2000 Annual Report

INTSORMIL

Sorghum/Millet Collaborative Research Support Program (CRSP)

INTSORMIL

...m/Millet International Research

Fighting Hunger with Research
... a team effort

Funding support through the Agency for International Develpoment

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Captions for INTSORMIL Four-Year Report (1996-2000)

Photo on front:

Dr. Medson Chisi, INTSORMIL sorghum breeder from Zambia at the Workshop on Farmer Participation in Pearl Millet Breeding and Farmer-Based Seed Production Systems in Namibia, March 24-26, 1998. Dr. Chisi received his doctorate from Kansas State University and is presently a member of INTSORMIL's Technical Committee.

Photo on back:

A "master farmer" and her child at the InterCRSP workshop on weevil disinfestation and storage techniques near Tamale, Ghana on November 5, 1997. Her t-shirt serves as a means of visually identifying farmers who know the techniques and can teach them to others. This technology transfer workshop is part of the project, "Adaptive Research with InterCRSP Natural Resource Management Technologies for Regional Transfer in West Africa," a collaborative effort of two Collaborative Research Support Programs which developed the technologies — the Bean/Cowpea CRSP and INTSORMIL — in partnership with a non-governmental organization — World Vision International (WVI) — which transfers the technologies to farmers and farm families. The project makes technologies such as improved varieties of sorghum, pearl millet, and cowpeas, improved cultural practices, improved post-harvest seed processing and storage techniques available to farm families throughout Chad, Ghana, Mali, Niger, and Senegal. This innovative partnership in which WVI extends technologies developed by the two CRSPs to end users in several West African Countries is supported by the Africa Bureau of the U.S. Agency for International Development.

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2000 Annual Report

Fighting Hunger with Research . . . A Team Effort

**Grain Sorghum/Pearl Millet Collaborative
Research Support Program (CRSP)**

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Crop Utilization and Marketing

Introduction and Program Overview

Presently, worldwide, more than 800 million people are hungry and over 1 billion are desperately poor, and food demand is increasing rapidly. The majority of poor live in rural areas in developing countries and agricultural and food systems development is vital to economic growth; improving environmental quality; strengthening nutrition, health and child survival; improving the status of women; and promoting democratization. It is estimated that by 2000, the number of people living in developing countries will grow from 4.9 billion to 6.8 billion people. More than 1.3 billion people today live on less than one dollar per day. It is estimated that the number of hungry people will exceed one billion by 2020. The global population of underweight children below age five is expected to increase from 193 million in year 2000 to over 200 million in year 2020. Increased production of cereals, which are crucial sources of food energy and other nutrients, is necessary to reduce world hunger.

Sorghum and millet are two major cereal grains, particularly in semi-arid regions of the world. In 1999, 65.8 million metric tons (MT) of sorghum were produced worldwide, of which 19.7 million MT were produced in Africa, mainly for direct consumption by humans, and 14.7 million MT were produced in the United States, mainly for livestock feed to produce meat for human consumption. In the crop year 1997-1998, the United States exported 5.3 million MT of grain sorghum mainly for livestock feed, and in 1998, U.S. grain sorghum exports were worth $531 million. Large areas are planted to sorghum each year. For example, in 1999 sorghum was produced on 44.8 million hectares (ha, or 173,036 square miles, [sq mi]) worldwide, 23 million ha (88,728 sq mi) in Africa, and 3.4 million ha (13,278 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. 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 more well adapted to arid ecosystems than is sorghum, and pearl millet, like sorghum, is a staple for 300 million people worldwide. Most of these people are in countries where malnourishment is a persistent problem. In 1999, 37.2 million hectares (143,793 sq mi) of millets were harvested worldwide, of which 19.7 million ha (76,170 sq mi) were harvested in Africa, and 120,000 ha (463 sq mi) were harvested in the United States. In 1999, the amount of millets harvested worldwide was 29 million MT, of which 12.9 million MT were harvested in Africa and 180 thousand MT were harvested in the United States. Millets are crops used mainly for direct consumption by humans in developing countries, and the millets are used mainly 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.

In October, 1999, the International Food Policy Research Institute (IFPRI) noted that in both developed and developing countries, the rate of increase in cereal yields is slowing from the days of the Green Revolution, partly due to reduced use of inputs like fertilizer and partly due to low levels of investment in agricultural research and technology. In *World Food Prospects: Critical Isssues 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 . . . ."

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. The CRSPs are communities of U.S. Land Grant 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 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 agriculture in the USA and Less Developed Countries (LDCs). Collaborating scientists in NARS developing countries and the USA. 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 on prime sites 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 and USDA currently active in the INTSORMIL CRSP are the University of Illinois, Kansas State University, Mississippi State University, University of Nebraska, Purdue University, Texas A&M University, and the USDA at the University of Georgia. 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.

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 which can compete successfully with wheat and rice products in village and urban markets. Couscous made from food quality sorghum is being market tested in Niger. The development of food sorghums and feed sorghums with improved properties such as increased digestibility and reduced tannin content has contributed to sorghum becoming a major feed grain in the USA and in South America. Pearl millet is also becoming an important feed source in poultry feeds in the southeastern USA. 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. These developments 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 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 of sorghum and millet, and strengthening the capabilities of NARS scientists to do research on constraints to production and utilization of sorghum and millet.

INTSORMIL has maintained 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 promotes educational outcomes in collaborating countries. The results include institutional strengthening, development of collaborative research networks, promoting and linking to technology transfer and dissemination, infrastructure development, and enhancing national, regional, and global communication linkages. A **major innovative aspect of the INTSORMIL focus is to maintain continuing relationships with collaborating country scientists 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:** Research results of the collaborative research teams include development and release of enhanced germplasm, development and improvement of sustainable production systems, development of sustainable technologies to conserve biodiversity and natural resources and to enhance society's quality of life, and to enlarge the range of agricultural and environmental choices. 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 has been strengthened by using U.S. and NARS multi-disciplinary research teams focused on common objectives and unified plans. INTSORMIL scientists provide global leadership in biotechnology research on sorghum and pearl millet. The output from these disciplinary areas of research are linked to immediate results. Molecular biology and other tools of science integrated with traditional science will contribute to alleviating production and utilization constraints in sorghum and pearl millet within the medium term of 5 to 10 years. New technologies are then extended to farmers' fields in developing countries and the United States through partnerships with NGOs, research networks, extension services, and the private sector. In addition, INTSORMIL plays a part in initiating consideration of economic policy and processing constraints to increasing the competitiveness of sorghum and pearl millet as a basic food staples.

- **Supporting information networking:** INTSORMIL research emphasizes working with existing 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 voluntary 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.

- **Promoting demand driven processes:** Development of economic analyses for prioritization of research and farm-level industry evaluation and development of sustainable food technology, processing, and marketing systems, are all driven by the need for stable markets for the LDC farmer. INTSORMIL seeks alternate food uses and new processing technologies to save labor and time required in preparation of sorghum millet for food. Research products transferred to the farm will seek to spur rural economic growth and provide direct economic benefits to consumers. INTSORMIL assesses consumption shifts and socioeconomic policies for reducing effects of price collapses, and addresses methods for reducing processing for sorghum and millet. Research outcomes seek to reduce effects of price collapse in high yield years, and to create new income opportunities. 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 agricultural production technology development for the developing world, especially the semi-arid tropics. There is international recognition by the world donor community that the developing country agricultural research systems 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 back to the U.S. agricultural sector and presents a win-win situation for international agricultural development.

Administration and Management

The University of Nebraska (UNL) is 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, support 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 and accomplishments of INTSORMIL during the past four years occurred in the United States and collaborating countries.

- USAID appointed Dr. John Swanson as Project Officer for INTSORMIL.

- USAID appointed Stephen Mason as Scientific Liaison Officer with CIAT.

- The 1999-2000 Technical Committee was elected. Its members are Dr. Gary Peterson, Chair, Texas A&M University; Dr. John Sanders, Vice Chair, Purdue

University; Dr. Gebisa Ejeta, Purdue University; Dr. John Axtell, Purdue University; Dr. Stephen Mason, University of Nebraska; Dr. Henry Pitre, Mississippi State University; Dr. Aboubacar Touré, Institut de Economie Rurale, Mali; and Dr. Medson Chisi, Golden Valley Research Station, Zambia.

- INTSORMIL, INRAN, ICRISAT and other sponsors held a Regional Hybrid Sorghum and Pearl Millet Seed Workshop in Niger, September 28-October 1, 1998.
- INTSORMIL and the Sorghum and Millet Improvement Program (SADC/ICRISAT/SMIP) signed a Memorandum of Understanding, providing the institutional framework to strengthen INTSORMIL collaborative research in Southern Africa.
- INTSORMIL PIs, the Program Director and Associate Program Director participated in the CRSP Symposium at the annual meeting of the American Society of Agronomy in Baltimore, MD, October 18-22, 1998.
- INTSORMIL and the University of Pretoria held the Sorghum Grain end Use Quality Assessment Workshop in Pretoria in Pretoria, South Africa, December 1-4, 1998.
- INTSORMIL played a major role in preparing a photographic exhibit on the CRSPs at USAID headquarters in Washington, D.C., September through December, 1998. A virtual tour of the exhibit is available at the CRSPs gateway web site.
- The INTSORMIL EEP conducted its five-year review of INTSORMIL activities in West Africa, Southern Africa, the Horn of Africa and Central America.
- INTSORMIL helped organize and participated in a USAID-sponsored Lessons without Borders Conference entitled "Global Agriculture and the American Midwest: A Win-Win Exchange," in Ames, Iowa, March 18-19, 1999.
- The Grant Renewal Proposal Committee was named and visioning statements for INTSORMIL from 2001 to 2006 were obtained from both inside and outside INTSORMIL.
- Principal Investigators and the Program Director participated in regional sorghum and millet research network meetings in Africa.
- New initiatives were developed for a multi-CRSP training activity in Mozambique and for a multi-CRSP research activity in the Amhara province of Ethiopia.

The major publications organized and published by the ME office during the past four years included:

* Publication 97-1: Policy and Operating Procedures
* Publication 97-2: Directory of U.S. CRSP PIs
* Publication 97-3: "Inside INTSORMIL" Newletter
* Publication 97-4: INTSORMIL Directory
* Publication 97-5: Proceedings of the International Conference on Genetic Improvement of Sorghum and Pearl Millet
* Publication 98-1: 1997 INTSORMIL Annual Report
* Publication 98-2: 1997 Annual Report Executive Summary
* Publication 98-3: "Inside INTSORMIL" Newsletter
* Publication 98-4: 1998 Annual Report
* Publication 98-5: 1998 Annual Report Executive Summary
* Publication 98-6: "Inside INTSORMIL" Newsletter
* Publication 99-1: Proceedings of the Global Conference on Ergot of Sorghum
* Publication 99-2: INTSORMIL Policy & Procedures Manual
* Publication 99-3: 1998 INTSORMIL Bibliography
* Publication 99-4: INTSORMIL CRSP Directory update
* Publication 99-5: "Inside INTSORMIL" Newsletter
* Publication 99-6: 1999 Annual Report
* Publication 99-7: "Inside INTSORMIL" Newsletter
* Publication 99-8: 1999 Annual Report Executive Summary

* Publication 00-1: 2000 Annual Report

* Publication 00-2: 2000 Annual Report Executive Summary

Training

Within INTSORMIL's regions of collaborative research, training of collaborating country 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 economic needs of the population in general and the nutritional needs of both humans and livestock. To this end, training is an extremely valuable component of development assistance.

Training

Year 21 Training (June 30, 1999-July 1, 2000)

During 1999-2000, there were 51 students from 22 different countries enrolled in an INTSORMIL advanced degree program and advised by an INTSORMIL principal investigator. This is the same number of students we had in the previous year. Approximately 73% of these students came from countries other than the USA. The number of students receiving 100% funding by INTSORMIL in 1999-2000 totaled 18. An additional 14 students received partial funding from INTSORMIL and the remaining 19 students were funded from other sources but are working on INTSORMIL projects.

Years 18-19-20 and 21 Training (June 30, 1996 through July 1, 2000)

During this four year period, there were 213 students from 33 different countries enrolled in an INTSORMIL advanced degree program and advised by an INTSORMIL principal investigator. Approximately 77% of these students came from countries other than the USA, which illustrates the emphasis placed on collaborating country institutional development. INTSORMIL also places importance on training women which is reflected in the fact that 22% of all INTSORMIL graduate students were women.

The number of students receiving 100% funding by INTSORMIL during this period total 79. An additional 62 students received partial funding from INTSORMIL and the remaining 72 were funded from other sources but worked on INTSORMIL projects. These students are enrolled in graduate programs in six disciplinary areas, agronomy, breeding, pathology, entomology, food quality, and economics. The number of students receiving 100% funding from INTSORMIL has dropped from a high of 71 in 1986 down to a low of 17 in 1993-94, and now 18 in 1999-2000. The reduction in total students being trained from INTSORMIL funds is, in part, due to training taking place under other funding sources, but an even more significant factor is that budget flexibility for supporting training under INTSORMIL projects has been greatly diminished due to reductions in our overall program budget and because of inflationary pressures.

Graduate degree programs and short-term training programs have been designed and implemented on a case by case basis to suit the needs of collaborating country scientists. Several collaborating country scientists were provided the opportunity to upgrade their skills in this fashion during this four year period. Students enrolled during these years are listed on pages 211 to 216 of this report.

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, WCAMRN, 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 excellent collaboration with each of these programs in co-sponsoring workshops and conferences, and for coordination of research and long term training. INTSORMIL currently cooperates with the ICRISAT programs in East, Southern, and West Africa, with WCASRN and WCAMRN in West/Central Africa, and with SMIP/SMINET in Southern Africa. Sudanese collaborators have provided leadership to the Pan African *Striga* Control Network. INTSORMIL collaboration with ROCAFREMI in West Africa has much potential in allowing INTSORMIL utilization scientists to collaborate regionally. ROCAFREMI is a good mechanism for promoting millet processing at a higher level than has been seen before in West Africa. During the last three 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. INTSORMIL will continue to promote free exchange of germplasm, technical information, improved technology, and research techniques.

Benefits to Collaborating Countries

West Africa

Research momentum has improved significantly the past two years in Mali, as well as morale and enthusiasm among researchers. The new Director General, Dr. Alpha Maiga, has gained a high level of confidence and support among researchers. A number of good trained scientists, have just recently returned to IER including Samba Traore, Minamba Bagayoko, and Moussa Sanogo, thus strengthening the IER research program especially in pearl millet. The millet breeding program is looking much stronger with the new breeder, Moussa Sanogo, and the anticipated strong collaboration with the new INTSORMIL Millet PI, Dr. Wayne Hanna. The multidisciplinary team approach has made excellent progress in Mali.

The Board mandate to regionalize the West African programs has progressed well but somewhat slowly, despite some well intended efforts by Malian scientists. INTSORMIL PIs now have new collaboration in Ghana and Burkina Faso, and a potential collaborator has been identified in Senegal. Efforts are underway to formalize the collaboration in Ghana and Senegal in the fall of 2000. Scientists in Mali and Niger are communicating in regard to research plans and collaborative projects. The regional networking with ROCARS and ROCAFREMI is working quite well. New contacts with SG2000 show excellent promise regarding the interaction of IER breeders in getting their improved new cultivars into the extensive SG2000 field trial system. This should not only be of benefit in Mali but throughout the region where SG2000 operates.

The on-farm trials and collaboration with NGO/PVOs is very good, especially with World Vision. This has helped the evaluation and movement of new-promising varieties on-farm. There is now extensive activities conducted on-farm.

The announcement of the commercialization of Dali-ken, a cookie made from a mixture of 20% flour from the tan-plant N'Tenimissa and 80% wheat flour, is a major step in demonstrating the potential for commercialization of sorghum provided a reliable source of value-added, identity-preserved-grain is available. It was slow coming, but hopefully will serve as a focal point to encourage other commercialization efforts.

The West Africa Hybrid Seed Workshop planned for the past several years was conducted in the fall of 1998. This was the first focused effort to inform West African sorghum and millet scientists about the potential for hybrids in West Africa. All the pros and cons were discussed and the general consensus of the 150 participants was that further research and development should be pursued. The hybrid NAD-1 in Niger is an excellent successful example for others to follow. Experiences in India, Zambia, Sudan and Nigeria provided a road map for other developing countries to follow in the development of a private sector seed industry in West African countries. This was the first focused effort to inform West African sorghum and millet scientists about the potential for hybrids in W. Africa.

One gratifying outcome from this workshop was the formation of a Niger Seed Producer's Association by the hybrid seed producers, independent of INRAN. The association is off and running with the purchase of the government seed farm at Lossa to begin private sector seed production on small holdings as well as larger farms. Secondly, this association recognizes INRAN as an honorary member, but is intent on controlling the seed association outside of the formal structure of the government. INTSORMIL thinks this is an encouraging development which should be nurtured. Third, the demand for hybrid seed far exceeds the supply even though the seed is sold at approximately eight times the price of grain. The important distinction between seed and grain is now recognized in Niger. We estimate that 60 tons of hybrid seed will be produced this year in Niger. A great deal of this seed production will be on small farms.

The farmer producer seed industry is going well in Niger. The pearl millet research program within INTSORMIL must be strengthened. The addition of Dr. Wayne Hanna at Georgia is a significant resource for future pearl millet research.

Horn of Africa

A promising regional sorghum and millet collaborative research program has been put in place in the Horn of Africa. A Memorandum of Understanding (MOU) has been signed with each of the five collaborating countries. A two-tier collaborative research initiative has been developed. At one level, we have identified individual collaborative research projects between NARS scientists and their respective collaborators at an INTSORMIL institution on a bilateral basis. At a second level, based on a series of interactions among those concerned, we have developed a regional research agenda with the goal of generating technologies that would have regional application. Research projects under the bilateral initiative have been implemented beginning with the 1997 crop season. Disciplinary projects in breeding, agronomy, entomology, pathology, food science, economics, and extension were undertaken. Examples of research results of collaborative experiments conducted in the region in the last four years are reported in this four year report. Interest in collaboration with INTSORMIL by NARS scientists in the Horn of Africa has been positive and continues to grow.

Southern Africa

During the 1996-2000 time period, INTSORMIL activity in Southern Africa has evolved into a truly regional, collaborative research program. Research accomplishments are reported in detail in this report.

Regional activity has evolved to now include research projects on breeding, pathology, food quality, insect pests, production and marketing, and ergot. Ergot was separated from other pathology research due to its importance to the U.S. seed industry. Project work plans are developed between host country scientists and U.S. counterparts. The work plans are approved by the SMIP Steering Committee as part of the total regional activity in Southern Africa. Funds are dispersed through ICRISAT/Bulawayo and expenditure receipts provided to INTSORMIL through the same facility. Project organization provides for integration of INTSORMIL activities into existing activities in the region. This insures that INTSORMIL conducts research and supports institutional development in areas of importance to collaborating institutions.

Central America

During 1996-2000, the Central America program has evolved from a program focused on Honduras to a more regional program with increased activity in El Salvador and Nicaragua. Concurrent with this has been increased collaborative research in plant pathology and agronomy. Memorandums of understanding have been signed with national research programs in El Salvador (CENTA) and Nicaragua (INTA), and with the National Agrarian University (Nicaragua) and the National Autonomous University of Nicaragua. Plant breeding research has emphasized development of improved maicillos criollos, but also has developed grain, forage and broomcorn hybrids. Entomology research has focused on the "langosta" complex of lepidopterous insect pest of maize and sorghum, and on sorghum midge. Grain quality research has focused on use of sorghum to replace maize in tortillas and rosquillos, and to replace wheat flour in cookies and sweet breads. INTSORMIL has had close ties with private industry through operation of the PCCMCA hybrid trials throughout Central America and the Dominican Republic. This activity provides useful information to seed companies, producers, and plant breeders throughout the region. The program changes put in place during the past year should lead to increased collaborative research productivity, but at the same time will require increased personal support by INTSORMIL principal investigators and increased financial support from INTSORMIL.

Regional Benefits by Technical Thrust

INTSORMIL provides a wide range of documented benefits to collaborating countries, U.S. agriculture, and the broader scientific community. Many of these benefits have reached fruition with improved sorghum and millet research programs, greater economic benefits to producers and consumers, and improvement of the environment. Others are at intermediate stages ("in the pipeline") that do not allow quantitative measurement of the benefits at present, but do merit identification of potential benefits in the future. The collaborative nature of INTSORMIL programs has built positive long-term relationships between scientists, citizens, and governments of collaborating countries and the United States. This has enhanced university educational programs and promoted understanding of different cultures enriching the lives of those involved, and hopefully making a small contribution to world peace, in addition to improving sustainable sorghum and pearl millet production in developing countries and in the United States.

Germplasm Enhancement and Conservation

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. Germplasm exchange, movement of seeds in both directions between the USA and collaborating countries, involves populations, cultivars, and breeding lines which carry resistance to insects, diseases, *Striga*, drought, and soil acidity. Research and germplasm development activities in INTSORMIL attempt to address these essential requirements. INTSORMIL/Purdue project (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 the last four years, research efforts in PRF-207 have focused on a selected core of constraints that limit the productivity and utilization of the sorghum crop. Specific research studies were conducted in an attempt to understand the genetic and physiologic basis of drought tolerance using a mix of both traditional and molecular approaches. They also conducted several studies in elucidating the basis of grain mold resistance in low and high tannin sorghums. Specific studies were undertaken in determining the role of physical and chemical kernel properties associated with mold resistance, and in assessing the nature of specific phenolic compounds that contribute to grain mold resistance. They also conducted a major study in assessing genetic diversity using molecular markers.

INTSORMIL plant breeders also develop elite materials with high yield potential which can be used as cultivars per se or used as parents in breeding programs. Specific germplasm releases (including breeding lines) for collaborating country use include the following.

- Improved yield (for all collaborating countries)
- Improved drought tolerance (Africa and drier areas of Latin America)
- Acid soil tolerance
- *Striga* resistance (West, Eastern Africa, and Southern Africa)
- Midge and greenbug resistance (Latin America)
- Downy mildew resistance (Latin America and Botswana)
- Anthracnose resistance (Latin America and Mali)
- Charcoal rot and lodging resistance (Africa and drier areas of Latin America)
- Head smut and virus resistance (Latin America)
- Foliar disease resistance (for all collaborating countries)
- Improved grain quality characteristics for food and industrial uses (for all collaborating countries). The commitment of INTSORMIL to integrated pest management of insect pests and pathogens has produced new lines of sorghum useful to commercial breeders and seed companies for both marketing hybrids and developing more advanced hybrids. Germplasm obtained and evaluated for resistance to economically important insect pests was used to combine insect resistance with other favorable plant traits. Germplasm was identified for advanced testing with resistance to selected insects and diseases, and will contribute to production of widely adapted, high yielding hybrids. Techniques of molecular biology are being used to help understand the inheritance of resistance to greenbug. Results from molecular mapping of sorghum are being used in marker-assisted selection studies for greenbug resistance and post-flowering drought tolerance.

Several U.S. seed companies are now producing seed of brown midrib sorghum sudangrass commercially. The response of livestock producers has been excellent due to improved digestibility and significantly improved palatability. Dairy farmers are the first to see the benefits of the improved nutritional quality in increased milk production. There are approximately five million acres of sorghum sudangrass in the United States at the present time, compared with nine million acres of hybrid sorghum for grain production. The potential of brown midrib sorghum sudangrass in West Africa is being explored through collaboration with Dr. Issoufou Kapran in Niger. The value of forage in West Africa is high and there is a chronic shortage of good quality forage which we believe can be partially alleviated by brown midrib sorghum sudangrass hybrids. At this point in time, there has been extensive cultivation of brown midrib sorghum hybrids in Pakistan and in some Asian countries. The potential value in India has been recognized since India is now the largest milk producer in the world and they are heavily investing in research on brown midrib forage cereals. As we enter the next decade of the "meat revolution" forage crops will increase in importance.

INTSORMIL/Purdue University have developed a rapid screening technique for breeders to assess the new high digestibility trait recently discovered in sorghum germplasm. The new rapid screening technique, which measures disappearance of alpha kafirin in sorghum grain has been developed by INTSORMIL P.I., Bruce Hamaker and his Nigerien Post Doctorate Fellow, Dr. Adam Aboubacar . The test is rapid and readily distinguishes between normal sorghum and the highly digestible sorghum cultivars. Mr. Lex Nduulu, Kenya, has tested this technique across several environments and found that it is accurate and yet simple enough to be applied to large populations of breeding materials. He is determining the mechanism of inheritance of the high digestibility trait.

Plant biotechnology has become a powerful tool to complement the traditional methods of plant improvement. This report includes the development of a protocol for sorghum transformation via Agrobacterium tumefaciens. It demonstrates that Agrobacterium-mediated transformation is a feasible technique for the genetic transformation of sorghum. Sorghum transgenic plants were produced via Agrobacterium tumefaciens, and the transformation evidenced by Southern blot analysis of T0 and T1 plants, detection of GUS activity, and production of T1 plants resistant to hygromycin. Immature embryos of sorghum were very sensitive to Agrobacterium, and embryo death after co-cultivation was considered the limiting step to increase the transformation efficiency. Key factors were the co-cultivation medium, the use of a genotype and an explant with good tissue culture response, and the addition of Pluronic F-68 to the inoculation medium. Sorghum transformation via Agrobacterium is still not a routine technique, but it seems to have good potential once the protocol is further refined and improved.

The mutable pericarp color gene designated as "candystripe" was first identified by Orrin Webster in Sudan. Research done in collaboration with Surinder Chopra and Tom Peterson at Iowa State University has now identified and cloned this mutable gene in sorghum. The transposon is a very high molecular weight element with all the characteristic properties of other transposable elements. The unique feature of these elements is that they can be used to identify agronomically important genes in sorghum. The probes are just now available which will allow scientists to isolate important genes for such important traits as drought resistance and to study them in other plant systems and other gene expression systems. This is an important step forward in the identification of important genes from sorghum which can now be studied in greater depth.

Collaborative research of an INTSORMIL research team (INTSORMIL/Texas A&M Project TAM-222) is proving useful to sorghum breeders worldwide. The use of DNA-based markers for genetic analysis and manipulation of important agronomic traits is becoming increasingly useful in plant breeding. In a recent study, 190 sorghum accessions from the five major cultivated races, namely *bicolor, guinea, caudatum, kafir, and durra*, were sampled from the world collection maintained by ICRISAT. Genetic variation was detected using RAPD primers. Only 13% of the total genetic variation was attributable to divergence across regions, but South African germplasm exhibited the least amount of genetic diversity, while the genetic diversity within the West African, Central African, East African and Middle Eastern regions was high among the 190 samples from the world collection. This research showed that molecular markers can be used to help identify suitable germplasm for introgression into breeding stocks. Selecting the most divergent accessions for introgression may increase the probability of extracting suitable inbred lines to improve the yields of varieties and hybrids.

Producing improved seed that seed companies and farmers can use, INTSORMIL researchers collaborated with LDC scientists to develop improved, high-yielding varieties and hybrids. Progeny were identified that combine several needed favorable traits into a single genotype. Advanced selections are an evaluation in on-farm trials to measure performance. As research continues to generate new technology, the importance of testing on-farm, and soliciting producer input on research activities will increase. Technology (germplasm) developed by this project has been adopted by private industry and used in hybrid production or breeding programs. Impact assessment studies have consistently shown a high rate of return on investment from research conducted by this project.

Sustainable Production Systems

In West Africa, INTSORMIL's main collaborative agronomy research activities have been focused in Mali and Niger. However, a Memorandum of Understanding was signed in 1999 with IN.E.R.A., the NARS of Burkina Faso, and collaborative research was initiated in Burkina Faso. INTSORMIL also participates in the West and Central African Sorghum and Millet Research Networks. In research conducted during the past four years, it was determined that high-yielding grain sorghum genotypes that are tall or have high vertical leaf area distribution can be more competitive with weeds and, therefore, be a useful component of integrated weed management programs. Studies on management of late-maturing Maiwa pearl millet in southern Niger were initiated. Because this variety of pearl millet tillers profusely, it provides a unique opportunity to integrate grain production for human consumption and forage production to support livestock. Initial results, such that tillers can be harvested 65 to 85 days after planting for use as livestock feed without reducing grain or stover yield, point to development of a more economically rewarding cropping system for millet farmers in the Sahel.

During the four-year time frame, the INTSORMIL/University of Nebraska (UNL-213) project has been extremely productive in graduate education of West African collaborating scientists agronomic research, which has led to publication in scientific journals, the production of extension bulletins, and the transfer of improved practices to pearl millet producers; and strengthening the activities of the West and Central Africa Pearl Millet Research Network. In the USA, 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. During this period, collaborative research was expanded from Mali and Niger to Burkina Faso, and in the near future, to Central America.

On-farm trials conducted by the INTSORMIL/University of Nebraska (UNL-214) have successfully demonstrated the value of using new hybrids, inorganic fertilizer and tied ridges to conserve moisture which is now being adopted in certain regions of Niger. Contacts have been made between NARS scientists in Ghana, Mali and Niger and WVI personnel as expedited by the UNL-214 PI. Collaboration between and among these individuals should result in greater efficiency for extending new technology. The underlying physiological mechanism for nitrogen use efficiency (NUE) has been determined to be a key enzyme in the photosynthesis pathway. This discovery will soon be published in a major journal.

A study conducted by INTSORMIL/Purdue University project (PRF-205) in Burkina Faso which focused on the impact of household and agricultural technologies on women in Burkina Faso showed the importance of household and agricultural technologies independent of decision-making in the household. Many new technologies, especially new seeds and inorganic fertilizers, increase the demand for labor and, therefore, result in female (and male) household members working more on the commonly farmed area and less on their private plots. This has been shown to reduce the income received by women. As technology introduction proceeds, however, increasing within-family contention over the new income streams would be expected, with an evolution towards the conflict and cooperation of bargaining household decision-making. As the bargaining position of women improved, there was a substantial, combined effect of the two types of technology on the potential income of women. With bargaining, agricultural technologies increase the income of women by 29% and the combined agricultural and household technologies by 68%. Policy recommendations are to accelerate the introduction of technological change onto the commonly farmed areas while also increasing the bargaining power of women.

Research in Mali by the West and Central African Millet Network (WCAMRN) showed that pearl millet grain production increased 10 to 19% of when millet was rotated with cowpea or peanut across West and Central Africa, while yield increases of pearl millet grain production due to other production practices appeared to be more site-specific. The highest grain yields required application of inorganic fertilizer or combined application of inorganic and organic fertilizer.

In Niger, several collaborative studies of INTSORMIL scientists from Niger, India, and the United States were finalized. The results of the research are now being written for publication by Drs. Pandey and Maranville at the University of Nebraska. The on-farm trials in Niger were inconclusive in 1998 due to adverse environment, but tended to show the value of NAD-1 and tied ridges for conserving moisture. In addition to preparing manuscripts, Dr. Pandey has conducted greenhouse studies at UNL to strengthen the field results from Niger. Dr. Pandey has returned to India and continues to work with Dr. Maranville on publication of the manuscripts. Dr. Samuel Buah has returned to Ghana to begin collaborative research under the new Memorandum of Understanding recently signed by INTSORMIL and the Savannah Agricultural Research Institute (SARI) of Ghana. INTSORMIL has provided Dr. Buah with a new computer and chlorophyll meter, and will also provide operating funds for him to conduct his collaborative research.

In Mali, studies on the effect of previous crop on sorghum yields showed that sorghum following corn or cowpea was better than sorghum after peanuts, pearl millet or dolichos. Sorghum following sorghum resulted in the poorest yields. Responses were modified positively and linearly by N application up to 60 kg ha^{-1}. Application of Malian rock phosphate also increased sorghum yield about nine percent.

Sustainable Plant Protection Systems

INTSORMIL's approach to developing sustainable plant protection systems is integrated pest management (IPM). Two key elements of IPM for sorghum and millet which are central to INTSORMIL plant protection research are genetic resistance of sorghum and millet to insect pests, pathogens, and the parasitic weed, *Striga*, and practices to control insects and pathogens with minimal use of chemical pesticides. INTSORMIL entomologists and plant pathologists work closely with plant breeders, agronomists, and food scientists to develop more effective means to manage pests of sorghum and millet in order to provide higher yields of higher quality grain per unit area cultivated. Intensification of agricultural production, which can help remove pressure on fragile ecosystems, depends on many factors; sustainable plant protection is essential to increase production of food and feed from sorghum and millet in economically and ecologically sustainable ways. In crop protection, a wide range of sources of resistance for insects, diseases, and *Striga* have been identified and crossed with locally adapted germplasm. This process has been improved immensely by INTSORMIL collaborators developing effective resistance screening methods for sorghum head bug, sorghum long smut, grain mold, leaf diseases, and *Striga*.

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. In the INTSORMIL/Purdue University project (PRF-213),the goal has been to exploit the unique life cycle and parasitic traits of *Striga* towards developing sorghum lines that are resistant to *Striga* because of disrupted interaction between the parasite and the host. In the last four years, significant results were obtained in both the research and development efforts of PRF-213. They established the simple inheritance of low production of the *Striga* germination stimulant in sorghum. New assays were developed for stages in host-parasite interaction beyond *Striga* germination. Using these assays, unique mutants were identified that have the capacity to disrupt normal parasitic association. These include sorghum lines with low production of the haustorial initiation factor, mutants with a hypersensitive response to penetration by *Striga* thereby delaying the growth and development of the parasite, and those with incompatible response to penetration where the host response results in eventual withering and death of the parasitic growth. Genetic and physiologic characterization of these mutants, as well as introgression into elite cultivars of the particular genes involved in each mutant, is currently underway. As a development effort, *Striga* resistant sorghum lines developed in the past have been effectively distributed and adopted. PRF-213 collaborated with World Vision International in distributing large quantities of eight *Striga* resistant sorghum varieties into 12 African countries. Following their introduction, the project worked with national programs in carrying out testing and demonstration of these varieties in farmers' fields. In Ethiopia, a collaborative relationship with the Ethiopian Agricultural Research Organization (EARO) and the Sasakawa Global 2000 program led to the evaluation, demonstration, and the eventual official release of two INTSORMIL varieties for commercial cultivation in the country. Seed supply is likely to be a bottleneck in efforts to promote an expanded cultivation of these varieties. INTSORMIL will continue to cooperate with the NARS in efforts to put in place an effective seed production and distribution mechanism to ensure reliable supply of these varieties in the future.

Research on the agroecology and biotechnology of stalk rot pathogens of sorghum and millet resulted in increased understanding of sexual reproduction of *Fusarium*, a fungal pathogen of both sorghum and millet.

Ergot, or *Claviceps africana*, is a fungal pathogen of sorghum which prevents pollination of the sorghum plant's ovaries if the ergot enters the ovary before pollination occurs, resulting in a sticky exudate and no grain formation. Ergot infestation of grain sorghum was a problem in Africa and Asia before 1996 when the disease was first detected in Argentina and Brazil. In 1997, ergot spread to Colombia, Honduras, Mexico, many islands in the Caribbean, and major sorghum-producing states in the United States (Kansas, Nebraska, and Texas). Losses due to ergot can include reduction in grain yield, loss of export markets of seed and feed grains to countries where ergot has not been reported, and loss of germplasm and hybrid seed increases in winter nurseries where ergot has been detected and quarantine regulations prohibit return of the grain to the United States. INTSORMIL researchers during the past year have focused their efforts on many aspects of the biology and ecology of ergot. These efforts have been collaborative and international, involving scientists in the United States, Central and South America, Africa, Asia, and Europe.

Important findings include:

- Sorghum accessions susceptible to *Claviceps africana* include *S. bicolor*, *S. drummondii*, *S. virgatum*, *S. arundinaceum*, and *S. halepense*. Ergot symptoms were not observed on *S. verticilliflorum* and some accessions of *S. drummondii*. Other economically important plant species surveyed which were observed to be not affected by ergot include finger millet, pearl millet, proso millet, foxtail millet, big bluestem, Osage indiangrass, switchgrass, maize, and Canadian wild rye.

