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Introduction and Program Review

The 2005 INTSORMIL Annual Report presents the progress and notable achievements by the Sorghum/Millet CRSP during the period of July 1, 2004 - June 30, 2005. These results are an outcome of partnerships between scientists at six U.S. Land Grant Universities (Kansas State University, Mississippi State University, University of Nebraska, Purdue University, Texas A&M University and West Texas A&M University) and scientists of the Agricultural Research Service of the U.S. Department of Agriculture at Tifton, Georgia and National Agricultural Research Systems (NARS) and National Universities in nineteen countries in Central America, West Africa, East Africa and Southern Africa.

Agricultural research provides benefits not only to producers of agricultural products but also to processors and consumers of agricultural products. Agricultural research has proven itself continuously in providing improved products of greater quantity and quality, as well as improved health to consumers and broad-based economic growth which goes beyond producers and consumers.

The Sorghum and Millet Collaborative Research Support Program (INTSORMIL CRSP) conducts collaborative research using partnerships between 18 U.S. university scientists and scientists of the National Agricultural Research Systems (NARS), IARCs, NGO/PVOs and other CRSPs. INTSORMIL is programmatically organized for efficient and effective operation and captures most of the public research expertise on sorghum and pearl millet in the United States. *The INTSORMIL mission is to use collaborative research as a mechanism to develop human and institutional research capabilities to overcome constraints to sorghum and millet production, marketing and utilization for the mutual benefit of the Less Developed Countries (LDCs) and the U.S.* Collaborating scientists in NARS of collaborating developing countries and the U.S. jointly plan and execute research that mutually benefits all participating countries, including the United States.

INTSORMIL takes a regional approach to sorghum and millet research in western, eastern, and southern Africa, and in Central America. INTSORMIL focuses resources in the four regions supporting the general goals of building NARS institutional capabilities, creating human and technological capital to solve problems constraining sorghum and millet production, marketing and utilization. INTSORMIL's activities are aimed at achieving sustainable, global impact, promoting economic growth, enhancing food security, and encouraging entrepreneurial activities.

INTSORMIL continues to contribute to the transformation of sorghum and pearl millet from subsistence crops to value-added, cash crops. Because sorghum and millet are

important food crops in moisture-stressed regions of the world, they are staple crops for millions in Africa and Asia, and, in their area of adaptation, sorghum and millet have a distinctly competitive advantage to yield more grain than other cereals. As wheat and rice products have been introduced to urban populations in developing countries, traditional types of sorghum, because of some quality characteristics, have not been able to effectively compete. However, as a result of research by INTSORMIL researchers and others, improved, food-quality sorghums produce grain that can be used for special ethnic and dietary products as well as for traditional food products. Special white sorghums developed by INTSORMIL collaborative research in Mali have improved characteristics which allow preparation of high-value food products made of as much as 100% sorghum which can compete successfully with wheat and rice products in village and urban markets. Couscous made from food-quality, hybrid sorghum developed with INTSORMIL support has been market tested in Niger. 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 in Central and South America. Pearl millet is also becoming an important feed source in poultry feeds in the southeastern United States. Improved varieties and hybrids of pearl millet, like improved lines of sorghum, can be grown in developing countries, as well as the United States, and have great potential for processing into high-value food products which can be sold in villages and urban markets, competing successfully with imported wheat and rice products. In the U.S. pearl millet is also finding a place in niche markets, i.e., heads of pearl millet for bird food and for floral arrangements. These emerging markets for sorghum and pearl millet are results of the training and collaborative, international scientific research that INTSORMIL has supported both in the United States and collaborating countries.

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

INTSORMIL maintains a flexible approach to accomplishing its mission. The success of the INTSORMIL program 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 do research on sorghum and millet, development of international, collaborative research networks, promoting and linking to technology transfer and dissemination of technologies developed by research, and enhancing national, regional, and global communication linkages. *INTSORMIL provides essential support to bridge gaps between developing countries and the United States.* A major innovative aspect of the INTSORMIL program is to maintain continuing relationships with scientists of collaborating countries upon return to their research posts in their countries. They become members of research teams of 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. Thus, INTSORMIL promotes conserving millet and sorghum germplasm, conserving natural control of arthropod pests and diseases of sorghum and millet, developing resource-efficient cropping systems, developing integrated pest management strategies, developing cultivars with improved nutrient and water use efficiencies, and evaluating impacts of sorghum/millet technologies on natural resources and biodiversity.

Developing research systems: Collaboration in the regional sites in countries other than the United States has been strengthened by using multi-disciplinary research teams composed of American and NARS scientists focused on unified plans to achieve common objectives. INTSORMIL scientists provide global leadership in biotechnology research on sorghum and pearl millet. The outputs from these disciplinary areas of research are linked to immediate results. INTSORMIL uses both traditional science of proven value and newer disciplines such as molecular biology in an integrated approach to provide products of research with economic potential. These research products which alleviate constraints to production and utilization of sorghum and pearl millet are key elements in fighting hunger and poverty by providing means for economic growth, generation of wealth, and improved health. New technolo-

gies developed by INTSORMIL collaborative research are extended to farmers' fields and to processors and marketers of sorghum and millet products in developing countries and the United States through partnerships with NGOs, research networks, extension services and the private sector. In addition, economic analysis by INTSORMIL researchers plays a crucial role by enabling economic policymakers to more intelligently consider policy options to help increase the benefits and competitiveness of sorghum and pearl millet as basic food staples and as components of value-added products.

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

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

The INTSORMIL program addresses the continuing need for development of technologies for agricultural production, processing and utilization of sorghum and pearl millet for both the developing world, especially in the semi-arid 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 the ownership of their development strategies, while at the same time resulting in significant benefits to the U.S. agricultural sector. These aspects of INTSORMIL present a win-win situation for international agricultural development, strengthening developing countries' abilities to solve their problems in the agricultural sector while providing benefits to the United States.

Administration and Management

The University of Nebraska (UNL) hosts the Management Entity (ME) for the Sorghum/Millet CRSP and is the primary grantee of USAID. UNL subgrants are made to the participating U.S. universities and USDA/ARS for the research projects between U.S. scientists and their collaborating country counterparts. A portion of the project funds, managed by the ME and U.S. participating institutions, supports regional research activities. The Board of Directors (BOD) of the CRSP serves as the top management/policy body for the CRSP. The Technical Committee (TC), External Evaluation Panel (EEP) and USAID personnel advise and guide the ME and the Board in areas of policy, technical aspects, collaborating country coordination, budget management, and review.

Education

During Year 26, 2004-2005, there were 62 students from 23 different countries enrolled in an INTSORMIL advanced degree program and advised by an INTSORMIL principal investigator. Approximately 69% of these students came from countries other than the U.S. The number of students receiving 100% funding by INTSORMIL in 2004-2005 totaled 13. An additional 45 students received partial funding from INTSORMIL and the remaining four students were funded from inter-CRSP activities. INTSORMIL places high priority on training of women. In 2004-2005, 29% 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 Year 26, eleven scientists improved their education as either postdoctoral scientists (1) or visiting scientists (10).

