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Introduction and Program Review

The 2004 INTSORMIL Annual Report presents the progress and notable achievements by the Sorghum/Millet CRSP during the period of July 1, 2003 - June 30, 2004. 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 as providing improvements which yield 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, 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 and utilization for the mutual benefit of the U.S. and Less Developed Countries (LDCs).*** 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 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 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 with wheat and rice products. 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 Cental 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 birdfood 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, 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 multidisciplinary 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 technologies 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 too 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 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 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 in the semiarid trop-

ics, 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 25, 2003-2004, there were 49 students from 19 different countries enrolled in an INTSORMIL advanced degree program and advised by an INTSORMIL principal investigator. Approximately 71% of these students came from countries other than the U.S. The number of students receiving 100% funding by INTSORMIL in 2003-2004 totaled 10. An additional 35 students received partial funding from INTSORMIL and the remaining four students were funded from other sources.

Another important category of education which INTSORMIL supports is non-degree research activities, namely postdoctoral research and research of visiting scientists with INTSORMIL PIs in the United States. During Year 25, twenty scientists improved their education as either postdoctoral scientists (6) or visiting scientists (14). Their research activities were in the disciplines of plant breeding, economics, entomology and pathology research. These scientists came to the United States as postdoctoral scientists or visiting scientists from Egypt, Ethiopia, India, Indonesia, Malawi, Mali, Niger, Senegal, South Africa, and the United States.

Networking

The Sorghum/Millet CRSP Global Plan for Collaborative Research includes workshops and other networking activities such as newsletters, publications, the 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, SADC/SMINET, SADC/SMIP 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 network, short-term and degree training plans for sorghum and pearl millet scientists.

Over the years, established networking activities have been maintained 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 Africa, West Africa and with SMIP/SMINET in Southern Africa. Sudanese collaborators have provided leadership to the Pan African *Striga* Control Network. INTSORMIL collaboration with WCAMRN/ROCAFREMI and WCASRN/ROCARS in West Africa had much potential in allowing INTSORMIL utilization scientists to collaborate regionally. ROCAFREMI was a good mechanism for promoting millet processing at a higher level than has been seen before in West Africa. During the last four years, INTSORMIL, the Bean/Cowpea CRSP and World Vision International had been working with NARS researchers and farmers in five countries under the West Africa Natural Resource Management Project, creating and using a technology-transfer network in West Africa. That project was terminated in 2003. 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 activities in the Western Region of West Africa proceeded well in 2003-2004. A planning workshop was held in Ouagadougou in April 2004 for merger of the INTSORMIL West African regional programs (Eastern and Western) into one six-country region. The new regional program will start in July 2004. In Niger, a project was begun with Rockefeller funding to introgress *Striga* resistance into a high quality local variety, El Mota. Further work showed that a midge resistant sorghum line identified by INRAN scientists holds promise. In the Niger couscous project, the CIRAD-designed agglomerator in the INRAN cereal processing unit was successfully fabricated locally and put in an entrepreneur's processing facility (funded through IFAD Sorghum-Millet Initiative). Good progress was made in development of millet hybrids with downy millet resistance at Lake Chad Research Institute, Maiduguri, Nigeria. At the University of Maiduguri, good progress was shown in using new hybrids/varieties of millets in high quality foods, and a move towards commercial processing of millet couscous was initiated. A project in Burkina Faso was initiated to improve production practices for sorghums optimum for *dodo* (traditional beer) making. A combination of microdose fertilizer application and Zai (water management) substantially improved yields of cv.Framida – a superior red sorghum for the brewing process. This is an interdisciplinary project developed and implemented by the Burkanabi scientists. Another positive outcome was the third year of INTSORMIL collaborative activities in Ghana and Senegal with activities in breeding, pathology, entomology, agronomy, and *Striga*. The strong Mali research program in IER continues to show leadership in the region by enhancing germplasm exchange, scientist to scientist cooperation, and collaborative research activities among scientists in several West African countries.

