**	**Colony characteristic on PDA**
Garasso	Grinkan	Fusarium sp.	White cottony
	Grinkan	Aspergillus sp.	Green dark in the center
	Grinkan	Colletotrichum sp.	Gray fluffy
	Grinkan	Curvularia sp.	Gray – clear
Kaniko	Grinkan	Curvularia sp.	Gray – black
	Grinkan	Fusarium sp.	Pink fluffy
	Grinkan	Fusarium sp	Pink-yellow fluffy
	Niatchichama	Colletotrichum sp.	White cottony
Dioila	Niatchichama	Colletotrichum sp.	Pink fluffy
	Niatchichama	Aspergillus sp.	Gray – dark

PDA. The cultures were kept at 3°C. Fungi identified were Colletotrichum sp., Fusarium sp., Curvularia sp., and Aspergillus sp. All species of fungi were isolated from Grinkan sorghum whereas only Colletotrichum and Aspergillus were isolated from Natchichama. Badly stored grain could be subject to contamination by fungal microorganisms some of which like Fusarium sp. cause human cancers, lymphatic diseases, and gastritis. Table 4

Sorghum leaf anthracnose caused by *Colletotrichum graminicola* is the most destructive disease of newly developed varieties at Sotuba, Mali. Dr. Diourté rated the severity of anthracnose in three breeder experiments under natural conditions. Five sorghum hybrids at the milk stage were resistant, while all other varieties were slightly susceptible to anthracnose. Table 5

Entomologist Niamoye Yaro and Péfoungo Konate assisted 20 farmers in evaluating the use of *Andropogon gayanus* to attract stalk borers away from millet at Finkolo and Zanradougou in different agroecological zones with Sudan climate in the Sikasso region of Mali. They also evaluated farmer awareness of the importance of wild grasses and adoption of the intercropping technique. Each farmer intercropped 5 rows 20 m long of a local variety of millet with or without (check) *Andropogon* at 10 m apart. A randomized complete block with each of 10 farmers as a replication was used per village. *Andropogon* plants were transplanted on 6 and 7 July at Finkolo and 8 and 9 July at Zanradougou in rows before millet was planted on 11 July at Finkolo and 12 July at Zanradougou. Damage by stalk borers and head miners on millet spikes was evaluated from planting to tillering and boot to flowering stages. Ten plants of millet and 10 of *Andropogon* were selected randomly from the diagonals of each plot to sample numbers of deadhearts and empty spikelets on 5 and 6 September at Finkolo and 7 and 8 September at Zanradougou. Transplanting coincided with a drought in June and July that killed the grasses, so *Andropogon* was transplanted several times. As a result, millet plants in some plots emerged before and were taller than *Andropogon*. After the drought, rainfall was regular and well distributed, and good results are expected after the millet is harvested. Table 6

Entomologist Hame Abdou Kadi Kadi and millet breeder Issaka Ahmadou assessed at the Regional Agricultural Research Center in Kollo, Niger, damage by millet head miner and yield of 12 pearl millets developed at INRAN. The design was a completely randomized block with three replications. Each sub-plot was 12 m2 with 4 rows 3 m long and 1 m between rows and hills. Five spikes of each genotype per replication were randomly selected and tagged. Five days later and until maturity, spikes were checked for larvae, pre-pupae, and pupae of millet head miner. At maturity, spikes were cut and damage assessed on a 1-9 scale where: 1 = <10, 2 = 11-20, 3 = 21-30, 4 = 31-40, 5 = 41-50, 6 = 51-60, 7 = 61-70, 8 = 71-80, and 9 = >81%. Infested spikes ranged from 24.2 to 62.4% for Tchoumo and SOSAT-C88 and were correlated with damage that ranged from 1.9 for Tchoumo to 4.3 for HKP GMS (20-50% mined spikes). Infested spikes were 38.4 and 40.9% on HKB and Taram (local varieties from Gaya Zone in Dosso); damage was 1.9 and 2.1 (10-30% mined spikes). H80-10GR, SOSAT-C88, and HKP GMS were transferred to farms. The other millets still are being evaluated. Table 7

At Bazaga (Birni N'Konni), Niger, sorghum midge-resistant SSD-35 and its early maturing female parent Mota Maradi were less damaged (1.5 = 10-20% and 3.0 = 20-31% damaged spikelets) and yielded more (862.5 and 737.5 kg ha-1) than local El Mota (4.3 and 587.5 kg ha-1). At the 1st planting at Doguérawa, damage by sorghum midge was 1.0, 3.9, and 2.9, but was 1.3, 3.9, and 2.0 for SSD-35, Mota Maradi, and El Mota at the 2nd planting. SSD-35 yielded 687.5 and 700.0 kg ha-1 from the 1st and 2nd plantings. Yield of Mota Maradi did not differ between the 1st (937.5 kg ha-1) and 2nd plantings (1,000.0 kg ha-1). Yield of El Mota was greater in the 1st (743.8 kg ha-1) than 2nd planting (562.5 kg ha-1). Table 8

In 2009, SSD-35 and Mota Maradi were introduced on farms in seven villages of Birni N'Konni and Madaoua, Niger. Nine extension agents, 20 men and eight women farmers, and the "Taymako" organization of 74 men and six women farmers at Doguéraoua multiplied seed of SSD-35 on 3.5 hectares. SSD-35 was evaluated by 48 farmers and produced by 184 farmers on 67 hectares in two areas of Tahoua, Niger. In six villages, 104 and 67 farmers adopted SSD-35 and Mota Maradi planted on 24 and 16 hectares, respectively. Seed of SSD-35 was multiplied on 43 hectares by 84 farmers from five villages, and Mota Maradi was multiplied on 12 hectares by eight farmers from three villages. In 2008, the two varieties were introduced at farms in five villages of two regions by four extension agents, 16 men and four women farmers, and "Taymako" who did four tests with two planting dates at a site. Farmers and extension agents appreciate SSD-35 that yields well, is resistant to sorghum midge, and has good color grain.