- An extremely high incidence of ergot was reported in grain sorghum over a several-week period in February 1997 on many islands of the Caribbean, probably due to an airborne spore shower. It is believed that Hurricane Mitch was the primary carrier of spores of ergot in the Carribbean region during its existence in 1998.

- In late 1998, *C. africana* demonstrated that it is a well-established, recurrent pathogen of Mexico and Texas with the capacity to survive under extended, unfavorable, dry environments and has the ability to quickly reach epidemic proportions over vast regions upon a return to favorable, wet, cool environments.

- The obvious honeydew exuded from parasitic sphacelia of ergot on sorghum is only one source of conidia. Any surface coated with honeydew (e.g., leaves, seeds, or soil) may also be a source.

- There is a marked effect of temperature on the survival of conidia, with storage of sphacelia at higher temperatures resulting in more rapid loss of viability, compared to storage at lower temperatures.

- Sorghum ergot caused by *Claviceps africana* was observed to persist in an active phase predominantly on feral grain sorghum in Mexico and as far north as Corpus Christi through February 1998. Feral and ratooned grain and forage sorghum and johnsongrass within fields and along roadsides were infected by large outbreaks of ergot in December 1998 due to a wet, cool environment.

- Experiments using a fungicide showed that it can be used to effectively prevent germination of ergot sphacelia and sclerotia, leading to the conclusion that sclerotia and sphacelia in seed treated with the fungicide should not be considered a potential source of the inoculum.

Triazole fungicides continue to be the most effective in controlling sorghum ergot in the field but aerial application proved ineffective due to poor contact and coverage of heads with the fungicide. Conidia of *C. africana* in sphacelia or on honeydew on seed surfaces do not survive well in storage environments. The combination of poor survival of conidia and the good efficacy of contact fungicide seed treatments make seedborne inoculum a negligible factor especially in areas where the pathogen is already endemic.

Sorghum diseases are, and remain important factors reducing the potential of sorghum. Ergot continues to threaten the seed industry worldwide. Grain mold and anthracnose resistance traits have been mapped and other useful loci to aid in the pyramiding resistance genes for more durable resistance is progressing. The next global conference on sorghum and millet diseases has been set for September 25-30, 2000 at Guanajuato, Mexico.

Acremonium wilt of sorghum has recently become a problem in the Konni area of Niger with the introduction of improved cultivars and hybrids. In order to determine the effect of plant pathogenic nematodes in the infection of sorghum by Acremonium wilt, INTSORMIL scientists conducted a nematicide trial near Konni on a farmer's field to determine whether two nematicides would be effective in controlling pathogenic nematodes, especially of *Pratylenchus spp.* For the susceptible hybrid, NAD-1, the presence of nematodes is not necessary for disease development. With the land race Mote, the level of infection increases as the nematode number increases. In the presence of nematodes, Mota becomes susceptible to *A. strictum. The nematicide treatments did not significantly affect the incidence of Acremonium wilt of sorghum either in 1997 (a droughty year) or 1998.*

In Mali, INTSORMIL scientists from the United States and Mali plan to develop IPM strategies for insect pests, especially panicle-feeding bugs and sorghum midge, that attack traditional and improved insect-resistant and susceptible sorghums.

Sorghum and maize are important grain crops for human consumption and animal feed in developing countries in Central America. The crops are damaged each year by soil inhabiting insects, stem borers, caterpillar defoliators, and panicle feeding insects that contribute to reduced yields of both crops on farms in this region. The complex of defoliators and sorghum midge are considered to be the most damaging to these crops in Honduras and Nicaragua, and annually cause extreme damage to the crops. The caterpillar pest complex has been identified by the INTSORMIL/Mississippi State University (MSU-205) project to consist principally of several armyworm species and a grass looper, and the impact that these insects and the sorghum midge have on sorghum production has been elucidated. Aspects of the biology, ecology, behavior and population dynamics of the armyworm species in Honduras and the sorghum midge in Nicaragua have been identified. This information has contributed to the successful conduct of entomological research designed to evaluate ecological relationships of the pest insects with crop and non-crop plants within various cropping systems, crop planting and management strategies, host plant resistance, influence of insecticides on pest and natural enemy populations, and roll of naturally occurring beneficial agents in regulation of pest populations. Insect pest management tactics have been investigated as independent control practices on subsistence farms in both Honduras and Nicaragua. Recommendations for planting dates, weed control, and insecticide applications to manage the caterpillar defoliators, as well as sorghum midge have been developed.

The information obtained in these MSU-205 studies on sorghum and corn will assist subsistence farmers in Honduras, Nicaragua and surrounding areas with similar insect pest constraints in producing grain crops with increased yield at minimum cost for pest control and with reduced risk to human health. The extension of the project into Nicaragua in 1998 expanded the scope of MSU-205 activities in this ecogeographic zone. Recent studies to determine minimum, effective rates of insecticide for control of whorl feeding lepidopterous insects, stem and stalk feeding insects, and panicle feeding insects in Mississippi will be useful technology for crop production in the United States and for transfer to developing countries.

Locating quality graduate students to train and conduct INTSORMIL research, and active participation of collaborator scientists, administrators, and in-country coordinators are significant to the success of the MSU-205 project. The project has been successful because each of the above has been realized.

In Southern Africa, collaborative research relationships were reestablished with Dr. Christopher Manthe in Botswana and Dr. Johnnie van den Berg in the Republic of South Africa. Research will be directed toward developing and evaluating sugarcane aphid-resistant sorghums adapted to the southern African region. During this reporting period, 50 sorghum lines were evaluated in the laboratory but not in the field because of severe drought.

A systematic strain collection and strain identification of Fusarium species has been progressing (INTSORMIL/Kansas State University project (KSU-210A), but many of the easy identifications have been made and the process is now much slower. Development of the AFLP technique has enabled them to group strains relatively quickly, but the formal descriptions still require significant effort, and additional collections will be needed to identify more members of relatively rare species. Adding global positioning capability to localizing collection sites for repeated sampling should be accomplished before the next major collecting expedition is conducted. The AFLP technique has been successfully transferred to South African colleagues who are now trained in the use of this technique. Training a student from sub-Saharan Africa in the use of these techniques needs to become a priority, if funds permit. Toxicology work now needs a collaborator who can test the effects of toxins in commercial animal feeds, and who can model their effects in laboratory systems using human and animal cell lines as models. Screening of grain for these toxins needs to be made to determine relative levels of these toxins in animal and human food supplies.

Scientific Writing and Fusarium Laboratory workshops by KSU-210A have increased the visibility of this program significantly. These workshops need to become a more visible part of the INTSORMIL program, as they 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. Activities growing out of this project have led to requests to update, along with South African collaborator, Prof. Walter F. O. Marasas, an introductory book on mycotoxicology, and that the KSU-210A PI participate in the development of a laboratory manual for general use in the identification of Fusarium species.

INTSORMIL/Texas A&M Project (TAM-225B) has made progress toward developing a "Millet Head Miner (MHM) Warning System" model to forecast the probability of MHM outbreaks in areas of West Africa so that appropriate measures can be implemented to control the pest before it damages pearl millet. A graduate student from Mali received his Ph.D. degree in 2000. His dissertation was developed from field studies begun in Year 17 on MHM immature stage mortality, adult MHM biology on alternate hosts and fecundity, and MHM biology on alternate host plants. Results from the Mali and Niger students' research will be used to construct a stage-specific life table, thus providing an understanding of factors that regulate the abundance of MHM. These results also can be used to develop an improved plan for managing MHM on pearl millet in West Africa. Using the database available on agro-climatic conditions in the Sahel, and research data from this and other research on MHM, improved approaches to managing MHM will be possible. Ultimately, these data will support developing a "Millet Head Miner Warning System" model to forecast the probability of MHM outbreaks in a given area so that appropriate measures can be implemented to control the pest before it damages pearl millet. This is an example of how research done by graduate students from developing countries can contribute significantly to long-term solutions to problems of production and utilization of sorghum and pearl millet.

Crop Utilization and Marketing

In a study of urban consumption patterns in Mali, INTSORMIL researchers showed the substitution potential between imported rice and the traditional cereals, sorghum and millet. With the reduction of import tariffs and devaluation, the net effect was an increase in the traditional cereal price relative to rice. Sorghum and millet were shown to be substitutes for imported rice, but not for domestic rice. Traditional cerals are still cheaper than rice in absolute terms with devaluation, and devaluation has an income reducing effect even if cereal prices do not increase. Income effects apparently encouraged a small increase in consumption of sorghum and millet. Work in Mali continued to demonstrate the high qualities of flour from N'Tenimissa sorghum in baked and other products. Progress can be made if identity preserved grains of consistent quality can be obtained for processing. The bland flavor and light color of white food type sorghums are superior to maize in composite baked products.

INTSORMIL/Purdue University cereal chemists have developed rapid screening techniques for breeders to use which assesses the new high digestibility trait recently discovered in germplasm of sorghum. This rapid screening technique, which measures disappearance of alpha kafirin in sorghum grain has been developed by Bruce Hamaker and Adam Aboubacar of Niger. The test is rapid and readily distinguishes between normal sorghum and the highly digestible sorghum cultivars. Lex Nduulu, INTSORMIL collaborator from Kenya, has tested this technique across several environments and found that it is accurate and yet simple enough to be applied to large populations of breeding materials. He is determining the mechanism of inheritance of the high digestibility trait. This technique is being used to accelerate the selection of lines of sorghum which have grain of high digestibility. Further research is being done to improve the assay by way of using microtiter plates to decrease sample size and increase sample throughput per day. This research was done with a buy-in to the INTSORMIL project by the Texas Grain Sorghum Board.

The Niger couscous project is advancing quickly. There is an excellent group of technologists/scientists in Niger that are committed to the project. With procurement of the new entrepreneurial-scale decorticator and mill, the INRAN cereal processing group are adding production of high quality flours and grits and other potential products to their research objectives. At this point, processing parameters have been optimized at least to a sufficient extent to produce four high quality products: two couscous' of different particle sizes, *degue* (a large particle agglomerated product used for breakfast), and flour. A market study has begun with participation of the INTSORMIL/UIUC/Nelson project, and about 1 MT of high quality couscous, *degue*, and flour from the sorghum hybrid NAD-1 has been produced. Packaging labels for the study have been made at Purdue. The INRAN Cereal Processing Lab group hopes to begin working with entrepreneurs/NGOs in Niamey and elsewhere to stimulate commercial processing of sorghum and millet products. Ideally, one or more processing units should probably be placed outside of INRAN to facilitate this. There continues to be a good deal of interest both within Niger and in neighboring countries about the potential of commercializing couscous made from sorghum and millet.

A stronger collaboration is being developed with the cereal technologist in Ethiopia. INTSORMIL is in the final stages of purchasing a decorticator and hammer mill for EARO's cereal technology laboratory located at Nazret. With this equipment, there are plans to develop high quality flours from sorghum that can be used commercially in local Ethiopian industries.

At INTSORMIL/Purdue project PRF-212, an active research program has concentrated on improving use of sorghum and millet grains through better understanding of their fundamental chemistry and physical properties. We now have a good understanding of the basis for couscous and porridge stickiness, which is an undesirable characteristic connected to some sorghum (and probably millet) cultivars. It has been shown that sorghum kafirin protein can participate in viscoelastic fibril formation with wheat gluten to strengthen dough and improve loaf volume. While not immediately transferable this knowledge may in the future become useful, perhaps even through genetic modification of sorghum. Studies on grain chemical interactions during food processing or cooking has revealed a three-component interaction/complex that greatly affects cooling paste viscosities, that relates to porridge quality.

The WCAMRN/ROCAFREMI participation has much potential in allowing INTSORMIL utilization scientists to collaborate regionally. So far WCAMRN/ROCAFREMI appears to be a very good mechanism for facilitating collaboration in millet processing research to a greater extent than has been seen before among the West African NARS.

INTSORMIL/Texas A&M Project TAM-226 reports that new markets for value-enhanced white food sorghums are being developed by the U.S. Grains Council from research on food sorghum processing and prototype products developed in this project. Value-enhanced white food sorghums sent to Japan made a positive impression. Sorghum is an excellent ingredient in extruded snacks and related food products. Sorghum flour was demonstrated effective in nearly 20 traditional Japanese foods in Tokyo.

A new snack from white sorghum was marketed in the United States. Several mills are producing sorghum flour for niche markets. In Central America, white sorghums are used in cookies and other products as a substitute for wheat or maize. Personnel in Honduras successfully conducted baking trials demonstrating the value of white food sorghums.

Special sorghums with high levels of phenols and antioxidants produce excellent chips and baked products. The antioxidant level in certain bran fractions is higher than that of blue berries.

New commercial sorghum hybrids with tan plant red and white pericarp color are nearing release from commercial hybrid seed companies and TAES. Several parental sorghum lines released from programs are used in commercial hybrids grown in Mexico and the United States. Atx635 hybrids have outstanding milling properties.

Antifungal proteins appear related to grain mold resistance in sorghum. A molecular linkage map for sorghum kernel characteristics, milling properties, and mold resistance is nearing completion.

New markets for value-enhanced white food sorghums are being developed by the US Grains Council from research and information on food sorghum processing and products developed by INTSORMIL/Texas A&M project TAM-226. The first value-enhanced white sorghums were sent to Japan. The Japanese have a positive impression of sorghum for extrusion in snacks and related food products. They believe it is better than rice for extrusion. Sorghum flour was demonstrated effective in traditional Japanese foods in Tokyo by chefs and dieticians.

A new snack from white sorghum has been marketed in the United States. Several mills are producing sorghum flour for niche markets. In Central America, white sorghums are being used in cookies and other products as a substitute for wheat or maize. Personnel in Honduras successfully conducted baking trials demonstrating the value of white food sorghums. Special sorghums have high levels of phenols and antioxidants. They produce excellent chips and baked products with high levels of antioxidants and dietary fiber. White food sorghum flour can be substituted for 50% of the wheat flour in Mexican cookie formuli. New commercial sorghum hybrids with tan plant red and white pericarp color are nearing release form commercial hybrid seed companies and TAES. Antifungal proteins may be related to grain mold resistance in sorghum. A molecular linkage map for sorghum kernel characteristics, milling properties, and mold resistance is nearing completion.

INTSORMIL research on processing of sorghum has yielded significant results over the past four year. Extensive multi-location, multi-year trials to evaluate the abrasive milling properties and factors affecting dry milling of sorghum were conducted. Conclusions are:

- The milling properties of sorghum are affected by hybrid and environmental conditions.
- Sorghums with purple or red plant color produce highly-colored, stained grits when the grain weathers during and after maturation; tan plant color reduces discoloration.
- The food sorghums released have about the same grit yields as cream hybrids, but the grit color is much better, especially when weathering occurs.
- The tan plant red sorghum hybrids produced about the same yields of grits; the grit color was much improved.
- Waxy sorghums have slightly lower density, test weights are generally low, and milling yields are lower.
- ATx635 hybrids all had significantly improved yields of grits with excellent color. The density and test weights were highest for ATx635 grains at all locations.
- It is possible to select for improved milling properties.

A workshop organized by Professor Taylor, University of Pretoria, Dr. Janet Dewar, CSIR, and Lloyd Rooney, Texas A&M University, was hosted by University of Pretoria. More than 36 participants from the food industry, university, and research institutes in Southern Africa interacted during the 3.5 day Sorghum Quality Assessment Workshop. It included tours to a Sorghum Brewery and the ARC Summer Grains Institute in Potchefstroom. Students at the University of Pretoria enrolled in the Southern African Regional M.S. Degree program at the University of Pretoria participated.

Future Directions

Based on its achievements, the INTSORMIL team is well positioned to contribute even more effectively to ending hunger and raise 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 21 years, INTSORMIL scientists in the United States, Africa, and Central America are now able to jointly plan and execute collaborative research which will have increased benefits to developing countries and the United States. 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 has a sustainable and global impact.

In the past, INTSORMIL focused a major part of its resources on graduate student training and generating research particularly useful within the scientific community. The INTSORMIL agenda for the future continues to include graduate student training and generation of scientific knowledge and inforamation to scientists, but will be more focused and directed toward users of the technology generated by INTSORMIL research. 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 strategies for the future are: 1) sustainable research institutions and human capital development; 2) conservation of biodiversity and natural resources; 3) research systems development with focus on relevant technology generation; 4) information and research networking; and 5) demand driven processes.

Sustainable Plant Protection Systems

Agroecology and Biotechnology of Stalk Rot Pathogens of Sorghum and Millet

Project KS-210A
John F. Leslie
Kansas State University

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Summary

We tested five members from each of five different *Fusarium* species for mycotoxin production, sorghum pathogenicity, growth rate, vegetative compatibility, sexual fertility, and DNA fingerprint. Based on vegetative compatibility tests each of the 25 isolates examined had a unique genetic background, and none were clones of a common strain. Three of these species had been previously described and could be distinguished on the basis of microscopic morphological characters. The other two species are not distinguishable on the basis of morphological characters, but can be identified on the basis of unique DNA fingerprints. Based on morphological characters, colony pigmentation and growth rates, the new species are most similar to *F. nygamai*. Mating type was identified in all five species using previously developed PCR diagnostic techniques. No female-fertile strains were identified within either Fsp1 or Fsp2, and sexual cross-fertility could not be used to confirm the uniqueness of these groups as separate species. Both of the new species have been recovered from the United States and multiple locations in Africa, and from sorghum, millet, and other agriculturally important crops. *F. thapsinum* and Fsp1 are considerably more pathogenic in sorghum seedling assays than are the other three species tested. Fsp2 may be more important as a millet pathogen than as a sorghum pathogen. More widespread testing of the pathogenicity of these strains is required to determine the role that these species play in the stalk rot and grain mold complexes of sorghum. Fumonisins were produced by two of the five species (*F. verticillioides* and *F. nygamai*), and moniliformin by three of the five species (*F. nygamai*, *F. thapsinum* and Fsp2). This pattern of toxin production, means that sorghum is much less likely to be contaminated by fumonisin toxins than other grains, e.g., maize. Toxin production does not appear to be associated with sorghum pathogenicity. Representatives of all species were toxic to ducklings, but Fsp1 strains were significantly less toxic than were those of the other species. Some of the toxigenicity observed may be attributable to the fumonisin and moniliformin toxins, but it is likely that additional, toxic secondary metabolites are synthesized by one or more of these species and that these toxins play a role in the duckling toxicity we observed.

Objectives, Production and Utilization Constraints

Objectives

- Increase collection of *Fusarium* samples from sorghum and millet, and identify the species recovered.
- Develop characters, such as mating type, for assessing genetic variability in fungal populations.
- Provide pure cultures of fungi from our extensive collection to U.S. and LDC investigators to expedite diagnoses of fungal diseases of sorghum and millet.

- Determine mycotoxigenic potential of *Fusarium* spp. from sorghum and millet.

Constraints

Fusarium spp. associated with sorghum and millet do obvious damage as stalk rot, grain mold and pokkah boeng. All of these diseases can cause intermittently heavy losses in the United States and in developing countries. Breeding for resistance to associated diseases with *Fusarium* is limited, because the strains responsible for disease often cannot be accurately identified and used repeatedly in field challenges. Correct identification of the fungi colonizing and causing disease is essential for the design of breeding and control measures. Without a thorough understanding of the pathogen's genetic diversity and population dynamics, effective control measures are difficult to design and resistant lines may have unexpectedly brief lives.

Mycotoxin contamination limits the uses to which harvested grain can be pu, and creates health risks for both humans and domestic animals. *Fusarium*-produced mycotoxins are among the most common mycotoxins found in cereal grains, yet have not been effectively evaluated in sorghum and millet. Since contamination often occurs on apparently sound grain, merely discarding obviously molded grain is not sufficient to avoid the mycotoxicity problems.

Research Approach and Project Output

Research Methods

Strains and Culture Conditions. We used 25 strains, five each from five of each different species. Three of these species could be distinguished on the basis of morphological characters - *Fusarium thapsinum* Klittich et al. (teleomorph *Gibberella thapsina* Klittich et al.), *Fusarium verticillioides* (Sacc.) Nirenberg (synonym: *Fusarium moniliforme* Sheldon, teleomorph *Gibberella moniliformis* Wineland), and *Fusarium nygamai* Burgess and Trimboli (teleomorph *Gibberella nygamai* Klaasen and Nelson). Two additional sets of five strains were used as representatives of species that as yet have no formal names, referred to here as Fsp1 and Fsp2. Each of these new species has been recovered from the United States and from Africa, i.e., they are geographically dispersed. Each of these species also has been recovered from sorghum, millet and at least one other agriculturally important crop. For consistency, all of the strains we examined for mycotoxins production and sorghum pathogenicity were from Southern Africa.

Strains were routinely cultured on carnation leaf agar, or on modified Czapek's complete medium. Strains are maintained as lyophilized cultures at the Medical Research Council in South Africa, or as spore suspensions in 15% glycerol frozen at -70°C at Kansas State University. We measured growth rates of strains from *F. nygamai* and the two new *Fusarium* species (which are morphologically similar) on Potato-Dextrose Agar (PDA) at both 25 and 30°C and incubated in complete darkness for threedays. Measurements were made on three replicate cultures per temperature for each strain.

Sexual crosses. Isolates were crossed with standard mating-type tester strains on carrot agar for *Gibberella nygamai, Gibberella thapsina*, and *Gibberella fujikuroi* mating populations A-E and H. These testers were developed by our colleagues and us, and are available to others through the Fungal Genetics Stock Center at the University of Kansas Medical School in Kansas City, Kansas. Within each of the two groups of strains that did not cross with an already identified species or mating population, isolates were intercrossed in all possible pairwise combinations, with each strain serving as both the male and the female parent in crosses with other members of the group. All crosses were repeated at least twice. Fertile crosses produced perithecia that exuded a cirrhus of ascospores.

DNA manipulations and molecular diagnosis of mating type. DNA was isolated using standard procedures and stored in 1×TE at 4°C until used. We determined the mating type of all 25 strains following PCR amplification with previously described primers. Successful amplification of a band of approximately 260 bp indicated that the strain carried the *MAT-2* allele, while lack of amplification indicated that the strain carried *MAT-1*. In cases where sexual crosses were not successful, molecular diagnoses of mating type were taken as definitive.

Vegetative compatibility tests. Nitrate nonutilizing (*nit*) mutants were generated from all strains belonging to the new groups and used in complementation tests to identify isolates that belonged to the same vegetative compatibility group (VCG). The *nit* mutants were generated on a minimal medium containing 2.5% $KClO_3$ and assigned to one of three classes – *nit1*, *nit3* or NitM – based on their ability to grow on media containing differential nitrogen sources (nitrate, nitrite, hypoxanthine and ammonium). Complementary mutants in the same VCG could form a prototrophic heterokaryon when cultured together on a minimal medium containing KNO_3 as the sole nitrogen source. Whenever possible, a *nit1* and a NitM mutant from each strain was used in the pairing procedure. All pairings were tested at least twice.

Amplified Fragment Length Polymorphisms (AFLPs) and analyses of molecular relatedness. We digested approximately 100 ng of DNA with two units each of *Eco*RI and *Mse*I, and ligated to *Eco*RI (an equimolar mixture of CTCGTAGACTGCCTACC and AATTGGTACGCA GTC, 5 pmole/µl) and *Mse*I adapters (an equimolar mixture of GACGATGAGTCCTGAG and TACTCAGGACT CAT, 50 pmole/µl) with T4 DNA ligase. These DNA fragments were pre-amplified using the adapter sequences to prime the reaction, and then amplified with more specific primers to reduce the number of bands in the gel. The *Eco*RI primers in the final amplification mixes were end-labeled with $\gamma^{33}P$, and fragments were separated in 6% polyacrylamide gels. Gels were dried and exposed to autoradiography film for 2 to 5 days at room temperature to identify DNA bands.

To analyze AFLP profiles, we manually scored the presence or absence of bands. We assumed that bands of the same molecular size in different individuals were identical. For each individual, we determined the presence or absence of each band. Within a species, each band was treated as a single independent locus with two alleles and unresolved bands or missing data were scored as ambiguous. UPGMA similarity indexes based on AFLP markers for strains belonging to the same species were usually 70% or greater. For strains in different species, these similarity indexes were usually 35% or less. Interspecies comparisons compared only the number of bands that are shared and do not count the joint absence of a band seen in another strain or species as a shared character.

Secondary metabolite production. Fumonisin B_1, B_2, and B_3 contents of cultures grown on cracked maize were determined by reversed-phase HPLC monitored by fluorescence detection of methanol:water (3:1) extracts. Moniliformin levels were initially determined by reversed phase HPLC with UV detection at 229 nm. Strains that produced little or no moniliformin in this assay were re-examined using a more sensitive method in which extracts were separated by paired ion chromatography in which the column eluent from C18 and neutral alumina columns was monitored at wavelengths between 200 and 350 nm with diode array UV detection.

Duckling toxicity protocol. All 25 strains were tested for toxicity to ducklings. The ducklings and their feeds were weighed at the beginning of each experiment, and the total feed intake value for each group of four ducklings was calculated from the amount of feed remaining at the end of the test. Mortality was recorded daily, and the mean day of death was calculated from the number of ducklings that died on different days. Cultures were considered toxic if they caused the death of three or four of the four ducklings in a single group. A toxicity index was calculated by multiplying the amount of feed intake, in grams, by the mean day of death to obtain an inverse measure of toxicity for the cultures.

Sorghum pathogenicity assays. Pathogenicity tests were conducted using an agar test tube assay. Twenty-five strains were assayed for pathogenicity by inoculating seedlings of sorghum cultivars PAN 8560 and PAN 8472. Seed was treated in a water bath at 55°C to eliminate seedborne fungi. Disinfested seeds were germinated on 0.6% water agar. After incubation for fourteen days, sterile germinated seeds were transferred to test tubes (200 x 30 mm) containing 20 ml of solidified sterile Hoagland's no. 2 medium; one seed per tube. The tubes were plugged with sterile nonabsorbent cotton and incubated for ten days with a 14-hr photoperiod at 25°C by day and 18°C by night. We rated roots for disease severity and measured root length. The foliage of the seedlings was excised and shoot length measured. Root and shoot dry mass were determined by weighing after drying at 60°C for three days.

The experiment was done twice. There were three replicates (blocks) in the first experiment and 12 in the second. The treatment design was a 2 x 26 factorial with two cultivars and 26 fungal treatments (one uninoculated control and five strains from each of the five species). An experimental unit was a single plant. Factorial analysis of variance was performed on the root and shoot length dry mass data. Disease severity ratings were ranked before the data were subjected to analysis of variance. Student's *t*-least significant differences at the 5% significance level were calculated to compare means.

Research Findings

Vegetative growth rates. Growth rates for all three taxa (Table 1) were similar at both 25° and 30°C, ranging from a mean of 25 mm in 72 hr at either 25° or 30° C for *F. nygamai,* to 32 mm in 72 hr at 30°C for Fsp1. Pigmentation was purple for Fsp1 and either white, peach or purple for *F. nygamai* and Fsp2. The similarity of these characters and of the morphology of the spores produced are probably why these groups have not been previously identified as separate species.

Mating type and sexual cross-fertility. We identified the *MAT* allele in all 25 strains following PCR amplification. We also identified strains in *F. thapsinum* and *F. verticillioides* in crosses with available standard tester strains. Strains of both mating types were observed in the strain sets from all five species. Fsp1 and Fsp2 strains were not cross-fertile with any of the standard female-fertile strains previously described. Within each species, we crossed the five strains in all possible pairwise combinations, but no fertile crosses were observed. If female fertility is as rare in these species as it can be in *F. thapsinum* (10-30%), then considerably more strains remain to be tested before we can be certain that we have tested enough strains to have found female fertile strains. We were unable to repeat a cross reported by other researchers in which strain 4011 was reported to be cross-fertile with one of the *G. nygamai* tester strains; however, we also were unable to obtain a positive control cross between the two *G. nygamai* tester strains. No fertile crosses were observed in the crosses with the testers for *G. fujikuroi* mating populations A, C-E and *G. thapsina.* In crosses with testers from *G. fujikuroi* mating population B, we found a few fertile perithecia in some crosses with *F. nygamai* strain 4012, Fsp1 strains 5993 and 6126, and with all of the Fsp2 strains. We think these fertile perithecia are a result of occasional homothallic reproduction by the testers for this mating population, as has previously been reported.

Vegetative compatibility. We tested five strains from each species for vegetative compatibility with the other strains in that species. We found that all of the strains were in different VCGs, indicating that none of the strains that we were working with were clones.

AFLPs and molecular relatedness. We have recently begun using AFLPs to estimate genetic variation within *Fusarium* populations. By using only 3 to 4 primer pair combinations, we can usually identify 40 to 70 polymorphic bands. Bands that do not vary are candidates for development as species-specific markers. At present we have identified PCR primer pairs that can be used to specifically detect the A and D mating populations, and are testing these primers to determine their utility in diagnostic settings. These populations are two of the three most common mating populations known on agriculturally important crops in Kansas. Within a species, UPGMA estimates of similarity are usually 70% or higher. In inter-specific comparisons, the level of similarity rarely exceeds 30 to 35%. Thus, by comparing banding patterns on a gel, it often is possible to assign a strain to a species if a known strain is included on the gel with the unidentified strain. Similarly it is possible to group unknown strains, and to distinguish groups of strains that are morphologically distinct. We used this approach to distinguish the two new *Fusarium* species, here termed Fsp1 and Fsp2, from each other and from other *Fusarium* species known to infect sorghum and millet. In addition to Fsp1 and Fsp2, we also have single representatives of what appear to be additional new, but as yet undescribed, species. Confirming that these species are globally distributed and are economically important remain important objectives for future studies. The molecular diagnostics we are developing should allow us to more quickly and accurately identify the species present in the stalk-rot and grain mold disease complexes.

Secondary metabolite production. Strains from all five species were screened for the ability to produce fumonisins and moniliformin (Table 1). *F. nygamai* and *F. verticillioides* were the only species to produce fumonisins. This finding suggests that sorghum grain is much less susceptible to be contaminated with these mycotoxins than is maize. Recent determinations that fumonisins are both cancer inducers and cancer promoters suggests that they will be legally regulated, at least in the United States, in the near fu-

Table 1. Growth rates, toxins produced, and toxicities of representative strains of *Fusarium nygamai*, *F. thapsinum*, *F. verticillioides*, and two new *Fusarium* species.

	Mycotoxin (µg/g)[2]			Duckling	Growth rate (mm/72 hr + s.d.)	
Strain[1]	FB_1	FB_2	Mon	Toxicity[3]	25°	30°
Fusarium nygami						
3997	3200	1600	2000	35	27 ± 3.1	28 ± 2.3
3998	3800	3200	140	45	26 ± 0.6	24 ± 2.0
4010	2300	700	Tr[4]	74	24 ± 1.5	24 ± 1.5
4011	Tr	ND[5]	49	5500(2)	26 ± 2.0	28 ± 1.2
4012	1500	5700	380	68	24 ± 0.6	22 ± 1.0
F. thapsinum						
6148	ND	ND	296	43	-	-
6001	4	3	698	35	-	-
6002	4	4	1198	18	-	-
6003	20	9	1742	18	-	-
6004	2	2	898	30	-	-
F. verticillioides						
826	3675	800	ND	95	-	-
1065	395	80	ND	120	-	-
4315	2948	647	ND	43	-	-
4317	121	20	ND	60	-	-
4321	1974	164	9	40	-	-
Fsp1						
5993	Tr	ND	ND	690	30 ± 1.5	31 ± 1.5
5995	Tr	ND	ND	7600(2)	33 ± 0.0	34 ± 2.6
6122	Tr	ND	ND	440	32 ± 0.6	33 ± 1.2
6123	Tr	ND	ND	590	29 ± 3.2	31 ± 0.6
6126	ND	ND	ND	420	28 ± 1.7	29 ± 1.0
Fsp2						
1240	Tr	Tr	2440	20	30 ± 0.6	29 ± 1.5
1247	ND	ND	270	18	27 ± 0.6	26 ± 1.5
2203	Tr	Tr	1070	170	25 ± 0.6	24 ± 0.0
4149	Tr	Tr	4800	20	27 ± 0.6	28 ± 0.6
4152	Tr	Tr	1900	48	24 ± 0.6	28 ± 0.6

[1] Strain number from the MRC strain collection.
[2] FB_1 = Fumonisin B_1; FB_2 = Fumonisin B_2; Mon = Moniliformin.
[3] Toxicity index = number of grams of feed consumed × mean day of death. Values with a numerical superscript in parenthesis indicate the number of ducklings that die during the 14-day examination period if that number was less than four.
[4] Tr = trace.
[5] ND = not detected.

ture. It also suggests that consumers of a diet high in sorghum would be less likely to have problems with esophageal cancer, such as those associated with a high maize diet in the Transkei.

Moniliformin also was produced by three of the five species, with *F. verticillioides* and Fsp1 producing little or none of this toxin. Moniliformin levels were especially high in strains of *F. thapsinum* and Fsp2. Moniliformin is known to be toxic to poultry, and sorghum grain with high levels of this toxin could be detrimental if used in poultry production.

Fusarium nygamai is the only species to synthesize both of these toxins. *F. thapsinum* and Fsp2 synthesize only moniliformin and *F. verticillioides* synthesizes only fumonisins. Fsp1 synthesizes neither of these toxins. From these data it is clear that neither of these toxins is essential as a cause of sorghum pathogenicity, although they may play a contributatory role in this process. This result is different from that in some other *Fusarium* species where mycotoxic compounds are known to be directly correlated with pathogenicity. The lack of production of fumonisins by both *F. thapsinum* and Fsp1 means that what appear to be the two most common *Fusarium* species on sorghum are unable to produce this toxin. The case for moniliformin is not as clear, and more information on the relative frequency of *F. thapsinum* and Fsp1 is needed to be able to evaluate the risk that this toxin could pose. In addition, recent work with a number of closely related *Fusarium* species has suggested that these fungi are capable of synthesizing significant quantities of a much larger spectrum of secondary metabolites. Identification and evaluation of the potential hazards posed by these compounds remain important objectives for future research on the utilization of sorghum and millet as both human foods and animal feeds.

Duckling toxicity. All of the species examined were toxic to ducklings (Table 1), when the ducklings were fed grain contaminated with these fungi. Fsp1 was significantly less toxic than were the other four species. Although this species makes neither fumonisins nor moniliformin, it is not clear that the absence of these compounds alone is responsible for the lack of toxigenicity observed. The other four species were difficult to distinguish on the basis of duckling toxigenicity, suggesting that other compounds in addition to fumonisins and moniliformin are involved in the duckling toxigenicity observed. This result is similar to one observed earlier when a larger group of strains of *F. verticillioides* and *F. thapsinum* were compared for toxin production and duckling toxicity.

Sorghum pathogenicity assays. Five representative strains of each of the five *Fusarium* taxa were all pathogenic to sorghum seedlings, as indicated by disease severity rank means that were significantly higher ($p < 0.05$) than the uninoculated control (Table 2). Fsp1 was significantly more pathogenic to the seedlings than were *F. verticillioides*, *F. nygamai*, and Fsp2 with respect to disease severity, root length, shoot length, and root dry mass. However, Fsp1 was significantly less pathogenic to sorghum than *F. thapsinum*, with respect to all of these parameters as well as root dry mass.

Seven of the eight known mating populations in the *G. fujikuroi* species complex have been associated with sorghum, although the F mating population (*F. thapsinum*) is usually reported to be dominant. Thus far, Fsp1 has not been widely recovered (Colorado, Nigeria, Ethiopia and South Africa) in large numbers (only 40 isolates confirmed), however, this shortage is probably due to a lack of an easily identified morphological character rather than to its limited presence. The possibility is quite good that some of the "sterile" isolates recovered from sorghum and millet in Tanzania, Nigeria, Lesotho, Egypt, Zimbabwe and the United States that were not cross-fertile with the testers from the known mating populations could be Fsp1. Fsp2 we have in even more limited numbers, but many of these isolates are from millet, and it is possible that this species is more important in millet than it is in sorghum.