Their research activities were in the disciplines of agronomy, plant breeding, economics, food science and animal nutrition research. These scientists came to the United States as postdoctoral scientists or visiting scientists from El Salvador, Ethiopia, Ghana, Mali, Morocco, Namibia, Nicaragua, and Niger. In addition to non-degree research activities there were 334 participants (228 male and 106 female) who were supported by INTSORMIL for participation in workshops/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 the 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), promote germplasm and information exchange, and facilitate impact evaluation of new technologies.
- Develops regional research networks, short-term and degree training plans for sorghum and pearl millet scientists.
- Over the years, established networking activities have been accomplished with ICRISAT in India, Mali, Niger, Central America and Zimbabwe, SAFGRAD, WCASRN/ROCARS, WCAMRN/ROCAFREMI, ASARECA, ECARSAM and SMIP/SMINET in Africa, CLAIS and CIAT of Central and South America and SICNA and the U.S. National Grain Sorghum Producers Association for the purpose of coordinating research activities to avoid duplication of effort and to promote the most effective expenditures of research dollars. There also has been efficient collaboration with each of these programs in co-sponsoring workshops and conferences, and for coordination of research and long-term training. INTSORMIL currently cooperates with the ICRISAT programs in East/Southern Africa and West Africa. In 2004 and 2005 INTSORMIL has been executing a Marketing-Processing Project funded by the USAID West Africa Regional Program (WARP) which focuses on responding to emerging market demand with improvements in the supply of consistent, quality grain of sorghum and pearl millet. Initial activities (2002-2004 supported by INTSORMIL) consisted of making contracts between farmers' groups and the rapidly grow-

ing sector of millet food processors (couscous, arraw, degue, sankal, tchakri, and yogurt with tchakri) in four countries of the Sahel (Senegal, Mali, Burkina Faso, and Niger). INTSORMIL will continue to promote free exchange of germplasm, technical information, improved technology, and research techniques.

Regional Activities and Benefits

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

The West Africa Regional Program now encompasses six countries of the Sahelian region – Burkina Faso, Ghana, Mali, Niger, Nigeria, and Senegal - following the merger of the INTSORMIL West Africa Eastern (Niger, Burkina Faso, Nigeria) and Western (Mali, Senegal and Ghana) Regional programs in July 2004. Core institution-building programs have existed in Mali (1984) and Niger (1983), and since 2000 a regionalization effort extended INTSORMIL collaborative research projects to the remaining four countries. In April 2004, a workshop was held in Ouagadougou, Burkina Faso for the purpose of regional strategic planning and implementation of the merger. INTSORMIL host country PIs and nine U.S. PIs, as well as select administrative staff, attended the three day meeting. Progress summaries from each country were presented and strategies and work plans for country and regional programs were developed. Additionally, two new regional projects were identified through a group prioritization process in crop utilization and technology transfer with a goal of developing concept papers and proposals to seek additional outside funding for future activities.

The detailed report in the body of the annual report shows the wide breadth of research and extension activities in the West Africa Regional Program. A complement of projects spanning genetic enhancement, sustainable plant protection systems, sustainable crop production systems, and utilization and marketing exist. In most countries of the region, multi-disciplinary teams have been developed to link production agricultural systems with markets. This is particularly true in the work plans and activity reports from Burkina Faso, Mali, and Niger. Programatically, the West Africa INTSORMIL program is well positioned and is active in working towards enhancement of sorghum and millet markets through high-yielding, quality grain production, supply-chain management, and processed product and animal feed endpoints.

Most notable are INTSORMIL efforts to improve and promote poultry production in West Africa. Close personal ties with Salissou Issa and Issoufou Kapran of INRAN, Niger have been established and these relationships with Salissou and Issoufou not only demonstrate INTSORMIL commitment to development of human capital in target countries,

but also evolved into demonstration experiments with broiler chicks showing the nutritional merits of sorghum-based diets. The results from these experiments were the cornerstone for a Producer Field Day held in Niamey, Niger. This Field Day drew all of the key poultry growers in the Niamey region (approximately 50) and was a tremendous success in facilitating technology transfer to end-users.

These research and extension activities and subsequent visits to poultry farms throughout the country also contributed to the formation of the Nigerien Poultry Producer's Association. Initially, the focus of this association will be on layer activities with eventual expansion into broiler production. So, INTSORMIL scientists are very excited to have been part of this critically important aspect of stimulating poultry production via technology transfer in Niger. The inevitable result of our activities is demand for sorghum as a preferred feedstuff for poultry and the generation of cash markets for sorghum producers in West Africa.

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

On-going collaborative research has progressed in each of the countries, namely Ethiopia, Eritrea, Kenya, Tanzania and Uganda. Results are highlighted in this report. Host country PIs in each country have taken keen interest in collaborating with U.S. PIs where partnerships have been developed. Because of expanded collaborative involvement in several countries in the Horn of Africa Region more U.S. PIs are needed to provide collaborative linkages with host country scientists. New PIs joining INTSORMIL are encouraged to take advantage of the opportunities for collaboration in the Horn of Africa region, where host country scientists and programs continue to appreciate and welcome technical support provided by INTSORMIL.

Sorghum breeding efforts in Ethiopia have been highly successful. Work on development and evaluation of experimental sorghum hybrids have resulted in identification of elite hybrids with potential for wide cultivation in lowland areas of the country. Efforts on *Striga* control have focused on regional testing of an integrated package of technologies that included tied-ridging as a water conservation measure, nitrogen fertilization, and *Striga* resistant sorghum cultivars. This activity is managed and implemented as a pilot project with supplemental funding from the Office of Foreign Disaster Assistance (OFDA) of USAID. Though, reports from Tanzania and Eritrea have not been submitted, the collaboration on sorghum breeding and in *Striga* control in both countries has progressed well. The program in Kenya has seen a setback as a result of C.K. Kamau, the sorghum breeder beginning Ph.D. degree training in South Africa. However, Christopher Mburu has continued efforts in *Striga* research in his absence. In Ethiopia a decision guide for targeting of tied-ridging is being developed, and

additional research has been initiated on tied-ridging by soil fertility interactions and on skip-row technology. Also, four opportunities for low-input management of soil fertility in semi-arid eastern Uganda have been verified as economical using farmer participatory approaches; information dissemination is scheduled to begin with the second season of 2005; and more detailed research has been initiated to assess the medium-term sustainability of these practices. A study of sorghum production areas in Ethiopia, Uganda and Kenya has identified stalk borer, water deficits, Striga, bird damage, N deficiency, weeds, and shootfly as the greatest causes of yield loss.

Additional data has been compiled on sorghum production areas of Ethiopia, Kenya, Mozambique and Uganda; a GIS referenced database is being created that should be valuable to regional networking activities. .

A new project, UNL 220 initiated March 10, 2005, is designed to promote increased use of sorghum and millet by establishing an entrepreneurship education/training program coupled with follow-up technical and business support services. This training program is being coordinated and offered through the Sokoine University of Agriculture's (SUA) Department of Food Science and Technology. It is anticipated that new individual and village/cooperative ventures will be established that use sorghum and millet grain and ingredients in food products to be sold locally and in urban markets. Draft entrepreneurship training materials were adapted from those developed by the University of Nebraska's Food Processing Center with the on-site collaboration between UNL's Entrepreneurship Program coordinator Ms. Gifford and Dr. Mpagalile (who was in Nebraska through May 2005). After his return to Tanzania, Dr. Mpagalile has further coordinated material refinement and localization by including local product photographs, Tanzania Food and Drug Agency (TFDA) regulations and Tanzania Bureau of Standards (TBS) specifications. A project coordinator was hired by SUA; the individual has a B.S. degree in agricultural economics and agribusiness with a wide experience in entrepreneurship and business incubator programs in Tanzania. The first Entrepreneurial Workshop is scheduled for September 20, 2005.