One concern regards the best way to organize, coordinate, etc., research activities among the various countries in West Africa. Bringing the countries of Mali, Niger, Ghana, Senegal, Burkina Faso, and Nigeria together into a single regional program strengthens the research effort across the region, but the limited funding for these new countries is still a problem. Also, the time and funding required for U.S. PIs to travel to more countries in West Africa is a concern. The addition of new INTSORMIL projects has been a positive development and should strengthen the West Africa regional program in the future. Positive moves in that area include John Leslie's travel and efforts on behalf of pathology. However, pathology needs assistance beyond grain toxin studies. The work of Dr. Jeff Wilson, USDA/ARS will strengthen the millet breeding and millet pathology area. Dr. Clint Magill, Texas A&M University has become involved in biotechnology collaborative research in the region. Dr. Bonnie Pendleton, West Texas A&M has shown a strong effort in strengthening collaboration in entomology. Dr. Mitch Tuinstra, Kansas State University has initiated collaboration in sorghum breeding and has established collaboration in 2003. Dr. Joe Hancock, Kansas State University brings poultry and livestock feeding experience to the program. The PI Conference in November 2002 and the regional workshop in April 2004 were excellent opportunities for scientific exchange and collaborative research development.

The loss of both the sorghum and millet networks in West Africa has been a major concern, and this loss has resulted in less funding, communication and cooperation among scientists doing research on production, utilization, and marketing of sorghum and pearl millet in West and Central Africa. INTSORMIL will work with and encourage NARS to develop a new framework to restore some of the important network functions such as scientific meetings, workshops, etc.

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

On-going collaborative research has progressed in each of the countries, namely Ethiopia, Eritrea, Kenya and Uganda. In this report, we document progress of some work in Tanzania and Eritrea. Host country PIs in each country has taken keen interest in collaborating with U.S. PIs where partnership has been developed. Because of expanded collaborative involvement in several countries, more U.S. PIs are needed to provide collaborative linkages with host country scientists. New PIs joining INTSORMIL are expected 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.

Work on integrated *Striga* management that started in Ethiopia has been extended to Eritrea and Tanzania. Field performance of the technology package of *Striga* resistant cultivars, fertilization, and water conservation practice has produced good results in both countries. Farmer response to the package has been, not surprisingly, excellent as well. Opportunities for advancing the program by putting in place an organized and functional seed production and a delivery mechanism as well as viable market outlets for both seed and grain in Tanzania look very promising. Availability of grain market outlets via cottage industries such as Power Foods and large-scale factories (brewery, feed processors) provides excellent opportunities to tie in research, extension and processing, so that investments in both research and on-farm could show profitable results.

We look forward to finding an appropriate forum for sharing these experiences with stakeholders from all over the region.

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

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. Although INTSORMIL has trained many Southern Africa students over the last 20-years few returned to their home institutions to conduct research in either sorghum or pearl millet. 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. These problems can also work to the benefit of sorghum and pearl millet if a production and marketing system can be developed for the crops. With the right varieties or hybrids and the right marketing system the natural stress resistance of sorghum and pearl millet can help provide a consistent supply of high quality grain for processors and consumers.

Most INTSORMIL activities in Southern Africa were carried out as planned. The collaborative research has produced results that are important to increasing the production and quality of end-products of sorghum and pearl millet in the Southern Africa region. Hybrid parents have been bred for sorghum and are nearing completion for pearl millet. A large amount of sorghum breeding material and varieties in use have been characterized for resistance to major diseases and sugarcane aphids. Multi-location testing of sets of such lines provides strategic geographic information on distribution and severity of diseases. Factors influencing the incidence and control of sorghum ergot are now better understood, leading to better control of the disease, especially in hybrid production fields. Food quality research can lead to increased use of sorghum in various products. Linking variety qualities to specific end uses is being shown to be very important.

Active, interdisciplinary collaboration exists in sorghum breeding, plant pathology, grain quality, and entomology. Regional pearl millet breeders continue interaction with INTSORMIL at a reduced level due to retirements of U.S. principal investigators. Efforts are underway to establish and strengthen collaboration with regional pearl millet breeders but progress is very slow. Efforts are on-going to continually refocus activity for increased relevance and generation of useful technology. Collaboration can be improved and increased in all research areas. Additional collaboration is needed in all disciplines for all research objectives. Unfortunately, there are more collaborators and opportunities in Southern Africa than there are INTSORMIL principal investigators in the United States.

The regional budget has been reallocated to contribute additional funds to collaborators and to improve accountability for the funds. Funds are passed to the host country research organizations and joined to specific work plan objectives. This enables scientists to have funds available on a more timely basis and increases accountability of the scientists for the funds and in providing research results. This brings collaborators more directly into INTSORMIL and provides a forum for dissemination of research results.

