Introduction and Program Review

From 1980 to 1999, according to the Food and Agriculture Organization of the United Nations (FAO), the number of food-insecure people in developing countries fell from 920 million to about 800 million, yet in 2003, the International Food Policy Research Institute declared that "without significant changes in policies, public investments, and institutions, we simply will not achieve the 1996 World Food Summit goal—reaffirmed at the 2000 Millennium Summit and again last year at the World Food Summit: five years later—of reducing the number of our fellow human beings who are food insecure by at least half by no later than 2015." FAO indicates that the number has been decreasing by barely 2.5 million per year over the last eight years. At that rate, we will reach these goals one hundred years late, in 2115. *Increased production of cereals, which are crucial sources of food energy and other nutrients, is necessary to reduce world hunger.*

According to *Entering the 21st Century–World Development Report 1999/2000,* about 900 million people in almost 100 countries are affected by drought and desertification, and by 2025, that number will double. The population of the world has doubled since 1940, but fresh water use has increased fourfold. Water scarcity is becoming more widespread, with concomitant effects on regional peace and global food security. Nearly all of the 3 billion increase in global population which is expected by 2025 will be in developing countries where water is already scarce. To meet the increasing demand for food in those countries, there is an increasing demand for more efficient production and new ways of utilizing drought-tolerant crops which have a competitive advantage to produce food under conditions of unpredictable and scarce rainfall. As water becomes more precious in the United States, cereals which can produce energy for feed and fuel in drought-prone areas of the country are demonstrating increasingly competitive advantages.

According to Sandra Postel of the Global Water Policy Project, "Some 40 percent of the world's food comes from irrigated cropland, and we're betting on that share to increase to feed a growing population." In developing countries of the semi-arid regions, *sorghum and millet*, two important cereal grains which are mainly rainfed and not irrigated, make the difference between food security and famine. As water for irrigation becomes more scarce for agriculture due to urban competition for water worldwide, drought-tolerant, rainfed sorghum and millet will continue to gain increased importance as efficient users of water to produce nutritious food for humans and feed for poultry and livestock.

Large areas are planted to sorghum each year. For example, in 2002 sorghum was produced on 42.6 million hectares (ha, or 164 thousand square miles, [sq mi]) worldwide, 23.6 million ha (91 thousand sq mi) in Africa, and 3.0 million ha (11 thousand sq mi) in the United States. About 500 million people worldwide depend upon sorghum for food, and most of these people are in developing countries where droughts and famine are common occurrences. In 2002, 54.5 million metric tons (MT) of sorghum were produced worldwide, of which 20.3 million MT were produced in Africa, mainly for direct consumption by humans, and 9.4 million MT were produced in the United States, mainly for livestock feed to produce meat for human consumption (FAO data). In the United States, sorghum is important to the balance of trade, is an important feed in the production of beef, and is increasingly in demand as a raw material for food and as a renewable feedstock for production of fuel. In 2002 through December, the United States exported 5.4 million MT of grain sorghum mainly for livestock feed worth $570 million (FAS data). In 2002, 1.1 million MT of sorghum were used to produce ethanol. *Clearly, sorghum production and utilization as food and feed are vitally important to developing countries and to the United States.*

Millets, which include several types such as pearl millet, finger millet and proso millet, are cereal crops even better adapted to arid ecosystems than is sorghum, and pearl millet is a staple for 300 million people worldwide. Most of these people are in countries within semi-arid regions where malnourishment is a persistent problem. In 2002, 33.4 million hectares (129,000 sq mi) of millets were harvested worldwide, of which 20.6 million ha (79,600 sq mi) were harvested in Africa, and 89,034 ha (344 sq mi) were harvested in the United States. In 2002, the amount of millets harvested worldwide was 23.3 million MT, of which 13.6 million MT were harvested in Africa and 74,979 thousand MT were harvested in the United States. Millets are crops used mainly for direct consumption by humans in developing countries, and for feeding livestock, particularly poultry, in developed countries. Pearl millet is an important cereal crop which provides food energy and other nutrients to hundreds of millions of people in areas which currently suffer from malnutrition, particularly Africa and southern Asia. *The United States and all other participants in the World Food Conference have a stake in promoting the production and utilization of sorghum and pearl millet to help end hunger, particularly in Africa.*

In *World Food Prospects: Critical Issues for the Early Twenty-First Century,* IFPRI points out that "without substantial and sustained additional investment in agricultural research and associated factors, it will become more and more difficult to maintain, let alone increase, cereal yields in the longer term. The gap in average cereal yields between the developed and developing countries is slowly beginning to narrow, but it is widening considerably within the developing world as Sub-Saharan Africa lags further and further behind the other regions . . . ." In its *2020 Global Food Outlook Report,* IFPRI observes that "Cultivating more and more

land will not solve Sub-Saharan Africa's food security problems for the long-term. Between 1967 and 1997, the region expanded cereal cultivation by 31 million hectares and roots and tubers cultivation by 8 million hectares. This rate of expansion is not sustainable; therefore, higher crop yields are needed to reduce malnutrition in 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. In the *U.S. Action Plan on Food Security – Solutions to Hunger,* published in March 1999, the United States government states that one of the ways that the United States plans to contribute to the global effort to reduce hunger is by the United States' continuing commitment to support international agricultural research through the Collaborative Research Support Programs.