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

Progress was made in all research areas. Technology (germplasm) developed by this project has been adopted by private industry and used in hybrid production or breeding programs. Germplasm was evaluated for resistance to economically important insect pests and other stresses. Selections were made to combine insect resistance with other favorable agronomic and plant traits. Germplasm was identified for advanced testing with resistance to selected insects and diseases that will contribute to production of high

grain yield hybrids with wide adaptation. Thirty-four advanced elite germplasm lines were proposed for release. The germplasm lines also exhibit wide adaptation and some grain weathering resistance. The lines will be suitable for use by private industry directly as hybrid parents or as breeding lines to contribute traits to a parental line development program. Thus, collaboration with Host Country scientists resulted in progress to develop improved, high-yielding varieties or hybrids. Progeny were identified that combine several favorable traits into a single genotype. Discussion with collaborators established a framework to allow for on-farm testing of experimental germplasm in South Africa and developed a procedure for potential release of new varieties. As research continues to generate new technology, the importance of testing on-farm and soliciting producer input on research activities will increase.

Activities described in individual work plans were carried out as planned and described. Unpredictable weather affected the condition of field nurseries and data collection at some locations. The results reported in the report are a summary of results from the collaborators. All collaborators develop and submit work plans prior to each growing season. All collaborators also submit a summary of the research conducted for inclusion in the annual report. The program is evolving to place more responsibility on collaborators for the activity and quality in their research program. Budgets will eventually be adjusted to reward the most productive collaborators while attempting to maintain a broad-based, multi-country, multi-institution, multidisciplinary program.

There are two major constraints to development of the South Africa regional program at this time. First is the lack of scientific expertise for sorghum and pearl millet in the region. Within each institution and discipline there is basically one scientist available for collaboration. This is contributing to the increasing emphasis of regional scientists collaborating across national boundaries. As capable students are identified and matched with available advisors additional graduate education will occur. The students need assurance of positions in sorghum and pearl millet research upon returning from their degree programs. The second constraint is the continued decline in the number of hectares devoted to sorghum (and pearl millet) production. As in most semi-arid regions the decline can be attributed to government policy, lack of a marketing system to handle either traditional grain or grain with enhanced end-use traits, and consumer preference for other grains. With the right varieties or hybrids and the right marketing system the natural drought stress resistance of sorghum and pearl millet can help provide a consistent supply of high quality grain for processors and consumers.

Central America (El Salvador, Nicaragua, Honduras)

Program implementation the past four years has leveraged new or increased research on grain sorghum by more than 25 scientists in national programs in the region (El Salvador, Nicaragua and Honduras). Administrative procedures for reporting research results and financial expenditures have been developed. A conference was held to report research results and plan collaborative research priorities for 2002-2006, and 11 of the research reports were published in La Calera. Present efforts are to continue implementation of these research priorities while expanding activity into Guatemala. Communication and coordination of the many groups involved in the program remains a challenge. The regional research directors developed a regional graduate education and short-term training plan. At present five students are in graduate degree programs. Short-term training is in progress or being planned for four scientists in food science, agronomy and agricultural economics.

On the whole, the present collaborative model being used by the Central America Regional Program is functioning well, due to the commitment of scientists in the region, and has resulted in transfer of improved cultivars with increased yield and nitrogen use efficiency. Grain utilization issues are increasing in importance in the program. Researchers participating in the INTSORMIL Central America Regional Program have also developed management strategies for fall armyworm and sorghum midge, identified priority disease problems, developed sorghum flour substitution technology, and implemented research on nitrogen rates and nitrogen use efficiency of sorghum germplasm adapted to the region. Improved germplasm, production practices and pest management methods are being moved to producers through validation and demonstration trials, collaboration with extension services and NGOs, and through workshops with producers. Major progress was made in developing forage and grain varieties/hybrids, including line identification, testing and in seed production. A forage sorghum hybrid is planned for formal release in El Salvador and Nicaragua in November 2005. Several grain sorghum varieties/hybrids are being validated during 2005, with plans to release the best ones in 2006.

Major achievements of the past year are transfer of the improved high N use efficient sorghum variety 85SCP805 (with and without fertilizer application) to 141 small farmers, and transfer of the improved varieties ES-790, CENTA S-3, 86EO226 and CENTA RCV to approximately 500 small farmers. The improved photoperiod sensitive variety 85-SCP-805 with high yield potential and nitrogen use efficiency was validated on 40 farms. The new variety with 47 kg ha⁻¹ N fertilizer application increased grain yield by 800 kg ha⁻¹ (about 25%) over the local variety without N fertilizer. In addition, rapid progress is being made in validation and seed increase of the forage hybrid ICSA275 X TX2784,

with formal release planned for November 2005. The variety/hybrid pipeline at CENTA and CNIA/INTA indicates the potential for release of several improved grain sorghum varieties/hybrids in 2006. Progress was made in developing improved integrated crop and pest management programs. Improved ties with the food processing industries in El Salvador and Nicaragua were achieved through workshops and personal contacts, and one company, GUMARSAL has participated in grain quality research and plans to mill sorghum flour. Graduate and undergraduate educational, and short-term training efforts have improved the human capital available for sorghum research and technology transfer in Central America. In addition research and technology transfer efforts in poultry nutrition in Central America have focused on seminars given in Nicaragua and at the RAPCO Short Courses in Costa Rica. Dr. Hancock/KSU 220B used the RAPCO short courses to promote sorghum as a component in animal feeds (especially for poultry). Attendees for the short courses (limited to 35 each year) were representatives from the major livestock/feed producers in most of Latin America (i.e., Mexico, Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica, Panama, Venezuela, Colombia, Ecuador, Peru, and the Dominican Republic). The unquestionable success of these short courses results from the organizational skills of Carlos Campabadahl (Universidad de Costa Rica). So, again, collaboration with in-country specialists is a key to the success of INTSORMIL in collaborating countries.

Regional Benefits by Technical Thrust

Germplasm Enhancement and Conservation

Pearl millet [*Pennisetum glaucum* (L.) R. Br] provides a staple, primary food source to millions of people in semi-arid tropical areas of Africa and Asia, and a high quality temporary grazing crop in livestock production in the U.S. The goals of Project ARS-206 are to improve the productivity, yield stability, and pest resistance of pearl millet for African and U.S. settings and to transfer the technology to the market. Achieving these goals require 1) identifying constraints limiting production or utilization, 2) evaluating germplasm for desirable characteristics, 3) developing regionally adapted breeding lines or cultivars, and 4) working with partners and stakeholders to transfer the products of research to the marketplace.