In conclusion, we have identified additional species of *Fusarium* from sorghum in both the United States and Africa. Up to a few years ago all of these species would have been identified as *Fusarium moniliforme* and no attempt to differentiate them would have been made. Yet, as our studies show, these species differ widely in their toxigenicity and pathogenicity profiles. Identifying the relative roles of these species in the stalk rot and grain mold complexes remains a critical need, and the possibility of obtaining data that can be relatively easily interpreted is now greatly increased.

Networking Activities

Editorial and Committee Service (1999)

Editor of Applied and Environmental Microbiology

Member of the International Society for Plant Pathology, *Fusarium* Committee

Research Investigator Exchange

Dr. Leslie made the following scientific exchange visits in 1999:

Egypt – May 4-18
South Korea – August 24 – 31
India – September 28 - October 5
Malaysia – October 6-9
Australia – October 9-26
Israel – November 5-10
Egypt – November 10-18
The Netherlands – November 19-21
South Africa – November 28 – December 15

Table 2. Disease severity, root and shoot length and dry mass of sorghum seedlings inoculated with *Fusarium nygamai*, *F. thapsinum*, *F. verticillioides* (=*F. moniliforme*), or two new species of *Fusarium*.

Isolate[1]	Disease severity[2,3]	Shoot Dry mass (mm)[3]	Shoot Length (mm)[3]	Root Dry mass (mm)[3]	Root Length (mm)[3]
F. nygamai					
3997	170 defg	55 abcdef	290 ab	18 abcde	110 cdefg
3998	260 cd	52 cdef	260 de	16 bcdef	98 g
4010	200 defg	61 a	290 ab	20 a	120 abcde
4011	100 gh	52 bcdef	280 bc	18 abcde	120 abcde
4012	130 fgh	54 abcde	280 bc	17 abcdef	100 fg
Mean	170 B	55 BC			
F. thapsinum					
6001	440 a	39 h	210 gh	14 fgh	66 i
6002	430 a	43 gh	220 gh	16 defg	66 i
6003	450 a	40 h	190 i	13 gh	68 hi
6004	440 a	39 h	190 i	13 gh	66 i
6148	460 a	39 h	210 hi	12 h	67 hi
Mean	440 E	40 E	210 D	13 B	67 D
F. verticillioides					
826	150 efg	59 ab	300 a	18 abcde	120 ab
1065	240 cde	50 defg	280 bc	15 efg	100 efg
4315	210 def	59 abc	290 ab	19 ab	120 abcde
4317	260 cd	57 abcde	290 ab	18 abcde	110 defg
4321	210 def	56 abcde	290 ab	18 abcde	110 bcdef
Mean	210 C	56 B	290 A	18 A	110 B
Fsp1					
5993	380 ab	46 fgh	250 ef	17 bcdef	66 i
5995	330 bc	52 bcdef	270 cd	18 abcd	80 h
6122	380 ab	43 gh	240 f	18 abcde	76 hi
6123	460 a	43 gh	230 fg	16 cdefg	71 hi
6126	310 bc	50 efg	260 de	19 abc	76 hi
Mean	370 D	47 D	250 C	17 A	74C
Fsp2					
1240	110 gh	51 def	280 bc	17 abcde	120 ab
1247	210 def	51 def	280 bcd	16 bcdef	100 fg
2203	140 fg	57 abcd	290 ab	19 abc	130 a
4149	160 defg	50 efg	280 bcd	16 bcdef	110 defg
4152	190 defg	51 def	280 bc	16 cdefg	100 fg
Mean	160 B	52 C	280 B	17 A	110 B
Control	43 h A	61 a A	290 ab A	17 abcde A	120 abc A

[1] MRC isolate number.
[2] Rank mean.
[3] Values within a column followed by the same letter are not significantly different ($p = 0.05$). Lower-case letters are used to compare individual isolates. Upper-case letters are used to compare means of species.

Seminar, Workshop and Invited Meeting Presentations

Plant Pathology Research Institute, Agricultural Research Center, Giza, Egypt – 5/99.

Symposium on "Biology of Fungal Secondary Metabolites", Seoul National University, Su-won, South Korea – 8/99.

ICRISAT Asia Center, Hyderabad, India – 9/99.

School of Biology, Universiti Sains Malaysia, Penang, Malaysia – 10/99

Department of Crop Protection, University of Sydney, Sydney, Australia – 10/99.

University of Tel Aviv, Tel Aviv, Israel – 11/99.

Plant Pathology Research Institute, Agricultural Research Center, Giza, Egypt – 11/99

Egyptian National Agricultural Library, Dokki, Egypt – 11/99.

Department of Genetics, University of Pretoria, Pretoria, South Africa – 12/99.

PROMEC, Medical Research Council, Tygerberg, South Africa – 12/99.

During 1999 Standard Fusarium Cultures were Provided To:

Dr. Angela Schilling, University of Hohenheim, Stuttgart, Germany.

Drs. Charles Bacon and Ida Yates, USDA Russell Research Center, Athens, Georgia.

Drs. Robert L. Bowden, Larry E. Claflin & Douglas J. Jardine, Department of Plant Pathology,Kansas State University, Manhattan, Kansas.

Dr. Lester W. Burgess, University of Sydney, Sydney, New South Wales, Australia.

Drs. Anne E. Desjardines and Ronald D. Plattner, Mycotoxin Research Unit, National Center for Agricultural Utilization Research, USDA/ARS, Peoria, Illinois.

Dr. S. Chulze, Universidad Nacional de Rio Cuarto, Rio Cuarto, Argentina.

Dr. Elhamy M. El-Assiuty, Plant Pathology Research Institute, Agricultural Research Center, Giza, Egypt.

Fungal Genetics Stock Center, University of Kansas Medical Center, Kansas City, Kansas.

Dr. Bettina Tudzynski, Westfaelische Wilhelms University, Muenster, Germany.

Dr. L. Hornok, Agricultural Biotechnology Center, Institute for Plant Sciences, Godollo, Hungary.

Dr. Yin-Won Lee, Department of Plant Pathology, Seoul National University, Su-Won, South Korea.

Dr. Amir Sharon, Department of Plant Sciences, University of Tel Aviv, Tel Aviv, Israel.

Drs. A. Logrieco & A. Moretti, Istituto Tossine e Micotossine da Parassiti Vegetali, Bari, Italy.

Dr. W. F. O. Marasas, PROMEC, South African Medical Research Council, Tygerberg, South Africa.

Dr. H. I. Nirenberg, Biologische Bundesantsalt für Land- und Forstwirtschaft, Berlin, Germany.

Dr. R. C. Ploetz, Tropical Research & Education Center, University of Florida, Homestead, Florida.

Dr. J. S. Smith, Department of Animal Sciences & Industry, Kansas State University, Manhattan, Kansas.

Dr. Dan Ebbole, Department of Plant Pathology & Microbiology, Texas A & M University, College Station, Texas.

Dr. C. Waalwijk, DLO Institute for Plant Protection, Wageningen, The Netherlands.

Dr. Evelyn Muller, University of Hohenheim, Stuttgart, Germany.

Drs. M. Wingfield and B. Wingfield, Forestry & Agricultural Biotechnology Institute, University of Pretoria, Pretoria, South Africa.

Dr. Hanna Wolffhechel, Danish Government Institute of Seed Pathology for Developing Countries, Copenhagen, Denmark.

Other Collaborating Scientists

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Drs. A. E. Desjardins & R. D. Plattner, USDA National Center for Agricultural Utilization Research, Peoria, Illinois

Dr. G. Odvody, Texas Agricultural Experiment Station, Corpus Christi, Texas

Publications and Presentations

Journal Articles

Bowden, R. L, and J.F. Leslie. 1999. Sexual recombination in *Gibberella zeae* (*Fusarium graminearum*). Phytopathology 89:182-188.

Britz, H., T.A. Coutinho, M.J. Wingfield, W.F.O. Marasas, T. R. Gordon and J. F. Leslie. 1999. *Fusarium subglutinans* f. sp. *pini* represents a distinct mating population in the *Gibberella fujikuroi* species complex. Applied and Environmental Microbiology 65:1198-1201.

Jardine, D. J. and J.F. Leslie. 1999. Aggressiveness to mature maize plants of *Fusarium* strains differing in the ability to produce fumonisin. Plant Disease 83: 690-693.

Kerényi, Z., K. Zeller, L. Hornok and J. F. Leslie. 1999. Standardization of mating-type terminology in the *Gibberella fujikuroi* species complex. Applied and Environmental Microbiology 65: 4071-4076.

Leslie, J. F. 1999. Genetic status of the *Gibberella fujikuroi* species complex. The Plant Pathology Journal 15: 259-269.

Kerényi, Z., J. F. Leslie and L. Hornok. 1998. A PCR-based method for the detection of El-Assiuty, E. M., A. M. Ismael, K. A. Zeller and J. F. Leslie. 1999. Relative colonization ability of greenhouse-grown maize by four lineages of *Cephalosporium maydis*. Phytopathology 89: s23.

Jurgenson, J. E., K. A. Zeller and J. F. Leslie. 1999. A genetic map using AFLP markers of *Fusarium moniliforme* (*Gibberella fujikuroi*). Fungal Genetics Newsletter 46 (Supplement):106.

Ploetz, R. C., J. L. Haynes, A. Vazquez, J. F. Leslie and A. El-Sattar. 1999. A preliminary study on the causal agent of mango malformation in Egypt. Phytopathology 89: s60.

Steenkamp, E. T., B. D. Wingfield, T. A. Coutinho, M. J. Wingfield, W. F. O. Marasas and J. F. Leslie. 1999. PCR-based differentiation of *MAT-1* and *MAT-2* from *Gibberella fujikuroi*. Phytopathology 89: s75.

Zeller, K. A., J. E. Jurgenson and J. F. Leslie. 1999. Mapping vegetative incompatibility (*vic*) loci in *Gibberella fujikuroi* (*Fusarium moniliforme*). Fungal Genetics Newsletter 46 (Supplement): 94.

Zeller, K. A., J. E. Jurgenson and J. F. Leslie. 1999. AFLP markers reveal genetic variation in Egyptian populations of *Cephalosporium maydis*. Fungal Genetics Newsletter 46(Supplement): 94.

Agroecology and Biotechnology of Fungal Pathogens of Sorghum and Millet

Project KSU-210B
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Summary

Ergot (*Claviceps africana*) was first detected in the Western Hemisphere in 1995 (Brazil) although reported from Africa and Asia since the early 1900s. Ergot was detected in Central and North America in 1997. Prevailing southerly winds and hurricanes are assumed to be the principal means of disseminating ergot spores from southern to northern sorghum production areas. Kramer-Collins fungal spore traps were used as a means of monitoring windblown ergot microconidia and macroconida. During the growing seasons of 1999 and 2000, spore traps were placed at Crosbyton and Corpus Christi, TX; Lahoma, OK; Garden City, Hays, Hesston, and Manhattan, KS; and Clay Center, NE. Traps were monitored on a weekly basis. Recovery of spores correlated to ergot disease of sorghum that occurred in Manhattan, KS. Otherwise, recovery of spores was only significant in Corpus Christi with no or very limited recovery from other stations. Hybrid sorghum seed companies used the recovery data to formulate control procedures. Elimination of chemicals and cost of application in Kansas that was not warranted for control of ergot was estimated at five million dollars.

Objectives, Production and Utilization Constraints

Objectives

- In the USA, Mexico, El Salvador, and Nicaragua, determine the survivability of macro- and microconidia of *Claviceps africana*, causal agent of ergot disease of sorghum on various surfaces.
- In the USA, determine the overseasoning survival of macro- and microconidia of *C. africana* in infected sorghum panicles.
- In the USA, Kenya, and Egypt, continue to screen for genetic variability of sorghum germplasm to covered kernel smut and ergot diseases.
- In the USA, Mexico, El Salvador, and Nicaragua, screen various genera of plants, including *Sorghum sp.*, *Andropogon*, *Cenchus*, etc., to ascertain potential alternate hosts of *Claviceps africana*. Evaluate the sorghum growth modeling program, SORKAM, in conjunction with the National Weather Bureau as a means of predicting ergot incidence and severity. This program would more closely approximate sorghum cultural practices and climatic conditions in the Americas.
- In the USA, Kenya, and Mali, develop an effective screening protocol to ascertain genetic variability of various sorghum accessions to *Ramulispora sorghi*, causal agent of sooty stripe disease.
- In the USA, Mali, and Kenya determine the causal agents of pokkah boeng disease of sorghum and millet.

Constraints

Ergot was only a problem in grain sorghum in Africa and Asia prior to 1996, when the disease was first detected in

Brazil and Argentina. In 1997, the disease spread to Colombia, Honduras, Nicaragua, El Salvador, Mexico, numerous islands in the Caribbean, and in the USA (Kansas, Nebraska, and Texas). This poses profound implications for the sorghum industry in North America. Losses due to ergot may be attributable to actual reduction in grain yields, loss of export markets of seed and feed grains to those countries where ergot has not been reported, and loss of germplasm and or hybrid seed increases in winter nurseries where ergot was detected and quarantine regulations prohibit return of the grain into the USA. Grain sorghum is used as a human food in numerous countries and may be the only food staple available in those areas where drought is a common occurrence and ergot contamination of such grain could result in extensive hunger. It is unknown if the macro-, microconidia or sclerotia will survive between sorghum cropping seasons in temperate areas.

Covered kernel smut is one of the more important diseases of grain sorghum in LDCs. The disease is easily controlled by chemical seed treatments, but these chemicals may not be available or the cost may be prohibitive for purchase by farmers. Incorporation of resistant or immune germplasm into acceptable cultivars would partially alleviate concerns about covered kernel smut.

Sooty stripe is a major disease of sorghum in those areas where the crop is primarily grown under limited or no-till cultural practices. Sooty stripe is also important in other countries such as Mali where yield reductions are common.

Research Approach and Project Output

Ergot

Overseasoning Survival

Durability of ergot conidia were determined by evaluating longevity of spores under natural field conditions. The survival rate was determined on the surface of various materials such as cotton to imitate clothing, leather to mimic shoes, and metal and rubber to simulate machinery used in producing grain sorghum. Monel metal disks were cleaned with several changes of acetone, washed in several changes of sterile distilled water, and dried. A portion of the disks were painted yellow, green and red to determine if pigments in paint used in painting agricultural implements were toxic to ergot conidia. Other disks were from rubber, tarpaulin, paper from corn seed bags, and leather. Panicles exhibiting honeydew symptoms were collected and stored at room temperature. Individual ergot-infected florets were removed and placed in a beaker containing a solution of 10 mM phosphate buffered saline (PBS). The final concentration consisted of 6.6×10^7 cells/ml of microconidia and 1.1×10^7 cells/ml of macroconidia. Disks were infested by placing 250μl of the suspension on each disk and then dried overnight in a laminar flow hood. Disks were placed in perforated paper bags for storage in an unheated building.

Sampling

Disks were removed at monthly intervals from the storage facility and placed in 6-well tissue culture flat bottom plastic plates. Four ml of PBS was added to each well. Plates were then placed on a Thermolyne rotator/shaker at a setting of 150 rpm for 45 to 60 minutes. Plates were removed and 250 μl from each well was added to a hemocytometer. Counts were determined primarily with the 10X objective, however the 40X objective was used to determine microconidia. At least 10 fields were counted in the hemocytometer.

Modeling System

Spore traps known as the Kramer-Collins trap were utilized in an attempt to detect wind movement of ergot spores from southern sorghum growing locations to the northern latitudes. The trap consisted of a vacuum pump, timer, and a rotating drum with a double sided adhesive tape where spores are fixed. The timer is on a seven day cycle. A quantity of air is forced through the container and particulate materials including pollen and fungi are trapped in the adhesive tape. Drums are sent to the laboratory by cooperators from the various locations at weekly intervals. During the growing seasons of 1999 and 2000, spore traps were placed at Crosbyton and Corpus Christi, TX; Lahoma, OK; Garden City, Hays, Hesston, and Manhattan, KS; and Clay Center, NE. Detection of ergot spores from the drums were reported to the stations where the information was gathered. Various private seed companies utilized the data to determine if controls were necessary. In addition, the data will be incorporated in development of a modeling system for predicting the incidence of ergot. In addition, the data will be incorporated in a model known as "SORKAM" that is based on growth and development of sorghum plants.

Sooty Stripe

The causal agent, *Ramulispora sorghi*, has been difficult to increase in culture due to finite growth conditions. Previously in this project, we were able to ascertain growth media and temperature requirements to increase inoculum for a screening protocol. Conditions that enhance disease incidence and severity remain unknown. A misting system to increase relative humidity was installed. The misting system is controlled by leaf moisture sensors that are connected to a controller regulated by a computer software program. It is believed that relative humidity is an important component for disease development. In addition, a dew chamber was purchased to determine the optimum epidemiological parameters for optimum disease severity under growth chamber conditions.

Pokkah boeng

Maize and sorghum samples with suspect pokkah boeng symptoms were collected from the USA, Costa Rica, and Kenya. Leaf and/or stalk tissues were washed with water and the surface sterilized by immersion in 10% NaOCl for four minutes, rinsed three times in sterile distilled water, placed on Nash-Snyder medium, and incubated at 28°C for one week. *Fusarium* isolates from each colony were single-spored with a micro manipulator. Morphological characteristics were determined from strains grown on carnation leaf, KCl agar, and fresh potato dextrose agar. All isolates of *F. proliferatum, F. subglutinans,* and *F. moniliforme* were identified to mating populations using the procedures described by Klittich and Leslie. Crosses were made on carrot agar and all strains (males) were crossed with the standard mating type testers (females) (Courtesy of J. F. Leslie, Kansas State University).

Greenhouse Experiments

Fusarium Strains and Germplasm Accessions

Three strains were selected for greenhouse experiments. L1 was a strain of *F. subglutinans* (mating group E) isolated from sorghum; L3 was *F. proliferatum* (mating group D) from maize; and L5 was *F. moniliforme* (mating group A) from sorghum. Preliminary experiments failed to show specificity between the strains and their maize and sorghum hosts. Eight sorghum inbreds (courtesy of D. T. Rosenow, Texas A & M University, Lubbock), two maize inbred lines and two maize hybrids were disinfected by soaking in distilled water at room temperature for 4 hour followed by a hot water (56-58°C) dip for eight minutes. Seeds were germinated by incubation on filter paper in petri plates at 28°C for two days. These were transplanted to plastic pots (5 plants/pot) containing steamed potting soil and then placed on greenhouse benches. Temperatures were 26°C (day) and 20°C (night) with 12-hour periods.

Inoculation

Preliminary experiments revealed that inoculum applied as a seed dressing, misting spore suspensions on seedlings or inoculated with infested toothpicks failed to induce pokkah boeng symptoms. Consequently, to reliably reproduce symptoms, spore suspensions were placed into the plant whorl. Inoculum was prepared from L1, L3, and L5 strains grown on PDA for five days. Conidia were removed from the colonies by washing with sterilized 0.25% Tween 20 solution. Ten-fold dilutions were made in 10 mM PO_4 buffer (pH 7.2). Conidia were counted with a hemocytometer and verified by plating a sample from each strain on NS medium. Plates were incubated at 28°C overnight and colonies were then counted. Plants were inoculated by placing one ml of a conidial suspension (150 µl) into the plant whorl with a pipette.

Conidial Concentration

Three experiments were conducted under greenhouse conditions over a two-year period. For the first experiment, plants were at the 4 to 5 leaf stage of growth; three plants per pot were inoculated and inoculum consisted of 1.4×10^7, 1.0×10^7 and 1.9×10^7 conidia/ml for L1, L3 and L5, respectively. Suspensions were also serially diluted (10-fold) to concentrations of 1.0×10^1 through 1.0×10^6 (conidia/ml). Plants were at the 6 to 7 leaf stage for the second and at the 7 to 8 leaf stage of growth for the third experiment. Four plants per pot were inoculated; inoculum was 2.8×10^7, 1.8×10^7, and 1.8×10^7 conidia/ml for L1, L3 and L5, respectively. A replication consisted of four pots with 4 to 5 plants per pot. After 22 days, plants were recorded for PB incidence.

Recovery of Strains from Inoculated Plants

Samples (ca. 2 mm^2) from each inoculated plant were taken from roots, symptomless leaves, twisted whorls with ladder-like symptoms, leaf and sheath tissue with fleck symptoms, epidermal tissue with lesions, cortex and vascular tissues with or without visible lesions. Samples were processed and fungi identified as described previously. One fungal colony from each sample was transferred to media for generation of *nit* mutants. The basic protocols were those used by Correll except the medium contained 3% $KClO_3$. Each *nit* mutant was paired with the *nit* 1 and *nit M* from the tester strains on 24-well hybridoma plates. Mutants that complemented with at least one of the two testers were designated as belonging to the same VCG.

Field Experiments

Field experiments on maize and sorghum were conducted over a two-year period at the Rocky Ford Farm near Manhattan. Seeds of eight sorghum and maize accessions were disinfected as previously described and hand-planted in single row plots. Three strains (L1, L3 and L5) were used as inocula. Spore suspensions were adjusted to concentrations of 1.0×10^2, 1.0×10^4 and 1.0×10^6 (conidia/ml) except the latter suspension was omitted the second year. Plants were inoculated by placing one ml of the suspension into whorls at the 8 to 10 leaf stage of growth. Pokkah boeng symptoms were recorded four to five weeks after inoculation.

Covered Kernel Smut

Seeds of true breeding varieties and crosses used in this study were supplied by Dr. P. J. Bramel-Cox and Dr. D. T. Rosenow (Texas A & M University, Lubbock). Immune accessions used were B35-6 (IS 12555 Derivative), SC414 (IS 2508 Derivative), and Sureño ((SC423 × CS 3541) × E 35-1). In all crosses, the susceptible parent was BTx623 (BTx 3197 × SC170-6). Crosses were made between resistant and susceptible accessions to determine the dominance or susceptibility and between resistant accessions to determine if they possess the same genes. Crosses between resistant varieties were SC414 × Sureño, SC414 × B35-6, and Sureño × B35-6. Crosses between resistant and susceptible varieties consisted of B35-6 × BTx623, SC414 × BTx623, and Sureño × BTx623.

Greenhouse

F_1 seed was increased to produce the F_2 generation. To produce the F_3 generation of crosses between resistant and susceptible varieties, F_2 seed was grown under greenhouse conditions in 1995. Shortly after the panicles of the F_2 plants emerged and before anthesis they were covered with pollinating bags to prevent outcrossing. The F_3 seed was harvested in May, 1995 and stored in paper bags until sown in the field (June).

Eight seeds of each line were planted in pots (28 x 46 cm) containing a sterile soil mix consisting of Baccto potting soil-sand-perlite (2:1:1). To study inheritance of resistance (segregation) in the F_2 generation, F_2 seed of all crosses were grown in pots in the greenhouse during the winter of 1995. The F_2 seed of the crosses between resistant and susceptible varieties were divided into two equal portions and planted in different greenhouses (1 and 2). Potted plants in greenhouse 1 were placed on the cement floor and those in greenhouse 2 were placed on benches. Both greenhouses were maintained at 27°C day, 21°C night, with a 12 hr photoperiod. Plants were thinned at the 3 to 4 leaf stage of growth and number of plants per pot varied from 3 to 5 depending on the size of the container.

Field Experiments

F_3 lines were machine planted in 3 meter rows spaced 76 cm apart at the Rocky Ford Experimental Farm, Manhattan, KS, in June 1995. Ammonium nitrate fertilizer (34:0:0) was applied pre-plant at 94.2 kg ha^{-1}. Weeds were controlled by applying ramrod/atrazine {Propachlor, (2-chloro-N-isopropylacetanilide, 48%); Atrazine, [2-chloro-4-(ethylamino)-6-(isopropylamino-s-tirazine, 15.5%]} preemergence at 12.6 L/ha followed by hand weeding as needed. B35-6 × BTx 623 consisted of 33 F_3 lines, Sureño × BTx 623 resulted in 38 F_3 lines and 41 F_3 lines were from SC414 × BTx623.

Seed Sterilization

Seeds were immersed in a mixture of formalin and water (1:300 v/v) for 1 hour. Seeds were then washed in running tap water for 30 minutes, air dried for 24 hours, and stored in paper envelopes.

Inoculum Preparation

Inoculum consisted of a mixture of *S. sorghi* teliospores from infected panicles of sorghum cultivars collected from the covered kernel smut nursery at the Rocky Ford Experiment Farm of Kansas State University, Manhattan, KS. Smutted heads were threshed by hand in plastic bags. The smut mass was sieved through 100 and 400 mesh screens to eliminate debris. Teliospores were stored at 4 C prior to use.

Seeds Infested with Teliospores

Dry teliospores (0.6% w/w) were added to F_3 seeds in a paper envelope. The envelope was thoroughly shaken to ensure uniform distribution of spores on the seed coat. Infested seeds were sown under field conditions within 2 hr of treatment.

Partial Vacuum

F_1 and F_2 seeds were mixed with teliospores (0.2% w/w), and a sufficient amount of water was added to wet the seed. The mixture was then placed under partial vacuum (18, 22) (180-200 mmHg) for 1 hr, and the vacuum was released at 15 min intervals. Seeds were dried at room temperature, and the procedure was repeated the following day. After the second application had dried, teliospores (0.2% by weight) were added to the F_1 and F_2 seeds in a paper envelope, shaken vigorously and planted in the greenhouse within 2 hr.

Research Findings

Ergot

Recovery of *C. africana* macroconidia was over 95% from surface materials infested with honeydew over the six-month sampling period. Less than 1% recovery of macroconidia of the diluted honeydew suspension was obtained. Over 90% of the macroconidia were recovered from painted metal. In general, recovery was less from the porous surface materials such as denim and wood. Viability of macroconidia rapidly declined over the six-month sampling period (Table 1).

Sorghum accessions *S. almum* (PI 204282, PI 339704), *S. arundinaceum* (IS 14359, PI 302232), *S. drummondii* (PI 196890, PI 213902), *S. virgatum*, *S. halepense* and the positive controls, *S. bicolor*, were found to be susceptible to *C. africana* (Table 2). *Neither of the two S. aethiopicum* or one of the *S. verticilliflorum* (IS 4330) developed panicles, possibly due to photoperiod sensitivity. Ergot symptoms were not observed on *S. arundinaceum* (PI 185574), *S. drummondii* (IS 14131), and *S. verticilliflorum* (IS 14357). Ergot symptoms were not observed on the millets or grass entries.

Table 1. Viability (%)[1] of Claviceps sorghi macroconidia over a two-year sampling period.

Year	December	January	February	March	April	May
1997-98	51.0	52.0	36	9.4	0.0	0.6
1998-99	10.0	10.0	23	7.4	3.9	13.6

[1] Viability determined by germination of conidia on water agar.

Table 2. Genetic variability of various *Sorghum sp.*, Millets, and Common grasses to *Claviceps africana*.

Species	Accession number	Susceptibility
S. aethiopicum	IS 14301	NPD
S. aethiopicum	IS 14567	NPD
S. almum	PI 204282	+
S. almum	PI 339704	+
S arundinaceum	IS 14359	+
S arundinaceum	PI 185574	-
S arundinaceum	PI 302232	+
S. bicolor	PI 408820	+
S. bicolor	TX 623	+
S. bicolor	P954063	+
S. bicolor	SC 414-12E	+
S. drummondii	IS 14131	-
S. drummondii	PI 196890	+
S. drummondii	PI 213902	+
S. halepense	PI 408820	0
S. verticilliflorum	IS 14257	NPD
S. verticilliflorum	IS 14330	-
S. verticilliflorum	IS 14357	-
S. virgatum	12-26	+
Finger Millet	NE FM	-
Foxtail Millet	NE SNO-FOX	-
Pearl Millet	NPM-1	-
Proso Millet		-
Big Bluestem, Kaw		-
Little Bluestem, Aldo		-
Canadian Wild Rye		-
Osage Indian Grass		-
Shattercane		+
Switch Grass		-

NPD – No panicle development

Pokkah Boeng

Recovery of Fusarium species. Recovery of *Fusarium* sp. isolates from various maize and sorghum samples exhibiting PB symptoms revealed that *F. moniliforme*, *F. proliferatum* and *F. subglutinans* predominated as 52 % of the maize samples and 45% of the sorghum samples were positive for at least one of the three species. Recovery of *F. subglutinans* was almost negligible as only the maize sample from Indiana and a sorghum sample from Kansas yielded more than one isolate per sample. Seventy-two percent of the maize and 74% of the sorghum samples were positive for at least one mating population.

Effect of inoculum on disease development. No significant differences were found between the two lines with a mean of 2.5 for LH82 and 2.4 for LH132. However, significant differences were noted among the three strains with a mean of 3.2 for *F. subglutinans*, 2.1 for *F. moniliforme*, and 2.0 for *F. proliferatum*.

F. subglutinans was the most aggressive of the species that we evaluated as a causal agent of pokkah boeng. At inoculum levels of 1.0×10^2 conidia/ml, fleck symptoms predominated. Suspensions of 1.0×10^3 and 1.0×10^4 resulted in ladder-like symptoms and higher levels ($>1.0 \times 10^4$) usually resulted in death. *F. proliferatum* failed to cause pokkah boeng symptoms below 1.0×10^2 conidia/ml. Fleck symptoms occurred in plants inoculated at concentrations between 1.0×10^2 and 1.0×10^5. Ladder-like symptoms were observed when concentrations were 1×10^5 conidia/ml. Similar symptoms occurred when *F. moniliforme* was used as inoculum. PB severity was highly related with R values of 0.83 and 0.89 for inoculum concentrations of the three species. PB severity was more rapid with *F. subglutinans* as the slope was 0.52 relative to the two other species (0.25 and 0.28).

Recovery of isolates. There were no visible symptoms in control plants with a pokkah boeng score of 1.0 although *F. moniliforme* was recovered from all tissues tested. *F. proliferatum* was only recovered from sheath tissue. Plants inoculated with *F. subglutinans* exhibited ladder-like symptoms with an average rating of 3.6 to 3.8. Greatest recovery was from the whorl (98%) and leaf sheath (93%) tissues. Low recovery was from root (30%) and pith tissues (33%). *Fusarium* species were recovered in low numbers from leaves without visible symptoms. Plants inoculated with *F. proliferatum* and *F. moniliforme* showed various symptoms from fleck to ladder-like symptoms with a PBR score of 2.3 to 3.0. Recovery was also high in the whorl (77-100%) and from leaves with visible fleck symptoms (75-83%). Recovery ranged from 30 to 48% in roots which is not indicative that infection was the result of pathogen ingress but was most likely attributable through air or water movement from tissues to roots.

Field Symptoms. In the two-year field experiments, symptoms and severity were recorded for each accession of maize and sorghum based on the pokkah boeng scale. Generally, more variation occurred in field symptoms than in the greenhouse. In maize, basic symptoms such as the fleck, ladder-like and top rot remained clear cut in relation to the species and inoculum concentrations. More variation in symptoms occurred in sorghum such as the fleck reaction which was not as prominent as in maize and ladder-like symptoms were not observed on some genotypes. Instead, there were many variations of malformed symptoms such as onion leaf, whorl with partially wrapped leaves, elongated stalks and dwarf plants. Diseased sorghum plants, in general, were noticeably stunted and excessive tillering occurred. Changes in symptomology were present among maize and sorghum genotypes although symptoms for a particular genotype were consistent from year to year.

F. subglutinans was the most aggressive to both maize and sorghum and results were similar to greenhouse data. The effects of inoculum concentrations on development of pokkah boeng were not as defined under field conditions as they were in the greenhouse experiments which indicates that environmental effects were another important factor.

Recovery from diseased plants in the field. Approximately one month after inoculation, samples were collected from each accession and VCG was used to confirm identity of the recovered strains. For the four sorghum genotypes, 53% of the 58 samples collected from plants inoculated with *F. subglutinans* (L1) were of the same VCG. Seventy-one percent of 41 samples were positive for strain L3 and 80% of the 84 samples recovered from plants inoculated with L5 were positive. The three maize accessions yielded 72% of the 97 samples as positive for L1, 79% of the 93 samples were L3 and 63% of the 79 isolates were L5. Three percent of the recovered isolates from control plants were contaminated with *F. moniliforme* (L5).

Complex of symptoms. Single spore cultures of *F. subglutinans, F. proliferatum and F. moniliforme* used as inoculum resulted in pokkah boeng symptoms. Based on our experiments, symptoms were differentiated as follows:

1. No visible symptoms.

2. Fleck symptoms: Chlorotic spots developed on inoculated leaves and sheath tissue. Necrotic areas gradually developed and resembled a "shot hole" appearance.

3. Ladder-like: Necrotic areas enveloped the whorl and later the leaf tissues resembled a dried onion leaf which remained attached to one of the lower leaves. Other whorls developed and usually emerged proximal to the point of attachment to the uppermost leaf and often at a 90° angle from the leaves giving the impression of ladder rungs. Below the initial sites of inoculation, extensive translucent chlorotic areas with brownish streaks developed.. *Pantoea herbicola* (Syn. *Erwinia herbicola*) was commonly isolated from chlorotic tissue.

4. Rat tail: Leaves failed to emerge from the whorl. Leaves were seemingly entangled in an adhesive matrix, which commonly resulted in tissue death. The necrotic tissue resembled a dried onion leaf or rat-tail 80 to 100 mm long which remained attached to the plant. Leaf sheaths below the uppermost developed leaf collar had extensive water-soaked brownish lesions. Similar lesions were also observed on the stalk surface. In some cultivars, extensive tillering from the base of the plant was common.

5. Top rot: Proximal and distal to the inoculated site, extensive necrosis occurred in the cortex and vascular tissues and the epidermal tissue assumed a brownish hue. Necrosis usually continued throughout the internodes until reaching the roots.

Covered Kernel Smut

Smut reaction of parents. Resistant parents remained immune to *S. sorghi* under field and greenhouse conditions. Incidence (76%) of smutted heads of BTx623 grown under greenhouse conditions was significantly higher than those plants grown in the field (2.3%).

Reaction of F_1 progenies of the crosses Sureño × B35-6 and Sureño × BTx623 favored dominance of resistance. However, dominance was obviously incomplete in the cross Sureño × BTx623. B35-6 is either dominant or has the same gene as Sureño (B35-6 × Sureño). Reaction of other F_1 progenies to covered kernel smut could not be determined due to limited seed stocks.

Smut reaction of R × R F_2 progenies. Variability existed in smut reactions among crosses of resistant (R) by resistant (R) germplasm. F_2 progenies of B35-6 × Sureño were free of smut and only two plants were smutted out of a total of 47 plants in the cross of SC414 × B35-6. Although unanticipated, 26 % of the F_2 progenies of Sureño × SC414 were smutted.

Smut reaction of R × S F_2 progenies. Covered kernel smut incidence varied among crosses of resistant (R) and susceptible (S) varieties, depending on the greenhouse in which each cross was grown. Greenhouse 1 was located on a north exposure in the complex and temperature gradients were more severe in the winter than greenhouse 2 which was located on the south portion of the wing. Both greenhouses contained the same heating and cooling equipment and were constructed the same year. Plants in greenhouse 2 matured earlier than those in greenhouse 1, with a maturity difference of two to four weeks, although the time of planting was identical in both greenhouses. Because of genotype by environmental interaction, a test for independence was performed. A contingency chi-square value of 0.28, $p = 0.70$ to 0.50, and 0.022, $p = 0.90$ to 0.70 for the crosses, SC414 × BTx623, and Sureño × BTx623, respectively, indicated no significant differences between greenhouses. Therefore, the chi-square test was calculated using the pooled data from both greenhouses.