The Collaborative Research Support Program (CRSP) concept was created by the U.S. Agency for International Development (USAID) and the Board for International Food and Agriculture Development (BIFAD), under the auspices of Title XII of the Foreign Assistance Act, as a long term mechanism for mobilizing the U.S. Land Grant Universities in the international food and agricultural research mandate of the U.S. Government. As amended in 2000, Title XII enables a wider inclusion of organizations by including land grant universities, other universities, and their public and private partners in the U.S. and other countries. The CRSPs are communities of U.S. Land Grant Universities and other universities working with USAID and other U.S. Federal Agencies, strengthening and enhancing National Agricultural Research Systems (NARS), collaborating country colleges and universities. The CRSPs also work closely with the International Agricultural Research Centers (IARCs), private agencies, industry, and private voluntary organizations (PVOs) fulfilling their mandate. The Sorghum and Millet Collaborative Research Support Program is one of nine CRSPs currently in operation.

The Sorghum and Millet Collaborative Research Support Program (INTSORMIL CRSP) conducts collaborative research using partnerships between U.S. university scientists and scientists of the 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, southern, and eastern 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. The six universities currently active in the INTSORMIL CRSP are Kansas State University, Mississippi State University, University of Nebraska, Purdue University, Texas A&M University and West Texas A&M University. In addition, scientists of the Agricultural Research Service of the U.S. Department of Agriculture at Tifton, Georgia participate in INTSORMIL. What were formerly referred to as "host" countries are now referred to as "collaborating" countries to indicate the closer and more collaborative relationships that have developed between the United States and those countries as a result of all that has been accomplished during the past twenty-two years of the INTSORMIL CRSP.

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 is being 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. and in 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 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 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. *From a strategic standpoint, the education of agricultural scientists and developing-country scientists by INTSORMIL contributes to the economic and political stability of developing countries, through cultural ties and long-term scientific collaboration, helping enable the collaborating countries to achieve economic growth necessary to becoming more significant trading partners with their neighbors and the United States. Strategically for the United States, it is crucial to maintain a cadre of both scientists knowledgeable about sorghum and millet within and outside the United States to assure the safety and growth of these two crops in the United States, since both crops are native to Africa. The bridges which INTSORMIL builds between the United States and developing countries are crucial components in the peaceful relations between the United States and the rest of the world.*

- ***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 programs, 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 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 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 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 does research to improve processing to yield 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 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, Lincoln (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 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.

Several major decisions, events and accomplishments of INTSORMIL during the past year occurred in the United States and collaborating countries:

The members of the 2002 - 2003 Technical Committee are:

- Dr. Gary Peterson, Chair, Texas A&M University (Southern Africa Regional Program Coordinator)
- Dr. John Sanders, Vice Chair, Purdue University (Agronomy/Physiology)
- Dr. Henry Pitre, Secretary, Mississippi State University (Plant Protection)
- Dr. Bruce Hamaker, Purdue University (Economics/Utilization)
- Dr. Gebisa Ejeta, Purdue University (Horn of Africa Regional Program Coordinator)
- Dr. Mitch Tuinstra, Kansas State University (Plant Breeding)
- Dr. Stephen Mason, University of Nebraska (Central America Regional Coordinator)
- Dr. Issoufou Kapran, (Niger Coordinator)
- Dr. Peter Esele (Uganda Coordinator)

Members of the External Evaluation Panel approved by USAID are:

- Dr. Walter de Milliano, Team Leader (Plant Protection)
- Dr. Jacques Faure (Utilization)
- Dr. John Lynam (Economics)

- Dr. John Mann (Plant Breeding)
- Dr. Moussa Traoré (Agronomy/Physiology)

- Mozambican scientists funded by a grant from USAID/ Mozambique and administered by the INTSORMIL Management Entity were studying for M.S. degrees through out the United States. Four of the ten (Mr. Uaiene, economics; Mr. Xerinda, soil science; Mr. Chitio, entomology; and Mr. Mutaliano, plant breeding) are supervised by INTSORMIL Principal Investigators at Purdue University (Dr. Sanders), the University of Nebraska (Dr. Wortmann), West Texas A&M University (Dr. Pendleton), and Texas A&M University (Dr. W. Rooney).