Central America (El Salvador, Nicaragua, Honduras)

Since 1999 the Central America program has increased activity in El Salvador and Nicaragua. A Memorandum of Understanding was signed with DICTA to allow future collaborative research in 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. The research activities developed for 2003-2004 were successfully completed, and administrative procedures for reporting research results and financial expenditures are proceeding satisfactorily. A regional graduate education and short-term training plan have been developed with the regional research directors. Three students are currently in graduate degree programs, and three more scheduled to start in 2004-2005. Short-term training in experimental design and data analysis was given to 30 collaborators in the region. 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 implement these research priorities while expanding activity into Honduras and Guatemala. Communication with and coordination of the many groups participating in the program remains a challenge. 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. 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. Major progress was made in developing forage and grain hybrids, including line identification, testing and in seed production. Grain utilization issues are increasing in importance in the program. Increased awareness of the desirable livestock feeding value of sorghum grain was created through workshops, and a keynote presentation on this topic was presented at the PCCMCA Annual Meeting. Equipment for efficient milling of sorghum grain was identified in El Salvador. 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.

Regional Benefits by Technical Thrust

Germplasm Enhancement and Conservation

The goals of pearl millet breeding research supported by project ARS-206 are to improve the productivity, yield stability, and pest resistance of pearl millet cultivars. Achieving these goals requires 1) identifying constraints limiting production or utilization within and across environments, 2) acquiring and evaluating new germplasm for desirable characteristics, 3) crossing selected germplasm with regionally adapted breeding lines or cultivars, 4) selecting and evaluating improved progeny as potential new cultivars.

Project collaborators at multiple locations have been identified. These individuals have contributed cultivars and experimental germplasm for evaluating genotype x environment interactions in grain yield, quality, and disease and pest resistance. Collaborators have reached a consensus on project objectives, methods and timetable to achieve these objectives. In Niger two research collaborators were identified and contributed to the 2003 workplan. Although seed for trials were sent to these individuals, no data have been received. Dr. Issoufou Kapran, INRAN sorghum program leader, has identified Issaka Ahmadou as a new collaborator for 2004 trials. A replicated set of selected pearl millet germplasm was distributed among collaborators. Multi-location experiments have been established in Ghana, Mali, Niger, Nigeria, and Senegal. The germplasm is being assessed for characteristics that contribute directly or indirectly to stability of grain yield and quality.

In an effort to expand the diversity in the breeding populations being selected at collaborating locations, crosses have been made between several African cultivars and U.S. breeding lines to develop new germplasm in the A1 and A4 male sterile cytoplasms, and also with corresponding genes for fertility restoration. The introduced accessions are being evaluated for pests and diseases of importance to growers in the U.S. and in Africa. Sources of resistance to leaf blight, rust, and root knot nematode have been identified in the African pearl millets.

Research and germplasm development in INTSORMIL sorghum breeding project PRF-207 addresses the objectives of proper recognition of the major constraints limiting production, knowledge of germplasm, and an appropriate physical environment for evaluation and testing of breeding sorghum varieties and hybrids for use in developing countries requires. Successful breeding efforts also require knowledge of mode of inheritance and association of traits that contribute to productivity as well as tolerance to biotic and abiotic stresses. Successful breeding efforts also require knowledge of mode of inheritance and association of traits that contribute to productivity as well as tolerance to biotic and abiotic stresses (drought, cold, grain mold, and other diseases). Research and germplasm development in PRF-207 attempts to address these essential requirements.

Over the years significant progress has been made in some of these areas. Superior raw germplasm has been identified, mode of inheritance established, chemical and morphological traits that contribute to productivity as well as to tolerance to these stresses have been identified. Selected gene sources have been placed in improved germplasm background, some of which have already been widely distributed. In this report, PRF-207 has included observations relative to identification and characterization of sorghum genetic variants in glycinebetaine accumulation and their role in tolerance to drought and salinity stresses. Selected gene sources have been placed in improved germplasm background, some of which have already been widely distributed in a number of African countries.

The principal objectives of INTSORMIL project TAM-222 are to identify and develop disease resistant and drought resistant sorghum germplasms in genetically diverse backgrounds for use by host country and U.S. scientists, to identify, evaluate, and utilize new elite exotic germplasm, and to collaborate with host country scientists in all aspects of their crop improvement programs. The disease and drought resistance-breeding programs continued to develop and evaluate new germplasm for use in the U.S. and host countries. Forty-nine new fully converted exotic lines and 71 partially con-

verted lines from the cooperative TAMU-TAES/USDA-ARS Sorghum Conversion Program were released. Sixty diverse breeding germplasm lines ranging from advanced generation to early generation with Pathotype three downy mildew resistance were selected for release. Numerous advanced generation B and R lines developed in TAM-222 were identified as potential releases for distribution to private companies and U.S. and host country public programs as the project moves to closure of the TAM-222 sorghum breeding project with the retirement of the project leader. More than 750 items were distributed to private seed companies with MOA's upon their request based on observation of a 500-entry B/R-line Observation Nursery in 2003.