Reaction of F_3 lines to smut. Conditions for smut infection were not as conducive under field conditions as shown by the low incidence (2.3%) of infection in the susceptible parent. However, all F_3 lines of the crosses were more diseased than the susceptible parent (BTx623) with a mean covered kernel smut incidence of 6.2 % in 38 F_3 lines of Sureño × BTx623, 3.8 % in 41 F_3 lines of SC414 × BTx623, and 3.7 % in 33 F_3 lines of B35-6 × BTx623. The chi-square and probability values indicated a close fit to a 1:3 ratio for the F_3 families of SC414 × BTx623 and Sureño × BTx623, respectively.

Networking Activities

Research Investigator Exchanges

A planning session was conducted in Tegucigalpa, Honduras in October 1999 for Central America. Other planning and strategy meetings were conducted in El Salvador and Nicaragua in January and June 2000.

Research Information Exchange

Books, specialty supplies and equipment were provided to collaborating scientists in El Salvador and Nicaragua.

Publications and Presentations

Journal Articles

Nzioki, H. S., L. E. Claflin and B. A. Ramundo. 2000. Evaluation of screening protocols to determine genetic variability of grain sorghum germplasm to *Sporisorium sorghi* under field and greenhouse conditions. Int. J. Pest Manag 46:91-95.

Frederickson, D. E., E. S. Monyo, S. B. King, G. N. Odvody, and L. E. Claflin. 1999. Presumptive identification of *Pseudomona syringae*, the cause of foliar leafspots and streaks on pearl millet in Zimbabwe. J. Phytopathology 147:701-706.

Presentations

X Congreso de la Asociacion Latinoamericana de Fitopathologia in Guadalajara, Mexico. Presented on September 29, 1999 and title was, "Ergot del Sorgo."

International Agricultural Seminar, Department of Agronomy, Kansas State University. January 29, 1999. Topic: "A sabbatical leave south of the border."

USDA/ARS Foreign Disease and Weed Unit, Ft. Detrick, Maryland, February 28, 2000. "Ergot disease of sorghum.

Voice of America, Washington, D.C., February 29, 2000. Two presentations; Announcement of Global 2000: Sorghum and Pearl Millet Disease Workshop in Guanajuato, Mexico and Ergot Disease of Sorghum.

Low Input Ecologically Defined Management Strategies for Insect Pests on Sorghum

Project MSU-205
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Summary

In Honduras, sorghum and maize are attacked annually by a complex of lepidopterous caterpillars consisting principally of four species of defoliator caterpillars and one species of stalk borers. This complex annually damages or destroys these grain crops on subsistence farms, thus, requiring costly replanting if resources are available. Studies on aspects of the biology, ecology, behavior and population dynamics of the three armyworm species in this complex have been identified and the role of each species in crop production systems in southern Honduras has been determined. A system was developed for integrated management of this lepidopterous pest complex and soil inhabiting insect pests and has been published for distribution by extension and EAP personnel in Honduras. Recommended practices include two low cost, but labor intensive cultural practices which include delayed planting and weed control after crop emergence. Improved sorghum cultivars and early maturing maize are recommended and a single insecticide application may be required. Seed treatment with insecticide provides some protection to seedlings. Natural enemy parasitoids and weed management practices do not appear to significantly influence infestations and crop damage by the defoliators. This information indicated the limited role that naturally occurring biological control agents play in developing integrated pest management strategies for this lepidopterous caterpillar complex on sorghum and maize during the early crop growing season in this agricultural ecosystem, and, may possibly relate to other areas in Central America with similar insect pest constraints to production of these grain crops in similar agricultural environments. Sorghum production using the published pest management system was increased 20% and maize 35% in an on-farm study. In years when grain yields and market prices are high, the recommended practices could return several million dollars a year to the production area in southern Honduras, and possibly similar returns in other areas experiencing identical insect problems in Central America. Increased yields of both crops would improve diets and nutritional level of farm families.

Investigations in Nicaragua concentrated on the principal insect pest constraint to sorghum production on large commercial farms on the coastal plains. Sorghum midge distribution, occurrence, host plants, aspects of population dynamics, and response to planting date, insecticides, and variety-insecticide interactions were studied. These studies provide a base for developing effective, practical and economical sorghum midge management systems for this region. A brochure on sorghum midge biology, and cultural and chemical control has been developed for distribution into farm communities.

Objectives, Production and Utilization Constraints

Objectives

- Determine ecological and biological relationships among the lepidopterous pests limiting sorghum and maize production, and their association with crop and noncrop vegetation in Honduras.
- Study feeding preferences and performances (developmental rates) of selected lepidopterous defoliators to assist in defining the population dynamics of individual insect species in this complex.
- Investigate the role of noncrop vegetation and weed management practices, and natural enemy parasitoid populations in the dynamics of the lepidopterous defoliators on sorghum and maize in Honduras.
- Conduct extensive survey of subsistence farmers in Honduras to determine sorghum and maize production practices for utilization of information in developing acceptable insect pest management practices.
- Investigate aspects of sorghum midge occurrence and population dynamics on sorghum in Nicaragua.
- Determine insecticide efficacy, and effects of variety-insecticide relationships and planting date strategies on sorghum midge infestations on sorghum and crop damage in Nicaragua.
- Evaluate insecticides for control of sorghum midge and improved management programs in Mississippi.
- Publish collaborative research in scientific journals, as well as in popular papers and extension articles for distribution in farm communities in Central America.
- Continue graduate student training, attend scientific meetings, and travel to collaborative host countries to plan and conduct collaborative entomological and other pest management research investigations.

Constraints

Honduras

Ninety percent of the sorghum acreage in southern Honduras is intercropped with maize because of adverse environmental and agronomic conditions. In this area, tall, photoperiod sensitive, low yielding sorghum, called "maicillo criollo" are intercropped with maize. If the maize crop is lost to drought, farmers substitute sorghum for maize to feed their animals and family. Thus, sorghum is an insurance crop during dry years when the maize crop fails, which occurs in about three of every five years. More than 40% of the sorghum harvested in southern Honduras is destined for human consumption.

A lepidopterous pest complex, referred to by the local farmers as the langosta, is the principal threat to sorghum-maize intercrops during the early period of crop development. Biological and ecological studies have been conducted with the armyworm species in this complex, namely *Spodoptera frugiperda* (fall armyworm), *S. latifascia* (black armyworm), and *Metaponpneumata rogenhoferi*, in determining the role of each species in causing damage to the intercropped sorghum and maize in Honduras. Noncrop plant habitats have been identified and crop mortality factors have been partitioned in limited studies in the intercropped sorghum and maize systems in this region of Honduras, with insects accounting for 65% of the crop damage.

During the past ten years, research emphasis was principally on *S. frugiperda, S. latifascia,* and *M. rogenhoferi*. Their roles as economic pests in the various intercropped systems in southern Honduras have been determined. During the past three to four years, particular attention has been give to *M. rogenhoferi*, since this species has been given little research attention in the past and the literature is relatively void of information. The relationships of this little researched species with noncrop vegetation and crop plants in sorghum-maize production environments was investigated. Studies were concluded on the morphology and identifying characteristics of this species (a taxonomic paper has been accepted for publication), influence of host plants on larval developmental time and adult survivorship, and influence of weed control programs on pests and their parasitoid populations. The pest population levels and dynamics of infestations on the crops during the growing season for this species, and others in the lepidopterous complex, assists in developing total insect pest management strategies for the insects in intercropped sorghum and maize in specific agroecosystems. Aspects of this research are transferable to other areas in Central America.

The international significance of *Spodoptera* species, as well as *M. rogenhoferi*, particularly in relation to migration, pest control, and insecticide resistance, has impact on sorghum production for various regions in the Latin American Ecogeographic zone, as well as potential impact on crop production in the United States (this is particularly significant for the fall armyworm, an insect that migrates throughout the Americas).

Alternative insect pest management practices (limiting insecticide use) which are practical for use by the subsistence farmer have been evaluated in MSU-205. Investigations have been completed elucidating specific aspects of lepidopterous caterpillar complex pest management tactics that were identified as practical for control of these insects that limit crop production. The sorghum breeding program with EAP was designed to develop improved maicillo criollo varieties and photoperiod sensitive hybrids.

MSU-205 has been active in this program, and has assisted in the identification of antibiosis resistance (harmful effects on insect biology) in the native land race cultivars, and research has elucidated the antibiosis mechanisms of resistance.

Research in MSU-205 has identified insect pest management tactics that are practical for use by low income subsistence farmers. A system of sustainable and economically feasible crop production practices has been developed for use by farmers who lack economic resources to purchase off-farm inputs such as herbicides, fertilizers, and insecticides. The publication, "La Langosta del Sorgo y el Maiz" (Pitre et al. 1999), has been published by EAP, Zamorano Academic Press and presents MSU-205 collaborative research results on the insect pests on intercropped sorghum and maize on subsistence farms in southern Honduras and recommendations for limiting insect pest damage to these grain crops. This publication has been distributed within farm communities.

Nicaragua

The extension of MSU-205 into Nicaragua has expanded INTSORMIL's entomological presence and collaborative participation in Central America. Sorghum production in Nicaragua is predominantly in commercial systems on large farms on the coastal plains. The crop represents 16% of the area planted to basic grains. The area with potential for sorghum production is six fold greater than that planted in 1999. The principal insect pest constraint to production is sorghum midge, although chinch bugs, fall armyworm and stalk borers can cause economic losses. Studies have been conducted on sorghum midge distribution, seasonal occurrence, host plant relationships, and cultural, chemical and biological pest control strategies that are effective and ecologically acceptable for this region. Studies completed in 1998 and 1999 indicated limited host range for this insect pest, with only sorghum, johnsongrass and broom sorghum identified as hosts. Infestations on each of these hosts have been completed, including aspects of midge seasonal survival (diapause) during the dry period. The influence of planting date, and variety-insecticide interactions on midge infestations was investigated. A popular article on the sorghum midge considering aspects of the insects biology and control has been prepared by MSU-205 and INTA for publication and distribution to farm communities in Nicaragua.

United States

Sorghum in many areas of the world are attacked by some of the same or related insect pests. The information on biology, ecology, and behavior of these pests in one area may be utilized in other areas when defining or refining aspects of insect pest management for the sorghum crops in the United States. Agriculture crop production technology can often be transferred from region to region. Therefore, studies on insect relationships with the sorghum crops in developing countries within the Americas zone can be beneficial for developing effective insect pest management practices for specific insect pests in the United States. Thus, MSU-205 project has emphasized research on defoliator pests (fall armyworm) and panicle pests (fall armyworm, sorghum webworm, corn earworm, and sorghum midge).

Research Approach and Project Output

Activities in Honduras

Weed Management. Influence on insect pest and natural enemy populations. The influence of weed management systems and natural enemy (parasitoid) populations in lepidopterous caterpillars on-farm studies with intercropped sorghum and maize in southern Honduras was completed and an M.S. thesis accepted in 1999. Weed control programs did not significantly influence weed species or insect species diversity and had no effect on levels of parasitization of the lepidopterous caterpillars in the cropping systems investigated. A nematode parasite of the caterpillar (as high as 68% parasitization of armyworms during certain periods in the growing season) was the most prevalent of the parasitoids attacking these defoliators. At this level of parasitization, the armyworms, predominantly fall armyworm, were not reduced below economically damaging levels on the sorghum and maize crops. This information, on naturally occurring parasitoid population levels and parasitization mortality, indicates the limited role that these biological control agents might have in developing integrated insect pest management strategies for the lepidopterous caterpillars on sorghum or maize in this agricultural ecosystem in Honduras; and, may possibly relate to other areas in Central America with similar insect pest constraints to production of these grain crops in similar agricultural environments.

Biology and taxonomy of Metaponpneumata rogenhoferi. The taxonomic characteristics of *M. rogenhoferi* were identified for the first time. This is an important consideration when identification of the particular pest species in a complex of species is critical in defining control recommendations. A taxonomic study of the morphology of *M. rogenhoferi* was completed and a manuscript prepared and accepted for publication in the scientific journal "Tropical Lepidoptera". The life stages of this important insect pest were described using illustrations and scanning electron microscope pictures of the egg, larva, pupa, and adult (♀ and ♂ genitalia) stages. Comparative notes on host plants and geographical distribution of related species in the tribe Eustrotiin: (Noctuidae) are presented in the publication.

Biology and ecology of caterpillar defoliators. Studies were conducted on *S. frugiperda*, *S. latifascia* and *M. rogenhoferi* in different environments. Pest life cycle, ecology, relationships with other insect pest species and seasonal dynamics were elucidated to identify the roles of the three species in causing economic damage to sorghum and maize. Noncrop plant "source habitats" and crop plant "sink habitats" have been identified. Crop mortality factors have been partitioned, with insects accounting for 65% of the mortality to the crops.

Survey of crop production systems. The survey was conducted to collect a base of information for the development of a practical insect pest management program on sorghum and maize in Honduras and areas with similar agricultural practices and insect pest constraints. The complexity of the sorghum-maize intercropped production systems in the foothills and on the coastal plains was identified. Four planting methods (systems) are used, but the most commonly used in the foothills is not the same as that used on the coastal plains. The insect pests are similar on the two grain crops in the two regions and the most commonly used insecticide is the same in both regions, but used more often during the season in the foothills. Fertilizers and herbicides are used to some extent in both regions, but lack of economic resources limits their use.

Economic evaluation of production systems. An economic evaluation of integrated pest management tactics in intercropped sorghum and maize production systems in the foothills and on the coastal plains was performed. Sorghum production, using the integrated pest management practices identified, was increased 20% and maize 35% at the farm level. In years when grain yields and market prices are high, the recommended practices could return $2.9 million a year to the production area in southern Honduras, and possibly similar returns in other regions experiencing identical insect pest problems in Central America. Increased yields of both crops would improve diets and nutritional level of families, and increase income.

As indicated above, the publication, "La Langosta del Sorgo y el Maiz" (Pitre et al. 1999) has been published as a collaborative effort among scientists in MSU-205 and at the agricultural institution (EAP) in Honduras. This publication has been distributed within farm communities and describes insect pest management tactics for the lepidopterous constraints to intercropped sorghum and maize production in Honduras, and could apply to areas in Central America with similar insect pest problems on sorghum and maize.

Activities in Nicaragua

Survey of crop production systems. This survey was conducted to identify the current sorghum production practices on the coastal plains where 95 percent of the sorghum fields (ca. 30, 000 hectares) averaged greater than 50 hectares. As in Honduras, this information is used to define acceptable integrated pest management practices for this region in Central America.

Fall armyworm was identified as the principal insect defoliator and sorghum midge the most important insect pest of panicles (seed damage). One or more chemical insecticide sprays are applied by 50% of the farmers for each of these two insect pests.

Population dynamics of sorghum midge. Sorghum midge reproduced throughout the year on the coastal plains, utilizing johnsongrass, broomcorn and sorghum as hosts. Midge emergence patterns from each of these hosts and host preferences for midge establishment and population buildup were identified for the coastal plains region.

Management tactics for sorghum midge. Sorghum midge management tactics were evaluated in 1998 and 1999 in southern Nicaragua. Early planting (immediately after the "canicula" or dry period) was identified as an extremely important midge control method. Susceptibility (tolerance) of sorghum varieties to midge was associated with agronomic characteristics of the specific genotype. Early blooming varieties were damaged less than varieties that bloom later. Chemical insecticides, including Decis, Lorsban, and Talstar, were effective in reducing midge infestations when applied at 10% bloom and at midge threshold.

Activities in United States

The efficacy of insecticides applied to sorghum was evaluated for insect pest control. A select group of insecticides was evaluated for control of fall armyworm and sorghum midge on sorghum in Mississippi. Insecticides were applied at various rates of application to plants in various growth stages. The efficacy of materials was recorded on armyworms in various instars to determine activity of the insecticides against larvae of various age classes. Insecticides were applied once or twice for sorghum midge control, depending upon pest thresholds. This information is useful in providing recommendations for control of fall armyworm and sorghum midge on sorghum. The data has been prepared and submitted for publication.

Direction of graduate students in the INTSORMIL program and travel. The PI directed the INTSORMIL research activities of four graduate students (M.S. degree candidates), coordinated thesis preparations, prepared papers for publication of INTSORMIL research in scientific journals, as well as popular articles. The PI traveled to Honduras and Nicaragua to work with collaborators and graduate students.

Networking Activities

Germplasm and Research Information Exchange

Supplies and equipment required by graduate students in performance of research activities in the laboratory and field in Honduras and Nicaragua were supplied by MSU-205. Some financial support has been provided annually to the graduate students for research expenses while in Honduras and Nicaragua. This support will continue with further INTSORMIL participation in Honduras and Nicaragua and other collaborating countries. A publication (popular article) presenting the lepidopterous caterpillar ("langosta") pest management practices (researched by MSU-205) that can be used by subsistence farmers in southern Honduras was prepared by EAP Press and has been distributed into farm communities. A similar article on sorghum midge was prepared by CNIA/INTA for distribution to farm communities in Nicaragua.

Publications and Presentations

Journal Articles

Ching'oma, G.P. and H.N. Pitre. 1999. Oviposition by fall armyworm, *Spodoptera frugiperda* (J.E. Smith): Effects of moth age and sorghum maturation stage. Ceiba. 40: 57-62.

Ching'oma, G.P. and H.N. Pitre. 1999. Fall armyworm, *Spodoptera frugiperda* (Lepidopterous: Noctuidae), larval development and moth fecundity on sorghum at various stages of maturity. Ceiba. 63-67.

Lopez, J.I., H.N. Pitre and D.H. Meckenstock. 1999. Changes in fall armyworm (Lepidoptera: Noctuidae) fitness over five generations after larval feeding on resistant tropical land race sorghum. Ceiba. 40:2.___. (accepted).

Lopez, J.I, H.N. Pitre and D.H. Meckenstock. 1999. Influence of nitrogen fertilizer on resistance to fall armyworm (Lepidoptera: Noctuidae) in tropical land race sorghum. Ceiba. 40: 2. ___. (accepted).

Vergara, O.R. and H.N. Pitre. 1999. Complexity of intercropped sorghum-maize production systems in southern Honduras. Ceiba. 40: 2.___. (accepted).

Dissertations and Theses

Cordero, Roberto. 1999. Relationships of weed management and parasitoids with lepidopterous pests in intercropped sorghum and maize in southern Honduras. M.S. Thesis. Mississippi State Univ. 62 pp.

Miscellaneous Publications (Presentations)

Pitre, H.N., H.E. Portillo, D.H. Meckenstock, M.T. Castro, J.I. Lopez, R. Trabanino, R.D. Cave, F. Gomez, O. Vergara, and R. Cordero. 1999. La Langosta del Sorgo y el Maiz. Zamorano Academic Press. Tegucigalpa, HO. 13 pp.

Zeledon, J., L. Pineda, and H. Pitre. 1999. Sorghum midge. Instituto Nicaraguense de Technologia Agropecuaria, Centro Nacional de Investigaciones Agricolos. 1 p.

Striga Biotechnology Development and Technology Transfer

Project PRF-213

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Summary

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.

In the last four years, significant results were obtained in both the research and development efforts of PRF-213. We established the simple inheritance of low production of the *Striga* germination stimulant in sorghum. We developed new assays for stages in host-parasite interaction beyond *Striga* germination. Using these assays, we identified unique mutants that have the capacity to disrupt normal parasitic association. These include sorghum lines with low production of the haustorial initiation factor, mutants with a hypersensitive response to penetration by *Striga*, thereby delaying the growth and development of the parasite, and those with incompatible response to penetration where the host response results in eventual withering and death of the parasitic growth. Genetic and physiologic characterization of these mutants, as well as introgression into elite cultivars of the particular genes involved in each mutant, is currently underway. As a development effort, *Striga* resistant sorghum lines that we developed in the past have been effectively distributed and adopted. We collaborated with World Vision International in distributing large quantities of eight *Striga* resistant sorghum varieties into 12 African countries. Following their introduction, we worked with national programs in carrying out testing and demonstration of these varieties in farmers' fields. In Ethiopia, collaborative relationship with the Ethiopian Agricultural Research Organization and Sasakawa Global 2000 led to the evaluation, demonstration, and the eventual official release of two of our varieties for commercial cultivation in the country. We will continue to cooperate with the NARS in efforts to put in place an effective seed production and distribution mechanism to ensure a reliable supply of these varieties in the future.

Objectives, Production and Utilization Constraints

Objectives

The overall objectives of our research are to further our understanding of the biological interactions between *Striga* and its hosts, and to devise control strategies based on host resistance. In addressing our goal of developing sorghum cultivars that are resistant to *Striga*, we emphasize the vital roles of the multiple signals exchanged between the parasite and its hosts, which coordinate their life cycles. To develop control strategies based on host-plant resistance, we employ integrated biotechnological approaches combining biochemistry, tissue culture, plant genetics and breeding, and molecular biology.

Striga spp. are economically important parasites of sorghum, millets and other cereals in tropical Africa and Asia.

Yield losses of sorghum due to *Striga* infestation, coupled with poor soil fertility, low rainfall, and lack of production inputs, all contribute to survival difficulties for subsistence farmers. Eradication of *Striga* has been difficult to the unique adaptation of *Striga* to its environment and the complexity of the host-parasite relationship. Suggested control measures including mechanical or chemical weeding, soil fumigation, and nitrogen fertilization, have been costly and beyond the means of poor subsistence farmers. Host plant resistance is probably the most feasible and potentially durable method for the control of *Striga*. Host resistance involves both physiological and physical mechanisms. Our goal is to unravel host resistance by reducing it to components based on the signals exchanged and disrupt their interactions at each stage of the *Striga* life cycle. The specific objective of our collaborative research project are as follows:

- To develop effective assays for resistance-conferring traits and screen breeding materials assembled in our *Striga* research program for these traits.
- To elucidate basic mechanisms for *Striga* resistance in crop plants.
- To combine genes for different mechanisms of resistance, using different biotechnological approaches, into elite widely adapted cultivars
- To test, demonstrate, and distribute (in cooperation with various public, private, and NGOs) elite *Striga* resistant cultivars to farmers and farm communities in *Striga* endemic areas.
- To develop integrated *Striga* control strategies, with our LDC partners, to achieve a more effective control than is presently available.
- To assess (both *ex ante* and *ex post*) of the adaptation and use of these control strategies, in cooperation with collaborating agricultural economists.
- To train LDC collaborators in research methods, breeding approaches, and use of integrated *Striga* control methods and approaches.

Research Approach and Project Output

Research Methods

Field evaluation of crops for *Striga* resistance has been slow and difficult, with only modest success. Our research addresses the *Striga* problem as a series of interactions between the parasite and its hosts, with potential for intervention. We recognize that successful *Striga* parasitism is dependent upon a series of chemical signals produced by its host.

The working hypothesis is that an intricate relationship between the parasite and its hosts has evolved exchange of signals, and interruption of one or more of these signals results in failed parasitism leading to possible development of a control strategy. Our general approach has been to assemble suitable germplasm populations for potential sources of resistance, develop simple laboratory assays for screening these germplasm, establish correspondence of our laboratory assay with field performance, establish mode of inheritance of putative resistance traits, and transfer gene sources into elite adapted cultivars using a variety of biotechnological means. Whenever possible, the methods developed will be simple and rapid, in order to facilitate screening large numbers of entries.

We place major emphasis on developing control strategies, primarily based on host-plant resistance. To this end, we have in place a very comprehensive *Striga* resistance breeding program in sorghum. Over the last several years, we have generated and selected diverse and outstanding breeding progenies that combine *Striga* resistance with excellent agronomic and grain quality characteristics. All previously known sources of resistance have been inter-crossed with elite broadly adapted improved lines. Almost all resistant sources ever recorded have been assembled and catalogued. We undoubtedly have the largest, most elite and diverse *Striga* resistance germplasm pool, unmatched by any program anywhere in the world. However, while all resistance sources have been introgressed to elite and most readily usable backgrounds, the only mechanism of resistance we have fully exploited has been the low production of germination signal. We have not had the ability to screen for other mechanisms of resistance in the infection chain or the host-parasite interaction cycle. In the last four years, we have placed significant emphasis on developing additional effective methods for screening host plants for *Striga* resistance at stages in the parasitic life cycle beyond germination, including low production of haustorial initiation signal, failure to penetrate, hypersensitive reaction, incompatibility, or general cessation of growth after penetration. Work is currently in progress on refining these assays and integrating them into our plant breeding procedures for effective transfer of genes of *Striga* resistance into new and elite sorghum cultivars.

The wealth of germplasm already developed in this program also needs to be shared by collaborating national programs in *Striga* endemic areas of Africa. To this end, we have organized international nurseries for distribution of our germplasm on a wider scale. This has served as an effective way to network our *Striga* research with NARS that have not been actively collaborating with INTSORMIL. As we combine and confirm multiple mechanisms of resistance in selected genotypes, the efficiency and durability of these resistance mechanisms can be better understood through such a wide testing scheme.

Furthermore, in cooperation with weed scientists and agronomists in various NARS, we plan to develop and test economically feasible and practicable integrated *Striga* control packages for testing on farmers' fields in selected countries in Africa. While most INTSORMIL projects have been directed as bilateral collaborative ventures, focusing on individual NARS, this *Striga* project is handled as a regional or more "global" program, because of the commonality of the *Striga* problem, and because no other agency has the mandate or is better suited to do the job.

Research Findings

Inheritance of low production of Striga Germination Stimulants in Sorghum (Ref: Crop Science, 1996, Vol. 36: 1185-1191).

Host plant resistance to *Striga* is a manifestation of one or more potential mechanisms. *Striga* seeds require after-ripening, conditioning, and chemical stimulation before they can successfully germinate and parasitize a host. Stimulation of the seeds to germinate initiates the potential host-parasite relationship. One of the better understood mechanisms of resistance against *Striga* by sorghum is low production of compounds by the host roots that *Striga* seeds require as stimulants for germination. Minute quantities of compounds, as low as 10 to 16M, exuded by host roots stimulate the conditioned *Striga* seeds to germinate. Sorghum cultivars differ in the amounts of stimulant compounds that their roots produce. This variation is responsible in part for the resistance against *Striga* found in some sorghum cultivars. A host plant that produces low amounts of stimulants will cause fewer *Striga* seeds to germinate, and thus, will be subject to less infestation. The production of germination stimulants is relatively simple to assay. We developed a simple and rapid assay in which we showed a close correspondence between a laboratory measure of stimulant production and field resistance in several sorghum cultivars. This assay screens individual sorghum seedlings for the capacity of their root exudates to stimulate the germination of conditioned *Striga* seeds embedded in water agar. We measure capacity to stimulate germination as the maximum distance from the sorghum root at which *Striga* seeds germinate. Germination distance in the agar medium, therefore, is a function of stimulant production and the interactions between the host root and conditioned *Striga* seeds. We also found out that there is a strong positive correlation between maximum germination distance and percentage of germinated *Striga* seeds in the agar medium.

Among a collection of sorghum germplasm assembled in our program, we have established, in field tests, that sorghum cultivar, SRN39, has the strongest expression of resistance. Resistance is measured as the capacity of a host plant to support fewer emerged *Striga* plants, and yield more grain than susceptible crop variety when grown under *Striga* infestation. The objective of our study, therefore, was to determine the mode of inheritance of stimulant production of *Striga* germination in SRN39. Crosses were made between the *Striga* resistant, low stimulant producer line, SRN39 and three high stimulant producer sorghum lines, Shanqui Red, IS4225, and P954063. F_1 progenies were selfed and also crossed back to both parents producing F_2 and backcross populations. *Striga* germination tests were conducted on parental lines, F_1, F_2, and backcross generations of these crosses. For each of the three crosses, significant differences between the mean maximum germination distances of the two parental cultivars were observed. No significant differences existed between mean germination distances of the F_1 and reciprocal F_1 progenies indicating absence of maternal effects in these crosses. The germination distance of the three F_1 populations were greater than their respective midparent mean values, suggesting partial dominance for high stimulant production. Chi-square values for Mendellian F_2 segregation ratios indicated that low stimulant production on SRN39 is inherited as a single, nuclear, recessive gene which is largely additive in action. These results suggest that selection for low stimulant production would be successful in generating *Striga* resistant sorghum cultivars when appropriate genetic variability is generated. Work in our program has also demonstrated this concept empirically where elite low stimulant producing *Striga* resistant germplasm have been produced using our laboratory procedure.

Evaluation of the Physiological Basis of Dormancy of Striga Seeds (Ref: Weed Research, 1998, Vol. 38, 257-265)

As a noxious parasitic weed of tropical cereals and legumes, *Striga* spp. are exquisitely adapted to the climatic and edaphic conditions in the areas where they have become endemic. Because *Striga* seeds are small, resource depletion must be controlled during the events before host attachment when host resources become available. Freshly harvested seeds of *Striga* will germinate in response to host-produced chemical stimuli, but only after the passage of time, an-after ripening period, and exposure to moisture at a suitable temperature, a conditioning period. However, dormant seeds are often unresponsive and may remain in the soil for decades and become sensitive to stimuli upon hydration and after-ripening. A second dormancy is associated with prolonged hydration and is termed "wet dormancy". *Striga* specie have used these two states of dormancy to time the events associated with germination and establishment of parasitism.

Striga seeds are small, with limited energy resources; the survival strategy of the seed could, therefore, be related to its moisture content. Data on moisture content of *Striga* seed has not been reported in the literature, so it is not clear whether seed moisture content is related to dormancy. The purpose of the *Striga* was, therefore, to establish the role of seed moisture content in the regulation of the after-ripening period. To test for the effect of relative humidity on after-ripening, seeds were sealed into small glass containers above saturated various salts selected because their vapor pressure creates a range in relative humidity that changes little with temperature. The moisture content and germination percentage of the seed s were determined monthly over a six-month period. The effect of storage relative humidity on the moisture content of *Striga* seeds were examined at intervals after placing fresh harvested seeds in containers with specific relative humidity. Seeds were placed in chambers having specific relative humidity of 6, 14, 33, 75, and 97% for 30, 60, 90 and 150 days. The initial seed moisture was 14.7%. The seeds were then conditioned and germination percentage, response to tetrazolium, and seed moisture contents were measured.

Several interesting results were obtained. In general, seeds at moisture content less than 10% at the start of conditioning had germination of greater than 93%. Seeds at moisture content of over 10% at the start of conditioning could germinate between 60% and 3%, with germination decreasing as seed moisture content at the start of conditioning decreased. The highest moisture content (17%), and lowest germination percentage (3%), occurred in seeds stored at 97% relative humidity for 150 days. There was a high degree of correlation ($r^2 = 0.997$) between a positive tetrazolium color test and germination percentage, indicating that seeds having a positive tetrazolium response will germinate if provided with chemical stimulants. Seeds brought to a low rate of germination, or which did not germinate after 30 days of storage at high relative humidity (91%), had a much less positive response to tetrazolium, even though initially they had nearly a 100% positive response. Seeds with as little as 3% positive response to tetrazolium can be brought back to give a high percentage positive response if they are placed in a container with 6% or 13% relative humidity for 2 to 3 months. The negative tetrazolium response was not due to loss in seed viability as previously reported, but we suggest that the tetrazolium test measure the ability to germinate in response to conditioning and was not strictly an indicator of viability.

To examine the effect of prolonged conditioning (wet dormancy) and its reversibility, *Striga* seeds with a high rate of germination were incubated in water for 16 weeks, and germination tests were run at 4-week intervals. Prolonged conditioning was only 3% after 16 weeks of incubation in water. When these non-germinated seeds were then stored at 13% relative humidity, germination increased from 3% to 92% after 16 weeks. Storage at 5.5% relative humidity, increased germination from 3% to 91% in 12 weeks. In these circumstances, wet dormancy appears to be a reversible process.

We believe that the results presented in this study have direct relevance to *Striga* research and control. Our results have ramification, for instance, on the widely accepted application of ethylene gas in a *Striga* eradication program. If seeds buried in the soil have a moisture content above the threshold, then application of ethylene will not cause suicidal germination. One does not need to condition the seed to observe readiness to germinate, but only need to measure moisture content. This information may also be used to manipulate the life cycle of the parasite for *Striga* control. Pre-watering the soil in irrigated fields, or under rainfed farming, delaying sowing dates would ensure that *Striga* seed moisture content would increase and reduce germination; this could be a strategy for an integrated approach to *Striga* control.

Development of New In-vitro Assays for Post-infection Striga Resistance (Ref:Agron. Abst......)

Conventional approaches to selection for resistance to *Striga* has involved evaluation of sorghum germplasm in *Striga* infested plots. This approach has not been widely successful because of the complexity of the biology of the host-parasite relationship and its interaction with other environmental factors. *Striga* resistance in sorghum results from one or a combination of several recognized mechanisms that influence the development of parasitism. An understanding of these mechanisms and the gene action associated with specific host plant reaction to *Striga* infestation are essential prerequisites for efficient exploitation of host plant resistance as a *Striga* control measure. We have stated, in the past, that lack of effective germplasm screening techniques, based on specific mechanisms of resistance, as well as the overall paucity of sorghum germplasm with a strong level of *Striga* resistance, is a major bottleneck to breeding for *Striga* resistance. Understanding specific mechanisms of resistance, based on better appreciation of the host parasite biology. can provide impetus for development of efficient screening techniques that can be used for characterizing crop germplasm for successful exploitation through conventional and/or new breeding strategies.

The agar gel assay, developed in our laboratory, has been effective in screening crop germplasm with *Striga* resistance, due to low production of compounds that trigger *Striga* seed germination. The assay was also effectively utilized in transferring genes for low stimulant production into elite, broadly adapted sorghum cultivars. Recently, we developed new assays for screening host germplasm for mechanisms of resistance beyond germination. One of these assays, the Extended Agar Gel Assay, as the name implies, is an extension in time of incubation of the agar gel assay described above. This assay allows us to evaluate host germplasm for their capacity to produce the chemical stimulants needed for haustorial initiation. The second assay, named the Paper Roll Assay, allows quantification of potential problems in the infection process beyond germination. In addition to lack of haustorial formation, we can also observe interactive responses such as the hypersensitive reaction where penetration of the parasite into host roots is followed by necrosis, or the incompatibility response, associated with stunted growth of the parasite which may cause its eventual death following penetration. We hope to utilize these assays in the routine screening of the large assembly of sorghum breeding germplasm in our *Striga* resistance breeding program. Furthermore, these assays will be very valuable in characterizing specific mechanism of resistance of unique mutants as well as for pyramiding multiple sources of resistance into one elite germplasm.

Characterization of Novel Mechanisms of Resistance to Striga in Sorghum: (Ref:Breeding for Striga Resistance in Sorghum, Haussman et al. (eds) Proc of Workshop held at Ibadan, Nigeria, 18-20, 1999)

The damage caused to cultivated sorghum by *Striga* spp. begins below ground where seeds of the parasite germinate in response to a stimulatory chemical signal from their host. In order to survive, emerged *Striga* radicles must quickly make their way to a host root, form an attachment organ, called a haustorium, and attach to the root of a host plant. The parasite must then penetrate its host's root and establish vascular connections for host-derived water and nutrients to support growth and development to the point of emergence. All this occurs hidden below ground. Ability to monitor these early parasitic interactions of *Striga* to the host could aid in the identification of ways in which a resistant host cultivar avoids cooperation in the parasitic association. Several years ago, we developed the agar gel assay which allows observation of early events in host-parasite interaction. Growing sorghum in an agar medium containing *Striga* seeds led to identification of sorghum lines that resist infection by *Striga* because they produce only very low amounts of the chemical compounds required for *Striga* germination. Recently, we developed new assays in a medium supporting the infection process so that we could select sorghum genotypes that disrupt association with *Striga* because of failure to produce the haustorial signal, or possess a defense system that discourages penetration or further growth of the parasite. Our objective is to utilize these assays to characterize specific mechanisms of resistance observed in unique variants of sorghum lines.