- Drs. John Sanders, John Yohe, and Thomas Crawford attended a workshop, "Impact Assessment of Agricultural and NRM Research: Needs, Challenges and Options" in Washington, D.C., September 12 - 13, 2002. Dr. John Sanders presented the paper, "Impact Assessments that Make a Difference: An Economic Input into the INTSORMIL Program."

- The INTSORMIL (http://intsormil.org/ intsormilatlas.htm) and CRSPs (http://crsps.org/ crspatlas.htm) digital atlases were prepared and placed in the INTSORMIL and CRSPs websites by Thomas Crawford in July, 2002.

- Drs. John Yohe, the Vice Chair of the CRSP Council, and Thomas Crawford represented INTSORMIL at the CRSP Council Meeting of CRSP directors in Spring Green, Wisconsin, September 15 -18, 2002. Dr. Yohe presented a historical perspective of the CRSPs and led a discussion on the membership of the CRSP Council. Dr. Crawford gave an update to the CRSP Council on the INIA/CRSPs Mozambique graduate training program and briefed the Council on the new CRSP atlas.

- The First National Workshop on sorghum and millet research, extension and production was held, with INTSORMIL support, in Nazret/Melkassa, Ethiopia, November 12 - 14, 2002. The workshop was attended by 200 participants from EARO, Jimma College of Agriculture, Alemaya University, and the Ministry of Agriculture, and by 12 participants from SG-2000, Pioneer Hi-Bred International, Inc., the Ethiopian Seed Enterprise, the Ethiopian national seed industry, ICRISAT, and INTSORMIL.

- The 2002 INTSORMIL Principal Investigators Conference was held in Addis Ababa, Ethiopia, November 18 - 20, 2002. The theme of the conference was "Increasing Profitability of Sorghum and Millets". Dr. Gebisa Ejeta was the Organizing Committee Chair, and the conference was sponsored by INTSORMIL, the Ethiopian Agricultural Research Organization (EARO), and USAID. The 147 participants were from more than 23 countries. In addition to the oral presentations, 78 posters were presented. Field trips were a part of the conference, and Career Achievement Awards were presented to Drs. Henry Pitre, Darrell Rosenow, Lloyd Rooney, Gebisa Ejeta and John Yohe for their leadership and service to the INTSORMIL CRSP.

- Dorothy (Dottie) Stoner, INTSORMIL Illustrator, retired on May 1, 2003, after working with INTSORMIL for 20 years.

- INTSORMIL scientists Gebisa Ejeta, Aberra Debelo, Medson Chisi, Issoufou Kapran, and Aboubacar Touré attended the conference, "From the Green Revolution to the Gene Revolution" in Bologna, Italy, May 28 - 31, 2003. Speakers from different countries illustrated the present status, opportunities and future perspectives of public and private research in plant biotechnology.

- *Sorghum and Millets Diseases*, the proceedings of the Third Global Conference on Sorghum and Millet Diseases in Guanajuato, Mexico edited by Dr. John Leslie, was printed and distributed in June, 2003. The book was published by Iowa State University Press.

- A Fusarium Laboratory Workshop co-sponsored by INTSORMIL was held at Kansas State University in Manhattan, Kansas, June 22 - 27, 2003. Drs. John Yohe and Thomas Crawford were interviewed regarding INTSORMIL on radio station KKSU following the workshop.

The major publications organized and published by the ME office during the year include:

- INTSORMIL Directory, Publication 02-04.
- INTSORMIL 2002 Annual Report, Publication 03-01.
- INTSORMIL 2002 Annual Report Executive Summary, Publication 03-02.
- INTSORMIL Newsletter, Publication 03-03.
- INTSORMIL Bibliography, Publication 03-04.

Education

Within INTSORMIL's regions of collaborative research and the United States, education of collaborating scientists contributes to the capability of each collaborating country research program to stay abreast of economic and ecological changes which alter the balance of sustainable production systems. The strengthening of collaborating country research institutions contributes to their capability to predict and be prepared to meet the challenges of economic and ecological changes which affect production and utilization of sorghum and millet. A well balanced agricultural research institution must prioritize and blend its operational efforts to conserve and efficiently utilize its natural resources while meeting eco-

nomic needs of the population in general and the nutritional needs of both humans and livestock. To this end, education is an extremely valuable component of development assistance.

Year 24 Education (July 1, 2002 - June 30, 2003)

During Year 24, 2002-2003, there were 58 students from 21 different countries enrolled in an INTSORMIL advanced degree program and advised by an INTSORMIL principal investigator. Approximately 72% of these students came from countries other than the U.S. The number of students receiving 100% funding by INTSORMIL in 2002-2003 totaled 12. An additional 46 students received partial funding from INTSORMIL.