Several very unique and promising new Durra and Durra-Bicolor and Durra-Dochna type cultivars from the dry northern part of Mali were identified in the Mali Sorghum Collection, and hold promise in sorghum improvement in the drought prone areas of Africa and the U.S. The B/R-line reaction and hybrid vigor of selected Malian and Sudanese cultivars continued. Twenty-five sorghums from the Mali Collection were selected for entry into the Sorghum Conversion Program. The Conversion Program, however, is in a temporary holding status since the USDA-ARS program in Puerto Rico dropped their portion of the Conversion Program in early 2004.

Breeding progeny developed in TAM-222 which had showed excellent potential in Zambia, South Africa, Nicaragua, El Salvador, and in south and west Texas with various combinations of high yield, drought resistance, grain quality, and disease resistance were again distributed to several host country scientists. They offer good potential for use as varieties directly where appropriate and also as parental lines for use in hybrids. Macia (an improved cultivar from Mozambique) derivative lines appeared especially promising and also offer potential to develop some improved white-seeded, tan-plant parental lines for U.S. use.

Sterilization and evaluation continued on a large number of new B-line breeding genotypes to assist decisions on which ones to release. These lines contain various combinations of stay green drought resistance, lodging resistance, improved grain quality, and head smut resistance. Several are white-seeded, tan-plant A-B pairs that could be useful in food-type hybrids.

The acceptance of white-seeded, tan-plant improved Guinea type sorghum cultivars, developed in the INTSORMIL/IER collaborative breeding program in Mali, by both farmers and in the marketplace has been excellent. The successful use of N'Tenimissa flour by a private bakery in Mali to commercially produce and market a cookie using some sorghum flour has demonstrated that new improved food quality cultivars can stimulate new commercialization of sorghum-based products. Another encouraging activity is the interest of farmers involved in the flawed 2002 identity preserved grain increase with N'Tenimissa in doing a similar thing with a different grain/market entrepreneur. It shows that new cultivars with improved grain quality traits can stimulate the development and commercialization of new sorghum-based products. Some of the new N'Tenimissa breeding progenies in Mali promise to be superior to N'Tenimissa in production and grain quality. Several (N'Tenimissa*Tiemarfing (local Guinea)) derivative breeding lines have been given cultivar names and released, including 97-SB-F5DT-63 as Wassa, 97-SB-F5DT-64 as KénikédiP, 99-BE-F4P-128-1 as Darrellken, 97-SB-F5DT-74-2 as Niéta, 96-CZ-F4P-98 as Zarra-blP, and 96-CZ-F4P-99 as Zarra-djé, along with one intermediate caudatum-guinea type 97-SB-F5DT-150 as Niétichama.

Collaborative INTSORMIL activities recently initiated in Senegal and Ghana continue in the areas of sorghum breeding, disease resistance, and *Striga*, as well as in entomology and agronomy research. The consolidation of all the West African INTSORMIL collaborative programs in six countries into one overall regional program was initiated in early 2004.

Progress was made in all research areas in INTSORMIL's project TAM-223 aimed at enhancing sorghum germplasm for resistance to insects and improving efficiency for sustainable agricultural systems. Germplasm was obtained and evaluated for resistance to economically important insect pests. Selections were made to combine insect resistance with other favorable plant traits. Germplasm was identified for advanced testing with resistance to selected insects and diseases that will contribute to production of high grain yield and widely adapted hybrids. A study to apply the results of previous molecular mapping studies on greenbug resistance and stay-green to compare the effectiveness of molecular versus conventional selection was completed. Collaboration with LDC scientists resulted in progress to develop improved, high-yielding varieties or hybrids. Progeny was identified that combines several favorable traits into a single genotype. 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 (seed containing improved germplasm) developed by this project has been adopted by private industry and used in hybrid production or breeding programs. Impact assessment studies show a high rate of return on investment from research conducted by this project.

Excellent progress was made in initiating nutrition research and germplasm characterization studies. Good progress also was made in initiating research plans with international collaborators in Africa and Central America. Several students from Central America and Africa were identified and selected for graduate training.