Table 5.

Anthracnose severity index on a sorghum hybrid at the milk grain stage, Sotuba, Mali, 2009		
Sorghum variety	**Disease severity index**	**Plant reaction**
Sewa	2	NS
02-SB-F4DT-12A*04-SB-F5DT-249	2	NS
97-SB-F5DT-150A*03-SB-F5DT-105	2	NS
97-SB-F5DT-150A*Grinkan	2	NS
02-SB-F4DT-12A*02-SB-F5DT-298	2	NS
PR3009A*Latabala	3	SF
02-SB-F4DT-12A*CSM-63E	3	SF
97-SB-F5DT-150A*98-SB-F2-78	3	SF
97-SB-F5DT-150A*MALISOR-84-7	3	SF
97-SB-F5DT-150A*03-SB-F5DT-249	3	SF
97-SB-F5DT-150A* 06-SB-F5DT-15	3	SF
97-SB-F5DT-150A*04-SB-F5DT-203	3	SF
98-SB-F2-82A*04-SB-F5DT-249	3	SF
97-SB-F5DT-150A*02-SB-F5DT-57	3	SF
PR3009A*CSM-63E	4	SF
97-SB-F5DT-150A*Latabala	4	SF
GPNA*Latabala	4	SF
FADA	4	SF
97-SB-F5DT-150A* CSM-63E	4	SF
GRINKAN	4	SF
97-SB-F5DT-150A*07-BE-F5DT-29	4	SF
CSM-63E	4	SF
97-SB-F5DT-150A*07-KO-F5DT-58	4	SF
97-SB-F5DT-150A*05-F5DT-67-1	5	SF
Siguicumbe	5	SF
CSM-388	5	SF
97-SB-F5DT-150A*Malisor-92-1	5	SF
97-SB-F5DT-150A*03-F4T-38	5	SF
GPNA*CSM-63E	5	SF
Malisor-92-1	5	SF
Témoin sensible IS18441	13	SE

NS: not susceptible (2-3), SF: slight susceptibility (3-8); SM: moderate susceptibility (8-13); SE: very susceptible (13-18)

Anthracnose severity index on yield of intermediate-maturing varieties at the milk grain stage		
Sorghum variety	**Disease severity index**	**Plant reaction**
09-KO-F5DT-61	3	SF
09-KO-F5DT-79	3	SF
09-KO-F5DT-19	4	SF
09-KO-F5DT-31	4	SF
09-KO-F5DT-32	4	SF
09-KO-F5DT-33	4	SF
09-KO-F5DT-35	4	SF
09-KO-F5DT-42	4	SF
09-KO-F5DT-45	4	SF
09-SB-F5DT-60	4	SF
09-KO-F5DT-63	4	SF
09-KO-F5DT-70	4	SF
09-SB-F5DT-80	4	SF
09-KO-F5DT-81	4	SF
09-KO-F5DT-107	4	SF
Grinkan	4	SF
Darell-Ken	4	SF
Nieta	4	SF
Témoin	4	SF
09-KO-F5DT-18	5	SF
09-KO-F5DT-47	5	SF
09-KO-F5DT-55	5	SF
Nietiama	5	SF
09-KO-F5DT-92	6	SF
09-KO-F5DT-1	7	SF
Témoin sensible IS18441	13	SE

NS: not susceptible, SF: slight susceptibility, SM: moderate susceptibility, SE: very susceptible

Table 5. cont'd

Anthracnose severity index on yield of intermediate-maturing varieties at the milk grain stage		
Sorghum variety	**Disease severity index**	**Plant reaction**
07-SIR-F5T-7 (TYP Grinkan)	3	SF
07-SIR-F5T-9	3	SF
07- KO-F5DT-44	4	SF
07-KO-F5DT-57	4	SF
07-KO-F5DT-62	4	SF
07-SB-F3DT-169	4	SF
07-SB-F3DT-173	4	SF
07-SB-F3DT-52 CT	4	SF
07-SB-F3DT-64	4	SF
07-SIR-F5T-8	4	SF
Darrell Ken	4	SF
Grinkan	4	SF
Témoin local	4	SF
07-KO-F4DT-28	5	SF
07-KO-F5DT-42	5	SF
07-KO-F5DT-58	5	SF
07-SB-F3DT-52 HT	5	SF
07-SB-F5DT-41	5	SF
CSM-388	5	SF
07-KE-GII T-103	6	SF
07-KO-F5DT-47	6	SF
07-KO-F5DT-78	6	SF
07-SB-F5DT-40	6	SF
07-SB-F3DT-335	7	SF
07-SB-F3DT-55	7	SF
Témoin sensible IS18441	13	SE

NS: not susceptible, SF: slight susceptibility, SM: moderate susceptibility, SE: very susceptible

Table 6.