Conferences and workshops are an important means of continuing education for scientists doing research on sorghum and millet. During Year 24, INTSORMIL supported several conferences and workshops, the largest of which was The 2002 INTSORMIL Principal Investigators Conference held in Addis Ababa, Ethiopia, November 18 - 20, 2002. One hundred forty-seven participants from more than twenty-three countries attended the conference at which they learned about worldwide state-of-the-art research on sorghum and pearl millet. More than 200 individuals participated in the First Ethiopia National Workshop on sorghum and millet research, extension and production which was held, with INTSORMIL support, in Nazret/Melkassa, Ethiopia, November 12 - 14, 2002. Five INTSORMIL collaborating scientists were sponsored to participate in the conference, "From the Green Revolution to the Gene Revolution" in Bologna, Italy, May 28 - 31, 2003. In addition, a number of scientific writing workshops were offered by Dr. John Leslie, an INTSORMIL PI, in Malaysia, South Korea and Nigeria. About 185 individuals improved their scientific writing skills by participating in these workshops. Forty-two individuals benefitted from the Fusarium laboratory workshop conducted with INTSORMIL support. Another benefit of the conferences and workshops sponsored by INTSORMIL is that they increase the sharing of information, a key factor in making more efficient research strategies and more efficiently carrying out research.

Another important category of education which INTSORMIL supports is non-degree research activities, namely post-doctoral research and research of visiting scientists with INTSORMIL PIs in the United States. During Year 24, 2 female scientists and 15 male scientists improved their education as either post-doctoral scientists (5) or visiting scientists (12). Their research activities were in the disciplines of plant breeding, economics, food science, pathology and *Striga* research. These scientists came to the United States as post-doctoral scientists or visiting scientists from Botswana, Burkina Faso, Ethiopia, Indonesia, Italy, Mexico, Nicaragua, Niger, Senegal, South Africa, Zambia, Zimbabwe, 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 (ROCAFREMI, ROCARS, ASARECA, 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 ICRISAT programs in East Africa, West Africa and with SMIP/SMINET in Southern Africa. Unfortuneately, during INTSORMIL's 2002 - 2003 year, the West and Central African Sorghum and Millet Networks were terminated due to the withdrawal of funding and plans were in place to terminate funding of the Sorghum and Millet Improvement Program in the SADC countries later in 2003. Sudanese collaborators have provided leadership to the Pan African *Striga* Control Network. INTSORMIL collaboration with WCAMRN/ROCAFREMI 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 have 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 2002 in spite of low and erratic rainfall over much of the area. A positive was the second full year of INTSORMIL collaborative activities in Ghana and Senegal with activity 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 that remains regards the best way to organize, and coordinate research activities among the various countries in West Africa. Adding the countries of Ghana, Senegal, Burkina Faso, and Nigeria 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. Also, the reduced number of PIs with active collaboration and travel in the area has been a problem. The addition of new projects and PIs is positive and should help in the future. Positive moves in that area include Dr. John Leslie's travel and efforts on behalf of pathology, however pathology needs assistance beyond grain toxin studies. The recent addition of Dr. Jeff Wilson as a new PI will contribute to the millet breeding and millet pathology area. Dr. Clint Magill may also become involved in collaborative research in the region. Dr. Bonnie Pendleton has already shown a strong effort in strengthening collaboration in entomology. Dr. Mitch Tuinstra has an interest in the area and plans travel there. There is still somewhat of a deficiency in the food technology and sorghum agronomy area. The PI Conference in Nov. 2002 provided an excellent forum for scientific exchange and collaborative research development. However, time constraints and the expectations of ideas for the next grant extension did not allow for meaningful discussions in many areas.

The termination of INTSORMIL's strategic marketing project in early 2002 created a problem regarding a follow-up and analysis regarding the contract production, marketing, and identity preserved (IP) issues, and use of the tan-plant variety, N'Tenimissa. The resulting lack of a market economist as a principal investigator, the former PIs collaborating scientist moving to Niger, and the loss of any support from ROCARS, greatly weakened the support mechanisms for the large scale IP production and commercialization of N'Tenimissa grain in 2002. This, coupled with problems of the grain trader entrepreneur late in the season created an unfortunate situation regarding the 2002 N'Tenimissa IP production and commercialization efforts. Hopefully, the momentum developed in 2001 and early 2002 can be recovered somewhat in 2003. The development of a new project (thrust) in commercialization of millet and sorghum in West Africa which is currently being planned through INTSORMIL should be very helpful to the N'Tenimissa promotion effort in Mali, as well as over the entire West Africa region. The new MOA with ITA in Senegal and the initiation of a limited INTSORMIL collaborative program there in millet commercialization is a promising development.