The emphasis of project KSU-220 is on developing high yielding sorghum varieties and hybrids with enhanced nutritional and grain quality characteristics for use as human food and in animal feed. Recent nutritional studies indicated that certain large-seeded hybrid sorghums were equivalent in feeding value to hybrid maize and were significantly better than conventional sorghum varieties. Breeding efforts have been initiated to transfer these enhanced feed quality characteristics into high-yielding sorghum varieties adapted for production in Africa, Central America, and the United States. This will be accomplished through conventional breeding strategies and by adapting marker-assisted selection technologies as appropriate. Several new large-seeded lines have been identified through applied plant breeding efforts.

Other research efforts have focused on the characterization and utilization of genes to improve resistance to grain mold and tolerance to weathering. Recent studies evaluating the efficacy of marker assisted selection for improvement of grain mold resistance indicated that QTL were only effective in the original mapping population. This fact limits their potential usefulness in an applied breeding program. Greater success has been observed through applied plant breeding efforts. These results suggest that more emphasis may be needed on applied plant breeding activities to ensure success of the project.

More than 80 disease resistant (R) genes have been identified and cloned based on database searches of sorghum expressed sequence tags and by PCR amplification using primers derived from motifs conserved in resistance genes cloned from other species. More than one-half of these have been placed on the genetic map of sorghum. Reports from other species suggest that these genes may confer disease resistance to fungal, bacterial, and viral pathogens and even to insects.

Technology transfer activities, particularly in the area of poultry nutrition and production, have been initiated in several countries. In Central America, technical assistance and technology transfer are being pursued through interactions with Dr. Carlos Campabadahl, one of the leading nutritionists in Central America. In West Africa, poultry feeding demonstrations have been initiated with great interest by producers. It is important that these demonstrations evolve into training programs directed toward key poultry producers and feed millers.

Sustainable Production Systems

INTSORMIL's project, PRF 205, has successfully completed its second principal year of the Marketing-Processing project which has indicated the importance of combining inorganic fertilizers with the new cultivars and of inventory credit even in a good rainfall year. In other fieldwork the same techniques of combining new technology introduction with marketing innovations were shown to be critical to introducing new maize technologies into central Mozambique.

The project has had a successful year in graduate student training. Besides the new marketing activity, economists in PRF-205 continue to do impact analysis. Graduate students in PRF-205, as in other INTSORMIL projects, develop their skills as researchers by actually doing research under the guidance of their major professor, an INTSORMIL principal investigator. The project PI supported four graduate students from INTSORMIL priority countries, two Ethiopians, a Mozambican, and a Nicaraguan. The two Ethiopians, Nega Wubenah and Yigezu Yigezu were directly supported by the INTSORMIL funding except when Yigezu was doing his fieldwork and then working full time on the impact of the *Striga* resistant cultivars. Both Ethiopian students have benefitted from the supplemental INTSORMIL funding for evaluating the impact of new technologies. Both have done fieldwork in different regions of Ethiopia on the impacts of *Striga* resistant cultivars and associated technologies. Mr. Nega finished his M.S. thesis on the diffusion of new technologies in Tigray and returned for more fieldwork there during the summer of 2003. This work will be supplemented by Mr. Yigezu's fieldwork and future thesis from the Ethiopia Amhara region on the same topic.

Mr. Rafael Uaiene (Mozambique) has been directly supported by another USAID training grant to INTSORMIL from the Mozambican USAID Mission. Felix Baquedano (Nicaragua) has conducted follow-up to the research of Tahirou Abdoulaye in western Niger. He has interviewed the same sample of farmers that Dr. Tahirou interviewed in 2000 and has evaluated their continuing use of inorganic fertilizer and their subsequent adoption of inventory credit. He has been supported by our PRF-205 project Impact-USAID funding in that field activity.

The PRF-205 project has been involved in the development of a Marketing-Processing Project for West Africa. During the first one and one half years the project was financed first by ROCAFRAMI (the previous 14 country millet network operating in West and Central Africa) and then by the USAID-Washington through the Impact Project with partial funding from INTSORMIL for Dr. Botorou Ouendeba's travel. During the past six months INTSORMIL set aside funding for the support of the Project coordinator and the six weeks of fieldwork in the summer of 2004 to evaluate the second year impact and to extend project operations to feed processors. WARP, the USAID regional mission in West Africa has indicated their intention of supporting this work for the next fiscal year. The project scientists will be extending this work from the four Sahelian countries presently involved (Senegal, Mali, Niger, and Burkina Faso) to include Nigeria in 2004.