The second year of multi-locational trials throughout West and Southern Africa was completed. Germplasm and cultivars were characterized for agronomic characteristics and resistance to pests and diseases. Trials were conducted in Kamboinse, Burkina Faso; Manga, Ghana; Cinzana, Mali; Bengou, Niger; Maiduguri, Nigeria; Bambey, Senegal; and Longe, Zambia. An additional trial was conducted in Kwa Zulu Natal, South Africa to characterize rust resistance. Correlations of yield with several agronomic characteristics and negative associations with pests and diseases were

identified. Genotypes with superior performance over multiple locations will serve as source material for breeding improved pearl millets.

Resistance to root knot nematode (*Meloidogyne incognita*) is important to provide stability to pearl millet production and to reduce nematode populations that can damage crops grown in rotation. Seventeen pearl millets from West and East Africa expressed some level of resistance. SoSat-C88, Gwagwa, Zongo, and P3Kollo were evaluated for heterogeneity of resistance, and patterns of segregation of resistance varied among the four varieties. Discrete resistant and susceptible phenotypes were identified in Zongo progeny, and it was estimated that two dominant genes for resistance segregated in this variety. Heritability of nematode reproduction determined by parent-offspring regression was 0.54. Realized heritability determined by divergent selection was 0.87.

Wild pearl millets (*P. glaucum* subsp. *monodii*) have been identified as potential sources of resistance to the parasitic weed, *Striga hermonthica*. Eighty wild accessions, nine U.S. inbreds and seven African open-pollinated varieties were evaluated with 60 EST primers and 35 SSR primers to identify genetic diversity and identify polymorphic markers that would be useful in transferring resistance. Out of 60 EST primers tested, 30 produced scorable and reproducible fragments. Out of 35 SSR primers, 33 primer pairs gave amplification products in most of the accessions. A dendrogram was constructed using the combined data of SSR and EST data. The wild accessions were grouped independently from the cultivated U.S. and African varieties. Resistant accessions PS 202, PS 637, PS 639 and PS 727 tended to be located in different clusters, suggesting they may possess different resistances to *Striga*.

Drought stress occurring from flowering through grain fill results in low and unstable yield of pearl millet. Delayed senescence, or “stay-green” is a mechanism of drought tolerance characterized by the retention of green leaf area at crop maturity. The relative chlorophyll contents of a putative stay-green and normal senescent pearl millet were compared over time, and segregation of the stay-green in an F_2 population was evaluated. The line 02F266-4 retained greater relative chlorophyll content 3 and 4 weeks after anthesis. Expression in F_1 and segregation in the F_2 indicated staygreen in this parent is a dominant or overdominant trait.

To expand domestic market outlets for pearl millet grain, four pearl millet genotypes were tested for their potential as feedstocks for ethanol production and for co-products from the fermentation process. Fermentation efficiencies of pearl millets, on a starch basis, were comparable to those of corn and grain sorghum. Because pearl millets have greater protein and lipid content, distiller’s dried grains with solubles (DDGS) from pearl millet also had greater protein content and energy levels than did DDGS from corn and

grain sorghum. Pearl millet should be an effective feedstock for ethanol production in the U.S.

The central clay plain of the Sudan is home to a great variety of sorghum types. With favorable rainfall distribution, heavy alluvial soils, and high seasonal temperatures the area has a long history of sorghum cultivation, and currently presents a well-developed irrigated and mechanized farming schemes. Several agronomically elite landraces have been collected from this region. Taxonomically, sorghums of the race Caudatum make up the most dominant type in Central Sudan and adjacent regions suggesting perhaps that Sudan was the center of origin for sorghums of the Caudatum race. Other studies have described Caudatum as a race with great agronomic value, better adaptation to harsh conditions, and a wide range of response to changes in photoperiod. This may explain the great contribution that sorghums from Sudan have made to global sorghum improvement efforts. The race caudatum is one of the most important races agronomically and provides genes for high yield and excellent seed quality. It has become one of the most important sources of germplasm in modern breeding programs throughout the world.

Project PRF 207 efforts led to the release in 2004 of 20 elite inbred sorghum lines including race Caudatum derivatives for use in the commercial sorghum seed industry. Material Transfer Agreements have been signed and seed distributed to seed companies in the U.S., India, South Africa, and Guatemala. Elite inbred lines of sorghum developed by PRF 207 and experimental hybrids generated from these inbred lines have been sent to collaborators in several countries. The programs in Niger, Ethiopia, and Eritrea, in particular, have made selections that are currently in multi-location testing.

Project TAM 223 made progress in all research areas. Germplasm was evaluated for resistance to economically important insect pests and other stresses. Selections were made to combine insect resistance with other favorable agronomic and plant traits. Germplasm was identified for advanced testing with resistance to selected insects and diseases that will contribute to production of high grain yield hybrids with wide adaptation.

Collaboration with LDC scientists resulted in progress to develop improved, high-yielding varieties or hybrids. Progeny were identified that combine several favorable traits into a single genotype. Discussion with collaborators established that 34 germplasm lines were proposed for release. The lines are in two sets of 17 lines each. Lines designated Tx2945 to Tx2961 are tan plant with red or white grain, resistance to biotype E greenbug, and mostly excellent disease (including foliar) resistance. Lines designated Tx2962 to Tx2978 are resistant to biotype E and I greenbug with varying levels of disease resistance. The germplasm lines also exhibit wide adaptation and some grain weather-

ing resistance. The lines will be suitable for use by private industry directly as hybrid parents or as breeding lines to contribute traits to a parental line development program framework to allow for on-farm testing of experimental germplasm in South Africa and to develop a procedure for potential release of new varieties. As research continues to generate new technology the importance of testing on-farm and soliciting producer input on research activities will increase.

During the life of this project significant research progress has been achieved. Technology (germplasm) developed by this project has been adopted by private industry and used in hybrid production or breeding programs. Collaboration with research programs in Nicaragua, El Salvador, and Southern Africa (South Africa, Botswana, and Zambia) gives TAM 223 significant international activity. Impact assessment studies show a high rate of return on investment from research conducted by this project.

The KSU 220 project is a mega project consisting of four parts, KSU 220A, KSU 220B, KSU 220C/TAM 220C and KSU 220D/TAM 220D. The major emphasis of this project is to develop sorghum varieties and hybrids with enhanced nutritional and grain quality characteristics. The marketing and utilization of sorghum grain often has been limited by lower grain quality and feed value compared to other cereals. Large-seeded sorghum genotypes with enhanced feed-value and grain-quality characteristics have been identified and these genes are being incorporated into improved genetic backgrounds for deployment in regions of Africa, Central America, and the United States. Thus research project KSU 220 attempts to address this weakness through plant breeding to develop elite varieties and hybrids with improved nutritional and grain quality traits and through development and transfer of animal feed and production technologies to developing countries. Past breeding efforts have significantly enhanced yield potential in semi-arid regions of the world, but little attention has been focused on feed value and grain quality in these production environments. Tan-plant sorghum hybrids with improved drought tolerance are being developed to address this problem. Large-seeded sorghum genotypes with enhanced feed-value and grain-quality characteristics have also been identified and these genes are being incorporated into improved genetic backgrounds for deployment in regions of Africa, Central America, and the United States. In the United States, food-grade hybrids are now commercially available in all maturity groups. These hybrids are high-yielding and well-adapted to dryland and limited-irrigation environments. Breeding efforts continue with the exchange and testing of new germplasm and improved varieties through collaboration of scientists around the world. Animal feed workshops and seminars as well as poultry feeding demonstrations are being conducted with collaborators in numerous countries in Africa and Central America.