The loss of both the sorghum and millet networks in West Africa is a major concern, this loss will result 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 needs to work with and encourage NARS to develop a new framework to restore some of the important network functions such as scientific meetings, workshops, etc.

INTSORMIL has made some major achievements in all the CRSP's four major objectives during this reporting period in West Africa. The contract production of over 11 tons of N'Ténimissa grain with about 50 farmers in four villages in 2001 and the movement of this identity preserved (IP) grain through the marketing channels certainly is a promising activity in promoting economic growth and moving sorghum to a value-added crop. The sale of 1 kilo bags of N'Tenimissa sorghum flour (Sorgho Phar), the Deli-ken cookies, the new effort on marketing a sorghum syrup, a non-alcohol sorghum beverage and other new sorghum products all promote economic growth and improve overall nutrition. The new sorghum breeding cultivars, such as "Wassa", and others in on-farm trials and in the advanced stage of the breeding pipeline offer potential to increase yields and improve quality and value of grain as a cash crop. Agronomic research helps exploit the genetic potential of new and existing cultivars and contributes to natural resource management and sustainable production. The development of hybrids in the future certainly would be a big step in improving yields. Pathology, entomology, and *Striga* research contribute to the host plant resistance components of control or managing pests, and also to development of other control/management strategies and techniques. The current people in training will strengthen the institutional capacity in Mali. New future training opportunities for Mali, Ghana, and Senegal scientists should be a high priority, and hopefully will materialize to strengthen institutional capacity in those countries.

Fifteen PI's from Niger, Burkina Faso, and Nigeria were supported to attend the All-PI INTSORMIL conference held in Addis Ababa, Ethiopia in November 2002. New second

generation sorghum hybrids look very promising in Niger for good combining ability and improved grain quality. The second phase of the couscous and high quality flour marketing project in Niamey was completed with a good market appearing for these products. Midge-resistant sorghum lines have been identified in the Niger program and advanced to the F4 generation. In the Nigerian millet hybrid project, results of combined analysis indicated two hybrids to perform better with yield advantage of about 20% higher than farmer's local varieties. These hybrids based on their 2001 performance were advanced to on-farm trials in 2002 season. Results from farmer's trial revealed that one hybrid has a good dehulling quality, better 'fura' processing, and is moderately resistant to downy mildew. Micro-dose fertilizer studies in Niger and Burkina Faso show the advantage of small additions of fertilizer during cropping. Economic studies show that farmers are investing in fertilizer and are gaining economic benefit.

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. Sorghum breeding efforts in Ethiopia have particularly gone well. Work on development and evaluation of experimental sorghum hybrids has resulted in identification of elite hybrids with potential for wide cultivation in the 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 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. In Eritrea, sorghum lines were evaluated at research locations in Goluj, Shambuka and Hagaz, and seed was multiplied at Goluj and Shambuko. All trials and seed multiplication in Eritrea were affected by drought, and most cultivars failed to produce grain. In Eritrea, the second largest crop is pearl millet, and in 2002, collaborative research was conducted on farmers' fields to evaluate crosses of land races with introduced lines for resistance to diseases, especially downy mildew. Exotic pearl millet varieties were also tested and compared to local landraces. The only collaborative research supported by INTSORMIL in Kenya was on testing of *Striga*-resistant sorghum, since two of the three collaborating scientists from Kenya are currently studying for PhD degrees in South Africa and the United States. In Uganda, research continues in sorghum pathology, and a new U.S. principal investigator has begun collaborative research with his Ugandan counterpart on sorghum agronomy.

Host country PIs in each country have taken keen interest in collaborating with US PIs where partnership has been developed. Because of expanded collaborative involvement in several countries, more US 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 HOA region, where host country scientists and programs continue to appreciate and welcome technical support provided by INTSORMIL.

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

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 aphid. 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)

Since 1999 the Central America program has increased activity in El Salvador and Nicaragua., INTSORMIL plans to initiate new activity in Honduras in the coming year. The

research activities developed for 2000 - 2001 were successfully completed, and administrative procedures for reporting research results and financial expenditures were 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 the regional journal *La Calera.* Communication and coordination of the many groups involved in the program continue to be a challenge. Graduate education and short-term training of scientists in national programs are needed, and priority needs were determined in 2002 - 2003. A plan based on the needs of highest priority is currently being implemented. On the whole, given the short time in implementing the present collaborative model in Central America, the program is functioning well, due to the commitment of scientists in the region, and the regional, collaborative research program has resulted in selection of improved cultivars with increased yield and nitrogen use efficiency. 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.

In the first year of this project, progress toward meeting these objectives has been made. 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 consensus on project objectives, methods and timetable to achieve these objectives. 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.