Village	Farmer	Millet and Andropogon plant heights	Percent infestation by stalk borers: Millet without A. gayanus	Millet with A. gayanus	Andropogon gayanus
Finkolo	Seybou KONE	Same	15.3	8.5	7.0
	Issouf BALLO	Same	9.3	3.5	7.0
	Abdoulaye KONE	Same	5.8	6.1	3.5
	Diakalia BALLO	Same	6.6	6.3	2.1
	Inzan TRAORE	Same	11.5	3.5	9.0
	Abou KONATE	Millet taller	14.5	17.0	3.0
	Lassina BALLO	Same	5.8	4.8	4.5
	Daouda CISSE	Millet taller	15.3	17.2	2.5
	Madou TRAORE	Same	1.5	3.4	3.0
	Amidou DIARRA	Millet taller	5.7	7.8	2.2
Mean			9.1	7.8	4.4
Zanradougou	Adama SANOGO	Same	14.5	6.0	9.3
	Konzié SANOGO	Millet taller	13.7	14.0	0.8
	Daouda DIARRA	Millet taller	8.3	9.3	1.0
	Nouhoum DJOURTHE	Millet taller	5.4	3.7	6.2
	Adama DJOURTHE	Millet taller	12.5	11.0	6.0
	Guédiouma DJOURTHE	Millet taller	6.9	7.1	2.3
	Siaka DJOURTHE	Same	9.3	5.5	5.5
	Abdoulaye DJOURTHE	Same	4.6	1.5	5.4
	Massaba TRAORE	Same	9.5	7.5	4.0
	Tidiani SANOGO	Same	17.0	13.7	9.0
Mean			10.2	7.9	5.0
Overall mean			9.7	7.9	4.7

Table 7.

Millet evaluated at Kollo, Niger	Damage (1-9 scale)	% spikes infested by millet head miner
Tchoumo	1.9 ± 1.0 a	24.2 ± 1.6 a
Mangarana	2.9 ± 2.0 b	28.4 ± 2.2 b
HKB	1.9 ± 1.1 a	38.4 ± 2.1 c
Taram	2.1 ± 1.2 b	40.9 ± 1.5 c
ICMV IS89305	2.2 ± 1.2 b	44.2 ± 2.6 ab
Zatib	2.8 ± 1.9 b	44.9 ± 2.3 ab
Mangarana x ICMV IS89305	2.5 ± 1.4 b	52.8 ± 3.1 bc
SOSAT-C x HKB	2.7 ± 1.3 b	55.6 ± 2.9 bc
H80-10 GR	2.8 ± 1.4 b	57.3 ± 1.3 abc
HKP GMS	4.3 ± 2.7 c	58.1 ± 1.7 abc
SOSAT-C 88 x Zatib	3.1 ± 1.5 ab	59.7 ± 3.3 abc
SOSAT-C88	3.8 ± 2.2 ab	62.4 ± 3.8 cd
CV (%)	2.8	47.2
LSD	2.5	52.3

Table 8.

	Damage by sorghum midge (1-9)			Yield (kg ha-1)		
Sorghum	Bazaga	1st planting, Doguérawa,	2nd planting, Doguérawa,	Bazaga	1st planting, Doguérawa,	2nd planting, Doguérawa,
SSD-35	1.5 ± 0.3c	1.0 ± 0.1c	1.3 ± 0.3a	862.5 ± 13.6a	687.5 ± 9.7a	700.0 ± 12.3b
Mota Maradi	3.0 ± 0.4b	3.9 ± 0.4c	3.6 ± 0.3b	737.5 ± 14.7b	937.5 ± 17.3c	1,000.0 ± 7.9c
El Mota (check)	4.3 ± 0.7a	2.9 ± 0.7b	2.0 ± 0.6c	587.5 ± 10.9c	743.8 ± 12.4b	562.5 ± 10.5a
CV (%)	35.5	43.2	36.8	48.6	39.7	45.4
LSD	1.5	1.9	0.3	139.0	193.7	137.5

"Increasing Farmers' and Processors' Incomes via Improvement in Sorghum and Pearl Millet Production, Processing and Marketing Systems" Project – Processing and Marketing

Food scientist Iro Nkama and millet breeder Ignatius Angarawai worked with food scientists Amina Jato and Hadiza Lawan, agricultural process engineer N. A. Aviara, poultry scientist J. Igwebuike, economist Binta Zangoma, and technologist Shuwa Mohammed at the University of Maiduguri in Nigeria, food scientist Mohammed Diarra from the Institut d' Economie Rurale in Mali, food scientist Bruce Hamaker from Purdue University, and animal scientist Joe Hancock from Kansas State University to analyze physical, chemical, and end-use quality properties of sorghum, millet, and acha (fonio) grown locally and from Lake Chad Research Institute, Institute for Agricultural Research, and ICRISAT. Traditional foods and new products (couscous, extruded fura, weaning foods and biscuits) were prepared to test the quality of the grain samples. Malting properties of some varieties were evaluated.

Performance of broiler chicks fed sorghum ground to different particle sizes was compared to maize as a source of energy. The effect of tray and sun drying on properties of ogi from millet, sorghum, and maize was studied. The viscosity of cooked paste decreased as the shear rate increased and decreased as temperature increased. Data generated were fitted to the power law equation and Arrhenius equation and the consistency index (k), power law index (n), and activation energy determined. All ogi samples were non-Newtonian based on the power law index that ranged from 0.14-0.33. Activation energy of the ogi samples ranged from 0.230-1.382. The drying method did not affect the properties of the ogi samples. Drying curves were generated from the drying data.

Food scientist Boniface Bougouma from Burkina Faso characterized sorghum and millet to identify suitable varieties for breads, biscuits, and dolo. A malting and brewing survey is being summarized and parameters of dolo characterized. Samples for Ouagadougou were analyzed and GC methods for alcohol, sugar, and organic acids are being set up. Table 9

The pilot plant of the research institute DTA Technopol and bakeries and breweries in Burkina Faso were used to teach new technologies for bread, biscuits, and dolo. Training sessions were held on new technologies for dolo based on a gas-improved fire box and optimized brewing process. The new technology saved 36% energy, increased brewing yield 20%, and improved dolo quality.