KSU 220D cooperating principal investigator at Texas A&M University is working to determine if high protein digestibility and grain mold resistance can be combined. Currently, small populations have been developed to test this relationship and we have begun to create larger populations in order to completely characterize this relationship. Plant pathologists in Burkina Faso, Mali and Nigeria have been enlisted as collaborators to survey disease problems of sorghum and millet. DNA comparisons made from non-viable spores of pearl millet downy mildew show differences great enough to predict that two different pathogen species may be involved.

Project KSU 220B training activities focus on the transfer of technology and knowledge to allow development and utilization of improved sorghum and pearl millet cultivars for animal feeding and human food. A key component of technical assistance and technology transfer in Central America is the RAPCO short course for animal nutrition. This week-long short course in animal feeding and nutrition is held each year and includes participants from Mexico, Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica, Panama, the Dominican Republic, Columbia, Venezuela, Peru, and Ecuador. Additionally, for the 2004-2005 budget year, a short course was held in Managua that was designed specifically to address issues (real and perceived) that limit the expanded use of sorghum as a feedstuff for poultry farming in Central America. Technology transfer efforts in West Africa were initiated in 2003 through interaction with Dr. Salissou Issa, Head of the Animal Husbandry Unit at the INRAN Rainfed Crops Program in Niger. Farm visits were accomplished in the Niamey area during 2003 and 2004 and animal feeding trials (accomplished in Niger) were completed in 2004 and 2005. Additional feeding trials are currently being conducted in Niamey to demonstrate the relative feed value of local and improved sorghum varieties in comparison to traditional corn-based feed rations.

In addition to providing new cultivars and the technology to utilize them effectively, graduate students and visiting scientists with interest in crop improvement, crop utilization, and molecular biology are being hosted for short-term and graduate training at Kansas State University and Texas A&M University. Student projects are strongly multidisciplinary and provide opportunities for collaboration with investigators from different departments and universities. The focus of this training is to enhance the human and institutional capacity of research institutions in developing countries.

Sustainable Production Systems

The PRF 205 project has been very active in the Horn of Africa region, the West Africa region and Mozambique this past year. The fieldwork in Amhara, Ethiopia on the introduction of *Striga* resistant cultivars and associated

technologies was Completed. Mr. Yigezu Yigezu (Ethiopia) is well into writing his M.S. thesis on the potential impact of the *Striga* resistant cultivars and associated technologies. Introducing inorganic fertilizer more rapidly and developing seed production systems (probably in the public sector) are two critical innovations to accelerate the introduction of *Striga* resistant cultivars and associated technologies in Amhara, Ethiopia. Mr. Rafael Uaiene (Mozambique) finished his thesis on marketing strategies and technology introduction in maize production in central Mozambique. Mr. Uaiene won one of the Purdue University Department of Agricultural Economics prizes for best M.S. theses and his thesis was forwarded to the National Agricultural Economics M.S. thesis Competition of the American Agricultural Economics Association.

Mr. Felix Bacquedano (Nicaragua) also finished his fieldwork in Niger continuing the technology introduction/inventory credit evaluation that Dr. Abdoulaye Tahirou had initiated. Mr. Bacquedano is also well into the analytical phase of his M.S. thesis. Both Mr. Yigezu and Mr. Bacquedano were delayed in finishing their theses by taking courses for the Ph.D. Both have been accepted into this program. Mr. Yigezu and Bacquedano are now working on their theses full time and both should be finished by September 2005. They have begun work on their prospectus for their thesis defense. Both will be concerned with constraints to technology introduction in their countries (Ethiopia and Mozambique).

Mr. Nega Wubeneh (Ethiopia) has submitted a paper to *Agricultural Systems* and Mr. Uaiene has finished a draft for a journal article submission.

The Marketing-Processing project continues to demand large amounts of field time including six trips to the Sahel in the past INTSORMIL budget year. Improving the grain quality is a critical problem area in getting farmers' incomes up, both for the farmers (doing it with tarps or threshers) and for the food processor (paying a quality premium. Farmers' incentives (higher prices for staples) are critical to the successful expansion of Inventory Credit systems.

In the Marketing-Processing project there is now more stress on quality control and on feed processors. For the feed processors and public policy makers project investigators are doing a bulletin on tannin and relative prices of sorghum as compared with maize over the last five years over all four countries, Senegal, Mali, Niger and Burkina Faso. Efforts are underway to have all English documents translated into French.

Project UNL 213 has been extremely productive in graduate education of West African collaborating scientists; agronomic research which has led to publication in scientific journals, the publication of extension bulletins, and the transfer of improved practices to pearl millet producers;

and strengthening the activities of the West and Central Africa Pearl Millet Research Network. In the U.S. the project has documented the potential for pearl millet as a new grain crop in the great plains, and developed production practice recommendations for planting date, row spacing, and nitrogen fertilizer application. Present research is on double cropping pearl millet after winter wheat. Research activities expanded from West Africa to Central America in 2001.

The major managerial issues facing Project UNL 213 is balancing INTSORMIL efforts with other responsibilities in National Research Systems and/or in U.S. universities. Although electronic communication has improved the situation, communication remains problematic both in planning and reporting research activities. There is continuing difficulty in identification of potential graduate students from West African and Central American countries largely due to the need for English language skills. Funding of graduate student studies is becoming increasingly difficult with flat budgets along with increased costs (especially overhead and stipend), and due to fewer supplemental funding opportunities from other sources. Although effective programs have been established, the future is somewhat uncertain due to the weak institutional strength of national programs. The collapse of the West and Central Africa Pearl Millet and Grain Sorghum Networks has reduced opportunity for meeting to share research results and plan research activities. Nebraska research on pearl millet is severely constrained by the lack of a pearl millet breeding program in the great plains, and the lack of private sector investment in developing pearl millet as an alternate grain crop.

Major accomplishments of UNL 213 in 2004-2005 were:

- In El Salvador, the improved photoperiod sensitive (maicillo criollo) sorghum variety 85SCP805 was identified with increased grain yield, improved NUE, and high % N fertilizer recovery for production in relay intercropping systems with maize. The variety produced higher yield in validation (40 farms) and transfer (260 farms) plots than local varieties, and showed greater response to N fertilizer application.
- Photoperiod insensitive sorghum lines were identified with high N use efficiency and/or high N fertilizer response in El Salvador (ICSVLM- 90520) and Nicaragua (ICSVLM-93076). These are being used in national program breeding programs.
- Large sorghum grain yield increases have been demonstrated in response to N fertilizer application, which is leading to an increased effort to promote N fertilizer use for grain sorghum production in Central America.
- In West Africa, research confirmed that microdose fertilizer application increases grain and stover yields of pearl millet (and grain sorghum) although the response varies greatly across location and year. Estimated nutrient removal indicated that this system mines nutri-

ents from the soil at approximately the same rate as with no fertilizer application.

- Research using nodulating and non-nodulating soybean isolines has contributed new insight into the basis for enhanced yields for sorghum rotated with soybean. Soil NO₃-N differences influenced sorghum growth and yields, indicating that part of the rotation effect was due to biological N fixation by soybean (about 17 to 33%) while the rest was due to N from other sources and non-N effects.