Breeding sorghum varieties and hybrids for use in developing countries requires proper recognition of the major constraints limiting production, knowledge of germplasm, and an appropriate physical environment for evaluation and testing. 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. Research and germplasm development activities in INTSORMIL sorghum breeding project PRF 207 attempts to address these essential requirements.

PRF 207 addresses major biotic and abiotic constraints (drought, cold, grain mold, and other diseases) that limit productivity of sorghum in many areas of the world. Over the years significant progress has been made in some of these areas. Superior raw germplasm have 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 a number of African countries.

Good progress was made in achieving the objectives of the INTSORMIL project which focuses on enhancing sorghum germplasm for resistance to drought and pathogens, while increasing genetic diversity in INTSORMIL project TAM 222. The Mali collection effort was completed, and some very unique elite-appearing exotic cultivars were identified. Broad-based germplasm development and distribution continued and showed promise in Mali, Nicaragua, El Salvador, Zambia, and South Africa.

New collaborative research continued to be established with Ghana and Senegal. There was much interest and desire in both countries to expand the initial collaboration to additional scientists and research areas, but with limited funding it will be difficult to obtain any major program growth in the near future. This could create some potential problems in West Africa. Several other countries have expressed intense interest on how they could get involved in INTSORMIL.

A good portion of the PI's time is devoted to evaluating, identifying, and deciding which germplasm lines and parental lines to release and how to release or distribute various

materials. A larger number of potential releases were evaluated for potential release next year, as the P.I. tries to close out some major portions of his project prior to retirement.

The successful use of N'Ténimissa flour by a private bakery in Mali to commercially produce and market a cookie using some sorghum flour was important and demonstrated that new improved food quality cultivars can stimulate new commercialization of sorghum-based products. A private entrepreneur successfully arranged for the production and harvest of identity-preserved grain in Mali with the assistance of the Institut d'Economie Rurale (IER) in 2001, which is a very positive development. However, his efforts in 2002 essentially failed late in the season due to financial and other problems within his company. The new white-seeded, tan-plant, true Guinea cultivars show adaptation superior to that of N'Ténimissa.

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 were identified that combine 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. Collaboration with research programs in Nicaragua, El Salvador, and Southern Africa (South Africa, Botswana, and Zambia) has significantly increased TAM 223 activity. Impact assessment studies show a high rate of return on investment from research conducted by this project.

Sustainable Production Systems

INTSORMIL's project, PRF 205, focusing on accelerated activity in marketing and impact analysis has made substantial progress in 2002-2003.

With the support of four NGOs working in four different Sahelian countries, INTSORMIL economists began a field-development project in this year. This shifted primary attention to the interaction between a new marketing strategy and the introduction of new technology. This has been an exciting experience working on an actual development project. The marketing research has revolved around this development activity. Two concept papers have been produced from the fieldwork involved with implementation. Also, this marketing activity has been incorporated into on going research activities and presented in conferences.

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. In the summer of 2003, graduate student Nega Wubeneh and Dr. Sanders, the principal investigator of PRF 205, went into the field in Tigray to continue the evaluation of the new *Striga*-resistant sorghum cultivars and associated technologies introduced there. Graduate student Rafael Uaiene spent the winter of 2003 interviewing farmers in central Mozambique. He is evaluating the role of marketing strategy in the introduction of new technologies for maize and sorghum as well as the importance of both in increasing farmers' incomes. Mr.Yigezu will begin his M.S. research in the fall of 2003 analyzing the introduction of N'Tenimissa and associated technologies including the importance of marketing improvements.

With other funding from USAID/Africa the principal investigator of PRF 205 and his graduate students have been studying the potential impact of biotechnology focusing, our 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 our scope and give us ideas for our INTSORMIL research.

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 United States, the project has identified through research and 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 issue facing project UNL 213 is balancing INTSORMIL efforts with other responsibilities in National Research Systems and 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 Research 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.

The implementation of the proposed work of INTSORMIL's project UNL 219 which conducts research on soil and water management for improving sorghum production in East Africa has been successful to date. The INTSORMIL-sponsored graduate student is completing his second year field trial on effects of starter fertilizer and is expected to complete his M.S. thesis in the Spring of 2004. The soils researchers of this project have initiated work in Uganda and are planning to continue giving technical support to researchers in Tanzania. Two M.S. students in Ethiopia have began their study at Alemaya University and have initiated their first season field research at Melkassa and Mekelle. Frequent communications would improve the quality of implementation in Ethiopia. The investigators in this project have experienced infrequent communications, and have re-emphasized to our partners the importance of communications to the success of the project. Girma Abebe is coordinating our research activities in the Melkassa area since he assumed responsibility for sorghum agronomy research.