With other funding from USAID/Africa the Principal Investigator of PRF-205 and his graduate students have con-

tinued studying the potential impact of biotechnology, focusing their attention on the costs to West Africa of not introducing Bt cotton. Another project has been an analysis of the effects of technology and policy on farm income and technology introduction in cacao production in Cameroon and Ghana. Both projects broaden the scope of PRF-205 and give the PI ideas for the projects INTSORMIL researches.

INTSORMIL's project UNL-213 which focuses on cropping systems to optimize yield, water and nutrient use efficiency of pearl millet 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, 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. 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 increasing 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.

During the 2003-2004 program year project output included the identification of the improved photoperiod sensitive (maicillo criollo) sorghum variety 85SCP805 with increased grain yield, improved NUE, and high % N fertilizer recovery for production in relay intercropping systems with maize in El Salvador. 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.

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

In eastern Nebraska, pearl millet grain yield is optimized with application of 90 kg ha^{-1} N fertilizer, while the response is minimal in western Nebraska due to the low rainfall conditions.

The UNL-219 project implementation has progressed as planned. Tie-ridge tillage and an implement for tie-ridging are proving to be agronomically sound and feasible for farmer use in some sorghum production areas of Ethiopia. However, communication with the project partners in Ethiopia is still a constraint to the progress and quality of implementation in Ethiopia.

Participatory research on soil and water management issues in Uganda is in its third season and is progressing well. Data have been collected for sorghum production areas in Ethiopia, Kenya and Uganda and are being compiled in GIS referenced databases. Arrangements have been made for collaborative work in Mozambique.

Use of starter fertilizer for no-till sorghum production infrequently resulted in a yield increase and in less grain moisture at harvest. The least expensive starter fertilizer option appears to be as good as other options. However, with typical planting dates, little or no economic benefit was found for starter fertilizer use for no-till sorghum production.

The INTSORMIL sponsored graduate student, Soares Xerinda, is scheduled to complete his M.S. degree in August 2004 and a work plan has been developed for collaborative work in Mozambique. Two graduate students supported by INTSORMIL, including Mr. Soares Xerinda, received their M.S. degrees in July 2004 and another expects to graduate in August 2004. Two EARO researchers completed their M.S. degrees at Alemaya University in July 2004; their study and research were partly supported by INTSORMIL with advisory support from UNL-219. The graduate research of three additional students at UNL is partly supported by INTSORMIL.

Sustainable Plant Protection Systems

INTSORMIL project KSU-211 is working on 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 my-

cotoxin 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). The KSU-211 project has identified an interspecific hybrid *Fusarium* strain that could be part of the explanation for the development of isolates that cause Pokkah boeng disease.

The Scientific Writing and *Fusarium* Laboratory workshops have become successful, visible outreach efforts and included more than one thousand participants in the 2003-2004 reporting period in Asia and Africa. A *Fusarium* Laboratory Workshop held at KSU in Manhattan had 43 participants from 17 countries in attendance. The 2004 workshop is scheduled for Pretoria, South Africa; the 2006 location will be in Bari, Italy. These 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 contract has been signed by Brett Summerell (Australia) and the KSU-211 PI to prepare a manual to accompany the Fusarium Laboratory Workshop, and the manuscript in camera-ready form should be delivered to the publisher in the 3rd or 4th quarter of 2004.

Work with the *Fusarium* collections is progressing. A visiting scientist, Dr. Giuseppe Mulé, from Italy did collaborative research in the laboratory of the PI of KSU-211. Upon her return to Italy, Dr. Giuseppe Mulé and her colleagues 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. W. Marasas in South Africa. The toxicology work needs a collaborator who can test the effects of toxins in commercial animal feeds, and who can model their effects in laboratory systems by using human and animal cell lines as models.

The KSU-211 project has begun working with Dr. Ranajit Bandyopadhyay of IITA (Ibadan, Nigeria) and his network of pathology collaborators in West Africa, including Dr. Stephen Nutsugah (Ghana), Dr. Adama Neya (Burkina Faso) and Dr. Zachee Ngoko (Cameroon) to identify causal agents of grain mold and head blight in sorghum in West Africa. Dr. Bandyopadhyay also will play a role in collecting samples to be analyzed by Prof. Marasas to evaluate mycotoxin levels in maize and sorghum planted side-by-side in West Africa.