The objectives of Project UNL 219 are to promote economic growth, improve nutrition and to increase yield. Opportunities to increase yield or to reduce production costs have been identified while promising research is continuing and technology dissemination activities have been initiated. Following verification and fine-tuning of the targeting of tied-ridge tillage for semi-arid areas of Ethiopia, extension efforts have been initiated. A decision guide for targeting of tied-ridging is being developed, two papers were presented at the 2004 ASA meeting, and a paper has been submitted to *Agronomy Journal*. Additional research has been initiated on tied-ridging by soil fertility interactions and on skip-row technology. Four opportunities for low-input management of soil fertility in semi-arid eastern Uganda have been verified as economical using farmer participatory approaches; information dissemination is to begin with the second season of 2005; and more detailed research has been initiated to assess the medium-term sustainability of these practices. Preliminary research was conducted on tillage and soil fertility management alternatives in Mozambique. Research on occasional tillage to improve the productivity of no-till sorghum production systems continues and are the subjects of the dissertation and thesis research of two graduate students; four papers are to be presented at the 2005 ASA meeting.

Improved institutional capacity. Tewodros Mesfin, who completed his M.S. degrees at Alemaya University with support from UNL 219, came to UNL as a visiting scientist. Gebreyesus Brhane has completed his M.Sc. degree with INTSORMIL support and is now the UNL 219 collaborator in Tigray, Ethiopia. Soares Xerinda completed his M.S. degree at UNL and is now the UNL 219 collaborator in Mozambique. The research of a U.S. and two international graduate students is currently supported by this project. Mr. Mesfin, Brhane and Xerinda were sponsored to IFDC training in integrated soil fertility management in Ghana. A study of sorghum production areas in Ethiopia, Uganda and Kenya has revealed stalk borer, water deficits, *Striga*, bird damage, N deficiency, weeds, and shootfly as the greatest causes of yield loss. Additional data has been compiled on sorghum production areas of Ethiopia, Kenya, Mozambique and Uganda; a GIS referenced database is being created that should be valuable to regional networking activities. Drs. Wortmann and Mamo visited their collaborators in Africa in February 2005.

Sustainable Plant Protection Systems

KSU 210 has demonstrated that identifying the correct causal agent(s) for grain mold requires that at the least the major species being recovered, be correctly identified, thus formal taxonomic descriptions of these new species needs to continue. Molecular diagnostic tools are being developed for these species, but validating them requires a sufficient sample to determine their validity. Studies of mycotoxin production under field conditions are needed, and the mycotoxigenic profiles of newly described species continue to need to be developed. As before, species identification appears to be critical in estimating the risks posed by mycotoxins, and many of the *Fusarium* species common on sorghum do not make high levels of many of the common mycotoxins (but are toxic). KSU 210 has been working with *Fusarium proliferatum*, a species known to be capable of producing high levels of the fumonisin toxins, in sorghum grain from Egypt. These strains may be the cause of the pokkah boeng disease that is common on Egyptian sorghum and, if these strains are producing mycotoxins under field conditions, they may pose an unanticipated mycotoxin exposure risk to both humans and domesticated animals.

The Scientific Writing and *Fusarium* Laboratory workshops have become successful, visible outreach efforts and that will continue. Scientific writing workshops are offered opportunistically while the KSU 210 PI is in travel status and although none were done in the 2004-2005 reporting period, over 1000 were trained in the 2003-2004 reporting period and a number of workshops have already been scheduled for the last half of 2005. Scientific Writing and *Fusarium* Laboratory workshops serve as interdisciplinary venues for scientists in developed and developing countries that work on various crops to exchange information and to interact with one another in an informal setting. Iowa State Press (now Blackwell Professional Publishing) is interested in publishing books to go with each of these courses. A 350 page manual based on the material taught in the *Fusarium* Laboratory workshop, needs to be converted to camera ready format, but otherwise is complete. *Fusarium* Laboratory workshops are held in odd-numbered years at KSU in Manhattan, Kansas, and in even-numbered years at a location outside the United States. The 2004 and 2005 workshops both fell into this reporting year, with 40 attendees from 16 countries in Pretoria, South Africa and 57 attendees from 17 countries in Manhattan, KS. The 2006 workshop is scheduled for Bari, Italy and the 2008 workshop is tentatively set for Penang, Malaysia.

Work with the *Fusarium* collections is progressing. Dr. Giuseppe Mulé and her colleagues in Italy have been sequencing extensively several phylogenetically informative loci from *Fusarium* strains from finger millet. The sequencing efforts have identified a large number of species,

at least 20, with much higher levels of variation than is reported from crops that are more widely cultivated. It is possible that finger millet may be serving as a center of diversity for *Fusarium* pathogens of a number of crops that originated in Africa. As such, sampling this crop as it is found in fields of indigenous farmers may be of particular importance in determining the intra- and inter-specific variation within these fungal pathogens. Work with the Tanzanian strain set has progressed to the point that the analysis of the identified species is essentially complete, and has led to the identification of a series of strains that represent a number of previously undescribed and uncharacterized species. Work with the strain set from Mali is continuing in collaboration with Prof. Walter Marasas of South Africa.

In collaboration with Dr. Ranajit Bandyopadhyay of IITA (Ibadan, Nigeria) KSU 210 is working on identifying causal agents of grain mold and head blight in sorghum in West Africa, and comparing the toxin-producing capability of these strains with similarly collected strains from maize and pearl millet. They also are organizing a conference on mycotoxins in Africa under the umbrella of the EU MycoGlobe project of which the KSU 210 PI and Dr. Bandyopadhyay are both on the steering committee, and will be co-editing the proceedings of that meeting for a volume to be published by CABI in the United Kingdom.

The extension of MSU 205 into Nicaragua and El Salvador during the past five years has provided this project the opportunity to investigate entomological constraints to sorghum production on large farms compared with the small field, low input, subsistence farming systems in which the project was involved in previous years in Honduras. In an on-farm demonstration-type program designed to compare insect and disease pest management, improved pest management technology involving timely application of selective insecticide and fungicide provided better management of a complex of insect and disease pests, respectively, and increased yield in an integrated approach to pest management than the conventional pest control practices used by local farmers in Nicaragua.

And, with the interdisciplinary participation of entomologists and plant pathologists during the past two years, considerable attention has been given to investigations involving integrated pest management within large monocropped sorghum production systems. Research collaboration with scientists in INTA, UNA and ANPROSOR in Nicaragua and CENTA in El Salvador has proved to be extremely beneficial in developing research plans and coordinating, implementing and conducting scientific investigations in these countries. Investigations of the specific insect pest and disease problems identified in the respective countries have yielded basic biological information needed for developing and recommending effective insect pest and disease management programs. Recommendations to manage the complex of lepidopterous caterpillars and

sorghum midge on sorghum in Nicaragua, and fall armyworm and stalk borers on sorghum in El Salvador represent some research successes of MSU 205. Recently, the multidisciplinary (entomology and plant pathology) on-farm crop production demonstration activities in both Nicaragua and El Salvador have been effective in the development of collaboration between scientists and farmers. The transfer of new crop production technology, particularly related to the integration of insect pest and disease management programs, will be achieved using this approach to working with sorghum producers in this region of Central America. In the United States, research continues on the occurrence, behavior and management of the principal insect pests and diseases of sorghum in Mississippi. This includes fall armyworm on whorl stage plants and sorghum midge, fall armyworm, sorghum webworm, corn earworm and stink bugs on the panicles, as well as the complex of diseases on whorl and reproductive plant growth stages. Effective insecticide and fungicide use practices for control of insect pests and diseases, respectively, on sorghum and defined economic threshold levels for stink bugs on whorl and panicle stages of sorghum and the complex of diseases will assist farmers in decision-making regarding the application and effective use of pesticides to manage these pests.