Food scientists Ababacar N'Doye, Ndeye Thi Thi Seye Ndoumouya, and Momar Talla Gueye, technologist Ibra Mbaye, bakers Jean Paul Diedhiou and Oscar Sambou, and nutritionist Ndeye Fatou Ndiaye from the Institut de Technologie Alimentaire, Dakar, Sénégal, food scientist Ndeye Thi Thi Seye Ndoumouya from the University of Maiduguri, and food scientist Bruce Hamaker from Purdue University focused activities in Senegal on market promotion of composite flour bread using millet, sorghum, or maize mixed with wheat; development of an economic millet/maize couscous prepared from grits instead of flour; implementing a new couscous line for preparation of new economical couscous; collaborating with Morgan Goodall on a baking test of the sorghum mutant; and training a bakers' corporation and women's group to prepare composite flour bread.

An economical millet/maize couscous was prepared from grits instead of flour in the traditional process. Couscous was prepared from thin particles (sankhal) of millet and corn. The couscous was subjected to sensory tests in comparison with a couscous sample bought from a local market (the blank). To prepare couscous, 1.5 kg of sankhal was soaked or dipped in water and the behavior of the two products assessed. The method in the project of ROCAFREMI was used by a panel of 50 tasters to assess color, taste, texture, size of granules, and acceptability of millet and corn products. The three samples (blank, couscous from soaking, and couscous from dipping process) were separated, coded randomly, and presented to tasters in disposable dishes. Tasters graded the products on a scale from 1 (very bad) to 5 (very good). Soaked sankhal of millet required less water for cooking than did dipped sankhal of millet. But, dipped sankhal of corn required less water than did soaked corn. Table 10

Color, size of granules, taste, and acceptability of soaked or dipped couscous from millet were significantly less preferred than those of the blank from the local market in Senegal. But, the texture of the blank and soaked sankhal did not differ. Samples of sankhal could be used to produce "thiakry" considering the size of the granules would be suitable for that kind of product. Table 11

The three samples of corn differed significantly in color, size of granules, texture, and acceptability but not taste between the blank and soaked sankhal. Table 12

A project on implementation for millet/maize couscous preparation was supported by a regional World Bank program called "West African Agricultural Productivity Programme' that allocated to ITA money to complete the couscous line using the agglomerator developed by ITA.

Table 9.

Chemical characteristics of dolo				
Sample	pH	d20/20	Acidity (mg eq lactic acid/l)	% alcohol
Enzymic extract	5.03 ± 0.12		2.99 ± 0.11	
Acidified wort	3.82 ± 0.14	1.0346 ± 0.0092	6.59 ± 0.07	
Concentrated wort	3.78 ± 0.15	1.0427 ± 0.0053	7.04 ± 0.11	
Dolo	3.56 ± 0.18	1.0183 ± 0.0110	7.59 ± 2.38	2.01 ± 1.01

Table 10.

Cooking tests of samples from dipped thin particles (sankhal) of millet and corn			
Behavior	Dipped millet (minutes)	Soaked corn (minutes)	
Time of dipping	30	30	
Time for draining	53	13	
Time of cooking	81	44	

Cooking tests of samples from soaked thin particles (sankhal) of millet and corn			
Behavior		Soaked millet	Soaked corn
Before cooking	Amount of water (ml)	670	600
	Time of absorption (minutes)	31	48
During cooking	Amount of added water	830	1,400
Total time of cooking (minutes)		31	82
Total amount of water used (ml)		1,500	2,000

Table 11.

Millet sample	**Color**	**Size of granules**	**Texture**	**Taste**	**Acceptability**
Blank	4.26 ± 0.93a	3.96 ± 0.96a	3.80 ± 0.98ab	3.90 ± 0.98a	3.98 ± 0.88a
Soaked sankhal	3.54 ± 0.94b	3.50 ± 0.85b	3.64 ± 0.91ab	3.44 ± 1.00b	3.44 ± 1.02b
Dipped sankhal	3.22 ± 1.12b	3.34 ± 0.93b	3.38 ± 1.04c	3.06 ± 1.01b	3.36 ± 1.05b

Means followed by the same letter in a column are not statistically different by the Student-Newman-Keuls test.

Table 12.

Corn sample	**Color**	**Size of granules**	**Texture**	**Taste**	**Acceptability**
Blank	4.50 ± 0.74a	4.34 ± 0.75a	4.32 ± 0.71a	4.36 ± 0.90ab	4.50 ± 0.74a
Soaked sankhal	3.86 ± 1.14b	3.88 ± 0.96b	3.86 ± 0.89b	4.02 ± 1.04ab	4.06 ± 0.96b
Dipped sankhal	3.22 ± 1.04c	3.20 ± 0.95c	3.02 ± 1.00c	3.02 ± 0.98c	3.24 ± 1.02c

Means followed by the same letter in a column are not statistically different by a Student-Newman-Keuls test.

Figure 1. INTSORMIL/INRAN PIs Moustapha Moussa, Soumana Souley, Hame Kadi Kadi, and Seyni Sirifi; Salami Issoufou, head of INRAN research station; Manzo Moussa, staff; and Haladou Salha, technician for entomology, ICRISAT-Niger discussing research to be done in 2008 at Birni N'Konni, Niger

Figure 2. Part of the pilot plant being set.