With the Agar Gel Assay and the Extended Agar Gel Assay, we have been able to observe sorghum lines that produce unusually low amounts of the chemical stimulants required for *Striga* germination and haustorial production, respectively. We have fully exploited the mutants that lack the ability to produce the germination stimulants in our breeding program as we have developed an extensive array of elite *Striga* resistant sorghum lines with this mechanism. A mutant sorghum line that lacks the ability to produce the haustorial signal has been identified recently. The capacity to produce this signal appears to be simply inherited and is likely to be an easy trait to work with in a breeding program. We have just made several selected crosses and began generating segregating populations to make selections. The Paper Roll Assay allows the identification of mutants that disrupt the penetration of host roots by *Striga* and retard the growth and development of the parasite. Two kinds of responses are characterized. In the first, the hypersensitive response, necrotic areas appear at *Striga* attachment sites on the sorghum root. These necrotic lesions, generally, start as red becoming brownish with time. They may be large, spreading up to 2mm from the center of attachment but most remain more localized. Attached *Striga* most often are discouraged, not developing, and eventually dying while attached to the host. Among the cultivars in which this phenomenon has been observed, the response appears to be graded. A single infected root may show reddening around most haustorial attachment sites. Some sites on the host root which appeared necrotic upon attachment fade and *Striga* grows normally. The overall character of lines possessing the hypersensitive response, however, is a greatly reduced percentage of *Striga* attachments developing successful parasitic associations relative to susceptible cultivars. The incompatibility response differs from hypersensitivity in that there is no apparent necrosis in host root tissue surrounding the attachment site. However, as in the hypersensitive response, it discourages development of *Striga* beyond attachment. Incompatibility is more consistently expressed in a given individual than the hypersensitive response, at least among the cultivars that we have screened to date. The refinement of these assays has continued. We will also continue to characterize the large collection of *Striga* resistant sorghums accumulated in our program as this has already produced promising results. We also plan to establish the mode of inheritance for each of these mechanisms in the near future. Crosses have already been made with some promising entries, and subsequent selection efforts will focus on identifying germplasm that combine more than one mechanism of resistance. Such a germplasm is expected to have an enhanced level of protection against *Striga* and its resistance is likely to be durable. Refinement of the paper roll assay seems to be painstakingly slow. However, once refined, this assay should facilitate characterization of mechanisms of resistance as well as pyramiding multiple sources of resistance into selected sorghum germplasm. This will be a powerful and inexpensive technology for breeding *Striga* resistant sorghums which research programs in developing countries can readily employ or adopt. Scientists in collaborating NARS will benefit from our development and refinement efforts as they adapt the assay to local resource availability.

International Testing, Demonstration, and Distribution of Striga Resistant Sorghum Selections (1996-2000)

Over the last 10 years, research on *Striga* resistance in sorghum has been conducted at Purdue University. The findings we have made in basic biology and genetics of *Striga* resistance are continually being incorporated into our sorghum breeding program to generate germplasm having good agronomic qualities, combined with varied mechanisms of resistance to *Striga*. Our breeding program is comprehensive and utilizes field and laboratory techniques in identifying superior genotypes with *Striga* resistance. Laboratory protocols developed in our laboratory are used to routinely monitor the transfer of genes for resistance to *Striga* from donor sources into improved lines. Elite selections identified through laboratory evaluations are tested for field resistance in Africa through our collaborative network of scientists in several NARS.

In December 1994, we released eight *Striga* resistant sorghum cultivars and distributed them to several African countries through a collaborative partnership with World

Vision International, an NGO with an extensive network of programs in the continent. Following this distribution, field tests were conducted in twelve countries, namely Senegal, Chad, Ghana, Mali, Eritrea, Mozambique, Sudan, Somalia, Rwanda, Niger, and Ethiopia. According to a subsequent report by World Vision, results were obtained from nine countries. The report indicated that different varieties were found to be better adapted in each of these countries. In general, these varieties were broadly adapted, earlier in maturity, had good response to inputs, and possessed better food quality characteristics. In Ethiopia, distribution of seed of the eight *Striga* resistant cultivars was initially curtailed because of bureaucratic irregularities. Seed shipment intended for Eritrea was also held in the Ethiopian capital, en route to Asmara, for the same reason. However, we managed to later send experimental quantities of seed of these eight varieties to both Ethiopia and Eritrea. Results obtained from these tests in 1996 convinced Ethiopian authorities that these cultivars possessed, in addition to their resistance to *Striga*, the additional important characteristics of early maturity and drought tolerance making them uniquely suitable for cultivation in *Striga* endemic areas of the country. Two of the eight entries, P9401 and P9404, were found to be particularly adapted to the conditions of the drier lowlands of Ethiopia. In collaboration with Sasakawa Global 2000 and the Ethiopian Agricultural Research Organization, seed of the two varieties were multiplied for large scale demonstration and dissemination of these varieties to major sorghum growing zones of the country. Several hundred one-half hectare demonstration plots of these varieties were conducted in these areas during the 1997,1998, and 1999 crop seasons. Data collected from these demonstration tests were presented to the Ethiopian Crop Variety Release Committee to evaluate their merit and place in sorghum agriculture in the country. The Committee found these varieties uniquely suited to the conditions of the *Striga* endemic sorghum areas of Ethiopia and approved their official release for commercial cultivation beginning with the current crop season. However, we are uncertain about the national plan for an expanded seed multiplication and quality control, as well as for continued testing and distribution in combination with other associated *Striga* control strategies.

A major activity of PRF-213, in the last few years, has been the testing and monitoring of an international nursery for *Striga* resistance. In order to allow selection of new experimental varieties in a field environment having *Striga* pressure, we rely on collaborators throughout Africa to establish an INTSORMIL International *Striga* Resistance Sorghum Nursery. We conduct this test for two important reasons. First, evaluation of experimental entries developed in our breeding program at Purdue, under African field environments with *Striga* pressure, allows us to confirm the utility of elite germplasm that we select through our established protocol. Secondly, in addition to providing a means of field testing resistant varieties, the INTSORMIL International *Striga* Resistant Sorghum Nursery serves as a vehicle to distribute germplasm to areas where *Striga* is an endemic problem. It is an effective mechanism for sharing a wealth of elite germplasm that we have accumulated in our program with our collaborators. In 1997, we sent 25 entries to scientists in 12 African countries for field testing in *Striga*-sick plots. A second trial of another set of 25 entries were sent out in 1998 and 1999 to 13 African locations. Data obtained to date, indicate that many of the entries possess *Striga* resistance and possess additional characteristics that are valued in these environments. The results from these tests will be summarized and distributed to collaborators in due course.

Networking Activities

Workshop and Program Reviews

Year 18

Served as a member of the organizing committee of both INTSORMIL Principal Investigators Conference and the International Sorghum and Millet Genetics Symposium held at Lubbock, TX, September 1996. Presented joint papers with several colleagues at these meetings.

Presented a paper at the Sixth International Parasitic Weed Symposium, Cordoba, Spain, April 1996.

Served as Visiting Faculty, University of Wisconsin, Summer Institute for African Agricultural Research, June 1997.

Participated in African Dissertation Internship Award selection, Rockefeller Foundation, November 1996, and April 1997.

Attended the American Society of Agronomy national meetings, Indianapolis, IN, November 1996.

Year 19

Traveled to Eastern Africa to visit NARS in the region with INTSORMIL Director, Dr. John Yohe, and held discussions leading to the establishment of an INTSORMIL Regional Collaborative Research Program in the Horn of Africa, June 1997.

Served as chair of the organizing committee of an INTSORMIL/Horn of Africa Traveling workshop. The week long traveling workshop was attended by three scientists from Kenya, two from Eritrea, one from Uganda, scientists from the Ethiopian Institute of Agricultural Research, four INTSORMIL principal investigators, and the associate program director.

Attended and participated in the 1997 World Food Prize Symposium, 16-17 October 1997, Des Moines, Iowa.

Served as Visiting Faculty, University of Wisconsin, Summer Institute for African Agricultural Research, June 1998.

Participated in African Dissertation Internship Awards Selection, Rockefeller Foundation, November 1997 and April 1998.

Attended the American Society of Agronomy National Meetings, Anaheim, California, October 1997.

Participated in Pioneer HI-Bred In-house Review of Public/Private Plant Breeding Programs, April 1997, Des Moines, Iowa.

Year 20

Participated in African Dissertation Internship Awards selection, Rockefeller Foundation, 18 May 1998, New York.

Evaluated and harvested sorghum winter nursery, NC+ Research Farm, 17-22 March 1998, Ponce, Puerto Rico.

Attended the INTSORMIL International Impact Assessment Workshop, Corpus Christi, Texas, 20-24 June 1998.

Attended the Sorghum Ergot Conference, Corpus Christi, Texas, 24-26 June 1998.

Participated in Summer Institute for African Agricultural Research. June 14-19, 1998, University of Wisconsin, Madison.

Participated in Regional Collaborative Research and provided technical guidance to sorghum research efforts in Ethiopia, 19-26 September 1998.

Attended and participated in the International Hybrid Sorghum Seed Workshop, Niamey, Niger, 27 Sept.-2 October 1998.

Participated in review and evaluation of INTSORMIL Horn of Africa program, 2-10 October 1998.

Attended the American Society of Agronomy National Meetings, 18-22 October 1998, Baltimore, Maryland.

Participated in African Dissertation Internship Awards selection, Rockefeller Foundation, New York, 11-12 December 1998.

Participated in a meeting of Board Members for the Essential Electronic Agricultural Library, Rockefeller Foundation, New York, 16-17 December 1998.

Year 21

Participated in the development of a Food Security project for the Amhara Region in Ethiopia at the invitation of USAID/Ethiopia, February 22nd to March 5th, 1999, Addis Ababa, Ethiopia.

Negotiated a contract for an INTSORMIL project to undertake a study on the development and diffusion of drought tolerant crops in Eastern Africa with the Inter-Governmental Agency for Development, 7-13 March 1999, Djibouti.

Participated in African Dissertation Internship Awards selection, Rockefeller Foundation, 4-5th May 1999, New York.

Participated in Summer Institute for African Agricultural Research, June 13-17, 1999, University of Wisconsin, Madison.

Participated in Workshop on Molecular Approaches for the Genetic Improvement of Cereals for Stable Production in Water Limited Environments, 21-25 June 1999, CIMMYT, Mexico.

Participated in Workshop on Breeding for *Striga* Resistance in Cereals and Molecular Application in Crop Improvement, 14-21 August 1999, IITA, Nigeria.

Participated in the Review and Evaluation of INTSORMIL programs by the External Evaluation Panel, West Lafayette, IN 22-24 September 1999.

Attended the American Society of Agronomy national meetings, 30 October - 5th November 1999.

Attended the American Seed Trade Association Meeting, Chicago, IL, 8-9 December 1999.

Research Investigator Exchange

Interactions with public, private, and international sorghum research scientists continues to be an important function of PRF-207. The following individuals visited our program or worked in our laboratory during the last four years:

Dr. Paula Bramel-Cox, Director, Genetic Resources, ICRISAT, February 1996 , June 1997, and June 1999.

Dr. Jill Lenne, Principal Plant Pathologist, ICRISAT, July 1996

Dr. Aberra Debello, Sorghum Breeder and Program Leader, Ethiopian Sorghum Improvement Project, September 1996, May 1998, and June 2000.

Dr. Abdel Gabar Babiker, Sudan National Coordinator for Sorghum and Millets, September 1996.

Dr. Abdel Moneim Bashir El Ahmadi, Director, National Seed Industry, Sudan, September 1996.

A large number of sorghum scientists from the USA and around the world visited our sorghum research program, field and laboratory facilities, on the way to and from the International Sorghum and Millet Genetic Conference in September 1997.

We were also visited by the Director General of ICRISAT, Dr. Shawki Barghouti, where the current state of ICRISAT and future collaborative possibilities with Purdue were discussed.

Dr. Yilma Kebede, Sorghum Breeder, Pioneer HiBred, November 1996, September 1997, and November 1999.

Dr. Brian Hare, Advanta, Pacific Seeds, Australia, October 1999.

Germplasm Exchange

We continue to provide an array of sorghum germplasm from our breeding program to national research programs in developing countries. Our germplasm is provided in either a formally organized nursery that is uniformly distributed to all collaborators that show interest, or upon request by a national program of specific germplasm entries or groups from our germplasm pool. Germplasm was distributed to cooperators in 25 countries in 1996, 15 countries in 1997, 10 countries in 1998, and 7 countries in 1999.

Publications

Refereed Papers

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Menkir, A., P.B. Goldsbrough, and G. Ejeta. 1997. RAPD based assessment of genetic diversity in cultivated races of sorghum. Crop Sci. 37:564-569.
Tuinstra, M., G. Ejeta, and P. Goldsbrough. 1997. Heterogenous Inbred Family (HIF) Analysis: A Method for Developing Near-Isogenic Lines that Differ at Quantitative Trait Loci. Theor. Appl. Genet. 95: 1005-1011.
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Mohammed, A., G. Ejeta, and T. Housley. 2000. *Striga* seed conditioning and 1-aminoacylopropane-1- carboxylate oxidase activity. Weed Research (In press)
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Disease Control Strategies for Sustainable Agricultural Systems

Project TAM-224
R.A. Frederiksen

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Summary

This is the final report of this project, as R. Frederiksen will retire August 31, 2000. However, the date on this report includes the period for the Global Conference on Sorghum and Millet Diseases to be held at Guanajuato Mexico, September 23-30.

Dr. Issoufou Kollo finished his dissertation research and returned to Niger. Specifically, his work demonstrated that Acremonium wilt is an important disease in Niger, some cultivars and hybrids are extremely susceptible to this disease and he demonstrated that nematode feeding enhances wilt even on resistant land race cultivars. Host resistance appears to be the best means of control as the agronomic controls evaluated had only minor affects on the disease. The paper on characterization of ergot isolates globally was published, based on our collaborative work with Dr. Sylvie Pazoutova and Ranajit Bandyopadhyay. The data based RAPD banding patterns and on sequences of the ITS region of isolates of the *Claviceps africana* and *Claviceps sorghi* was used to determine that the pathogen found in the America's came from Africa and not Asia. In addition, we learned that *C. africana* is present in India and we speculate that it is replacing *C. sorghi*. We further suggest that the disease in Australia is probably caused by Asian strains. This is important because it accounts, in part, for some differences noted in toxicology between Australian and American isolates. The aggressiveness of the *C. africana*, is probably caused in part because of its secondary sporulation which accounts for its rapid dissemination in Asia and the Americas. Mapping of disease resistance genes has been a major objective of this project over the past four years. Head smut resistance has remained elusive, particularly the "non meristematic" or generalized resistance has been stable against all races of the pathogen for decades. Other mapping included finding probes for resistance to anthracnose, leaf blight and sorghum downy mildew. This work is continuing under the direction of collaborators.

Research Objectives

India/ICRISAT

- Continue collaboration with ICRISAT on growing, distributing, and evaluating the International Sorghum Anthracnose Virulence Nursery.
- Continue collaboration on sorghum ergot with Dr. Bandyopadhyay.
- Transfer collaborative initiative on application of biotechnology for control of grain mold to Dr. Clint Magill's program.
- Develop technical program for the Global Conference on Sorghum and Millet Diseases in Mexico.

Mali

- Continue efforts to encourage collaboration with the National Sorghum and Millet Disease Program.
- Evaluate the Texas A&M/INTSORMIL nurseries for reaction to the prevalent pathogens in Mali.
- Study the interaction of mold and insects on grain deterioration.

Niger

- Continue monitoring resistance to long smut in the Niger Sorghum Improvement Program, along with evaluation for resistance to head smut, acremonium wilt, and anthracnose.
- Summarize data on the survival of spores of the long smut pathogen.
- Summarize data on a trial on the effect of different fertilization treatments on the incidence of *Striga hermonthica* in pearl millet.
- Determine the role of nematodes in diseases of sorghum and pearl millet.

Domestic

- Identify sources of resistance to disease.
- Assist in the incorporation of multiple sources of resistance to disease.
- Determine inheritance of resistance.
- Genetically map disease resistance traits by both conventional and bio-technical methods.
- Improve disease-screening methods.
- Study the biology of sorghum pathogens and disease epidemiology as needed.
- Organize, maintain, and distribute the international sorghum disease and pathogen identification nurseries in collaboration with ICRISAT, and with TAM-222 and TAM-228.
- Detect, identify and catalogue *Colletotrichum graminicola* and *Sporisorium reilianum* isolates worldwide.
- Develop program for Global Conference on Sorghum and Millet Diseases.

Research Approach and Project Output

We use virtually identical approaches to domestic and international work on the control of sorghum and millet diseases. This involved the identification of sorghums with excellent resistance(s) to specific pathogens and to collaborate on the incorporation of the resistance(s) into useful cultivars. Most of this work is done in cooperation with plant breeders, biotechnologists, geneticists, and entomologists in the Texas programs, but also occasionally with breeders in other states, nations (NARS), or with International Crop Research Centers, specifically ICRISAT and CIMMYT. This includes the application of such technologies to manage ergot.

Collaborative Research in Niger

Collaborative work with Niger was done with Issoufou Kollo both at College Station and in Niger. During this period, he completed his dissertation and summarized data on control of pearl millet downy mildew with Apron plus® which will be reported as part of the conference proceedings from the 3rd Global Conference on Sorghum and Millet Diseases in Guanajuato, Mexico. Dr. Kollo returned to Niger on June 1st, 2000. The general accomplishments of this research included the role of nematodes in the Acremonium wilt of sorghum. In Niger, this disease can be serious on susceptible sorghum cultivars, particularly the new hybrid NAD-1. Under growing situations in which there are high numbers of plant parasitic nematodes, even wilt resistant land race cultivars will become diseased. Consequently, this disease must be managed with host resistance and included as a component of the national crop improvement scheme. I wish to take this time to express my appreciation to the Rockefeller Foundation for providing "in-country" support in order for Dr. Kollo to complete his work in Niger. The fieldwork was expensive, tedious and could only be done in Niger. The Foundation also made it possible for him to carry an excellent computer and appropriate software to Niger, which he also used in analyzing his research data.

Collaborative Research in Mali

Work in Mali has been in collaboration with Dr. Mamourou Diourte who is developing a national sorghum research program following his finishing his doctorate at Kansas State University. Dr. Diourte and I discussed his program at regional meetings in 1998 and during my visit to Mali in October 1999 we reviewed the research in progress on cultural control of anthracnose at Sikasso. This work was part of a coordinate project across several West African sites. The designers of these experiments thought it reasonable that crop rotation would be effective in reducing the onset of the disease. I concur with the hypothesis. Our work (Casela and Frederiksen, 1993) demonstrated that the pathogen is unlikely to survive longer than two years in the field. Dr. Diourte will be evaluating these same survival structures, known as microsclerotia, of *Colletotrichum graminicola* in Mali using similar techniques. This is particularly important in light of the regional experiments described earlier. Information and suggestions for a study on the effect of plant height on anthracnose was discussed. In the absence of having isogenic lines with different height genes, a technique using a random breeding approach was suggested to Dr. Diourte. Dwarf sorghum appears to need a higher level of resistance than those sorghum cultivars that are very tall. Height vulnerability has been managed in other crops with dwarf genes but in sorghum it would be another reason to avoid the shorter cultivars grown in the western world. Experimental evidence on this factor will be invaluable to the sorghum breeding programs throughout tropical regions with an annual threat of anthracnose.

Collaborative Research in Honduras

The program in Honduras has been in collaboration with Ing. Jorge Moran and Dr. Bill Rooney on vulnerability among sorghum genotypes and the relationship between stigma receptivity and ergot. Mr. Moran began this work in Honduras and continued his evaluations at several locations in Texas. This work constituted the data for Ing. Moran's master's thesis. In this research he determined that all of the germplasm used in his study was susceptible, however, there are significant differences among the lines in their reaction to ergot. A-lines are the most vulnerable followed by hybrids, R-lines and B-lines. The reason for these differences in reaction is not always clear. In studies examining genetic effects on these levels of resistance, it was learned that there is a strong genotype by environment interaction. While flowering and sigma receptivity may play an important role in the vulnerability of sorghum to ergot, it is not the only factor based on the differential seed set and ergot severity among parental lines in his trials. Clearly, there is much more work needed on mechanisms affecting severity levels of ergot in sorghum.

Domestic Research

Fine mapping of non-meristematic head smut (Sporisorium reilianum) resistant gene in Sorghum

Ramasamy Perumal was required to return to his position in India and he completed most of the research on the mapping of resistance to sorghum head smut among the parents used in his experiments. Most of the details of this research was reported last year. Currently, Dr. Perumal will prepare his findings for publication. Since this was continuing the research conducted by Dr. Jairo Osorio, Dr. Perumal and Dr. Osorio will have an opportunity to collaborate on summarizing their data during the Conference in Mexico.

Mapping of anthracnose resistance will continue under the direction of Drs. Bill Rooney, Louis Prom and Clint Magill.

Disease evaluation studies are conducted primarily in large research nurseries in south Texas. Several uniform nurseries are grown in locations where sorghum/millet diseases are important. These include the International Sorghum Anthracnose Virulence Nursery (ISAVN), in collaboration with ICRISAT, the Uniform Head Smut Nursery (UHSN), the Sorghum Downy Mildew Virulence Nursery (SDMVN), the International Sorghum Virus Nursery (ISVN), and also a uniform nursery for grain mold (GWT). These nurseries provide quick assessment of disease severity and pathotype differences among locations.

Networking Activities

Conferences Attended or Organized

R. Frederiksen traveled to Hyderabad, India, Cameroon and Mali in September - October 1999. In India, he was able to meet and discuss several aspects of continuing collaborative research on sorghum/millet and reviewed sorghum work at both the All India Sorghum Research Program and the sorghum and millet research at ICRISAT. It was during these meetings that the idea of a joint "Futuring Conference" between INTSORMIL and ICRISAT take place immediately following the Global Conference in Guanajuato. While the number of individuals working on sorghum and millet has been reduced, the enthusiasm and professionalism on sorghum remains high.

In Cameroon, Dr. Zachee Ngoko met me and arranged for my visit with the Director General Jacob A. Ayuk-Takem in Yaounde. Because of the local flights being canceled, I was unable to visit the sorghum/millet growing regions in the north, Dr. Ngoko and I traveled in the Eastern Highlands and discussed his potential for collaboration with INTSORMIL. His interests are similar with those of Dr. Leslie and they have entered into research dialogues.

In Mali, (October 7-10) Dr. Frederiksen met with Dr. Alpha Maiga, Dr. Mamourou Diourte, Dr. Aboubacar Toure of IER and Dr. Dale Hess, Plant pathologist with ICRISAT.

Finally, in May 2000, I traveled to Denmark and the Czech Republic. In Denmark, I visited with Professor Eigel de Neergaard at the Royal Veterinary and Agricultural University at Frederiksberg, Denmark (RVL). Dr. Neergaard has developed techniques for observing early infection responses using state of the art histopathological methods. Additionally, I visited with Dr. S. B. Mathur, Director of the Danish Institute of Seed Pathology. This Institute is located (effective 1999) at the University but remains a separate entity, except in the training of students from developing countries. Additionally, I flew to Prague to visit with Dr. Sylvie Pazoutova. Dr. Pazoutova and I have collaborated over the past three years on variability in the sorghum ergot fungus.

During the year, R. Frederiksen served as a member of the Editorial Advisory Board of the African Crop Science Journal.

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Insect Pest Management Strategies For Sustainable Sorghum Production

Project TAM-225
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Summary

During the four-year period covered by this report, the PI annually traveled to Mali to maintain collaborative sorghum entomology research with Drs. Niamoye Diarisso and Yacouba Doumbia, both IER entomologists. In 1999, the PI participated in the review by the External Evaluation Panel of the IER/INTSORMIL collaborative research program. The collaborative sorghum entomology research in Mali has contributed methods to evaluate sorghum genotypes for resistance to panicle-feeding bugs and provided valuable information on bug biology, seasonal abundance, and damage severity. Dr. Diarisso, a Texas A&M University graduate whose Ph.D. program was directed by the PI, initiated research to assess insect pest severity on newly developed and deployed sorghum varieties in farmers' fields and as a venue for technology transfer. The PI also traveled to South Africa and Botswana during this reporting period. An INTSORMIL collaborative research program was established with the goal to manage sugarcane aphid, *Melanaphis sacchari*, and develop integrated pest management (IPM) approaches for sorghum insect pests in southern Africa. Collaborators are Dr. Christopher Manthe, Department of Agriculture Research (DAR), and Dr. Johnnie van den Berg, Agriculture Research Council (ARC) entomologist, Potchefstroom, South Africa. Resistance of sorghum lines and hybrids to greenbug, *Schizaphis graminum*, and sorghum midge, *Stenodiplosis sorghicola*, was evaluated in collaboration with Dr. Gary Peterson (TAM-223). Insect-resistant sorghum genotypes were advanced in crosses with elite germplasm. Several new sorghum midge- resistant parental A- and R-lines alone and in hybrid combination were evaluated for release to commercial seed companies. Numerous selections to advance, cross, and evaluate further were made among segregating lines. Lines and hybrids for resistance to greenbug biotypes E and I were evaluated for TAM-223 and commercial seed companies. These evaluations were to determine the appropriateness of the material for release or involved segregating material being phenotyped for use in mapping genes resistant to greenbug. Experiments identified insecticides effective against sorghum midge and fall armyworm, *Spodoptera frugiperda*. QTLs for greenbug resistance in sorghum were identified, and progress was made on cloning and differen-

tial expression of genes in response to greenbug infestation. Graduate education programs of six students were directed during this reporting period. Three Ph.D. and one M.S. students graduated. QTLs for resistance to greenbug were identified. DNA sequences from the mitochondrial genome were used to assess genetic diversity among populations of greenbug. A Ph.D. student is determining fitness and virulence of 11 greenbug biotypes to sorghum genotype differentials. Education programs of two African graduate students, one Malian and one Nigerien who conducted research in Niger, were co-directed with Dr. Frank Gilstrap. One of the African students graduated and one will complete degree requirements in August 2000. The P.I. cooperated with extension education personnel on sorghum insect IPM. Also, in collaboration with extension personnel, the extent of IPM adoption by farmers and the role public IPM specialists and private agricultural consultants played in this adoption were surveyed. Based on responses to two questionnaires, it was very apparent that farmers benefit from using IPM, and private agricultural consultants well understand IPM is a multi-tactic approach to managing pests and recommend IPM tactics to their clients. Risk, economics, and the environment were important considerations in using IPM. This project has contributed much of the research on which IPM in sorghum is based. Most (87%) of sorghum growers use IPM, and IPM use has resulted in a 65% reduction in insecticide use. Greenbug-resistant sorghums were assessed to benefit society by $130-300 million per year.

Objectives, Production and Utilization Constraints

Objectives

Mali

Long-term objectives were:

- To collaborate with IER/Malian scientists to develop IPM strategies for insect pests, especially panicle-feeding bugs and sorghum midge, that attack traditional and improved insect-resistant and susceptible sorghums.
- Increase entomological research efforts in farmers' sorghum fields.
- Direct graduate education programs, provide technological assistance, and promote technology transfer and networking.

Objectives for this reporting period were:

- To substantiate, for use by sorghum breeders, the most reliable and efficient method to protect sorghum panicles from bugs so resistance could be assessed by comparing protected with naturally infested panicles
- determine the role of insects and pathogens in kernel deterioration by applying different combinations of insecticides and fungicides.
- Assess the importance of panicle-feeding bugs and sorghum midge on traditional and improved sorghum varieties in farmers' fields.

Southern Africa

The long-term objective was:

- To collaborate with southern African scientists to develop IPM strategies for sorghum insect pests.

In collaboration with breeders, objectives during this reporting period were:

- To identify, evaluate, and incorporate resistance to sugarcane aphid into sorghum varieties and hybrids adapted to southern Africa agricultural systems.
- Develop IPM strategies for sorghum insect pests in southern Africa.
- Identify opportunities for graduate education of southern Africans.
- elucidate needs for technical assistance, technology transfer, and networking.

USA

Long-term objectives were:

- To provide the research base for IPM of sorghum insect pests. Emphasis was on collaborating with breeders to develop, evaluate, and deploy sorghums resistant to sorghum midge; greenbug; yellow sugarcane aphid, *Sipha flava*; and sugarcane aphid. In collaboration with molecular biologists, biotechnology techniques were applied to increase resistance durability by understanding the genetic relationship of insects and resistant plants. Ancillary research included assessing abundance/damage relationships of insect pests on resistant and susceptible sorghum genotypes and determining mechanisms and causes of resistance. In collaboration with extension personnel, IPM tactics and how they function were delivered to sorghum growers.

Objectives during this reporting period were:

- To evaluate sorghums resistant to greenbug, sorghum midge, and yellow sugarcane aphid in the field and greenhouse.
- Supervise graduate student research.

Graduate students supervised were a Ph.D. student from Mali assessing spikelet flowering time and morphology as causes of sorghum resistance to sorghum midge; U.S. Ph.D. student assessing areawide management of Mexican corn rootworm through adult suppression and crop rotation; U.S. Ph.D. student using RFLP technology to assess genetics of greenbug resistance in sorghum; U.S. Ph.D. student using RFLP/RAPD technology to assess genetic variability of greenbug and its biotypes; U.S. Ph.D. student assessing fitness and virulence of greenbug biotypes to sorghum genotype differentials; M.S. student from Niger researching field biology and laboratory life-fertility of millet head miner in Niger (committee co-chair); and a Ph.D. student from Mali studying natural mortality of millet head miner in Niger (committee co-chair). The PI also participated in Entomological Society of America, International Plant Resistance to Insects Workshop, Consortium for International Crop Protection, CRSP, and other professional and scientific activities and meetings.

Production Constraints

Mali

Deploying improved, non-photoperiod sensitive, compact-panicle sorghum varieties that yield more than traditionally grown, local varieties is constrained by insect pests, especially panicle-feeding bugs. Damage by bugs is exacerbated by pathogen infection that significantly increases in damaged kernels. Damage by bugs and infection by pathogens dramatically reduce grain yield and quality and render it unusable for human consumption. Resolution of the interrelationship of damage by bugs, infection by pathogens, and reduction in grain yield and quality requires an interdisciplinary, team approach. Other insect pests might occur when agronomic practices are changed and new sorghum varieties used. This project is central to the interdisciplinary team of INTSORMIL and IER scientists improving sorghum yield and quality in West Africa.

Southern Africa

In Southern Africa (mainly Botswana, Zimbabwe, and South Africa), aphids, especially sugarcane aphid, commonly infest and reduce sorghum yield. Infestation by aphids and moisture stress often occur at the same time in the region and in combination are serious production constraints. This project contributes to a team effort to improve sorghum production and develop IPM strategies for sorghum insect pests in Southern Africa.

USA

In the USA, monoculture production of sorghum exacerbates the severity of insect pests, leading to reduced yield and increased production costs. Although insecticides are available readily and can be used to lessen the yield-reducing impact of insect pests, their sole use results in significantly increased production costs and can cause outbreaks of secondary insect pests, insect pest resurgence, ecological disruption, and environmental contamination. Consequently, the researchable constraints addressed in the USA by this project were yield-reducing effects of insect pests and economic and ecological costs associated with chemical control. IPM is a universally accepted approach to dealing with insect pests. This project used the IPM approach that requires developing cultural and biological tactics to prevent yield-reducing effects of insects and determining the prerequisites for use of insecticide, when remedial action is needed, based on economic and ecological parameters. In collaboration with plant breeders and molecular biologists, the project emphasized development and use of insect-resistant sorghums. Insect pests given most attention were greenbug, sorghum midge, yellow sugarcane aphid, and panicle-infesting bugs and caterpillars.

Research Approach and Project Output

Four approaches were used to achieve project output – collaboration/partnership with developing country scientists, technology development in collaboration with plant breeders and molecular biologists, graduate student education, and technology transfer in cooperation with extension education personnel. Project outputs were divided into these approaches.

Collaboration/Partnership with Developing Country Scientists

Collaborative Sorghum Panicle-feeding Bug Research in Mali

The collaborative research program between IER/Mali and INTSORMIL/U.S. scientists is one of the true successes of the Collaborative Research Support Program (CRSP) model. The program is an outstanding example of collaborative, multi-disciplinary, team research. The IER/INTSORMIL association has been on-going for many years and has matured into an effective research, technology development, and technology transfer program. Much success is a result of long-term efforts in graduate student education, financial support, and research partnering.

During the four-year period covered by this report, the collaborative sorghum entomology research program in Mali contributed significantly to sustainable sorghum production. In collaboration with Drs. Yacouba Doumbia and Niamoye Diarisso, a simple method was developed to assess resistance of sorghum to panicle-feeding bugs. The method involved using plastic pollinating bags placed over a few sorghum panicles at the flowering stage to prevent infestation by bugs. At maturity these panicles were compared to nonprotected panicles naturally infested with bugs. A comparison easily could be made between the damaged and non-damaged panicles to assess relative resistance within and among sorghum genotypes. This research and in collaboration with Dr. Alain Ratnadass, ICRISAT entomologist at Samanko, led to development of a universally used damage rating scale. The resistance evaluation method and damage rating scale were used in collaboration with Dr. Aboubacar Toure to evaluate new and improved sorghum varieties and phenotype segregating sorghum populations being used for RFLP analysis for resistance to bugs. Research on panicle-feeding bugs in Mali was conducted at Sotuba, Samanko, and Cinzana. Much useful information was collected on bug biology, seasonal distribution, and damage severity.

The TAM-225 PI participated in a collaborative technology transfer program in Mali with personnel of World Vision International. Dr. Diarisso, the PI, and others with INTSORMIL and the Bean/Cowpea CRSP evaluated field demonstrations of sorghum and cowpea rotations and intercroppings. Entomologists assessed insect pest severity in these demonstrations. Collaboration with World Vision is an excellent approach for technology transfer.

Having two IER entomologists to conduct research on insect pests of sorghum is a luxury that needs to be exploited. Critical research responsibilities for each person must be identified and justified. Budgeting individual researchers from the country budget, based on work plans, will be a workable approach to resolving problems that might be caused by two scientists working in similar areas.

Collaborative Sorghum IPM Research in Southern Africa.

The TAM-223 and TAM-225 PIs traveled to South Africa and Botswana during this reporting period. The trip established (reestablished) an INTSORMIL research program in Southern Africa directed at managing sugarcane aphid and developing IPM approaches for sorghum insect pests. The entomology/breeding program in conjunction with Dr. Christopher Manthe previously conducted research on sugarcane aphid in Botswana and Zimbabwe when Dr. Manthe was a Ph.D. student at Texas A&M University. The rejuvenated collaborative research program involves Dr. Manthe, Department of Agriculture Research (DAR) entomologist, Gaborone, Botswana, and Dr. Johnnie van den Berg, Agriculture Research Council (ARC) entomologist, Potchefstroom, South Africa. Other Southern African scientists will be included in the project as they are identified.

The Agriculture Research Council Grain Crops Institute, Potchefstroom, has responsibility in South Africa for research on summer grains including sorghum. It is a large institute, about 70 personnel, with excellent facilities and research programs. Dr. van den Berg currently is conducting many research projects on several insect pests of sorghum. Most of Dr. van den Berg's research has been directed at large commercial sorghum production. Research on sugarcane aphid will represent an expansion of his research program, including activity in Botswana with Dr. Manthe, and in other countries as collaborators are identified. Dr. van den Berg proposed a survey of insect pests of sorghum and millet on small farms. He believes insect diversity in small-farm sorghum and millet was 10 times greater than in commercial (hybrid) fields. An insect identification publication for Southern Africa would be beneficial. Dr. van den Berg has developed ties with extension specialists working with producers on small farms.