The project, PRF 213, supports research and training of scientists combating a widespread parasitic weed in Africa which can severely decrease yields of sorghum and millet. Witchweeds (*Striga spp.*) are obligate parasitic weeds of significant economic importance. Control methods available to date have been costly and beyond the means of farmers in developing countries. While the combining of several control measures may be necessary for eradication of *Striga*, crop losses to *Striga* can be effectively minimized through host-plant resistance. The project's goal is to exploit the unique life cycle and parasitic traits of *Striga* especially the chemical signals required for germination, differentiation, and establishment. Recent activities in screening wild sorghum accessions for their potential as sources of powerful *Striga* resistance genes for sorghum breeding have identified unique sources of *Striga* resistance in wild sorghum accessions (PQ-434). The new genes inhibit haustorial formation and disrupt parasitic association with host plants. A small collection of wild sorghums screened for potential *Striga* resistance mechanisms allowed the project to identify some unique reactions that prevent the parasitic invasion. The bioassays used were designed to take a quick look at the earliest steps in parasitic establishment. Among the germplasm studied were sorghums around which *Striga* did not germinate. Accessions were also identified that had reduced capacity to elicit haustorial.

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Witchweeds (*Striga* spp.) are obligate parasitic weeds of significant economic importance. Control methods available to date have been costly and beyond the means of farmers in developing countries. While combining several control measures may be necessary for eradication of *Striga*, crop losses to *Striga* can be effectively minimized through host-plant resistance. The goal of Project PRF 213 is to exploit the unique life cycle and parasitic traits of *Striga* especially the chemical signals required for germination, differentiation, and establishment. The project has developed an integrated *Striga* management (ISM) package (combining a resistant sorghum cultivar with inorganic fertilization and a soil moisture conservation) and has tested this in Ethiopia in a farmer-participatory approach for the last four years. The demonstration trials were performed by over 6000 farmers and adopted by tens of thousand others because of its efficacy in reducing *Striga* infestation and increasing sorghum grain yield. Over 25,000 farmers have received seed of *Striga* resistant cultivars directly from project leaders at research stations, regional bureaus of agriculture, and collaborating NGOs. These farmers have in return distributed seed to neighboring farmers through local informal seed exchange mechanisms. It is estimated that over 100,000 farmers have grown seed of *Striga* resistant sorghums from INTSORMIL. In addition to the *Striga* resistance traits, farmers have liked the varieties for their early maturity, drought tolerance, and favorable grain quality in making local food products. Agronomically, these varieties have been well suited for many of the sorghum growing regions of Ethiopia except in higher altitudes (>2700m), where long season (>180days) maturity sorghums are preferred. Fortunately, the *Striga* problem has not been as severe in the highlands of Ethiopia.

During this year the WTU 200 project PI traveled to southern Africa to review INTSORMIL activities and dis-

cuss collaborative research and educational programs. Research to manage insects of sorghum was reviewed and discussed in March with scientists in Botswana, Mozambique, and South Africa and research was planned for Ph.D. students. Research was conducted as planned with scientists in Africa. Resistance of sorghums developed by TAM 223 and commercial seed companies were evaluated for resistance to aphids. Greenbugs from Kansas and Texas were identified as biotype I. Tritrophic effects of resistant sorghum on beneficial insects were assessed. The evaluation of resistance of 20 genotypes of stored sorghum were completed and light and scanning electron microscopy used to compare morphology of seed coats of resistant versus susceptible sorghums. Graduate programs of five M.S. students and one Ph.D. student were directed. Two M.S. students graduated in August 2004, one will graduate in December 2005, and one learned English and began graduate studies. Two African students did not qualify for admission to West Texas A&M University and one potential Ph.D. student needs to take the Graduate Record Exam before admission. As planned, research results were presented at entomology, extension, farmer, and sorghum meetings.

Utilization and Marketing

Collaborative efforts continue in Niger and the surrounding region to stimulate processing of commercial sorghum and millet foods. INTSORMIL Project PRF 212 continues efforts to push high quality sorghum couscous and flours, and has recently started a project to explore the use of pregelatinized flours for thin and thick porridges and weaning foods for urban areas of the sorghum and millet growing region of West Africa. Studies at Purdue University are designed to investigate a low-cost low pressure/high temperature extruder. A West African regional team of food scientists is working on an integrated, regional crop utilization project that will culminate in a proposal for funding a larger processing effort for the region.

In 2004-05, PRF 212 showed continued progress toward nutritional improvement of sorghum grain. Improved grain quality lines of the high protein digestibility/high-llysine sorghum mutant show promise and they have a better understanding of the biochemical changes in the grain due to the mutation. The marketing and utilization of sorghum grain often has been limited by lower grain quality and feed value compared to other cereals. This research project attempts to address this weakness through plant breeding to develop elite varieties and hybrids with improved nutritional and grain quality traits and through development and transfer of animal feed and production technologies to developing countries. Breeding efforts continue with the exchange and testing of new germplasm and improved varieties through collaboration of scientists around the world. Animal feed workshops and seminars as well as poultry feeding demonstrations are being conducted with collaborators in numerous countries in Africa and Central America.

The major emphasis of the TAM 226 project is to develop sorghum varieties and hybrids with enhanced nutritional and grain quality characteristics. Large-seeded sorghum genotypes with enhanced feed-value and grain-quality characteristics have been identified and these genes are being incorporated into improved genetic backgrounds for deployment in regions of Africa, Central America, and the United States. The project is cooperating with principal investigators at Texas A&M University to determine if high protein digestibility and grain mold resistance can be combined. Currently, small populations have been developed to test this relationship and they have begun to create larger populations in order to completely characterize this relationship.

Past breeding efforts have significantly enhanced yield potential in semi-arid regions of the world, but little attention has been focused on feed value and grain quality in these production environments. Tan-plant sorghum hybrids with improved drought tolerance are being developed to address this problem. In the United States, food-grade hybrids are now commercially available in all maturity groups. These hybrids are high-yielding and well-adapted to dryland and limited-irrigation environments.

The TAM 226 training program focuses on the transfer of technology and knowledge to allow development and utilization of improved sorghum and pearl millet cultivars for animal feeding and human food. A key component of technical assistance and technology transfer in Central America is the RAPCO Short Course for animal nutrition. Additionally, for the 2004-2005 budget year, a short course was held in Managua that was designed specifically to address issues (real and perceived) that limit the expanded use of sorghum as a feedstuff for poultry farming in Central America.