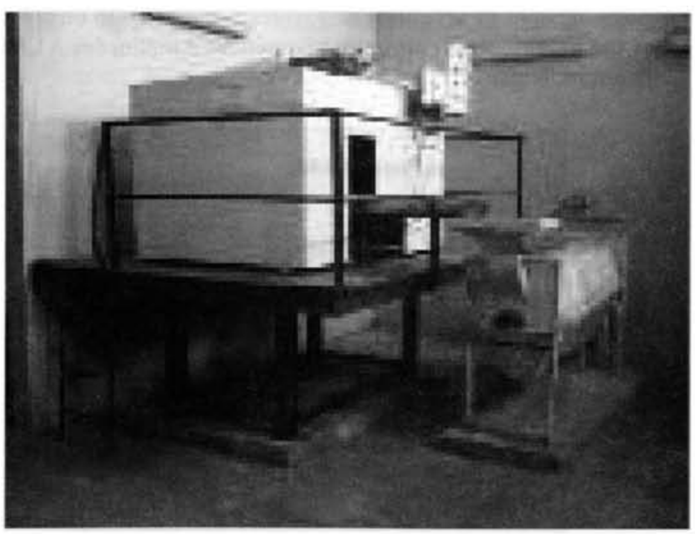

Figure 3. Training to prepare composite flour bread from 85% wheat and 15% millet or maize for market testing by ITA in Senegal.

Figure 4. Bagged seeds of sorghum midge-resistant SSD-35 on store shelves of the private seed company "Semences Améliorées ALHERI", Doutchi, Niger.

Educational Activities

INTSORMIL

Educational Activities

INTSORMIL gives high priority to training host country scientists who will have major responsibilities for sorghum and millet research in their home countries. Training is also provided for young U.S. scientists who plan for careers in international development work.

The most frequently used mode of training is graduate study for advanced degrees, with the students' research forming an integral part of an INTSORMIL project. During the years covered by this report, 40 students were enrolled in an INTSORMIL advanced degree program. Approximately 73% of these students come from countries other than the U.S. which shows the emphasis placed on host country institutional development (Figure 1).

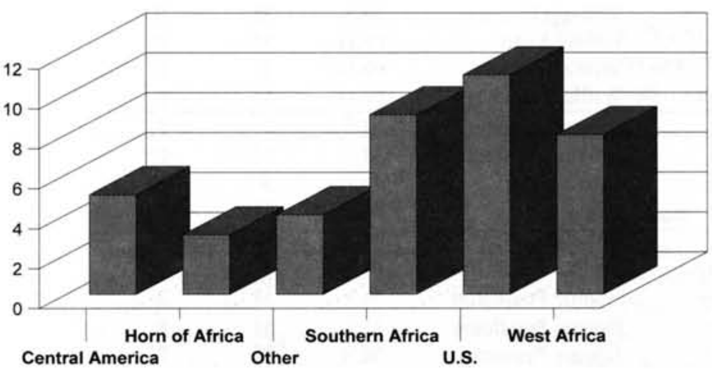

Figure 1. Degree Participants by Region

INTSORMIL also places a high priority on training women which is reflected in Figure 2. From 2008-2009, 48% of all INTSORMIL graduate participants were female. Thirty-seven of the 40 students received partial INTSORMIL funding and 3 received full INTSORMIL scholarships.

All 40 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.

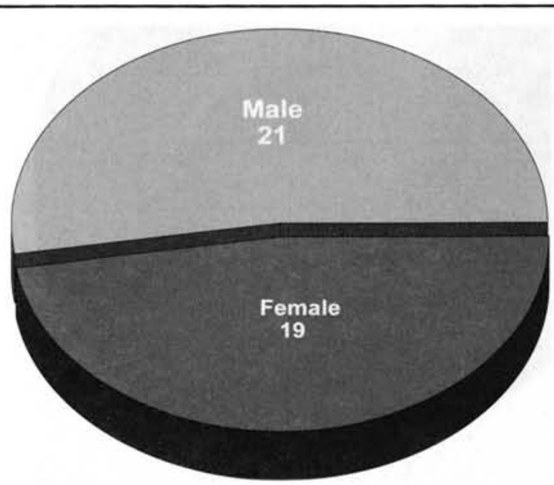

Figure 2. Degree Participants by Gender

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 2008-2009 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. Two postdoctoral scientists and 8 visiting host country scientists were provided the opportunity to upgrade their skills in this fashion from 2008-2009.

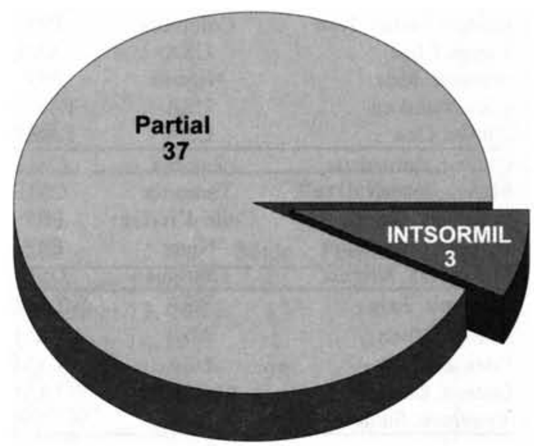

Figure 3. Degree Participants Funding

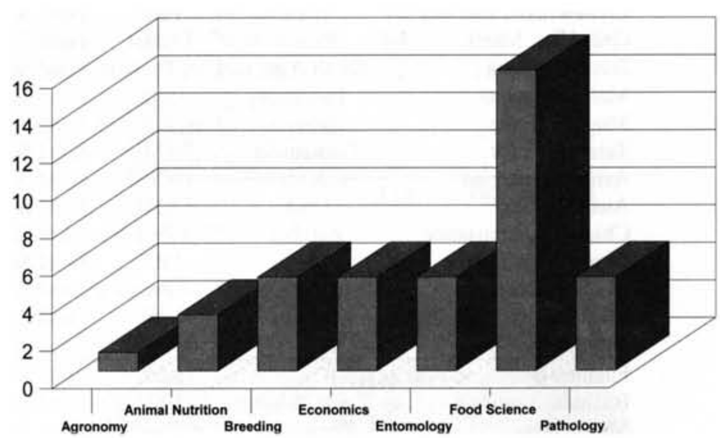

Figure 4. Degree Participants by Discipline

Year 3 INTSORMIL Degree Training Participants September 30, 2008 – September 29, 2009