Sustainable Plant Protection Systems

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. In the project which concentrates on agroecology and biotechnology of stalk rot pathogens of sorghum and millet (KSU 210), 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. The identification of a compound that can be misidentified as zearalenone when "quick and dirty" techniques are used should relieve some concerns about mycotoxins in sorghum and ease trade barriers. 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 Scientific Writing and *Fusarium* Laboratory workshops have become successful, visible outreach efforts that will continue. Scientific writing workshops are offered opportunistically while the PI travels. *Fusarium* Laboratory Workshops are held in odd-numbered years at KSU in Manhattan, and in even-numbered years at a location outside the United States. The 2002 workshop was held in Sydney, Australia; the 2004 workshop is scheduled for Pretoria, South Africa; the 2006 location has not been set, but either Europe or Southeast Asia is the most likely at the moment.

Publication of the *Sorghum and Millets Diseases* book is a major accomplishment, with 198 authors from 39 countries making a contribution to the final volume. The PI of KSU 210 was on sabbatical (Senior Fulbright Fellow) in Australia for much of the past year (January – August 2002), and used much of this time to complete the technical editing of the *Sorghum and Millets Diseases* volume. As it was being completed, the additional size resulted in a request that the PI prepare camera-ready copy as well to help keep the price reasonable. This added an additional five months of editing time, but reduced the final price by $30-40 per volume.

Work with the fusarium collections is progressing. Visiting scientist Dr. Giuseppe Mulé, from Italy did collaborative research in the laboratory of the PI of KSU 210. Her focus had been on the strains from finger millet in Uganda, which are proving to be both diverse and puzzling. 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. 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. 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 is interested in publishing books to go with each of these courses. A contract has been signed by Brett Summerell and the PI of KSU 210 to prepare a manual to accompany the Fusarium Laboratory Workshop.

Collaboration with Dr. Mamorou Diourté in Mali has yet to be successful. The PI did not visit Dr. Diourté this year (2002). As a substitute the PI has begun working with Dr. Ranajit Bandyopadhyay of IITA and Dr. Stephen Nutsugah (Ghana) and Dr. Adama Neya (Burkina Faso) to identify causal agents of grain mold and head blight in sorghum in West Africa.

KSU-211 is INTSORMIL's project which conducts research and trains scientists in agroecology and biotechnology of fungal pathogens of sorghum and millet. Collaboration with scientists in El Salvador and Nicaragua in 2002 - 2003 was satisfactory. Extensive surveys were conducted for the past two years and research objectives emphasizing the principal diseases are in place. Rust and fungicidal control are being investigated in El Salvador and gray leaf spot and anthracnose will be researched in Nicaragua. Sergio Pichardo is now in a Ph.D. program at Mississippi State University, and this is important for future scientific programs in Nicaragua. A change in the pathology program occurred at CENTA as Carlos Borja will now be the INTSORMIL sorghum pathologist. A need exists for Ph.D. training of a pathologist in El Salvador. The objectives of the collaborative project are on schedule as were initially planned.

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.

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 towards a fully integrated collaboration.

MSU-205 is a project with research activities in collaboration with scientists at the Panamerican School of Agriculture in Honduras during the past 23 years which concluded in 2002. Students from the school trained in MSU-205 have returned to Central America to provide agricultural expertise. The extension of MSU-205 into Nicaragua and El Salvador in 1998 has provided MSU-205 the opportunity to investigate entomological constraints to sorghum production on large farms compared with the low input, subsistence farming systems in Honduras. The research collaboration with scientists in INTA, UNA, UNAN and ANPROSOR in Nicaragua and CENTA in El Salvador has proved to be extremely beneficial in developing 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. This coordinated effort among scientists and administrators was particularly obvious in the planning and conduct of the Sorghum Crop Protection Workshop held in Managua in 2002. In the United States, research investigations in 2002 - 2003 have been conducted and are in progress to determine levels of damage by fall armyworm on sorghum in different plant growth stages, as well as refining economic threshold levels for this lepidopterous pest on whorl stage plants and for sorghum midge on the panicles. This information will assist farmers in decision-making regarding the application of insecticides to control these pests.

The project, PRF-213, supports research and training of scientists combatting 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. Our goal is to exploit the unique life cycle and parasitic traits of *Striga*, especially the chemical signals required for germination, differentiation, and establishment.

INTSORMIL's program using research to combat *Striga* emphasizes identification and characterization of genetic variants of sorghum with known inheritance and expression of biological defense responses. The project employs simple laboratory bioassays and molecular markers in identifying new variants and introgressing genes for *Striga* resistance from various sources into desired genotypes. Sorghum cultivars with single as well as multiple mechanisms of *Striga* resistance have been generated. Field evaluations are conducted in Africa to test efficacy of each putative *Striga* resistance mechanism as well as level and durability of the resistance acquired by pyramiding genes from several sources. In 2002, after extensive testing in multi-location tests, one of our elite lines was officially released for commercial cultivation in the Amhara region of Ethiopia. The cultivar was recommended and seed disseminated under a local name, "Brhan", translated as "light" in the midst of the darkness, *Striga*.