In addition to providing new cultivars and the technology to utilize them effectively, graduate students and visiting scientists with interest in crop improvement, crop utilization, and molecular biology are being hosted for short-term and graduate training at Kansas State University and Texas A&M University. Student projects are strongly multidisciplinary and provide opportunities for collaboration with investigators from different departments and universities. The focus of this training is to enhance the human and institutional capacity of research institutions in developing countries

INTSORMIL project TAM 226 continues to work on the importance of grain supply chain management in being recognized as a vital part of crop improvement programs and utilization of grains. They have publicized the need for this approach to provide for sustainable utilization of sorghum and millets in food products.

New markets for value-enhanced white food sorghums are being promoted by the U.S. Grains Council from their

research on food sorghum processing and prototype products. In Japan, value-enhanced white food sorghums are processed into several commercial snack foods. Sorghum flour was demonstrated to be effective in nearly 20 traditional Japanese foods by Japanese chefs and food processors.

Several mills are producing sorghum flour for niche markets in the U.S.A. Total use is still very low but new products for celiac patients and ethnic foods exist.

In Central America, white sorghums are used in bakery products as a substitute for wheat or maize. Some vertically integrated farmers market special white sorghums as value-added baked products in local villages.

The antioxidant level in certain bran fractions of special sorghums is higher than that of blueberries. These brans and their extracts are useful as food ingredients in a number of applications. Extrusion processing of sorghum reduced the tannins into smaller polymers with improved health promoting effects.

Several parental sorghum lines released from the Texas A&M program are used in commercial hybrids grown in Mexico and United States. ATx635 hybrids have outstanding milling properties. The protein content of food sorghums is higher than that of other commercial sorghums.

A method was developed to effectively evaluate milling properties of sorghums when light colored meals were desirable.

Antifungal proteins (AFP) are related to grain mold resistance in sorghum. However, the measurement of AFP levels must be accomplished when the sorghums are exposed to molding conditions. Thus, it may be easier for breeders to evaluate mold resistance by subjective methods. The AFP levels remain high in resistant cultivars that are exposed to high levels of mold infection.

A new project, UNL 220 was initiated on March 10th, 2005 and is designed to promote increased use of sorghum and millet by establishing an entrepreneurship education/training program coupled with follow-up technical and business support services. This training program is being coordinated and offered through the Sokoine University of Agriculture's (SUA) Department of Food Science and Technology. It is anticipated that new individual and village/co-operative ventures will be established that use sorghum and millet grain and ingredients in food products to be sold locally and in urban markets. Draft entrepreneurship training materials were adapted from those developed by the University of Nebraska's Food Processing Center with the on-site collaboration between UNL's Entrepreneurship Program coordinator Ms. Gifford and Dr. Mpagalile (who was in Nebraska through May 2005). After his return to Tanzania, Dr. Mpagalile has further coordinated material refinement

and localization by including local product photographs, Tanzania Food and Drug Agency (TFDA) regulations and Tanzania Bureau of Standards (TBS) specifications. A project coordinator was hired by SUA; the individual has a B.S. degree in agricultural economics and agribusiness with a wide experience in entrepreneurship and business incubator programs in Tanzania. The first *Entrepreneurial Workshop* is scheduled for September 20, 2005.

Biotechnology

Biotechnology encompasses a number of concepts and techniques based on recent knowledge of genetics, biochemistry, computer science. INTSORMIL scientists employ techniques of biotechnology, such as marker-assisted selection to accelerate plant breeding and laboratory assays to accelerate selection of *Striga* resistant germplasm. INTSORMIL scientists see biotechnology as a means, not an end. INTSORMIL's ends to which the tools of biotechnology may be applied are summarized in its four main objectives, namely 1) promote economic growth, 2) improve nutrition, 3) increase yield, and 4) improve institutional capability to do research on sorghum and millet.

The goal of project TAM 230 is to combine the high grain protein digestibility trait with grain mold resistance in sorghum through the use of molecular techniques. The objectives set forth for this project are: 1) identifying high grain protein digestibility (HPD) lines from crosses between HPD line P851171 and P850029 and elite grain mold resistant lines; 2) defining molecular markers for both the HPD trait, and grain mold resistance; 3) defining the molecular basis of grain mold resistance; and 4) determining the possible gain of function the HPD trait may convey for improved animal feed nutrition and food manufacturing. The project seeks to train graduate students from Central America/Mexico and the U.S. in strategies to integrate plant molecular biology tools with pathology, breeding, nutrition and cereal chemistry to improve sorghum nutritional quality.

In one year three Ph.D students from Mexico and the U.S. and one M.S. student from Honduras have been recruited into this project. These students have been recruited with funds (\$197,740) over the next 2-3 years from Texas A&M University, USDA, and Fulbright Fellowship programs. These funds represent a substantial buy-in to the funds provided by INTSORMIL. One student, Esten Mason, has accomplished our first goal by identifying four HPD lines from crosses with grain mold resistant parents. Two of these lines exhibit a floury endosperm phenotype while two lines exhibit a more desirable hard/flinty endosperm. Each line has acceptable levels of grain mold resistance. Esten is currently testing the functional use of the modified endosperm carbohydrate and surrounding protein body matrix in the HPD lines for improved ethanol production and in poultry feed. Collaboration with PIs working on existing

INTSORMIL projects at Texas A&M, Kansas State, and Purdue have provided invaluable interaction and improved productivity.

Future Directions

During the past 26 years, INTSORMIL has educated more than one thousand scientists in degree programs, visiting scientist experiences, postdoctoral training, workshops, conferences, and scientific publications. About one-third of those trained are Americans 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, since 500 million people directly consume sorghum, 300 million people directly consume pearl millet. Sorghum is a key element in the food chain of the United States, being a key feed for livestock. What, then is the future for collaborative, international sorghum and millet research supported by INTSORMIL? The future is bright.

There continues to be a need for highly qualified researchers for these two crops both in developing countries and the United States. INTSORMIL fulfills a unique role in providing postgraduate training (M.S. and Ph.D. level) to meet this need. As the demand for water in cities continues to put greater pressure on the use of water for irrigated crop production, sorghum and millet which are, for the most part, rainfed will gain increased importance in meeting the caloric needs of developing countries, particularly in the semi-arid tropics, and of the livestock feed industry in the United States. Recent INTSORMIL research on the nutritional benefits of sorghum and millet form a strong base for future research to enable the commercialization of nutritionally superior sorghum. Based on its achievements, the INTSORMIL team is well positioned to contribute even more effectively to ending hunger and raising incomes. With its increasing strength of scientific expertise in developing countries, INTSORMIL is now able too 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 first 26 years and the training of sorghum and millet scientists by INTSORMIL in the United States, Africa and Central America now enable scientists from developing countries and the United States to jointly plan and execute mutually beneficial collaborative research. These collaborative relationships are keys to INTSORMIL's success and will continue as fundamental approaches to meeting the INTSORMIL mission. In the future,

Introduction

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 a finite scientific capability on sorghum and millet, and creates technological and human capital that have a sustainable and global impact.

Future strategies of INTSORMIL will maintain INTSORMIL's current, highly productive momentum, build

on its record of success, and accomplish a new set of goals. INTSORMIL's global strategy for 2001-2006 is intended to contribute to the shift of sorghum and pearl millet from subsistence crops to value-added, cash crops, and proposes to produce scientific knowledge and technologies to: contribute to economic growth, improve nutrition, increase yield, and improve institutional capability to meet global, regional and national needs.