Name	Country	Univ.	Discipline	Advisor	Degree	Gender	Funding
Abunyewa, Akwasi	Ghana	UNL	Agronomy	Charles Wortmann	Ph.D.	M	P
Paulik, Chad	USA	KSU	Animal Nutrition	Joe Hancock	M.S.	M	P
Feoli, Carolina	Costa Rica	KSU	Animal Nutrition	Joe Hancock	Ph.D.	F	P
Issa, Salissou	Niger	KSU	Animal Nutrition	Joe Hancock	Ph.D.	M	I
Barrero Farfan, Ivan	Colombia	PRF	Breeding	Mitch Tuinstra	M.S.	M	P
Hayes, Chad	USA	TAMU	Breeding	William Rooney	M.S.	M	P
Amusan, Idris	Nigeria	PRF	Breeding	Gebisa Ejeta	Ph.D.	M	P
Corn, Rebecca	USA	TAMU	Breeding	William Rooney	Ph.D.	F	P
Packer, Dan	USA	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
Coulibaly, Jeanne	Coite d'Ivoire	PRF	Economics	John Sanders	Ph.D.	F	P
Ibrahim, Abdoulaye	Niger	PRF	Economics	John Sanders	Ph.D.	M	P
Makindara, Jeremia	Tanzania	OSU	Economics	Erbaugh/Larson	Ph.D.	M	P
Gilchrest, Jody	USA	WTAMU	Entomology	Bonnie Pendleton	B.S.	F	P
Diarra, Drissa	Mali	WTAMU	Entomology	Bonnie Pendleton	M.S.	M	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
Boswell, Sara	USA	TAMU	Food Science	Lloyd Rooney	M.S.	F	P
Cardenas, Ana	Mexico	TAMU	Food Science	Lloyd Rooney	M.S.	F	P
Chiremba, Constance	Zambia	TAMU	Food Science	John Taylor	M.S.	F	P
Cholewinski, Jennifer	USA	PRF	Food Science	Bruce Hamaker	M.S.	F	P
Gritsenko, Maria	Russia	TAMU	Food Science	Lloyd Rooney	M.S.	F	P
Jacobs, Helena	South Africa	U of Pretoria	Food Science	John Taylor	M.S.	F	P
Mella, Onesmo	Tanzania	UNL	Food Science	David Jackson	M.S.	M	I
Mugode, Luke	Zambia	U of Pretoria	Food Science	John Taylor	M.S.	M	P
Taleon, Victor	Guatemala	TAMU	Food Science	Lloyd Rooney	M.S.	M	P
Asif, Muhammad	Pakistan	TAMU	Food Science	Lloyd Rooney	Ph.D.	M	P
Austin, Dilek	USA	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
Njongmeta, Nenge	Cameroon	TAMU	Food Science	Lloyd Rooney	Ph.D.	F	P
Fuentes-Bueno, Irazeuma	USA	KSU	Plant Pathology	John Leslie	M.S.	F	P
Bushula, Vuyiswa	South Africa	KSU	Plant Pathology	John Leslie	Ph.D.	F	P
Mpofu, Leo	Zimbabwe	U of Free State	Plant Pathology	Neil McLaren	Ph.D.	M	P
Nor, Nik	Malaysia	KSU	Plant Pathology	John Leslie	Ph.D.	M	P
Schafert, Caitlin	USA	KSU	Plant Pathology	John Leslie	Ph.D.	F	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 3 INTSORMIL Non-Degree Training Participants September 30, 2008 – September 29, 2009

Name	Country	Univ.	Discipline	Advisor	Activity	Gender	Funding
Mutwale, Mercy Nkumbu	Zambia	UNL	Agronomy	Wortmann	VS	F	P
Dighe, Nilesh	India	TAMU	Breeding	Rooney, W	PD	M	P
Hien Yeri, Esther	Burkina Faso		Food Science	Bougouma	VS	F	P
Hoang, Kim	USA	TAMU	Food Science	Rooney, L	VS	F	P
Rodriguez, Alecia	El Salvador	TAMU	Food Science	Rooney, L	VS	F	P
Saleh, Amgad	Egypt	KSU	Plant Pathology	Leslie	PD	M	P
Hachibamba, Twambo	Zambia	KSU	Plant Pathology	Leslie	VS	F	P
Manani, Tinna	Malawi	KSU	Plant Pathology	Leslie	VS	F	P
Postic, Jelena	Croatia	KSU	Plant Pathology	Leslie	VS	F	P
Tok, Faith	Turkey	KSU	Plant Pathology	Leslie	VS	M	P

VS = Visiting Scientist PD = Post Doctoral

Year 3 INTSORMIL Conference/Workshop Activities September 30, 2008– September 29, 2009

Name	Location	Date	Participants Male	Female	Total
Scientific Writing Workshop	Various	November 2, 2008	54	42	96
Scientific Writing Workshop II	South Africa	November 13, 2008	17	19	36
Camilo Garzon	Nevada	November 16-19,	1	0	1
Scientific Writing Workshop	Korea	January 15, 2009	98	117	215
Zachary Eder	Oklahoma	February 23-26,	1	0	1
Camilo Garzon	Oklahoma	February 23-26,	1	0	1
Scientific Writing Workshop	Brazil	April 3, 2009	22	24	46
Scientific Writing Workshop	Brazil	April 6, 2009	22	25	47
Tropical Fusarium Workshop	Brazil	April 7-10, 2009	18	14	32
Scientific Writing Workshop	Various	June 2, 2009	94	124	218
Fusarium Laboratory Workshop	Kansas	June 21-26, 2009	12	16	28
Zachary Eder	Texas	August 10-12, 2009	1	0	1
Suhas Vyavhare	Texas	August 10-12, 2009	1	0	1
Jody Gilchrest	Texas	August 10-12, 2009	0	1	1
TOTAL			**342**	**382**	**724**