The extension of MSU-205 into Nicaragua and El Salvador during the past four 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, MSU-205 was involved during the previous 20 years in Honduras. The economic threshold (ET) level for a fall armyworm on sorghum was confirmed to be one larva per plant on plant growth stage two (five leaves), but was determined to be too low for subsequent stage plants, thus allowing farmers greater latitude in the use of the ET concept for application of insecticide on older plants and reducing the cost to manage this pest. 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 problems identified in the respective countries have yielded the basic biological information needed for developing and recommending effective insect pest management programs. Recommendations to manage the complex of lepidopterous caterpillars on intercropped sorghum and corn in Honduras, sorghum midge in Nicaragua and fall armyworm 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 of sorghum in Mississippi. This includes fall armyworm on whorl stage plants and sorghum midge, fall armyworm, sorghum webworm and corn earworm on the panicles. Effective insecticide use practices for control of sorghum midge on sorghum panicles and redefined economic threshold levels for fall armyworm on whorl stage sorghum plants will assist farmers in decision-making regarding the application and effective use of insecticides to manage these pests.

The emphasis of project KSU-220 is on developing high-yielding sorghum varieties and hybrids with enhanced nutri-

tional and grain quality characteristics for use as human food and in animal feed. Recent nutritional studies indicated that certain large-seeded hybrid sorghums were equivalent in feeding value to hybrid maize and were significantly better than conventional sorghum varieties. Breeding efforts have been initiated to transfer these enhanced feed quality characteristics into high-yielding sorghum varieties adapted for production in Africa, Central America, and the United States. This will be accomplished through conventional breeding strategies and by adapting marker-assisted selection technologies, as appropriate.

Other research efforts have focused on the characterization and utilization of genes to improve resistance to grain mold and tolerance to weathering. Studies evaluating the role of known defense response pathways have shown that factors other than the activation of defense genes account for differences among sorghum genotypes with contrasting host-plant resistance characteristics. Marker-assisted selection studies indicated that a subset of grain mold resistance genes tagged in the variety SureZo are expressed across environments and in diverse genetic backgrounds. These genes represent excellent candidates for utilization in crop improvement programs via marker-assisted selection.

A training program is being developed to transfer the technology and knowledge needed to effectively utilize improved sorghum and millet cultivars for animal feeding and human food. Technical assistance and technology transfer are being pursued through interactions with Dr. Carlos Campabadahl, one of the leading nutritionists in Central America, and Mr. Salissou Isa, Head of the Animal Husbandry Unit at INRAN in Niger. These efforts include the development of training programs directed towards key poultry producers and feed millers in West Africa and Central America, including demonstration experiments and workshops.

The efforts of the investigators in KSU-220 to improve and protect sorghum grain quality include integrated research projects involving pathology, breeding, and poultry nutrition within the framework of a "mega-project" involving the four principal investigators and collaborating scientists in developing countries. Although good progress has been made to initiate interdisciplinary research projects and collaborations to address this objective, the group has not yet coalesced into a fully integrated team. Some interdisciplinary components of the project have been very effective and productive, but these synergies are less evident in other areas. In these areas, the amount of collaboration among principal investigators within this project is comparable to interactions with principal investigators of other INTSORMIL-CRSP projects. Thus, the KSU-220 team continues working toward fully integrated collaboration.

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 combining 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 induction of *Striga asiatica*. To the project scientists this is the first report of low haustorial initiation activity. Up too now, this potentially useful trait has not been found among any of the *Striga* resistant sorghums. Thus, low haustorial initiation capacity may be a good trait to transfer from wild to cultivated sorghums. None of these wild sorghum accessions has yet been field tested in *Striga* sick plots so at this point the project cannot correlate these phenomena observed in the laboratory with actual *Striga* resistance. Chemical and genetic characterization of the traits reported here for PQ-434 are currently underway.

INTSORMIL project WTU 200 has achieved significant research output in 2003-2004. The PI of INTSORMIL's project for sustainable management of insect pests (WTU-200), traveled to West and Southern Africa to review INTSORMIL activities and discuss collaborative research in entomology. Research was done as planned with scientists in Africa. An African Sorghum and Millet Entomology Workshop to discuss current and future research was held in Burkina Faso in April 2004. Resistance of sorghum lines developed by project TAM-223 and a commercial seed company were evaluated for resistance to greenbug biotypes. Fitness of greenbugs on sorghum was assessed in relation to host and soil water and nitrogen. Tritrophic effects of resistant sorghum on beneficials were assessed. Resistance of genotypes of sorghum and cowpeas was evaluated in 230,000 observations. Thesis programs of five graduate students were directed; two M.S. degree students graduated in August 2003, two will graduate in August 2004, and one Malian student learned English and began graduate studies in 2004 and an Ethiopian student will begin a Ph.D. degree in 2004. As planned, research results were presented by the PI and graduate students at entomology and other scientific meetings.