Dr. Manthe conducts some entomological research in addition to numerous administrative duties. Dr. Manthe has had significant responsibility in the DAR sorghum-breeding program because the DAR breeder is in a Ph.D. program at the University of Nebraska. Dr. Manthe anticipated returning to more entomological research, however, this now is questionable because he has taken a position at the University of Botswana.

Research on developing resistance to sugarcane aphid increased for 1999-2000. INTSORMIL, through the Texas A&M University breeding/entomology program, provided to regional scientists a replicated 50-entry test to evaluate for resistance to sugarcane aphid and local adaptation at sites determined by regional collaborators. INTSORMIL also will develop new sorghum germplasm lines with novel gene combinations and provide to local collaborators germplasm to evaluate for resistance to sugarcane aphid. INTSORMIL will lead in developing a regional sorghum disease/insect/adaptation test for planting at numerous locations. Material in the test will represent a range of diversity to stress resistance, plant type, and yield. The material will be available to regional scientists for use in research programs.

Technology Development

Results of research beneficial to U.S. agriculture and in support of international research collaboration, especially evaluating sorghums for resistance to sorghum midge and aphids (greenbug and sugarcane aphid), are summarized below. Research efforts of TAM-225 are in collaboration with TAM-223, the project of Dr. Gary Peterson, Sorghum Breeder at the Texas A&M University Agricultural Research and Extension Center at Lubbock.

Evaluation of Insect-resistant Sorghums

Standard, annual evaluations of sorghum midge-resistant lines and hybrids were conducted at Corpus Christi and College Station. Resistance to sorghum midge of several hundred hybrids (including resistant × resistant experimental hybrids, resistant × resistant checks, a resistant × susceptible check, and susceptible checks), several thousand elite lines (including resistant and susceptible checks), more than 700 converted sorghum lines, several hundred segregating lines, and several thousand breeding lines were evaluated. Susceptible sorghum planted three weeks early adjacent to the experimental area provided a source of sorghum midge to infest the experimental sorghums. At Corpus Christi, seeds of the experimental sorghums were planted in mid-April in 6-m-long plots with 97.6 cm between rows. Sorghum was planted at College

Station in early May, with 76.2 cm between rows. Grain yield (kg ha^{-1}) and damage caused by sorghum midge were compared between experimental hybrids and checks. Sorghum at physiological maturity was rated by plot for sorghum midge damage based on a scale of 1 = 1-10, to 9 = 81 to 100% of kernels that failed to develop. Sorghum panicles from 0.0025 ha per plot were hand harvested. Threshed grain weight (g) was converted to kg ha^{-1} to obtain grain yield. ANOVA and $LSD_{0.05}$ were used for data analysis and mean separation, respectively. Data are provided in the report for project TAM-223.

In all evaluations during the four-year reporting period, experimental hybrids, for the most part, and resistant x resistant checks, were significantly less damaged by sorghum midge and produced significantly more grain within and ver locations than did susceptible × susceptible checks. Sorghum at Corpus Christi was damaged more by sorghum midge than at College Station. Hybrids that performed well under high sorghum midge abundance at Corpus Christi also performed well under moderate abundance at College Station. Evaluation of sorghum parental lines for resistance to sorghum midge, yield, and other agronomic qualities provided strong support for release of several lines for commercial use. Selections were made among the better genotypes and advanced for future evaluation, and some were crossed with other genotypes. Several lines from the sorghum conversion program showed significant levels of resistance to sorghum midge but need further evaluation. Several lines will be used to make crosses that will be evaluated more at Corpus Christi and College Station. Numerous selections were made from segregating breeding lines. A diversity of phenotypes was selected, but some need further evaluation. Overall, even under very unfavorable weather conditions, good progress was made during this reporting period in identifying sorghum lines useful for production of commercial sorghum midge-resistant hybrids.

More than 1000 sorghum lines developed through project TAM-223 and being selected as parental lines for release and use in hybrids were evaluated for resistance to greenbug biotypes E and I in greenhouse experiments. Several of these lines were moderately resistant to biotype I. Six hundred forty sorghum lines from Cargill Seed Company were evaluated for resistance to biotype E. Results indicated that both INTSORMIL scientists and the commercial seed industry are making progress in developing hybrids resistant to greenbug biotypes. Details of results of these evaluations are not presented here because of space limitations. However, sufficient progress is being made to conclude that sorghum lines resistant to these greenbug biotypes will be released soon. Agronomic data required for release and registration are being collected. Greenbug biotype E- and I-resistant lines are agronomically diverse. For example, some are tan plants with red kernels and tan glumes. These lines will be valuable to the sorghum seed industry both for these agronomic characters and for resistance to greenbug.

Evaluation of Insecticides for Sorghum Insects

During this reporting period, insecticides were evaluated for control of fall armyworm and sorghum midge at College Station. Results have been published.

QTL Cloning and Differential Expression of Greenbug Resistance Genes

For physical mapping of QTLs using a *Sorghum propinquum* BAC library, two approaches were used to better understand and clone greenbug resistance genes in sorghum. Greenbug-resistant QTLs previously were mapped to different linkage groups in sorghum (Katsar 1998). Physical mapping of these QTL loci was initiated using the BAC clones. A total of 198 markers linked to various greenbug-resistant QTLs in sorghum (for biotypes C, E, I, and K) was probed on the *S. propinquum* (a parent used in the mapping population) BAC library. Gel-purified inserts of the markers were isolated and five probes were pooled for each filter set and hybridized with high-density BAC library filters. A total of 1608 unique BAC clones was identified and rearrayed in 96-well and 384-well micro-titer plates. High-density filters were made with these rearrayed BAC clones and probed individually with markers associated with the QTL for resistance to biotypes C and E on linkage group E around CSU 0330. This region was chosen because these loci accounted for more than 45% of the phenotypic variation. Forty-six markers were used. Based on the hybridization, five contigs were assembled in this region. To examine gene expression after greenbug infestation, several experiments were conducted. The genotypes of sorghum resistant and susceptible to greenbug biotypes E and I were grown in a greenhouse. Fourteen pots of each resistant sorghum genotype, each containing about 20 plants, were used. Ten apterous greenbugs were placed on the second true leaf of each three-leaf-stage plant when plants were 6 to 8 inches tall. Pots of infested plants were covered with a 62 x 75 x 75 cm cage. At 0, 1, 4, 7, and 10 days after infestation, plants were harvested and leaf tissue washed and frozen in liquid nitrogen for isolation of RNA. For each pot containing infested plants, a pot of noninfested plants served as a check. Sorghum genotypes were PI550607 (resistant to biotypes E and I) and RTx430 (susceptible), and Tx2783 (resistant to biotype E) and IS7173C (susceptible). Two cDNA libraries were constructed from greenbug-infested leaf tissue of PI550607 and Tx2783 in lambda ZAP vector and mass excised in pBluescript (SK+) ordered in 384 micro-titer plates (approximately 18,000 clones per library). Also, a cDNA library from biotype I greenbug was constructed and ordered in 384 micro-titer plates. A differential hybridization approach was undertaken to isolate genes induced or repressed by greenbug infestation.

Graduate Student Research

Summaries of graduate student research projects are presented below.

Cathy Sue Katsar. This student graduated in August 1998 and her research on molecular analysis of greenbug resistance in sorghum and other *Poaceaous* host plants was summarized in previous annual reports. However, based on her research, she formulated a new concept in IPM to be considered for deployment of insect-resistant sorghums. The concept relates to correspondence among greenbug resistance loci in grain crops and implications for gene rotation strategies. Management of biotic constraints to crop production, such as insect pests, is complicated by the ability of some insects to propagate virulent biotypes rapidly. In only 30 years, greenbug gave rise to eight new biotypes that overcame plant resistance or organophosphate insecticides. Sorghum, wheat, and barley, distantly-related grain crops often grown near each other or in rotation, contain resistance genes at some corresponding chromosomal locations, suggesting similar resistance mechanisms may be used in each. In sorghum, some genes resistant to greenbug occur at putatively-duplicated chromosomal locations, possibly suggesting further redundancy in the resistance mechanisms being deployed. Traditional crop rotation merely may be challenging the greenbug with a series of related resistance genes, thereby providing only a minimal barrier to biotype formation.

Andrea B. Jensen. This Ph.D. student's research is on biotype-associated genetic variation in greenbug. It involves use of RFLP to characterize genetic diversity of natural populations of greenbug. Sequences from the mitochondrial genome were used to determine the degree of divergence among greenbug biotypes and whether biotypes are derived from one or several maternal lineages. Fragments from the 16S rRNA and cytochrome oxidase II (COII) genes have been PCR amplified from the mitochondrial genome of greenbug biotypes and isolates B, C, E, F, G, H, I, K, Canada wild rye, New York, and South Carolina, and an outgroup. These fragments have been sequenced with forward and reverse primer sets. Forward and reverse sequences have been compared using Sequencher 3.1. Alignments have been performed using CLUSTALX. Preliminary analyses were performed with PAUP 3.11. A third mitochondrial gene fragment (COI) was PCR amplified and sequenced.

Microsatellite probes are being used to determine genetic variation in natural populations of greenbug. Microsatellites are nuclear genomic markers used to infer population structure and subdivision including estimates of levels of gene flow, sexual reproduction, and effective population size. Microsatellite primers have been developed and screened for polymorphism. Microsatellite primers were developed to evaluate field-collected greenbugs.

Hame Abdou Kadi Kadi. This Nigerien M.S. student conducted laboratory and field research on fecundity, longevity, and oviposition of millet mead miner in Niger. He graduated in December 1999 and returned to Niger as an INRAN employee. Results of this student's research were summarized in previous annual reports.

Soualika Boire. This Malian Ph.D. student conducted research on the impact of natural enemies on millet head miner abundance in Niger. He completed his research, courses, and preliminary exam. His dissertation is written and is being reviewed. He will defend his dissertation research in August 2000. Results of his research were summarized in previous annual reports.

Niamoye Yaro Diarisso. This Ph.D. student from Mali graduated in August 1997. Her dissertation research was to assess spikelet flowering time and morphology as causes of sorghum resistance to sorghum midge. Results of her research were summarized in previous annual reports.

Scott Lingren. This U.S. Ph.D. student graduated in August 1999. His dissertation research was on the role of sorghum in rotation with corn to manage Mexican corn rootworm. Results of his research were summarized in previous annual reports.

Roberto Gorena. The research objectives of this Ph.D. student are to determine fitness and virulence of 11 greenbug biotypes to sorghum genotype differentials. Preliminary data using choice procedures are provided in the table below.

Mean Damage to Sorghum Genotypes by Eleven Greenbug Biotypes, 1999

Sorghum	C	E	NY	B	F	S CAR	I	H	CWR	K	G
Winter Data											
TX7000	8 0 a	6 8 a	6 5 a	6 3 a	5 8 a	5 5 a	5 0 a	5 0 a	5 0 a	4 0 a	3 8 a
TX2737	4 3 ab	4 8 ab	1 5 c	2 0 bc	4 8 a	1 8 b	7 3 a	4 3 a	1 5 a	2 5 ab	2 0 b
TX2783	4 5 ab	1 5 b	3 8 b	5 3 ab	4 5 a	4 0 a	7 3 a	1 5 b	4 0 a	1 0 b	2 5 ab
P1550607	1 0 b	3 8 ab	1 0 c	1 0 c	4 0 a	1 3 b	4 0 a	2 5 b	1 3 a	2 5 ab	3 0 ab
Summer Data											
TX7000	7 0 a	7 0 a	7 0 a	8 5 a	7 8 a	7 0 a	6 3 a	6 5 a	5 8 a	7 8 a	5 5 a
TX2737	3 8 b	4 8 ab	5 0 ab	4 5 c	4 0 b	6 5 a	4 0 ab	5 3 a	3 0 a	4 3 b	3 5 ab
TX2783	1 5 b	1 3 c	4 0 b	6 5 b	6 5 ab	5 0 a	4 3 ab	1 0 c	4 3 a	2 5 b	4 8 ab
P1550607	1 0 b	2 0 bc	2 8 b	2 0 d	3 8 b	4 8 a	2 8 b	3 0 b	2 3 a	3 0 b	3 3 b
Winter and Summer Data Combined											
TX7000	7 5 a	6 9 a	6 7 a	7 4 a	6 8 a	6 3 a	5 6 a	5 8 a	5 4 a	5 9 a	4 6 a
TX2737	4 0 b	4 8 b	3 3 bc	3 3 b	4 4 ab	4 1 ab	5 6 a	4 8 a	2 3 bc	3 4 b	2 8 b
TX2783	3 0 bc	1 4 c	3 9 b	5 9 a	5 5 ab	4 5 ab	5 8 a	1 3 b	4 3 ab	1 8 b	3 6 ab
P1550607	1 0 c	2 9 bc	1 9 c	1 5 b	3 9 b	3 0 b	3 4 a	2 8 c	1 8 c	2 8 b	3 1 ab

Means followed by the same letter for each data set in a column are not significantly different.

Technology Transfer

Much emphasis during this reporting period was placed on technology transfer. For this reason, several surveys were conducted to assess the extent of IPM use by sorghum growers, their perceptions and private agricultural consultants perceptions of IPM. Summaries of the results of those surveys are provided here.

Quantifying Texas Sorghum Growers' Use of IPM for Insect Pests

Much valuable integrated pest management information was obtained from responses to a six-page "Questionnaire on Insect IPM of Grain Sorghum" mailed to 739 members of the Texas Grain Sorghum Association. Responses were received from 522 of the 739 (70.6%); 398 (76.2%) of the questionnaires returned were usable. Most respondents completed college (38.5%) or had some college education (30.2%). Usable responses were received from growers who farm in a total of 94 counties. Usable questionnaires were from 184, 80, and 134 growers in the northern, central, and southern regions of Texas, respectively. Questionnaire respondents grew an average of 643.7 acres of grain sorghum during each of the past five years. Most growers grew sorghum for profit (94.0%), or as a rotation crop (65.1%), and desired better price (96.2%) and yield (89.4%). The most important insect pests to 84.3 and 74.2% of growers were greenbug and caterpillars in the panicle. Statewide, 77.4% of growers did their own scouting for sorghum insect pests, and 55% said they used IPM. Growers used multiple IPM tactics to manage sorghum insect pests. Totals of 93.7 and 92.4% of growers used good seedbed preparation to promote rapid seed germination and crop rotation, respectively, whereas only 38.6, 53.5, and 60.3% applied insecticides in-furrow or banded at planting, foliarly, and to seed. From 75 to 80% of growers attended chemical company-, seed company-, and Extension Service-sponsored meetings to help manage sorghum insect pests. From 82 to 94% of growers found bulletins or other written information, Extension Service advice, and shortcourses/seminars/meetings helpful in managing sorghum insect pests.

Responses to a three-page IPM specialists' questionnaire mailed to 106 private agricultural consultants and 36 Texas Agricultural Extension Service specialists and county agents-pest management were used to quantify how many of the Texas sorghum growers could be considered IPM users. Of the 142 IPM specialists, 85 (59.9%) returned their questionnaires. Completed, usable questionnaires were received from 82 (57.7%). More than 70% of the specialists ranked caterpillars in the panicle, sorghum midge, and greenbug very important pests of sorghum. Greenbug was ranked very important by twice as many specialists in the northern as in the southern region. Sorghum midge was very important to more specialists in the southern than central or northern regions. At least 70% of specialists ranked economic thresholds, planting date, scouting, natural enemy conservation, applicator calibration, and fertilizer management as very important. At least 50% considered resistant varieties, crop rotation, harvest time, and promoting rapid seed germination and seedling growth as very important. Scouting and economic thresholds were the IPM tactics considered most important for management of most sorghum insect pests. IPM specialists listed scouting, economic thresholds, natural enemy conservation, and resistant varieties as important for management of greenbug. Planting date, scouting, and economic thresholds were important for sorghum midge. Scouting, economic thresholds, natural enemy conservation, and selective/biological insecticide use were most important for caterpillars in the panicle.

Farmer and Agricultural Consultants' Perceptions of Use and Contributions of IPM.

A "Questionnaire on Importance of IPM" was administered to Board members and Extension Agents-Pest Management at the Texas Pest Management Association Mid-year Board of Directors' Meeting held 2 October 1998 in El Paso. A "Questionnaire on Pest Management Practices by Crop Consultants" was handed out at the Texas Association of Agricultural Consultants' Annual Conference and Exhibition held 14-16 December 1998 in Lubbock, and returned by mail.

All farmers said they benefit from using IPM. Ninety-two percent of consultants think their clients benefit very much from IPM. To farmers and consultants, respectively, IPM means considering pesticides only when needed (100%), multiple pest management tactics (95 and 92%), natural enemies (90 and 92%), and practices to prevent/avoid pests (95 and 84%). Farmers would use more IPM if it resulted in less governmental regulation (90%), decreased production costs (90%), or more money (79%). Consultants (44%) said IPM use slightly increases their risks but slightly lessens clients' risks. Most farmers (68%) said IPM greatly lessens risks. Reduced farming risks (79%), less harm to the environment (79%), less trouble or complication than current practices (79%), and making money (74%) were very important to farmers when considering implementing a new IPM practice. Making money for clients (92%) and reducing client risk (83%) were very important when consultants recommended new practices.

To farmers and consultants, respectively, very important indicators of IPM program success were that farmers knew more IPM (95 and 96%), increased net profits (95 and 96%), used a variety of practices (90 and 96%), more used IPM (90 and 96%), increased yields (74 and 67%), and used less pesticide (79 and 46%). Farmers and consultants, respectively, thought it very important that the Extension Service demonstrate and evaluate new practices and technology (94 and 92%), provide information and trouble shoot (83 and 80%), be available to help decide on IPM practices year around (83 and 68%), write crop-pest status newsletters (74 and 72%), and scout (90 and 24%). Most farmers (82%) did not want Extension IPM programs moved after a number of years.

Most consultants (46%) thought Extension IPM programs should not be moved but that acreage scouted should be limited.

Most farmers (74%) think IPM can improve environmental quality, and most consultants (72%) think IPM can greatly improve environmental quality. Ninety percent of farmers believe preserving environmental quality is very important and that their farming practices do not harm the environment. Preserving environmental quality was very important to 72% of consultants. Most farmers and consultants would use less pesticide if farmers could make the same or more money (95 and 100%) or other practices were available (95 and 88%). They would use a less environmentally toxic pesticide if it cost the same (84 and 83%) or slightly more (74 and 63%).

Governmental regulations of pesticides have somewhat hurt consultants' ability to consult (52%) and somewhat helped the need for their services (48%). Most farmers (68%) think governmental regulations have somewhat hurt their ability to farm. Forty-two percent of consultants would be interested or perhaps interested in being certified IPM consultants, and 44% thought their clients would be interested in being certified IPM users. Most farmers (63%) would be interested in being certified IPM users, especially if government would regulate farming less (90%) and the public better regarded IPM products (95%). Seventy-seven percent of consultants would be interested in being certified IPM consultants if IPM products were more regarded by the public and worth more.

Most consultants obtain information on economic thresholds (92%) and monitoring procedures (80%) from experience and on new pesticides (88%) and technology (96%) from workshops and conferences. Consultants provided services for insect pests (100%), weeds (88%), and diseases (72%) in 41 counties. Consultants had consulted for averages of 16 years on 18719 acres. Farmers had farmed for averages of 25 years on 2621 acres.

Farmers commented that IPM lowers risk and production costs while maximizing profits and is less harmful to the environment. They said IPM is the best economic solution to a pest problem and allows chemicals to remain on the market longer. A consultant commented that pest management uses all the tools available to produce the highest quality, least expensive product with the least damage to himself, the consuming public and the environment as possible.

Collaboration with Extension Service Personnel and Others

Research by the PI is the basis for IPM of sorghum insect pests in the U.S., especially Texas. The information from this project is used extensively by Extension personnel, private agricultural consultants, and farmers. A survey conducted in 1997, using a questionnaire sent to 739 sorghum growers, showed 87.4% of Texas sorghum growers use IPM for insect pests of sorghum. Criteria used to determine an IPM user were very stringent and based on quantitative assessment. Other impact assessments showed that research, primarily from this project, resulted in 65% reduction in insecticide use in Texas during the past two decades. The PI for this project provides technical assistance to sorghum seed company representatives and private agricultural consultants. Collaborative research results in West Africa, especially Mali, provided the methodology to evaluate sorghums for resistance to panicle-feeding bugs. Several new, improved, bug-resistant sorghum varieties were developed and are being tested in on-farm experiments.

Networking Activities

Workshops and Presentations

Bonnie B. Pendleton and George L. Teetes. Introduction: so many biotypes, so little time. ESA Section F Symposium: Greenbacks to Genebugs: the centennial celebration of the greenbug's landing? Annual Meeting of the Entomological Society of America, 12-16 December 1999, Atlanta, Georgia.

George L. Teetes, Gary C. Peterson, Bonnie B. Pendleton, Roberto L. Gorena, Andrea B. Jensen, and Catherine S. Katsar. Research program to develop and evaluate greenbug-resistant sorghums and study interactions between greenbug biotypes and their hosts. Annual Meeting of the Entomological Society of America, 12-16 December 1999, Atlanta, Georgia.

George L. Teetes and Bonnie B. Pendleton. Update on sorghum midge management. Texas Plant Protection Conference, 7-8 December 1999, College Station, Texas.

George Teetes and Bonnie Pendleton. Update on sorghum midge. 1999 Entomology Science Conference, 9-11 November 1999, College Station, Texas.

Greenbug Research Consortium, 21-22 September 1999, Stillwater, Oklahoma.

Research Information Exchange

The PI provided much information in different forms to scientists from several developing countries. Journal reprints were sent to 73 scientists. The newly revised insect management guide for sorghum is extremely popular, and 35 copies were sent to scientists in developing countries. The most rapidly increasing way to request information on sorghum entomology is electronically. The PI receives many requests for sorghum entomology information via e-mail. Also, he authored an Internet site on plant resistance to insects that often is used as an information source. The PI is developing a sorghum entomology Internet site that contains information, including photos, of sorghum insects and damage they cause. During travel to Mali in 1997, the PI and collaborator Dr. Niamoye Diarisso interacted with World

Vision personnel and traveled with them to on-farm sites where local farmers were using a variety of sorghum developed by IER/INTSORMIL plant breeders. This relationship with World Vision has continued.

The PI serves as Chair of the Board of Directors and Executive Committee of the Consortium for International Crop Protection (CICP). The goal of CICP is to provide information electronically on IPM to all parts of the world. CICP's Internet site, IPMnews.org, is a popular source of IPM information to scientists and practitioners in developing countries. From funding sources other than INTSORMIL, the PI is contributing to development of a Comprehensive Sorghum Crop Management Manual. The PI contributed to revision of the Sorghum Disease Compendium and wrote a chapter in a sorghum monograph. The PI continues to serve on the Editorial Board of the Journal of Insect Science and Its Application.

Germplasm

PIs for projects TAM-225 and TAM-223 annually evaluate sorghum germplasm for resistance to insects. Converted exotic sorghums regularly are evaluated for resistance to sorghum midge. Also, sorghum accessions regularly are evaluated for resistance to greenbug and yellow sugarcane aphid.

Each year, the TAM-225 PI receives many requests for seeds of sorghums resistant to insect pests. These requests are forwarded to the TAM-223 PI

Impact

Four studies have been published on the value or cost/benefit of the development and deployment of insect-resistant sorghums with which this project was associated. Greenbug-resistant sorghum hybrids, developed in collaboration with breeders, have been calculated to have a net benefit to the USA of $113 million, with an annual rate of return on the research investment of 33.4%. For each dollar invested in research and development of a sorghum midge-resistant hybrid, the value of benefits to increased crop yields from the use of the resistant hybrid ranges from $24.2 to 2.7, depending on the discount rate. Other calculations indicated the value of sorghum midge-resistant hybrids to be $9.3 million annually. The information was obtained from the following.

Dharmaratne, Gerald S., Ronald D. Lacewell, John R. Stoll and George Teetes. 1986. Economic impact of greenbug resistant grain sorghum varieties: Texas Blacklands. MP-1585.

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Eddleman, B. R., B. A. McCarl and Chi-Chung Chen. 1998. Potential economic benefit of midge resistant sorghum variety improvements for Texas. Annual Report. The Agriculture Program, Texas A&M University.

Ervin, R. Terry, Tieiso M. Khalema, Gary C. Peterson and George L. Teetes. 1996. Cost/benefit analysis of a sorghum hybrid resistant to sorghum midge (Diptera: Cecidomyiidae). Southwestern Entomologist 21:105-115.

Publications

Abstracts

Abdou Kadi Kadi, H., F. E. Gilstrap, G. L. Teetes, O. Youm and B. B. Pendleton. 2000. Population reproductive statistics of millet head miner (Lepidoptera: Noctuidae) reared in a laboratory in Niger. International Sorghum and Millets Newsletter (in press).

Peterson, Gary C., Jerry W. Jones, George L. Teetes, Bonnie B. Pendleton and Kenneth Schaefer. 2000. Grain yield of sorghum midge-resistant sorghum hybrids, 1999. Arthropod Management Tests (in press).

Refereed Publication

Pendleton, Bonnie B., George L. Teetes and Roy D. Parker. 2000. Quantifying Texas sorghum growers' use of IPM for insect pests. Southwestern Entomologist 25:39-53.

Book Chapter

Teetes, George L. and Bonnie B. Pendleton. 2000. Insect and mite pests of sorghum. In C. Wayne Smith and Richard A. Frederiksen (Eds.). Sorghum. John Wiley and Sons, Inc. (in press).

Thesis

Abdou Kadi Kadi, Hame. 1999. Laboratory life-fertility table assessment and field biology of millet head miner (Lepidoptera: Noctuidae) in Niger. M.S. thesis. Texas A&M University, College Station.

Miscellaneous

Teetes, George L. and Bonnie B. Pendleton. 2000. Insect pests of sorghum. Internet site sorghumipm.tamu.edu.

Biological Control Tactics for Sustainable Production of Sorghum and Millet

Project TAM-225B
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Summary

Project TAM-225B addresses arthropod-insect pests of millet. These pests are key constraints to production in West Africa, and require detailed ecological understanding for a sustainable management strategy, especially during times of year when pests occupy noncrop portions of an agroecosystem. Our collaborative research program in Niger focuses on biological control of the millet head miner (MHM). An important part of the program in the USA. has been to provide training for graduate students; develop theory and concepts for implementing biological controls in West Africa, concepts and definitions for functional agroecosystems, methods for measuring impacts of natural enemies, and validate results of biological controls when implemented.

In Year 17 (January 1996), I accepted two NARS scientists from West Africa to begin research programs in Niger, and they have worked at the International Crops Research Institute for the Semi-Arid Tropics-Sahelian Center (ISC) in collaboration with Dr. Ousmane Youm. These students were S. Boire a Ph.D. candidate from Mali, completing his degree in August 2000, and H. Kadi Kadi, Niger, a M.S. candidate completing his degree in August 1999. Their research objectives and results, built on findings for MHM biological control, were reported by this project in INTSORMIL Years 15 and 16.

In Year 20, both students completed their graduate degree programs. Boire has been writing his dissertation on field studies that began in Year 17 on MHM immature stage mortality, adult MHM biology and fecundity, and MHM biology on alternate host plants. All of his field work was conducted at ISC or nearby farmers' fields. In Year 20, Kadi completed his thesis work initiated in Year 17 on MHM immature stage development and adult biology using four temperatures and four artificial diets.

Results from these students' research have been developed into stage-specific life tables, and provide understanding of factors that regulate the abundance of MHM. The collective work will be useful for developing improved management tactics for MHM on pearl millet in West Africa. Ultimately, these data will contribute to a "Millet Head Miner Warning System" model that forecasts probability of MHM outbreaks in given areas so that management measures can be implemented to prevent damage from MHM.

Objectives, Production and Utilization Constraints

Objectives

Sorghum and Millet Collaborative Research Objectives

- Assess natural enemies for biological control of stalk borers and the MHM.
- Implement effective biological controls.
- Provide graduate level training on processes and strategies for biological controls in sorghum and millet
- Assess biological control for on-farm pest management of sorghum and millet pests in local crop protection practices. The listed objectives have been

pursued in the United States and in the Republic of Niger.

Graduate student research objectives

- Improve methodologies for sampling and manipulating populations of MHM.
- Assess the spatial distribution and mortality of all life stages of MHM.
- Conduct experiments to show age-specific mortality in populations of MHM.
- Identify and assess the role of alternate host plants occupied by MHM.
- Determine the optimal survival of MHM in a laboratory environment.
- Conduct field cage experiments to assess MHM fecundity.

Constraints

Insect pests of sorghum/millet addressed by this project are key pests and constraints to production in the USA and West Africa. Detailed ecological understanding of pests and their natural enemies is integral to a sustainable management strategy for an annual crop, especially during times of year when pests occupy noncrop portions of an agroecosystem. Collaborative research in Niger addressed biological control of MHM. USA research provided training for graduate students on implementing biological controls in West Africa, concepts and definitions for functional agroecosystems, methods for measuring impacts of natural enemies, and validating results of biological controls when implemented.

Research Approach and Project Output

Millet Head Miner Research in Niger

IPM of millet pests is a prominent goal of ROCAFREMI. Early in network discussions, participants identified key pests of Sahelian millet as the millet head miner (MHM) [*Heliocheilus albipunctella* (de Joannis)], millet stalk borers [*Coniesta ignefusalis* (Hampson)] and downy mildew disease [*Sclerospora graminicola* (Sacc.) (Schroter)]. The MHM infestations sometimes approach 95% with a collective grain loss of 60%. Current management options are mainly cultural practices (e.g., late planting and deep plowing), and these are generally impractical. However, MHM is a good candidate for a control strategy emphasizing effective natural enemies, i.e., biological control. It supports a large guild of natural enemies (reported in previous TAM-225B annual reports and by others), occupies a predictable habitat in an ecosystem with consistent annual presence, and has one generation per year. Before advocating a strategy using biological controls, however, we began in 1993 assessing extant natural enemies, a particularly important step for low input and fragile Sahelian farming systems. Specific objectives of our research have been to 1) expand aspects of MHM biology; 2) evaluate the impact of MHM enemies; and 3) construct an age-specific life table (k-factor analysis) for MHM.

Research Results

Soualika Boire

The seasonal abundance of MHM and its life stages, and the impact and contributions of natural enemies on abundance of MHM were assessed to determine causes of mortality of MHM. Partial ecological life tables were used to quantify and assess frequency and sources of MHM mortality. Mortality was attributed to parasitism, predation, intrinsic pupal mortality, and unexplained mortality.

Natural abundance of MHM was 3.0 eggs and 2.6 larvae per spike, with maximum mean numbers of 15.0 eggs and 13.5 larvae per spike. Most eggs were collected in August and larvae in September of each growing season. The overlap of eggs and larvae generally occurred during the third week of August and ended in mid-September. Egg abundance decreased during the last two weeks of September, and larvae decreased in abundance through mid-October. Most larvae collected in October were dead and dried in their mines on spikes of pearl millet plants. Of the larvae collected on spikes of pearl millet in the field in 1996, 1997, and 1998, 67.1, 49.8, and 4.6% were alive in August, September, and October, respectively. Percentages of parasitism of MHM larvae increased from 17.3 in August, to 30.5 in September and 71.1 in October. During the same period, predation on larvae ranged from 12.5 to 19.2%.

Most prepupae and pupae were found during the dry and cold months from October through January each year. Very few prepupae and pupae were found in May, June, or July. In general, distribution of prepupae and pupae in the soil was similar through time. However, the seasonal distribution of prepupae seemed constant while that of the pupae declined slightly. In 1990, Nwanze and Sivakumar noted abundance of diapausing pupae decreased as the dry season progressed from November to May, and that the decrease in pupal abundance could be attributed to pupal mortality.

In 1996, most prepupae and pupae were found at depths of 10 (0.66 prepupa and 0.91 live pupa, respectively) and 20 cm (0.87 prepupa and 0.89 live pupa, respectively). In 1997, most prepupae and pupae were collected at 10, 15, 20, or 25 cm. Most live pupae were at 10, 15, or 20 cm. Abundance of dead pupae increased as soil depth increased from 25 to 35 cm. Most dead pupae were collected at 25 (0.14), 30 (0.07), and 35 cm (0.03). In 1998, percentages of prepupae and dead pupae totaled 61.1% pupal mortality. There were 0.7 live pupa, 0.2 dead pupa, and 0.3 prepupa per square meter.

Few pupae were found in June or July. Pupal mortality was greater from February through May, with maximums of 1.0 and 1.2 pupae per square meter. Abundance of live and dead pupae decreased in April and May.

All natural enemies collected from spikes of pearl millet in the field were brought to the laboratory, counted, identified, and preserved. A total of 15 species of natural enemies of MHM was identified. A total of 8,611 natural enemies was collected in the field, including 6,933 *Orius* sp., *Cardiochiles sahelensis*, *Dolichogenidea* sp., *Campylomma angustior*, and chalcid superparasites captured on a total of 2,883 spikes of pearl millet. These predators and parasites attack MHM eggs and larvae. The egg and larval predator *Orius* sp. occurred commonly throughout the growing season of the three-year of study. The parasite *C. sahelensis* was abundant from early August through the first three weeks of September. *Dolichogenidea* sp., *C. angustior*, and Chalcidae were less abundant.

The hymenopterous parasites *Ammophila* sp., *Cerceris* sp., *Rhynchium* sp., *Synagris* sp., *Belonogaster* sp., and *Polistes* sp. were observed frequently extracting MHM larvae, especially large larvae, from their mines. *Cotesia* sp. occasionally was collected on spikes of pearl millet. Some species of this parasitoid such as *Cotesia sesamiae* (Cameron) attack stem borers.

Several natural enemies were reared from MHM larvae. These included the primary egg-larval parasitoid *Chelonus curvimaculatus*, ectoparasite *B. hebetor*, polyembryonic parasitoid *C. obscurum*, *Dolichogenidea* sp. (probably *polaszeki*), koinobiont endoparasitoid *Meteorus* sp., primary or secondary parasite *Pediobius* sp., *Pristomerus* sp., and the parasitoid tachinid fly, *Goniophthalmus halli*.

Observations at night in the field revealed many predators and parasites of MHM. Flashlights were used to detect feeding predators by inspecting entire spikes of pearl millet. Predators such as *Orius* sp., *Chiracanthium* sp., *Peucetia gerhardi*, tree crickets, and the earwig *Forficula senegalensis* were the most important nocturnal predators of MHM. The predators *Orius* sp., *Chiracanthium* sp., and tree crickets frequently preyed on MHM eggs and were most active between 2000 and 2200 h.

Analysis of partial ecological life tables constructed for MHM indicated that mortality was attributed to parasitism, predation, intrinsic pupal mortality, and unexplained mortality. Total cohort mortality of MHM was 94.3, 99.8, and 99.6% in 1996, 1997, and 1998, respectively. Average mortality was 97.9%. Survivorship curves for each of the 3 yr were Type II, in which more mortality occurred during immature than later stages of development of MHM.

Mortality of MHM eggs was attributed to predation and unexplained causes. Unexplained mortality included brown and 'blackhead' eggs (unhatched) from which predation or parasitism could not be confirmed. Missing eggs also were considered to have died of unexplained causes. Most larvae, especially large larvae, were killed by parasitism. Dead larvae without evidence of parasitism or predation were considered to have died of unexplained causes. Weather conditions such as heat during September and October could contribute to much unexplained mortality.

MHM mortality was further studied using key-factor analysis to elucidate sources of mortality. K-values were obtained from ecological life tables by subtracting each log population from the previous one. Eleven key factors were considered. These key factors provided insight into changes in MHM abundance during the growing season. Parasitism of large larvae and predation on eggs contributed most to the overall mortality of MHM and were the key factors. Predation on small larvae, unexplained mortality of small larvae, predation on medium larvae, unexplained mortality of medium larvae, predation on large larvae, and unexplained mortality of large larvae contributed in minor ways to changes in MHM abundance.