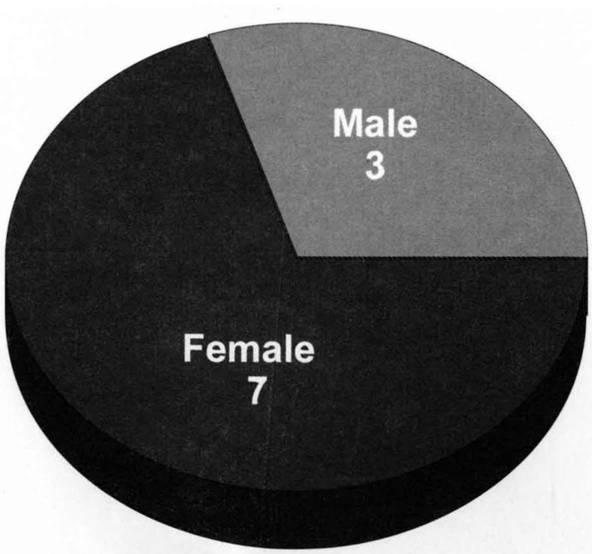

Figure 5. Total Non-Degree Participants by Gender

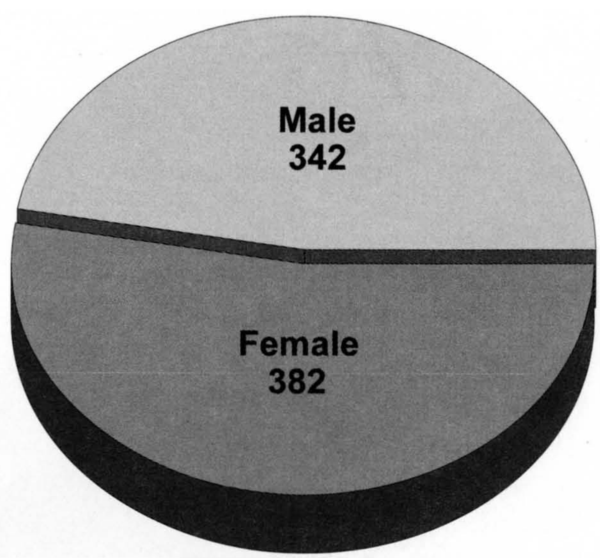

Figure 6. Total Conference/Workshop Participants by Gender

Appendices

INTSORMIL

INTSORMIL Sponsored and Co-Sponsored Workshops 2006-2009

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

Acronyms

AAA/SFAA	American Anthropological Association/Society for Applied Anthropology
ABA	Abscisic Acid
ADC's	Advanced Developing Countries
ADIN	All Disease and Insect Nursery
ADRA	Adventist Development and Relief Agency
AFLP	Amplified Fragment Length Polymorphisms
AID	Agency for International Development
AID/H	Agency for International Development in Honduras
ALDEP	Arable Lands Development Program
AMEDD	Association Malienne d'Eveil Au Développement
ANOVA	Analysis of Variance
ANPROSOR	Nicaraguan Grain Sorghum Producers Association
APHIS	Animal and Plant Health Inspection Service, U.S.
ARC	Agricultural Research Corporation, Sudan
ARC	Agriculture Research Council, South Africa
ARGN	Anthracnose Resistant Germplasm Nursery
ARS	Agricultural Research Service
ASA	American Society of Agronomy
ASARECA	Association for Strengthening Agricultural Research in Eastern and Central Africa
ATIP	Agricultural Technology Improvement Project
AVES	Associación de Avicultores de El Salvador
BAMB	Botswana Agricultural Marketing Board
BIFAD	Board for International Food and Agricultural Development
BFTC	Botswana Food Technology Centre
CARE	Cooperative for American Remittances to Europe, Inc.
CARO	Chief Agricultural Research Officer
CARS	Central Agricultural Research Station, Kenya

CATIE	Centro Agronómico Tropical de Investigación y EnseZanza, Costa Rica
CEDA	Centro de EnseZanza y Adiestramiento, SRN, Honduras
CEDIA	Agricultural Document and Information Center, Honduras
CENTA	Centro Nacional de Technologia Agropecuaria y Forestal, El Salvador
CFTRI	Central Food Technological Research Institute, India
CGIAR	Consultative Group on International Agricultural Research
CIAB	Agricultural Research Center of the Lowlands, Mexico
CICP	Consortium for International Crop Protection
CIDA	Canadian International Development Agency
CIAT	International Center for Tropical Agriculture, Colombia
CILSS	Interstate Committee to Combat Drought in the Sahel
CIMAR	Centro de Investigación en Ciencias del Mar y Limnologia, Costa Rica
CIMMYT	International Maize and Wheat Improvement Center
CIRAD	Centre International en recherche Agronomique pour le Développement
CITESGRAN	Centro Internacional de Tecnologia de Semilla y Granos, EAP in Honduras
CLAIS	Comisión Latinoamericana de Investigadores en Sorgho
CMS	Cytoplasmic Male-Sterility System
CNIA	Centro Nacional de Investigaciones Agricoles, Nicaragua
CNPQ	Conselo Nacional de Desenvolvimento Cientifico e Tecnologico
CNRA	National Center for Agricultural Research, Senegal
CORASUR	Consolidated Agrarian Reform in the South, Belgium
CRSP	Collaborative Research Support Program
CSIR	Council for Scientific and Industrial Research
CSIRO	Commonwealth Scientific and Industrial Research Organization, Australia
DAR	Department of Agricultural Research, Botswana
DARE	Division of Agricultural Research and Extension, Eritrea
DICTA	Dirección de Ciencia y Tecnologia Agricola, Mexico
DR	Dominican Republic
DRA	Division de la Recherche Agronomique, IER Mali