The PI of INTSORMIL's project for sustainable management of insect pests (WTU-200) traveled to Mali to review INTSORMIL activities and discuss collaborative research in entomology. Research on management of insect pests of sorghum and pearl millet was done as planned with entomologists and other scientists in Botswana, Mali, Niger, and South Africa. New sorghums and an insecticide developed by commercial companies were evaluated against greenbugs. Fitness of greenbugs on sorghum was assessed in relation to temperature, soil water and nitrogen, and host. Thesis programs of six graduate students were directed. One student completed her M.S. degree in May, and two will finish in August 2003. Tiecoura Traoré from Mali came to West Texas A&M University to learn English before beginning graduate studies in fall 2003. Research results were presented at sorghum and entomology meetings including the INTSORMIL Principal Investigators' Conference in Ethiopia.

Utilization and Marketing

Areas of increasing importance within the INTSORMIL Collaborative Research Support Program are utilization, health aspects, and marketing of sorghum and millet. The project with emphasis on chemical and physical aspects of food and nutritional quality of sorghum and millet (PRF-212) is a key element in the INTSORMIL program. In our continued work on nutritional quality of sorghum grain, processing of sorghum and millet to commercializable processed products in West Africa, and fundamental aspects of grain related to its use in food, perhaps our most noteworthy contribution this year relates to work on starch digestion characteristics in cooked sorghum foods. Sorghum foods, ranging from porridges to couscous to flat breads, have a slowly digesting starch property that results in somewhat lower starch digestibility as demonstrated in human and animal studies. Last year INTSORMIL investigators reported on a previously identified sorghum mutant with high protein digestibility which also has higher starch digestibility. Wild-type sorghum cultivars with comparably higher protein digestibility also had higher starch digestibility. This finding has relevance to foods for weaned infants and others who consume marginal intakes of energy. Further work on the basis of the slowly digesting starch property of sorghum revealed this year that sorghum proteins behave dramatically differently during the cooking process from those in other cereal flours tested (maize and rice) in that extensive web-like structures formed. African and American researchers conducting research in project PRF 212 have additional evidence that these protein structures can form associations with gelatinizing starch that reduces access of the starch degrading enzymes to some of the starch; thus, creating a slower digesting product. This finding opens the door for further research to determine the factor(s) that cause this occurrence with the goal of manipulating starch digestion rate either up for groups needing rapid and complete digestion or down for reasons of health related to diabetes, and perhaps obesity and cardiovascular disease.

In other studies, work was reinitiated on the high protein digestibility sorghum mutant with the objective of further improving kernel texture. Lines were identified with a good degree of modification and consistency that have been planted in diverse locations for further evaluation on stability of trait. A swine study was also initiated to determine digestibility and feed value of the mutant sorghum.

In Niger, work continued towards commercialization of sorghum and millet agglomerated products (couscous and other similar particle size foods) and high quality flours. Further optimization and market testing has been done. Other collaborators have been added in the region to include millet varietal evaluations for food products in northern Nigeria and in Dakar, Senegal for evaluation of high food quality local millet varieties. A trip to Dakar in January 2003 with Dr. Lloyd Rooney showed a very active millet processing scene that can and already is being used as a model for the region regarding entrepreneurial commercialization of processed products. The issue of the necessity of having high quality grain for processing and the appropriate contracting and marketing channels that must be developed are being actively pursued by a number of groups. In Burkina Faso, a collaboration will begin in the upcoming year.

Of great importance to developing demand-driven value chains is food with value-added characteristics and nutritional benefits for a range of nutritional needs. The INTSORMIL project dealing with food and nutritional quality of sorghum and millet (TAM 226) complements research being done in PRF 212. The importance of grain supply chain management is being recognized as a vital part of crop improvement

programs and utilization of grains. Investigators in INTSORMIL project TAM 226 have tried to publicize 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 US Grains Council from our 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 effective in nearly 20 traditional Japanese foods by Japanese chefs and food processors.

Several mills are producing sorghum flour for niche markets in the USA. Total use is still very low but new products for celiac patients and ethnic foods exist. In Central America, white sorghums are used in cookies and other products as a substitute for wheat or maize.

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 our program are used in commercial hybrids grown in Mexico and the 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.

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.

Future Directions

During the past 24 years, INTSORMIL has educated over 1000 scientists by degree programs, visiting scientist experiences, post-doctoral 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. Five hundred 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 semiarid 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 24 years and the training of sorghum and millet scientists by INTSORMIL in the United States, Africa and Central America now enable scientist 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 sor-

ghum 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.