Intra-age specific mortalities of MHM eggs exposed to natural enemies were assessed. Unexplained mortality and predation of eggs and larvae were the most important causes of mortality of MHM exposed to natural enemies. Unexplained mortalities of eggs were 63.9, 66.9, and 71.1% in 1996, 1997, 1998, respectively, and averaged 67.3%. Parasitism ranged from only 6.0 to 13.3% and, thus, was not an important cause of mortality of small larvae of MHM.

Assessment of survival of pupae placed at different depths in the soil showed that fewer pupae survived at deeper soil depths such as ≥35 cm in 1997-1998. Most survival (63.3%) was of pupae at a depth of 20 cm. Survival of pupae at 35 cm was only 13.3%. Most pupal cases were at 20 cm deep, followed by those at 15 or 25 cm. Pupal survival was 60.0% at 20 cm deep in 1998-1999. Also, many pupae survived at depths of 5-15 cm where pupal mortality was only 15.0%. Pupal mortality was 70.0, 85.0, and 90.0% at 30, 35, and 40 cm, respectively. Few pupal cases, only 5.0%, were at 35 or 40 cm deep. Pupal survival was greatest at depths of 5-25 cm. Survival decreased from 25.0% at 5 cm to only 2.5% at 40 cm. Conversely, mortality increased at deeper soil depths such as 40 cm (95.0%).

Daily soil temperatures during 1996-1997 were cooler (31.6° C) at 20 cm than at shallower or deeper depths. Temperature differed among months and ranged from 31.5° C in September to 33.3° C in October. Soil moisture was not significantly different in November (0.014%) and December (0.017%) and the minimum significant difference was 0.012%.

During 1997-1998, soil temperatures at the upper levels of 5-10 cm were slightly warmer than at deeper depths. Soil temperature at 40 cm deep was cooler (31.3° C) than at other depths. A Pearson coefficient of correlation of -0.1 indicated a negative correlation between soil temperature and depth. Also, a correlation coefficient of -0.25 indicated negative correlation between month and soil temperature. Temperatures were warmest in April (35.1° C), May (35.3° C), and June 1998 (32.9° C). Soil moisture differed significantly among soil depths. Pearson correlation coefficients of 0.04 and 0.09 indicated slight positive correlation between soil temperature and soil depth and moisture. Pearson correlation indicated positive correlation between soil depth and moisture. Soil moisture increased from 0.6% at 10 cm to 4.9% at 40 cm. A correlation coefficient of -0.5 indicated negative correlation between soil moisture and month.

During 1998-1999, soil temperatures at upper soil depths were not significantly different. Temperatures at 10, 15, and 20 cm were almost equal (29.3, 29.4, and 29.3° C, respectively). Temperatures were cooler at deeper soil depths. A Pearson correlation coefficient of 0.9 indicated positive correlation between soil depth and temperature. Temperatures were warmest from February (32.0° C) to May 1999 (34.3° C) and cooler from November 1998 (28.8° C) to January 1999 (25.2° C). Average amounts of soil moisture differed for each soil depth but was low (0.5%) in upper soil levels (10 cm) and high (3.4%) at deeper levels (40 cm). There was a positive correlation between soil depth and moisture based on a correlation coefficient of 0.7.

A total of 116 MHM larvae was collected on a total of 156 spikes of Chibra millets. These included particularly *Pennisetum violaceum* and *P. sieberianum*. A total of 62 larvae was collected on 89 spikes of an unidentified *Pennisetum* subspecies. Unidentified plant species (88 spikes) were infested by 38 MHM larvae. Of a total of 10 species of Poaceae, 7 including *P. sieberianum*, were infested by MHM.

The perception of some authorities that earwigs are agricultural pests needs to be clarified. Night observations in the field and experiments on predation showed that earwigs were not feeding on flowers of pearl millet spikes, but were predators of MHM eggs and larvae. Thus, predation by earwigs on eggs showed an average of 99% egg consumption in 24 h. The average number of eggs consumed per earwig was 4.3, but ranged from 1.0 to 10.5 depending on the availability of MHM eggs per earwig. The number of larvae killed per earwig averaged 8.2 in 24 h.

In brief, results of these studies showed natural mortality of MHM was important in all stages of development. Several predators and parasites attack MHM. Also, weather such as soil temperature and moisture contributed substantially to pupal mortality during diapause and emergence of adult moths. Some predators and parasitoids identified during this study may be useful to target and reduce abundance of MHM eggs and larvae in August and September, respectively. Other tactics such as tillage in December or January could expose diapausing pupae to predators. Existing predators and parasitoids could be conserved and/or augmented. Plowing to a depth of 10-25 cm could be effective in preventing increases in abundance of MHM in June or July of each growing season. Improved IPM programs can be implemented at regional and national levels by farmers' cooperation.

Networking Activities

Networking activities consisted of Hame Kadi Kadi sharing his research results with his colleagues at INRAN. See country report for Niger.

Publications and Presentations

Dissertations and Theses

Ph.D.

Boire, Soualika. 1999. Assessment of mortality and life tables for millet head miner (Lepidoetera: Noctuidae) in Niger. Ph.D. Diss. Texas A&M University, College Station, TX.

M.S.

AbdouKadi Kadi, Hame. 1999. Laboratory life-fertility table assessment and field biology of millet head miner (Lepidoptera: Noctuidae) in Niger. M.S. thesis. Texas A&M University, College Station, TX

Development of Plant Disease Protection Systems for Millet and Sorghum in Semi-Arid Southern Africa

Project TAM-228
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Summary

In the 1999-2000 season, a 100-entry two replicate multilocational nursery, initially dubbed the Southern Africa Breeding Nursery, was developed from the disease, drought, and sugarcane aphid nurseries of previous years to identify cultivars that have both broad adaptation to the SADC region, and resistance to major disease and insect pests. This initial nursery was planted at locations in Zimbabwe, Zambia, Botswana, and South Africa. The eventual goal is a more space efficient 50 entry two replicate test re-named as the SADC Regional All Disease and Insect Nursery for widespread deployment in the SADC region. Grown over several years, the nursery of genetically diverse sorghums will identify cultivars adapted to individual locations, determine relative importance of specific pest constraints, determine needed types of pest resistance, and identify potential cultivars with adequate individual and multiple pest resistance. TAM-228 was instrumental in tracking the spread of sorghum ergot from Brazil across the Western Hemisphere beginning in 1996 and, especially, through Mexico and the USA beginning in early 1997. TAM-228 helped establish a global network of scientists working together on various aspects of the epidemiology

and spread of sorghum ergot, its biology, and its potential immediate and continuing impact on the international sorghum industry. TAM-228 developed extensive collaboration with INIFAP of Mexico to conduct ergot research in Mexico and the USA during 1997-2000. In 1998-99 a special INTSORMIL sorghum ergot project allowed world sorghum ergot expert, Dr. D. Frederickson, to work on the biology of sorghum ergot in collaboration with TAM-228. Contact fungicides, thiram and captan, at standard treatment rates completely prevented conidial germination and production of conidia of *C. africana* present in honeydew on seed surfaces, but triazole fungicides had no apparent effect. Captan seed treatments greatly reduced germination of conidia of *C. africana* on external surfaces of fresh sphacelia but only slightly reduced their germination on internal sphacelial tissue cores. Low temperature (6°C) and low relative humidity (6%) provided the greatest survival of conidia of *Claviceps africana*. Conidia of *C. africana* in sphacelia or on honeydew on seed surfaces do not survive well in storage environments. The combination of poor survival of conidia and the good efficacy of contact fungicide seed treatments make seedborne inoculum a negligible factor, especially in areas where the pathogen is already endemic. Triazole fungicides were the most effective in controlling sorghum ergot in the field, but aerial application proved ineffective due to poor contact and coverage of heads with the fungicide. TAM-228 participated in publication of an ergot training manual and a sclerotia identification pamphlet, utilized in several workshops that trained personnel involved in identifying and detecting sorghum ergot in seed. TAM-228 participation in workshops in 1999-2000 was intended to increase accuracy of ergot detection, reduce misidentification, and promote seed import and export regulations based on readily available scientific data.

Objectives, Production and Utilization Constraints

- Evaluate the ecology and economic importance of *Exserohilum turcicum* and *Ramulispora sorghi*, and evaluate specific versus general leaf disease resistance.(Zambia and Zimbabwe)

- Identify adapted sources of drought tolerance with adequate charcoal rot and other disease resistance. (Botswana, Zimbabwe, and South Africa)

- Assist national programs in identification of adapted foliar disease resistant cultivars that have stable disease resistance reactions in strategic multilocational nurseries over several years. (Botswana, Zambia, Zimbabwe, and South Africa)

- Develop controls for sorghum ergot (*Claviceps africana*) through chemical control, identification of host plant resistance, and other means as determined through biological investigations of *C. africana*. (Zimbabwe, Zambia, South Africa, Botswana, Puerto Rico, Mexico, and the United States)

- Determine the level of host:parasite compatibility that exists for *C. africana* and several previously reported alternate hosts including pearl millet. (Mexico and the United States)

Research Approach and Project Output

Foliar Diseases (Anthracnose, Leaf Blight, Sooty Stripe)

From 1996-2000, several sorghum disease nurseries were planted at one or more locations in Zambia, and two locations in Zimbabwe to evaluate response to anthracnose, leaf blight, and sooty stripe. Two or three new locations in South Africa were added during the 1999-2000 growing season. During the last two years the Anthracnose Resistant Germplasm Nurseries (ARGN-1 and ARGN-2) were consolidated from two separate nurseries into a single nursery (ARGN, 61 entries, 2 reps). Several entries were new to the ARGN during the last two years because they were being evaluated elsewhere for sugarcane aphid resistance, or they had parents (SC326-6 or 86EO361) previously associated with progeny having good adaptation and foliar disease resistance in the SADC region. Unfortunately, most of these new materials had a high susceptibility to either or both sooty stripe and anthracnose. Some of these materials may still have value in other SADC locations where foliar pathogens are not consistently a problem. The adaptation of SC326-6 derived material like 86EON 361 and 86 EON362 continued to be very good across Zimbabwe and Zambia; however, even some of these materials developed higher than normal levels of sooty stripe at Golden Valley, Zambia under heavy sooty stripe pressure.

Cultivar Evaluations for Drought Tolerance, Sugarcane Aphid, and Disease in Botswana, Zimbabwe, Zambia, and South Africa

Several drought resistant materials were tested yearly at the Sebele station and, occasionally, at the Pandamatenga station in Botswana. Yearly response to drought stress and agronomic appearance was utilized to identify those cultivars for continued and expanded evaluation, and to target potential new cultivars for inclusion in drought resistance nurseries. Beginning in 1998, cultivars previously tested in Botswana or closely related cultivars were selected for expanded evaluation at the Matopos station in Zimbabwe and the Golden Valley station in Zambia. Derivatives of EO366 were susceptible to sooty stripe at Golden Valley and did not appear to have good adaptation at that location. In a previous season some EO366 × WSV387(Kuyuma) derivatives had shown good drought tolerance and agronomic characteristics at Sebele. Derivatives of SRN39 had both acceptable adaptation and at least moderate or good resistance to sooty stripe. Macia derivatives had both resistant and susceptible representatives, but those of Macia × Dorado and ICSV1089 × Macia commonly had both excellent sooty stripe response and good agronomic characteristics at Golden Valley. These derivatives also had good to excellent drought tolerance at the Sebele station in Botswana over more than one season.

Sugarcane aphid resistant sorghums were concurrently evaluated with drought tolerant sorghums at the Sebele station. From these and related materials, a sugarcane aphid resistance nursery (50 entries, 2 reps) was initiated in 1998 in collaboration with TAM-223, TAM-225, TAM-222, and other NARS scientists and planted in two seasons at several SADC locations including Matopos, Zimbabwe; Golden Valley, Zambia; and other locations in South Africa. Most entries were susceptible to sooty stripe at Golden Valley but may be useful elsewhere in the SADC region where sooty stripe is not a production problem.

Virus Identification

Virus reactions in the International Sorghum Virus Nursery (ISVN) at the Sebele and Pandamatenga Research Stations in Botswana were typical of previous years, but do not appear to adequately fit host differential response patterns for SCMV-B. Live virus specimens, collected two years ago in Botswana and Zambia, were identified as being similar to SCMV-B by S. Jensen. Mahube, an early maturing released variety in Botswana, was identified as being vulnerable to the virus at both the Sebele and Pandamatenga locations where it sometimes showed extensive Red Leaf Necrosis (RLN) when virus-infected plants were exposed to cool night temperatures.

SADC Regional All Disease and Insect Nursery

In the 1999-2000 season, a 100-entry two replicate multilocational nursery, initially dubbed the Southern Africa Breeding Nursery, was developed from the disease, drought, and sugarcane aphid nurseries to identify cultivars that have both broad adaptation to the SADC region and resistance to major disease and insect pests. This initial nursery was planted at the following research stations: Matopos, Zimbabwe; Golden Valley, Zambia; Sebele, Botswana; and Potchefstroom and Cedera, South Africa. The eventual goal is a more space efficient 50-entry two replicate test re-named as the SADC Regional All Disease and Insect Nursery for widespread deployment in the SADC region. Grown over several years, the nursery of genetically diverse sorghums will identify cultivars adapted to individual locations, determine relative importance of specific pest constraints, determine needed types of pest resistance, and identify potential cultivars with adequate individual and multiple pest resistance.

Sorghum Ergot

TAM-228 was instrumental in tracking the spread of sorghum ergot from Brazil across the Western Hemisphere and especially through Mexico and the USA beginning in early 1997. TAM-228 helped establish a global network of scientists working together on various aspects of the epidemiology and spread of sorghum ergot, its biology, and its potential immediate and continuing impact on the international sorghum industry. USDA-ARS funding allowed extensive collaboration of TAM-228 with INIFAP of Mexico, who provided a scientist based at Corpus Christi, to conduct ergot research studies in both Mexico and the USA during 1997-2000 (R. Velsaquez-Valle, May 1997 to May 1998, N. Montes, Feb 1999 to current). In 1998-99 a special INTSORMIL sorghum ergot project provided the basic support which allowed world sorghum ergot expert, Dr. Debra Frederiksen, to work on the biology of sorghum ergot at Texas A&M in collaboration with TAM-228. Dr. Frederiksen is now at SADC/ICRISAT where, as a consultant research scientist supported by TAM-228, she is investigating various aspects of sorghum ergot in Zimbabwe and the SADC region.

Geographical Spread of Sorghum Ergot Across the Western Hemisphere and into the USA

Sorghum ergot caused by *Claviceps africana* spread to Tamaulipas and surrounding states of Mexico in February 1997. In Southern Tamaulipas and surrounding areas in adjacent states of Mexico, sorghum ergot was a problem in hybrid seed production nurseries and commercial grain sorghum fields during the winter months where fields were exposed to cool temperatures that induced some sterility. Cool temperature sterility also appeared to increase incidence of ergot in johnsongrass. By late March 1997, sorghum ergot was observed by T. Isakeit in the Lower Rio Grande Valley (LRGV) of Texas. The initial reports of ergot in northern Tamaulipas, Mexico and in the LRGV were on ratooned or "volunteer" sorghum plants from seed of the previous crop growing in abandoned fields. This was an initial observation of what was to be a recurring pattern of survival and re-occurrence of sorghum ergot. As the 1997 season progressed in the LRGV, sorghum ergot was observed at low levels on the commercial grain sorghum crop and on some populations of johnsongrass. The incidence of ergot in the commercial grain sorghum crop in south Texas was minimal, generally one to several florets on less than 1% of the heads, and sometimes non-detectable. However, this incidence was higher than expected for grain sorghum hybrids because their self-fertility usually gives them a high level of post-fertilization acquired resistance to the disease. Commercial hybrid seed production fields of sorghum in Tamaulipas and in the LRGV had some low levels of ergot, primarily, in late-season axillary tillers of the seed parent. Following the progressive maturity of the sorghum crop across Texas and weather patterns that sporadically favored development, sorghum ergot continued its spread across the state and reached the hybrid seed production region of the Texas High Plains in August 1997. By October 1997, sorghum ergot was reported as far North as Kansas and Nebraska but was not reported in Kansas again until 1999 and has not again been reported in Nebraska. In 1997, ergot was also reported in New Mexico, Mississippi, and Georgia; and, in 1999 in Missouri and Florida.

TAM-228 promoted the use of male-sterile forage sorghums as a trap or indicator crop to detect the presence of ergot. In collaboration with several U.S. scientists and sorghum workers, we successfully utilized these sorghums across many areas of the Texas and U.S. sorghum production region to detect spread of *C. africana*. These forages are very susceptible to ergot because they have no pollen source, and prolonged tillering produces a relatively continuous, proximal source of susceptible ovaries. This allows a rapid cycling and buildup of ergot so the disease becomes easily observable in a short period of time. The vulnerability of tillers to a high incidence and rapid build up of ergot was also evident on late-season stem or axillary tillers (side branches) of specific female seed parents. The tillers emerged prior to harvest, but well after the male pollinator had ceased pollen production which allowed a high incidence of ergot. Some of these hybrid seed production fields in south Texas had a significant problem in 1997 during harvest, either with ergot honeydew hindering harvest through clogging of the combine and creating other grain handling difficulties, or through seed contaminated with the honeydew and ergot sphacelia. Similar but less serious problems also occurred in 1997on the Texas High Plains in the primary hybrid seed production areas.

Survival of Claviceps africana in Mexico and Texas, 1997-2000

Winter survival of *C. africana* in northern regions of the USA in 1997-98 was questioned because of the extended exposure to freezing conditions and freeze:thaw cycles. Winter environments in South Texas are extremely mild and freezing conditions are either limited or absent. Ergot surveys were conducted throughout the winter months because cool and near freezing temperatures might actually increase likelihood of ergot through induced sterility in normally fertile sorghums. Cool temperatures during a November bloom period contributed to a high incidence of ergot in a few commercial grain sorghum fields near Corpus Christi in late 1997. Ratooned and feral sorghum in abandoned fields, along roadsides, and near grain storage facilities developed relatively high levels of ergot under cool temperatures throughout south Texas. This ergot persisted in an active phase until plants were killed by frost. Some regions of the Rio Grande valley and areas near Corpus Christi escaped frost damage and ergot continued to develop throughout the winter months as new tillers emerged. Some ergot-infected plants had above ground foliage and stalks killed by frost, but ergot later re-occurred on heads of new basal tillers. In the Corpus Christi area, ergot was not seen on johnsongrass until cool temperature sterility occurred in the fall of 1997 in a manner similar to grain sorghum. Persistence of ergot on feral sorghum and johnsongrass throughout the winter months of 1997-98 was similar to the initial observations of ergot in the LRGV and portions of northern Mexico in early 1997.

Sorghum ergot caused by *Claviceps africana* persisted in an active phase, predominantly, on feral grain sorghum as far north as Corpus Christi, Texas through February 1998. In Mexico, sorghum ergot was observed in Tamaulipas state only in early January 1998 at the INIFAP San Fernando Experimental Station. In the Pacific Coast states of Sonora, Sinaloa, and Nayarit, the El Nino storms provided rainy, cloudy, cool conditions which favored ergot development from February through May of 1998. During September, sorghum ergot was observed in several states in the Bajio and High Plains regions of Mexico. Cool temperatures favored ergot expression in sorghum hybrid seed production fields where incidence was sometimes severe, despite application of preventative fungicides. Incidence of ergot in some commercial grain sorghum fields averaged 1% with slightly higher incidence in commercial fields of forage sorghum. Despite active *C. africana* through February 1998, season-long drought and heat stress prevented observation of any naturally-occurring sorghum ergot across South Texas and northern Mexico during the normal 1998 growing season. However, sorghum ergot was observed at low levels at a limited number of hybrid seed production fields in the Texas High Plains in 1998.

In Tamaulipas and surrounding states in Mexico, sorghum ergot began to be observed again in September 1998. During September 1998, high rainfall and extensive flooding across South Central Texas produced a flush of sorghum growth that bloomed into increasingly cool temperatures from October through December 1998. The wet, cool environment and extended bloom period promoted a rapid increase and spread of sorghum ergot on feral and ratooned grain and forage sorghum and johnsongrass within fields and along roadsides. Increased incidence and severity of sorghum ergot was related to cooler temperatures that progressively reduced pollen fertility on later blooming sorghum heads. In November 1998, male-steriles in some commercial hybrid seed production fields in the LRGV had a high incidence of ergot despite aerial applications of propiconazole (Tilt). Commercial grain sorghum fields and a test of commercial grain sorghum hybrids in the LRGV also had an increased incidence of ergot at this same time. By mid-December 1998, sorghum ergot was easily observed in every surveyed area of Texas where a sorghum crop was at a growth stage capable of infection by *C. africana*. It is unknown whether the sources of initial inoculum for this late season epidemic of sorghum ergot came from local or distal sources or both.

In 1999 and 2000, the pathogen was again present across several areas of Mexico at various levels, including winter nurseries in the Pacific Coast states. In Texas, the pathogen continues to be routinely observed at minimal levels in the commercial grain sorghum fields during the growing season with increased observation on feral sorghums during cooler temperatures in the fall and winter. Winter nurseries of sorghum in the LRGV and northern Mexico can develop problems with ergot, especially, if cool temperatures contribute to male-sterility. Volunteer and ratoon sorghum appear to be major factors contributing to survival of *C. africana* as far north as Corpus Christi, TX. Occurrence of ergot in the hybrid seed production regions of Texas has been minimal.

Low level or epidemic occurrence of sorghum ergot in planted and feral sorghum outside of the normal growing season may have minimal or no economic impact, but it demonstrates that *C. africana* is a well-established, recurrent pathogen of Mexico and Texas. *Claviceps africana* has continuously demonstrated its capacity for survival under extended unfavorable dry environments and its ability to quickly reach epidemic proportions over vast regions upon a return to favorable wet, cool environments. Its occurrence, in an active phase, can perhaps be demonstrated in almost any month of the year somewhere in Mexico or south Texas.

Hosts of C. africana in Puerto Rico, Mexico and the USA

Despite extensive surveys over several years in Puerto Rico, Mexico and the USA, and the evaluation of ergot from several grasses, only *Sorghum* spp. were observed to be naturally infected by *C. africana*. Pearl millet (*Pennisetum glaucum*) remained uninfected at Corpus Christi despite being grown among sorghum plants of a male-sterile sorghum heavily infected with *C. africana*.

Chemical Control of Ergot in the Field

In 1997, an evaluation of 100 A-lines and 40 R-lines, provided by commercial seed companies, was conducted at Corpus Christi to determine potential phytotoxicity of propiconazole (Tilt) and triadimefon (Bayleton). Both fungicides, at concentrations of 500 and 1000 ppm, were applied three times at weekly intervals to sorghum heads beginning at initiation of bloom. There was no observable phytotoxicity on head or plant tissue with any fungicide treatment. In comparisons of treated (1000 ppm) versus non-treated seed, there were no apparent effects on seed weight or viability on any sorghum producing enough seed for comparison.

Fungicide trials were conducted in south Texas and northern Mexico from 1997 through 2000, primarily utilizing male-sterile sorghums, pathogen inoculation, and absence of pollen to maximize the ergot potential in all available ovaries. Application methods from best contact and coverage to worst included hand sprayer to individual heads, row applications with a CO2 hand sprayer, ground application equipment with head directed spray, and aerial applications. A few trials were conducted with multiple applications, but most tests utilized single applications to heads at bloom initiation and later tests included completely bloomed heads protected from pollination and *C. africana* infection until treatment.

In fungicide tests conducted in 1997 through 2000, it was determined that triazole fungicides were the most effective ones for control of sorghum ergot in the field. However, even with the most effective fungicides, it was determined that contact and coverage of the head, at or prior to bloom, were the most important factors in protecting ovaries from infection by *C. africana*. Several fungicides had minimal or no activity in preventing sorghum ergot. Benomyl provided some but unacceptable activity against ergot at high concentrations. The strobilurin fungicides azoxystrobin (Quadris) and trifloxystrobin (CGA279202, Flint) were ineffective when applied at or prior to bloom initiation. The anilinopyrimidine fungicide cyprodinil (Vanguard), and thiabendazole (Mertect) provided no protection against sorghum ergot when applied at bloom initiation in concentrations of 2000 ppm.

Actigard, an SAR (systemic acquired resistance) chemical from Novartis that stimulates host plant defense mechanisms, provided apparent control of sorghum ergot that was similar to the best triazole (triadimefon, Bayleton) when applied at bloom initiation; however, phytotoxicity was usually present in the form of reduced or complete prevention of seed set. Seed set was sometimes completed prevented by concentrations as low as 12 ppm when application was made until runoff on individual heads at bloom initiation. At Actigard concentrations above 50 ppm foliar and head tissues often had a slight reddening or bronzing symptom of phytotoxicity. Actigard is thought to rapidly elicit a physiological response that makes the ovary nonreceptive and incapable of either fertilization by pollen or infection by *C. africana*. Application of Actigard to plants with unexposed heads prior to bloom initiation provided no control of sorghum ergot.

The triazoles propiconazole (Tilt), tebuconazole (Folicur), and triadimefon (Bayleton) effectively controlled sorghum ergot when applied by hand sprayer to heads at bloom initiation using concentrations as low as 125 to 250 ppm. In 1999, field tests utilizing different blooming male-steriles at Corpus Christi, TX (ATX623) and Rio Bravo (AVar), triadimefon was at least three times more effective than propiconazole or folicur in control of *C. africana* when data was analyzed using exponential decay regression models (Figure 1).

Machine application tests done in 2000 at Corpus Christi, utilized propiconazole and triadimefon at 31, 62, and 125 g a.i./ha (1,2, and 4 oz of Tilt or Bayleton equivalent/ac) in a spray volume of 187 l/ha (20 gal/ac) of water. All applications were made to heads of ATX623 that had completed bloom (Completed) after being bagged at bloom initiation to prevent seed set and infection by *C. africana*. One group of heads received the ground machine application using a head-directed fungicide spray and the other received the same fungicide concentrations using a hand sprayer. Hand sprayer fungicide concentrations calculated from the spray volume and fungicide rates of 31, 62, and 125 g a.i./ha were 168, 336, and 671 ppm, respectively. All plots were inoculated with a macroconidia suspension of *C. africana* after fungicide treatments. At eight days after treatment, ground application control of sorghum ergot was excellent at all treatment rates of both fungicides with 2 to 11 % ergot se-

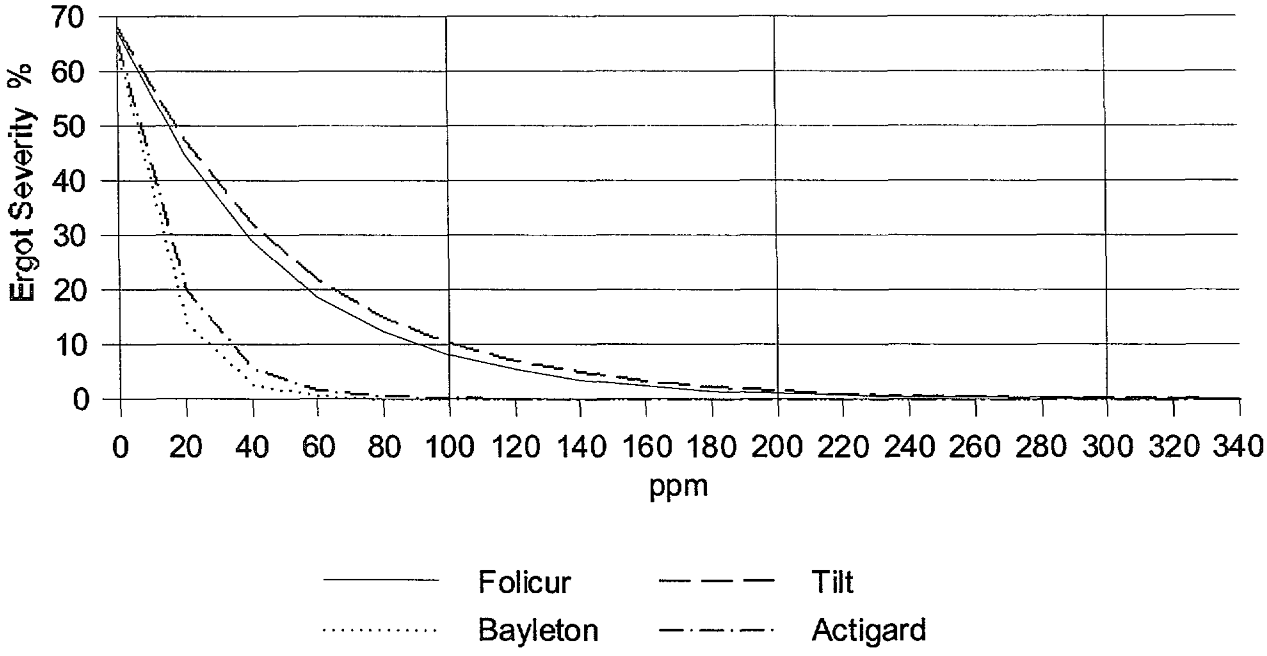

Figure 1. Exponential decay regression models showing the effect of fungicide rate on ergot severity on male-sterile sorghum heads. Ergot severity is average percent of florets infected per head.

verity compared to 42 % in the controls (Table 1). At 14 days, all treatments had dramatically increased ergot severity with Control heads at 90 to 91% and fungicide-treated heads at 38% and 59% for the 125 g a.i./ha high rate and 72% for the 31 g a.i./ha rate. Heads hand sprayed with fungicide had 0 to 0.1 % and 0 to 2 % ergot severity at 8 days and 14 days after treatment, respectively.

Triadimefon was also the most effective triazole when aerial applications were made to heads at bloom initiation in 1999 at rates of 125 g a.i./ha (4 oz of Tilt or equivalent/ac) in 47 l/ha (5 gal/ac) of water. However, the 5 to 12 % ergot severity and 49 to 77% reduction in ergot provided by these triazole fungicides at 12 days after aerial application and inoculation disintegrated to 85% ergot severity and only 5 % disease reduction by 19 days after treatment. Even poorer results were obtained in 2000 with aerial applications of propiconazole and triadimefon at Corpus Christi in 2000. Prior to aerial application of fungicides and inoculation at Corpus Christi sorghum heads of male-sterile ATX623 were selected that had either just initiated (Initiation) or completed (Completed) bloom. One group of heads were sprayed by hand at 168-672 ppm which had also been used in the ground application tests. The other heads and the remainder of the plots received aerial applications of propiconazole (125 g a.i./ha) and triadimefon (62 and 125 g a.i./ha) in 47 l/ha. After treatment all plots were inoculated with a macroconidia suspension of *C. africana*. The initial ergot observations were made eight days later for Completed heads which had synchronous ergot expression across the control treatment heads. Initiation heads were evaluated 11 days after treatment to allow full expression of ergot in the control treatment heads. The individualized controls within treatment plots had an ergot severity of 81 to 90% (Table 2). Heads receiving any aerial application of fungicides had significantly lower ergot severity from 44 to 66%. However, this lower level of ergot control was much higher than the ergot severity of hand sprayed fungicide heads which was 0.1 to 2.5%. At 14 days after treatment, there was little change in ergot severity in heads of any hand sprayed treatment or the Completed heads receiving aerial application of either fungicide at 125 g a.i./ha (Table 2). The ergot severity in Completed heads receiving the lower aerial application rate of triadimefon (62 g a.i./ha) and Initiation heads of all aerial application treatments increased to near control treatment levels of 95 to 96 % (Table 2). The field results from 1999 and 2000, indicate that aerial application provided poor fungicide contact and coverage of the head and the ensuing control of sorghum ergot was minimal and transitory.

Our tests maximized the potential for sorghum ergot in male-sterile sorghums through inoculation and absence of pollen. The ergot potential is likely to be much less in hybrid seed production fields. However, our results indicate the probable protection from ergot that could be expected with aerial application of these triazole fungicides at these rates. Multiple applications done to protect later-emerging heads might also increase efficacy on previously-sprayed heads, but probably not significantly. Costly aerial applications of triazole fungicides might provide inadequate control of ergot just when it may be most needed. Head-directed spray

Table 1. Effect of fungicide rate and hand-spray versus ground machine application on average percent severity of sorghum ergot on a male-sterile sorghum at Corpus Christi, TX in 2000.[1]

	Propiconazole [2]		Triadimefon [2]	
Rate (g a.i./ha)	Hand	Machine	Hand	Machine
		8 Days after Treatment		
0	42.00 a	42.00 a	41.88 a	41.88 a
31 (168 ppm)	0.09 b	10.74 b	0.02 b	5.62 b
62 (336 ppm)	0.03 b	6.36 c	0.00 b	1.68 c
125 (671 ppm)	0.00 b	2.33 d	0.00 b	1.31 c
		14 Days after Treatment		
0	90.63 a	90.63 a	91.12 a	91.12 a
31 (168 ppm)	2.09 b	2.50 b	0.26 b	71.63 b
62 (336 ppm)	0.31 c	63.00 c	0.02 b	50.88 c
125 (671 ppm)	0.04 c	59.12 c	0.00 b	38.22 d

[1] Percent severity of sorghum ergot (percent of infected florets/head) was determined from 40 heads in each of four replicate plots of ATX623 that had completed bloom at the time of fungicide treatment and inoculation with *C. africana*.

[2] Treatments followed by the same letter in the same column are not significantly different according to Tukey P < 0.05.

Table 2. Effect of bloom stage, fungicide rate, and aerial versus hand-spray application on average percent severity of sorghum ergot on heads of a male-sterile sorghum at Corpus Christi, TX in 2000.[1]

	Propiconazole [2] (125 g a.i./ha)			Triadimefon [2] (125 g a.i./ha)			Triadimefon [2] (62 g a.i./ha)		
	Application Method			Application Method			Application Method		
Bloom Stage	Control	Hand	Aerial	Control	Hand	Aerial	Control	Hand	Aerial
				8 and 11 Days after Treatment					
Initiation	81.00 a	1.96 a	52.89 b	90.00 a	0.05 a	43.79 b	88.77 a	0.21 a	48.61 a
Completed	83.25 a	0.80 a	66.13 a	86.38 a	0.02 a	61.00 a	86.06 a	0.04 a	59.38 a
				14 Days after Treatment					
Initiation	98.50 a	2.42 a	95.75 a	97.50 a	0.09 a	96.00 a	97.50 a	0.30 a	96.00 a
Completed	98.00 a	1.57 a	68.89 b	98.00 a	0.10 a	70.75 b	98.00 a	0.14 a	94.00 a

[1] Percent severity of sorghum ergot (percent of infected florets/head) was determined from 40 heads in each of four replicate plots of ATX623 that were at bloom initiation or had completed bloom at the time of fungicide treatment and inoculation with *C. africana*. Initial ergot readings were taken at 8 and 11 days after treatment of Completed bloom and Initiation heads, respectively.

[2] Treatments followed by the same letter in the same column are not significantly different according to Tukey P < 0.05.

with ground application equipment may be impractical for most producers, but it provides the fungicide contact and coverage of heads needed for adequate control of sorghum ergot.

Seed Treatments to Control Sorghum Ergot

In early 1997, the sorghum industry was concerned about the safe movement of seed from ergot-affected production areas so they could assure there was no introduction or re-introduction of ergot to other areas. J. Dahlberg et al. determined that the contact fungicides thiram (42-S Thiram) and captan (Captan 400), at standard treatment rates, completely prevented conidial germination and production of conidia of *C. africana* present in honeydew on seed surfaces. Maxim 4FS (4-(2,2-difluoro-1,3-benzodioxol-4-yl)-1H-pyrrole-3-carbonitrile) allowed a trace of conidial germination and production of conidia at the lowest treatment rate, but allowed only a sparse segmented mycelial growth at the higher treatment rate. Neither of the triazole fungicides, triadimenol (Baytan 30), or difenoconazole (Dividend 3MG), had any apparent effect on conidial germination or production of secondary conidia as they were indistinguishable from the control seed coated only with ergot honeydew. Results were similar when the germination tests were conducted on the surface of nonsterile soil.