DRI-Yoro	Integrated Rural Development Project, Honduras-Switzerland
EAGA	Extended Agar Gel Assay
EAP	Escuela Agricola Panamericana, Honduras
EAVN	Extended Anthracnose Virulence Nursery
EIAR	Ethiopian Institute for Agricultural Research
EWA	Austrian NGO
ECARSAM	East Central Africa Regional Sorghum and Millet
ECHO	Educational Concerns for Hunger Organization
EEC	Euorpean Economic Community
EEP	External Evaluation Panel
EIME	Ensayo Internacional de los Maicillos Enanos
ELISA	Enzyme-linked Immunosorbent Assay
EMBRAPA	Empresa Brasileira de Pesquisa Agropecuaria, Brazil
EMBRAPA-CNPMS	EMBRAPA - Centro Nacional para Maize e Sorgo
ENA	National School of Agriculture, Honduras
EPIC	Erosion Productivity Impact Calculator
ERS/IEC	Economic Research Service/International Economic Development
ESBESA	Escobar Betancourt S.A.
EZC	Ecogeographic Zone Council
FAO	Food and Agriculture Organization of the United States
FDS	Fonds de Développement pour la Solidarité
FENALCE	Federación Nacional de Cultivadores de Cereales
FHIA	Fundación Hondureña de Investigación Agricola, Honduras
FPX	Federation of Agricultural and Agro-Industrial Producers and Exporters
FSR	Farming Systems Research
FSR/E	Farming Systems Research/Extension
FUNDESYRAM	Fundación Para E Desarrollo Socio-Económico y Restauración Ambiental
FUNPROCOOP	Fundación Promotora de Coopertivas
GART	Golden Valley Agricultural Research Trust
GASGA	Group for Assistance on Systems Relating to Grain after Harvest

GMB	Grain Marketing Board
GOB	Government of Botswana
GOH	Government of Honduras
GRADECOM	Groupe de Recherche et d'Action pour le Développement Communautaires
GTZ	German Agency for Technical Cooperation
GWT	Uniform Nursery for Grain Mold
HIAH	Honduran Institute of Anthropology and History
HOA	Horn of Africa
HPLC	High Pressur Liquid Chromatography
HR	Hypersensitive Response
IAN	Institute Agronomia Nacional, Paraguay
IANR	Institute of Agriculture and Natural Resources, University of Nebraska, Lincoln
IARC	International Agriculture Research Center
IBSNAT	International Benchmark Soils Network for Agrotechnology Transfer
ICA	Instituto Colombiano Agropecuario/Colombian Agricultural Institute
ICAR	Indian Council of Agricultural Research
ICARDA	International Centre for Agricultural Research in the Dry Areas
ICC	International Association for Cereal Chemistry
ICRISAT	International Crops Research Institute for the Semiarid Tropics
ICTA	Instituto de Ciencias y Technologia Agricolas, Guatemala
IDIAP	Agricultural Research Institute of Panama
IDIN	International Disease and Insect Nursery
IDRC	International Development Research Center
IER	Institute of Rural Economy, Mali
IFAD	International Fund for Agricultural Development, Rome
IFPRI	International Food Policy Research Institute
IFSAT	International Food Sorghum Adaptation Trial
IGAD	Intergovernmental Authority on Development
IHAH	Instituto HondureZo de Antropologia e Historia

IICA	Instituto Interamericano de Cooperación para la Agricultura
IIMYT	International Improved Maicillo Yield Trial
IITA	International Institute of Tropical Agricultura
ILRA	International Livestock Research Institute, Niger
INCAP	Instituo de Nutrición de Centro America y Panama
INERA	Institut d'Environnement et de Recherche Agricoles
INFOP	National Institute for Professional Development
INIA	Instituto Nacional de Investigaciónes Agricoles, Mexico
INIAP	National Agricultural Research Institute, Ecuador
INIFAP	Instituto Nacional de Investigaciones Forestales y Agropecuarias, Mexico
INIPA	National Agricultural Research Institute, Peru
INRAN	Institut National de Recherches Agronomiques du Niger
INTA	Instito Nicaragüense de Tecnologia Agropecuaria, Nicaragua
INTSORMIL	International Sorghum/Millet, Collaborative Research Support Program (CRSP)
IPA	Instituto de Pesquisas Agronómicas, Brazil
IPIA	International Programs in Agriculture, Purdue University
IPM	Integrated Pest Management
IPR	Intellectual Property Rights
IRAT	Institute of Tropical Agriculture and Food Crop Research
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

IER AGRONOMIST, Abdoul Wahab Toure, INTSORMIL Décrue Sorghum Project Coordinator with student assistants from the Institut Rural de Katibougou (Mamadou Sanogo, left and Ibrahim Toure, right) who are conducting studies in the Lake Faguibine area near Tomboctou, Mali.

Ibrahim Toure preparing a décrue sorghum field experiment in the Lake Faguibine area near Tomboctou, Mali as the flood water recedes at the end of the rainy season.

Funding support through the
Agency for International Development

Leader with Associates
Cooperative Agreement

EEP-A-00-06-00016-00

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