Crosses of Malisor84-7 and improved sorghums were evaluated and found resistant to panicle bugs and grain mold in Mali. Sorghum sprayed with extracts from local plants were less damaged by sorghum midge than the nontreated check in Mali. Twenty times more stalk borers infested millet in a field, especially when sorghum residue was left after harvest in Mali. More borers infested millet than maize or sorghum. Nineteen sorghums from SADC were evaluated and found susceptible to sugarcane aphids and stalk borers, but 13 were resistant to termites in Botswana. Two hundred sorghum lines were evaluated for resistance to greenbug biotypes C, E, and I, and one line developed by Pioneer Hi-Bred International, Inc. was very resistant to biotype I. Resistant sorghum did not affect the number of biotype I greenbugs consumed by convergent lady beetles but negatively affected numbers of eggs laid and hatched, especially at 30ºC. Greenbug fecundity and longevity were 4.4 and 2 times less on barnyardgrass than sorghum. Soil water potential, but not nitrogen, affected greenbugs, with twice as many nymphs and 6.4 more days of life per greenbug on sorghum in soil with -33 versus -300 kPa of water. Stored grain of resistant SureZo, Sima, and Macia sorghum retained 94.6-99.2% of original weight at 105 days after infestation by maize weevils.

Utilization and Marketing

INTSORMIL project PRF-212 has made progress in better understanding the mechanism causing the comparably low starch digestibility characteristic of cooked sorghum foods. Novel web-and sheet-like protein structures that form during the cooking process were shown to directly relate to starch digestion properties. This knowledge can form the basis for manipulation of starch digestion rate either up or down to provide greater energy availability in sorghum foods or slowly digestible starch for health benefit. They now know how to improve starch digestibility in cooked sorghum foods – by using a high protein digestibility sorghum or addition of reducing compounds – and have gained knowledge on how to moderate starch digestion rate of sorghum and other starchy foods. This has important implications in areas of obesity, diabetes and pre-diabetes, and cardiovascular disease that is not only important in the U.S., but is becoming a large problem in urban areas of developing countries.

The project also made headway in finding ways to improve starch digestibility of raw sorghum grain for animal feed use. Starch granule morphologies were identified that show promise as more easily digested. In the area of sorghum porridges, starch structural properties were shown to affect storability and staling characteristics of sorghum-based foods. Such information is important in putting together a strategy to fundamentally change sorghum grain for better food and feed use.

Work continues toward commercialization of sorghum and millet products in West Africa as this effort takes on a more regional approach. The project PI will work with the team formed in the integrated, regional crop utilization project that will culminate in a proposal for funding a larger processing effort for the region.

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.

Activities in Honduras, El Salvador and Southern Africa are top priority. The hiring of Dr. Javier Bueso at EAP in Honduras was encouraging. The opportunity to develop a more comprehensive program in El Salvador and Honduras

is challenging because there is a lack of effective personnel with the knowledge required to do value-added processing research. The TAM 226 PI will try to develop a relationship with Dr. Saldivar at ITESM in Mexico to help with the program in El Salvador. The chance to interact with a good cadre of Southern and East African students at University of Pretoria is a unique opportunity.

The uncertainty of funding from year to year inhibits commitments to graduate training. Inflation has eroded away much of our graduate training capabilities. The project utilizes significant research funded by other sources for the mold and breeding research support that is necessary for this project. Their ability to attract additional financial support for the work has allowed continued productivity. The funds from INTSORMIL have relatively little buying power since they have about the same number of total dollars they had 20 years ago. The addition of new PIs working on breeding and molds at TAMU will help. Also, the project on animal feeding and breeding at KSU will provide useful interaction.

Millet research has been minimized as funds from INTSORMIL decrease in actual buying power. Millet is not a crop in Texas and leveraged funds from other sources are all for sorghum research which makes it difficult to significant work on pearl millet. Overall, TAM 226 is quite productive, but cannot do everything that is required.

Biotechnology

Biotechnology encompasses a number of concepts and techniques based on recent knowledge of genetics, biochemistry, and 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.

Future Directions

During the past 25 years, INTSORMIL has educated more than one thousand scientists by 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, and 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 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 first 25 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, 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.