The apparently contrasting activities of triazole fungicides and contact fungicides, regarding ergot control in the sorghum ovary versus conidia in honeydew, on mature seed is probably related to the mode of action of the fungicides and their ability to directly interact with the pathogen at specific sites. In the field, triazole fungicides can prevent infection of ovaries because of their systemic translocation within plant tissues. Contact fungicides are ineffective in preventing infection in the field due to their lack of systemic activity. On the seed surface, the contact fungicides have good activity because they are in direct contact with the conidia of the fungal pathogen. Triazole fungicides prevent synthesis of sterols by the pathogen, but they apparently do not prevent the conidia from utilizing their own endogenous reserve of sterols which appear to be sufficient to complete the entire sporulation process in less than 24 hours.

The need for seed treatments to control sorghum ergot was questioned when it became apparent that conidia in surface honeydew apparently had a short life span in seed storage environments. Seed treatment efficacy studies were somewhat difficult to conduct on seed naturally coated with honeydew during harvesting operations because viability of conidia in surface honeydew tended to decline so rapidly within the first one to three months. Standard contact fungicide treatments should easily control any residual conidia surviving in surface honeydew on seeds or sphacelia that somehow remained in seed after conditioning operations. Despite their almost nondetectable numbers, in most cases, there was concern about survival of conidia within sphacelia and the possibility that contact fungicides might not penetrate sufficiently into the sphacelia to kill them. In work done by D. Frederiksen, in collaboration with TAM-228, fresh sphacelia/sclerotia of *C. africana* were mixed with sorghum seed and the mixture treated with captan fungicide (Captan 400 at 3.0 fl oz/100 wt). After treatments had completely dried (24-48 hr), sphacelia/sclerotia were manually removed for viability assessments of conidia. Compared to controls (95-100%), external sphacelial surfaces of intact sphacelia and internal tissue cores of fresh sphacelia treated with captan had visible conidial germination that was greatly (39%) and slightly reduced (85%). Of the sphacelia that did have visible conidial sporulation, the amount was near non-detectable levels on the external surfaces of intact captan-treated sphacelia, but very abundant from the internal cores of captan-treated sphacelia and both controls.

Seed is subject to a rigorous cleaning process and sclerotia/sphacelia are removed at many stages, e.g., following the screen-cutting (sieving) and air-blowing stages and the gravity table. With good cleanup, very few are incorporated into seed, and captan seed treatment would coat them and any ergot-contaminated seed. The percentage germination of conidia from those few remaining sclerotia/sphacelia is negligible compared to the fresh sphacelia used in our tests, and is reduced by captan beyond the threshold of detection. Furthermore, seed and sphacelia are destined to be buried below the soil surface where, in the improbable event of any spores being produced, they would have no potential as inoculum below the soil surface. If some conidia are formed at the soil surface there must be a susceptible blooming host in the vicinity. When seed is to be planted in an area/region where *C. africana* is already endemic, disease outbreaks, following windborne spread of inoculum from already present sources, are almost certain to occur provide conditions are favorable for disease development. Therefore, captan-treated seed should not be considered as a potential source of inoculum, especially in those regions where the pathogen is already endemic.

Biology of C. africana

In other collaborative work, D. Frederiksen determined that temperature and relative humidity clearly interacted to affect survival of conidia of *Claviceps africana* with greatest survival associated with low temperature (6°C) and low relative humidity (6%). Seed storage environments would be unfavorable for survival of conidia in sphacelia mixed with seed with most conidia expected to be dead within 15 to 20 weeks.

Susceptibility of macroconidia and secondary conidia of *C. africana* to UVB irradiation are similar and suggest that the windborne hyaline secondary conidia may remain viable over distances of 10s to 100s of Km. However, they are unlikely to survive travel over 100s to 1000s of Km like the pigmented rust spores. Disease spread over a large continent like North America would, therefore, be due to inoculum dispersal in a series of moderate "leaps" rather than one long distance dispersal event. It also negates the possibility of the initial origin in the western hemisphere as being due to windborne spread from Africa to Brazil.

Sclerotia of *C. africana* develop from within, and to the base of, sphacelia. The ergot fungal body may, thus, range from being entirely sphacelial to having a large proportion of sclerotial tissue present. However, sclerotia always have residual sphacelial tissue attached. Therefore, the sphacelia and sclerotia of *C. africana* should be thought of as different tissues of the same structure rather than entirely independent structures. A four-page pamphlet in both English and Spanish versions was published outlining the prominent features of sphacelia and sclerotia.

Host Plant Resistance

TAM-228 and Noe Montes are collaborating with T. Isakeit, J. Dahlberg, and others in evaluating commercial sorghum hybrids from Mexico and the U SA for susceptibility to sorghum ergot at several locations in Mexico and the USA. At some of the locations, sorghum heads were inoculated with *C. africana* at bloom initiation to provide a uniform level of inoculum for sorghums with different maturities. In 2000 tests at Corpus Christi, inoculum was provided to each hybrid until all primary heads had completed bloom. Even under this heavy inoculum pressure, only a few commercial hybrids, out of the 60 tested, developed any significant amount of ergot and these were the same hybrids that had shown vulnerability at this and other locations in previous years' tests. Late planted trials were also conducted at some locations to evaluate cool temperature pollen sterility and its effects on incidence and severity of ergot. A greater number of hybrids showed vulnerability under these conditions and information from at least two of these locations are being used to develop a more regionalized ergot prediction model. This model assumes the presence of inoculum and, thus, predicts or assesses the susceptibility of the host crop to infection by *C. africana* rather than predicting specific times of occurrence and spread of the pathogen.

Susceptibility to other naturally-occurring diseases is also being evaluated concurrently if they occur at sufficient severity at these locations.

Networking Activities

Chronology of Networking Activities (Primarily Sorghum Ergot-related)

September 23, 1996 - TAM-228 and TAM-224 were co-coordinators and co-moderators of an Ergot Awareness session held in conjunction with the International Conference on Genetic Improvement of Sorghum and Millet held in Lubbock, Texas. TAM-228 also made a presentation on Chemical Control of Sorghum Ergot.

Feb 19, 1997 - Continued Spread of Sorghum Ergot in the Western Hemisphere presented at Grain Sorghum Research and Utilization Conference in New Orleans, LA.

Feb 28, 1997 - Odvody, G. 1997. Chemical control of sorghum ergot presented at GSPA-sponsored ergot discussion session for industry, commodity and regulatory groups, and public scientists at Lubbock, TX.

March 15-16, 1997 - Biology and spread of sorghum ergot and opportunities for international collaboration presented to INIFAP scientists at Rio Bravo Experiment Station, Rio Bravo, MX. Sorghum ergot survey in Texas Department of Agriculture grow outs near Tampico, Mexico and enroute through northern Tamaulipas state.

April 7, 1997 - Appointed as member of Texas A&M University Sorghum Ergot Extension and Research Task Force.

May 1, 1997 - R.Velasquez-Valle initial INIFAP, Mexico scientist based at Corpus Christi May 1997-98 to conduct sorghum ergot research in Mexico and the U.S. Funding provided by USDA-ARS.

May 9, 1997 - Sorghum ergot survey and interaction with area farmers near San Fernando, MX.

May to June, 1997 - Ex-officio member of all subcommittees of the American Seed Trade Organization Ad Hoc committee on sorghum ergot.

May 16, 1997 - Sorghum Ergot in the United States presented at South Texas Country Elevators Association Conference, South Padre Island, Texas.

. June 1-7, 1997 - Presented a paper, chaired the Country reports session, and chaired the Working Group on Control and Management of Sorghum Ergot, and was appointed as INTSORMIL representative and chairman of the Global Steering Committee at the Global Conference on Ergot of Sorghum. Sete Lagaos, Brazil.

June 11, 1997 - Chemical control of Ergot in Sorghum Hybrid Seed presented at the U.S. Conference on Sorghum Ergot in Amarillo, TX.

July 2, 1997 - Presentations on the epidemiology and spread of sorghum ergot (R. Velasquez) and Chemical Control of Sorghum Ergot (TAM-228) were made at the symposium "Ergot (Cornezuelo), Situacion Actual y Problematica en Sorgo" held during the 24th National Congress of the Mexican Society of Plant Pathology, Obregon, MX

August 26, 1997 - Spread of Sorghum Ergot and Projected Research Areas (TAM-228) and Research Progress: Chemical control and alternate hosts (R. Velasquez) were presented at the II International INIFAP-TAMU-USDA/ARS Planning Conference on Sorghum Ergot. Rio Bravo, MX. Appointed to INIFAP/TAMU/USDA Steering Committee to develop collaborative sorghum ergot research between the USA and Mexico.

September 12, 1997 - Presentation on biology and spread of sorghum ergot in the Western Hemisphere and the USA at a Sorghum Ergot Review and Strategy meeting in Colwich, Kansas.

Nov 10-12, 1997 - Spread of sorghum ergot in the U.S.A. and Mexico (R. Velasquez) presented at APS Caribbean Division Meetings, in San Jose, Costa Rica.

November 20, 1997 - Spread and Importance of Sorghum Ergot in the Western Hemisphere presented at the Conference on Grain Sorghum for the 21st Century: Working Together as an Industry at Corpus Christi, TX.

December 9, 1997 - Sorghum Ergot in the U.S. and Mexico (R. Velasquez) presented at the 9th Annual Texas Plant Protection Conference in College Station, TX.

December 11, 1997 - Ergot - A New Threat to Commercial Sorghum Seed Production. presented at the 52nd Annual Corn and Sorghum Research Conference of the ASTA in Chicago, IL.

January 27, 1998 - Ergot of Sorghum - Update at the Texas Seed Trade Association Production and Research Conference in Dallas, TX.

February 5, 1998 - Sorghum Ergot. presented to 1st Annual South Texas Crop Management Technical Seminar

May 1, 1998 to July1, 1999 - Special INTSORMIL sorghum ergot project provided base funds for Dr. D. Frederiksen to conduct research on the biology of sorghum ergot at Texas A&M in collaboration with TAM-228.

June 23-24, 1998 - Local arrangements chairman for the INTSORMIL Principal Investigators Meeting and Impact Assessment Workshop held in Corpus Christi, TX.

June 24-26, 1998 - Local arrangements chairman, member of conference organizing committee, and oral presentation made in the control session of the Conference on the Status of Sorghum Ergot in North America held in Corpus Christi, TX.

June 24, 1998 - Ergot of Sorghum–A Global View. D. Frederiksen, Keynote address. In: Conference on the status of sorghum ergot in North America. Corpus Christi, TX.

June 26, 1998 - Organizer for SICNA South Texas Sorghum Nursery Field Day and Tour held in conjunction with the Conference on the Status of Sorghum Ergot in North America.

June 27 to July 5, 1998 - Hosted Medson Chisi, sorghum breeder and sorghum team leader from Zambia, to interact with other sorghum scientists in South Texas sorghum nurseries following INTSORMIL and Ergot conferences and to collaboratively evaluate sorghum cultivars in South Texas nurseries for future testing in Zambia.

July 27-28, 1998 - Member of a Texas Seed Trade Association delegation that visited Sanidad Vegetale officials in Mexico City to discuss Mexican seed import restrictions related to sorghum ergot in commercial sorghum seed from the USA.

September 10, 1998 - Participated in meeting of NC-501 project, Ergot: A New Disease of U.S. Grain Sorghum, Manhattan, KS.

October 18-22, 1998 - Odvody, G. N. and R. A. Frederiksen. INTSORMIL: Integrated Disease Management for Sorghum. Poster at National meetings of ASA,CCSA, and SSSA Baltimore, MD.

February 2, 1999 - Current Research on Sorghum Ergot of Special Relevance to the Sorghum Seed Trade (Including how to recognize sclerotia). D. Frederiksen, Invited Speaker at the Texas Seed Trade Association Production and Research Conference, Dallas, TX.

April 19-20, 1999 - Sorghum ergot training workshop at Sanidad Vegetale Headquarters in Mexico City. Noe Montes presented the sorghum ergot information at the workshop and provided translation for the other speakers.

April 29-30, 1999 - TAM-228 participated in a review of current and projected sorghum ergot research activities at a USDA-ARS sponsored review (S. Jensen) at Kansas City, MO.

June 1999 - Prepared slide text descriptions and pathogen summary for eight project slide images that became part of a new American Phytopathological Society slide set of emerging diseases that was released in mid-1999.

September 1, 1999 - Report of Texas A&M sorghum ergot research activities and progress for NC-501 (NC-227 after October 1, 1999) meeting in Lincoln, NE. Elected secretary of NC-227 September 1999-2000.

October 4-6, 1999 - Participated in USDA Review, Plant Diseases National Program Workshop, Beltsville, MD.

October 7, 1999 - Presented sorghum ergot seminar at USDA-ARS Research Lab, Ft Dietrick MD.

October 14, 1999 - Sorghum ergot training workshop at Rio Bravo Experiment Station, Rio Bravo, Mexico. TAM-228 and N. Montes.

October 26, 1999 - A web page was developed to display approximately 90 diverse images of ergot taken primarily by TAM-228. Images may also be saved offline for use in documents and related purposes. Many ergot images from this project continue to be used on several web sites.

January 25-27, 2000 - Sorghum ergot training workshop, N. Montes, Managua, Nicaragua sponsored by Monsanto, Inc.

April 1, 2000 - Dr. Debra Frederiksen established as consultant research scientist (TAM-228 support) stationed at the SADC/ICRISAT facilities on the Matopos Experiment Station, Zimbabwe.

Plant pathology discipline chairman of the Sorghum Improvement Conference of North America 1997-2001.

Member of USDA-ARS Sorghum Germplasm Committee, First appointed February 1997.

Member of organizing committee for the Global Review of Sorghum and Millet Diseases conference to be held in Mexico in September 2000.

Co-editor along with R. Frederiksen, TAM224, Compendium of Sorghum Diseases. Revised with expected publication by September 2000.

Member TAES Grain Sorghum Research Task Force, November 1998.

International Travel

TAM-228 PI traveled to Southern Africa for three weeks yearly in late March-April 1997-99 to evaluate nurseries and determine future collaborative research activities in the region. Locations visited included SMIP scientists and Zimbabwe national sorghum breeder in Bulawayo (Matopos), Zimbabwe; and collaborating scientists at PPRI/RSS in Harare, Zimbabwe; Mt. Makulu and Golden Valley Stations in Zambia; DAR in Sebele and Pandamatenga Stations, Botswana; and the sorghum pathologist and sorghum entomologist at Grain Crops Institute in Potchefstroom, South Africa.

Through Southern Africa Regional Program funds, TAM-228 sponsored N. McLaren of South Africa to travel with him during April 1999 through Zimbabwe and Zambia to establish collaborative linkages with scientists participating in the SADC regional ergot research project being led by McLaren. Similar travel was arranged for April 2000 but TAM-228 was unable to travel to Southern Africa. McLaren visited scientists and collaborators and evaluated collaborative disease nurseries at all locations in Zimbabwe, Zambia, and Botswana.

Germplasm Exchange

Over 500 lines and cultivars were evaluated yearly for response to various diseases, adaptation, drought response, and sugarcane aphid resistance in the SADC region (collaborative with TAM-222, B. Rooney, TAM-223, and TAM-224).

Publications

Journal Articles

Bailey, C. A., J. J. Fazzino, Jr., M. S. Ziehr, A. U. Haq, G. Odvody, and J. K. Porter, 1999. Evaluation of Sorghum Ergot Toxicity in Broilers. Poultry Sci. 78:1391-1397.

Bandyopadhyay, R., D. E. Frederiksen, N. W. McLaren, G. N. Odvody, and M. J. Ryley. 1998. Ergot: A New Disease Threat to Sorghum in the Americas and Australia. Plant Disease 82:356-367.

Dahlberg, J. A., G.. L. Peterson, G. N. Odvody, and M. Bonde. 1999. Inhibition of germination and sporulation of *Claviceps africana* from honeydew encrusted sorghum with seed treatment fungicides. Crop Protection 18: 235-238.

Frederiksen, D. E., E. S. Monyo, S. B. King, G. N. Odvody, and L.E. Claflin. 1999. Presumptive identification of *Pseudomonas syringae*, the cause of foliar leaf spots and streaks on pearl millet in Zimbabwe. Journal of Phytopathology 147:701-706

Isakeit, T., G. N. Odvody, and R. A. Shelby. 1998. First report of sorghum ergot caused by *Claviceps africana* in the United States. Plant Dis. 82:592.

Rodriguez, J. Gonzalez-Dominguez, J. P. Krausz, G. N. Odvody, J. P. Wilson, W. W. Hanna, and M. Levy. 1999. First report and epidemics of buffelgrass blight caused by *Pyricularia grisea*. Plant Disease 83 (4):398.

Velasquez-Valle, R., J. Narro-Sanchez, R., Mora-Noasco, and G. N. Odvody. 1998. Spread of ergot of sorghum (*Claviceps africana*) in Central Mexico. Plant Disease 82: 447.

Velasquez-Valle, R., F. San Martin, G. Odvody, y J. Narro. 1999 (1998). Reporte preliminar sobre especies del genero Claviceps asociadas a pastos en algunos estados de Mexico y Texas, EUA. Revista Mexicana de Fitopatologia 16(1): 42-45.

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Isakeit, T., R. Bandyopadhyay, G. N. Odvody, J. Dahlberg, and J. Narro-Sanchez. 1999. Reaction of sorghum hybrids to ergot in South and Central Texas, Puerto Rico and Guanajuato, Mexico T. p. 63 *In* Proceedings of the 21 Biennial Research and Utilization Conference. Tucson, AZ, Feb 21-24, 1999.

Odvody, G.N., D. E. Frederickson, T. Isakeit, J .A. Dahlberg and G. L. Peterson. 1999. The role of seedborne inoculum in sorghum ergot. Proceedings of 3rd International Seed Testing Association-PDC, Seed Health Symposium, August 16-19, 1999. Ames, IA. p. 136-140.

Odvody, G. N., T. Isakeit, N. Montes, J. Narro-Sanchez, and H. Kaufman. 1999. Occurrence of Sorghum Ergot in Texas and Mexico in 1998. p. 62 *In* Proceedings of the 21st Biennial Research and Utilization Conference. Tucson, AZ, Feb 21-24, 1999.

Miscellaneous Publications

Frederickson, D., G. Odvody, and N. Montes. 1999. El ergot del sorgo, Diferenciación de los esfacelios y los esclerocios de *Claviceps africana* en la semilla. L-5315S, 7-99 5 p. Texas Agric. Ext. Svce.

Odvody, G., R. Bandyopadhyay, R. Frederiksen, T. Isakeit, D. Frederickson, H. Kaufman, J. Dahlberg, R. Velasquez, and H. Torres. 1998. Sorghum Ergot Goes Global in Less Than Three Years. APSNET feature article for June 1998 published online.

Sustainable

Production Systems

Economic and Sustainability Evaluation of New Technologies in Sorghum and Millet Production in INTSORMIL Priority Countries

Project PRF-205
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Summary

Programs for food crops in semiarid Sub-Saharan Africa often focus on one-input, low farmer-expenditure solutions. Miracle varieties, manure, rock phosphate, and compost heaps are some of the recent recommendations. Across African countries only, where new sorghum/millet cultivars were combined with increased water availability and moderate levels of inorganic fertilizers, did the successful diffusion of new cultivars lead to increased aggregate yields. There are substantial differences in the types of water-retention/soil-fertility strategies in different soil types from the sandy dune soils to the soils with some clay, and hence crusting, to the heavy vertisols with drainage problems. On the heavier soils, substantial yield increases are possible with water-retention techniques done within the crop season, such as ridging, tied ridging, improved land preparations, combined with inorganic fertilizers. The other approaches to soil fertility (especially manure, crop residues, and rotations of cereal/legumes) are useful complements to the inorganic fertilizers, but cannot substitute for them in providing sufficient quantities of the two basic nutrients of N and P.

Objectives, Production, and Utilization Constraints

Objectives

The general objectives of this research are:

- To estimate the potential effects of new technologies
- To identify the constraints to their introduction
- To recommend complementary policies to accelerate the introduction process.

In this condensation of activity from July 1996 until July 2000, we report on five of our principal research themes: a) impact of new cultivars and associated technologies in Sub-Saharan Africa, b) alternative water-retention/soil-fertility increasing technologies on different types of soils, c) technologies and other determinants of the income and welfare of women, d) consumption and production consequences for sorghum-millet of the devaluation of 1994, and e) evolution of the input markets.

Research Approach and Project Output

New Sorghum/Millet Cultivars and Associated Technologies

With growing expertise in national and international breeding programs, a large number of new cultivars have been successfully released in Sub-Saharan Africa. In the mid-'90s, ICRISAT estimated that 40 sorghum cultivars had been released in 23 countries and 16 millet cultivars in 12 countries (1998 Annual Report of INTSORMIL, p. 60). So the breeders have been doing their job.

Two important questions are the extent of diffusion and, therefore, the rate of return to the research and then the overall effects on aggregate yields. To respond, we reviewed the performance of new sorghum/millet cultivars in seven Sub-Saharan countries over the last decade.

The focus has been on open-pollinated, short-season cultivars. Rainfall has been approximately one standard deviation below the long-term normal from 1967 to the present. One problem with short-season cultivars is that this risk-reduction technique also leads to lower potential to respond to higher input levels in normal or good rainfall years. The short-season cultivars were generally utilized as part of portfolio diversification, so they did not entirely displace traditional cultivars.

Of the seven cases of new cultivar introduction, five were short-season cultivars (Table 1). Sorghum area diffusion for these cultivars ranged from 26 to 37%. Rates of return on research were marginal in most of these cases, except in Zimbabwe. The costs of the research were not high. However, the benefits of cultivar alone, generally without fertilization, were not great either.

In the two other cases in the irrigated regions of Sudan and drylands in South Africa, medium-length cultivars were introduced and fertilization levels increased. In Sudan, in spite of the low total area of diffusion due to the lack of sufficient seed supply and inadequate access to inorganic fertilizer, returns to research were reasonably high. Here the combination of moderate levels of inorganic fertilizer and the new cultivar approximately tripled yields. In South Africa, farmers take advantage of a sub-surface crust at 1 to 2 meters depth. By controlling weeds and cultivating in the off season, they store water and then use moderate fertilization to get yields with substantial variability but generally between 2 to 3 t ha^{-1}.

The bottom line for new cultivar introduction is what happens to aggregate yields. During the past two decades, sorghum and millet output expansion have been dependent upon area expansion in Sub-Saharan Africa as aggregate yields have been declining. Over the 1980 to 1996 period, yield declines were -0.8% for sorghum and -0.7% for millet. (Ahmed, Sanders, and Nell, 2000, p. 59).

With increasing population density, fallow systems have been breaking down. Due to governmental price distortions to keep food prices low for urban consumers and the failure to utilize demonstration trials to show farmers the potential of new technologies with purchased inputs, there has been little substitution for the disappearing fallow system with increased input purchases. Hence, nutrients have been mined, soils depleted, and cultivation of the basic cereals pushed into former grazing areas even more marginal for agriculture.

For these seven countries, where there has been significant introduction of the new sorghum-/millet cultivars, what has happened to aggregate yields? In the Sudan, mechanized dryland sorghum yields (with some new cultivars but without fertilization) have fallen from approximately 1 t ha^{-1} to 600 kg ha^{-1}. In contrast in the irrigated area, yields have increased from 1.3 -1.5 t ha^{-1} to 2 t ha^{-1} over the same period (Ahmed, Sanders, and Nell, 2000, p. 60). On the drylands of the other countries evaluated only South Africa has substantially increased its aggregate yields. Yields in these countries stagnate at less than 1 t ha^{-1} while yields in South Africa though very erratic range from 1.5 to 3 t ha^{-1}.

In conclusion, cultivar-alone strategies may give temporary yield increases or be useful in portfolio diversification to reduce the risk of poor crop seasons. However, they do not provide large yield gains in most years and they mine the soil nutrients, so they are not sustainable. Combining new cultivars with water-retention techniques of some type and with moderate fertilization did make a significant difference in yield increases in both South Africa and the Sudan. These improved systems are also more sustainable as major soil nutrients are being replaced.

Governments in Sub-Saharan Africa need to move away from a focus on maintaining low urban food prices, and be more concerned with the profitability of food production, and with conserving their natural resources from nutrient depletion and other soil degradation effects of the extensification process (area expansion while mining soil nutrients).

Water Retention/Soil Fertility

The principal constraint to increasing yields in semiarid regions is implied by the description of the region: lack of water at the appropriate times. A series of techniques are

Table 1. Selected characteristics of the successful new sorghum and millet cultivar introductions.

Cultivar[1]	Country	Year of release	Season length	Current adoption[2]	Internal rate of return	Change in input use
HD-1 (S)	Sudan	1983	Medium	17% (1993)	36% (low fertilization)	Fertilization (irrigated area
S-35 (S)	Cameroon Chad	1986 1989	Short	33% (1997) 27% (1997)	2% (1994)	No change observed
SV-2 (S)	Zimbabwe	1987	Short	36% (1995)	18%	No change observed
Zambian cultivars[3] (S)	Zambia	1987-1993	Short, medium, and long	35% (1996)	12%	Fertilized only on large farms
PMV-2 (M)	Zimbabwe	1991	Short	26% (1995)	31%	No change reported
Okashana-1 (M)	Namibia	1990	Short	35% (1993)	13%	No change reported
NK-283 (S)	South Africa	Unknown	Medium to long	50-70% (1998)	NA	Fertilization and water retention

[1] Sorghum and millet, respectively, are identified by the letters S and M in parentheses.
[2] Latest available information with the year in parentheses.
[3] Include two hybrids and three open-pollinated cultivars of which Kuyuma and Sima (released in 1989) and MMSH-928 (released in 1993) are the most widely adopted.

Sources: Anandajayasekeram et al., 1995; Ahmed, 1996; Ahmed and Sanders, 1992; Chisi et al., 1997; Sanders et al., 1994; and Yapi et al., 1997.

utilized to make more water available on the heavier (some clay) crusting soils, including the traditional zaï, bunds or dikes, the higher-yielding tied ridges, better land preparation, and watershed management methods. On the sandy soils, where infiltration is the principal problem, there is an even wider range of methods to slow the flow of water within the soil. On very heavy soils, such as vertisols, water-retention techniques can lead to excessive water and the consequent need to knock down these devices. Nevertheless, whether the problem is infiltration, crusting and excessive runoff, or drainage, the initial problem of regions with insufficient rainfall (the definition of semi-arid) is increasing the availability of water at the critical periods of plant growth.

Once more water is made available, the return to fertilization is increased and its riskiness reduced. As with water availability, there are a wide range of techniques. Manure, crop rotation, and local rock phosphates are widely recommended especially for crops primarily grown for home consumption. When the subsidies were taken off inorganic fertilizers in the '80s, techniques for increasing organic matter from crop residues and for maintaining the quality of manure (covered compost heaps) were diffused across the Sahel. Unfortunately, basic nutrient levels of N and P are too low in manure and the rock phosphate is too insoluble (except in acidic, higher rainfall regions). So these intermediate solutions to soil fertility improvement have not been very effective and detract attention from the need to utilize inorganic fertilizers to provide the principal plant nutrients. Without these basic nutrients (N and P) on a sustained basis, any cropping system is unsustainable.

Combining the organic with inorganic fertilizers can increase the water and nutrient-holding capacity of the soil, increase the biological activity, and provide other nutrients. However, there is no substitute for the soluble inorganic fertilizers. Poor countries and food crop producers need to be using them or yields stay low and soils continue to degrade. Low inputs result in low outputs and the continuation of poverty and malnutrition.

Presently, fieldwork and modeling are being undertaken in Mali, Senegal, and Niger to evaluate the potential profitability of inorganic fertilizers often combined with new cultivars. This research focuses on identifying constraints to a more rapid diffusion of these technologies. In Mali, the water-retention device of ridging (without the tying) is widely practiced. In Niger, millet producers in several regions have begun mixing small quantities of inorganic fertilizers with their seed before putting both in the holes. In Senegal, there is domestic, inefficient production of inorganic fertilizers. Removing the protection decreases the fertilizer price and increase farmers' incomes in the peanut zone by 14% (Mamadou Sidibe, thesis research).

Another central component of this research is the identification of agricultural and economic policies to accelerate the introduction process. Three central economic problems for sorghum-millet technology diffusion have been identified: the between-year price variability, the seasonal price fluctuation, and the liquidity problem. Most food staples face inelastic demands (with respect to price) so in years with normal or good weather, prices rapidly decline or collapse. Technology introduction can accelerate this price decline process. Technology development for food staples then needs to be accompanied with research on processing and alternative uses.

Much of the technology developed for wheat and rice can be adapted to millet and sorghum in the Sahelian countries. Notable examples are the couscous of millet and the parboiling technique for sorghum. The former technique for couscous is principally used for wheat and the latter for rice. Processing equipment and small-scale cereal processors have been increasing rapidly in Senegal and interest is spreading to other Sahelian countries. The big demand shifter for the cereals will be their use in feed. The poultry revolution is just getting underway in Sub-Saharan Africa and has led to very rapid demand growth for cereals for feed in other developing countries. African countries need to be anticipating these demand shifts or they will require large feed imports in the near future (next five to ten years).

Another price problem is the post-harvest price collapse. Farmers often have a pressing cash requirement for family emergencies, ceremonies, marriages, educational expenses, and loan repayments, forcing them to sell at the seasonal low prices after harvest. Farmers also have a requirement to put aside grain reserves for family consumption and will pay a fairly high risk premium to avoid being dependent upon grain purchases later in the season (unpublished field data from Mali, Senegal, and Niger). Also, there are village pressures to share grain stocks in excess of anticipated family requirements with the needy. For all these reasons, farmers find it difficult to hold their cereals to take advantage of the within-season price recovery. This price variability is often substantial and can mean the difference between higher input use being profitable or not. Over the last decade in Mali, a 35% seasonal price variation for sorghum has been estimated (Jeffrey D. Vitale, unpublished data).

To develop policy alternatives, our field research in Niger has been studying the income sources and consumption patterns of farmers, including the performance of a recent FAO pilot project, which has been pooling part of the farmers' grain production in a community stock, selling them when the price recovers and buying fertilizers for sale in the village at profit.

Finally, the most frequent hypothesis to explain the failure to intensify production of cereals with higher input levels is the lack of credit. The assertion that farmers do not have capital to invest in divisible inputs, such as fertilizer and new cultivars, is not consistent with our data on consumption, income, and capital stocks of the small farmers in Niger, Senegal, and Mali. Farmers put their capital in animals, which they then cash in for pressing expenditures.

They have many sources of family income. Unfortunately, farmers are often not convinced that the new technologies are sufficiently profitable at the levels of risk they are willing to take. Hence, the problem is not the supply of credit but the demand for the new technologies based upon farmers' perceptions of the returns and riskiness of the new technologies.

In summary, the principal barriers to the adoption of new cereal technologies appear to be the opportunity of seeing them in the field, reducing the seasonal price variability, and expanding the demand for cereals. Appropriate policy recommendations are then farm-level demonstrations, village storage programs for the cereals, and public and private investments in processing of cereal food and feeds.

Technologies and Other Determinants of Income of Women

A major concern in technology development was raised in the Women in Development literature. Are women in African agriculture made worse off by the introduction of new technologies? After substantial fieldwork in southern Mali and the continuation of modeling in Burkina Faso, three Ph.D. theses in this project have been completed, specifically focusing on technology and other factors influencing the incomes of women.

A predominant belief is that with the traditional social patterns, the household head can exploit his wives and capture all the gains of new technologies. In Mali in five villages with three ethnic groups, the within-family economic organization functioned as in any other labor market. When higher levels of new technology were introduced on the plots collectively farmed by the family, the household head had to pay higher wages to the wives. However, these wage increases were small compared to the time reduction on the private plots of the females. Reduced time on these plots results in a lower value of output, which the women can sell. So the net effect of these two changes was a welfare reduction for the women.

There is a third change of the welfare effect on women from the increased household income. In the calculation of wage gains to women, the value of gifts of food and clothing were included as wages. Nevertheless, the increased income to the household head may have resulted in other expenditures by him benefitting women and children. Further analysis of income sources and consumption expenditures by various family members is presently underway in Niger.

Technological change results in increased income streams; those with greater bargaining power have advantages in capturing a larger share. There are several institutional changes underway in the region to contest the increased income flows resulting from these new technologies. First, the movement from extended to nuclear families is one response to the income concentration for the household heads. This movement to nuclear families is more advanced in East and Southern Africa but is getting underway in West Africa. This family organization shift does not necessarily benefit women but would affect male household members.

Secondly, traditional gender workgroups have been changing their methods of operation. These groups perform seasonal agricultural operations for a fee and benefit from the increased value of output and the higher seasonal labor demands with technological change. Previously, these workgroups would accumulate funds to pay for a village social function. Now members are demanding individual wage payments from the group fees.

Shifting attention to the within-household decision making based upon the Burkina Faso research: In societies at the subsistence level, very authoritarian decision-making to produce and save a cereal surplus would be expected. Over time with new income streams, increased competition for income and for making decisions would be expected within the family. Where bargaining occurs in within-house decision-making, agricultural technologies increase the income of women by 29% and the combined agricultural and household technologies increase income by 68%, according to model results (1999 Annual Report of INTSORMIL, p. 57). Nevertheless, the introduction of household technologies benefitted women even where there were exploitative household heads. In these cases, the women did not obtain income increases from the introduction of agricultural technologies.

The econometric results from Mali also give some guidelines for policies to increase the bargaining power of women and, thereby, push faster toward family decision-making of the bargaining type. Measures to increase the opportunity costs of women, such as increased education and job opportunities, have been shown to significantly increase the within-household wages paid to women.

In summary, extended families function internally as any other economic unit but as yet the wives have very little bargaining power. This is in a process of change as institutions evolve to contest the new income streams from technological change. Meanwhile, priority measures identified to increase the income of women are 1) raising their opportunity costs and thereby their bargaining power, 2) introducing household technologies, and 3) continuing the rapid introduction of technological change in agriculture for the households.

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[1] In the second half of the '80s, there was a sharp decline of the world prices of cocoa, coffee, cotton, and petroleum.

Consumption and Production Effects of the 1994 Devaluation on the Sorghum/Millet Sector

The 14 African members of the French monetary union (CFA zone) had a fixed exchange rate with France for almost 50 years. On Jan. 12, 1994 after a decline of 50% in their terms of trade[1] since the mid-'80s, they devalued the CFA by 50%. Devaluation makes imports more expensive and exports more profitable.

Production effects[2] of devaluation are on input and product prices. For some time, many Sub-Saharan countries have overvalued exchange rates and implemented other policies to subsidize imported cereals and maintain low domestic prices for their basic cereals. Devaluation first increases the prices of agricultural inputs, including inorganic fertilizers and pesticides. The favorable effect for agriculture is that it will also increase the prices of imported cereals, especially rice and wheat. To the extent that the traditional cereals are substitutes for imported cereals, the prices of traditional cereals will increase. Since cereals are bulky, hence expensive to import, there should be a comparative advantage for local cereal production once domestic subsidies are removed.[3] With a lag, the price of traditional cereals has increased faster than inorganic fertilizer prices in southern Mali. By 1996, there was an increased economic incentive to farmers for more intensive production. Modeling results indicated that at these relative prices, farmers would fertilize small areas of sorghum (see INTSORMIL Annual Report 18). Once the diffusion process is started, it is expected to accelerate as farmers observe the gains from improving soil fertility.

On the consumption side, the changes in household consumption of cereals before and after devaluation were evaluated in urban Bamako. When rice was separated into imported and domestically produced, the econometric results clearly showed substitution between imported rice and domestically produced sorghum. There were only small changes in actual consumption patterns as the removal of the tariffs on rice offset the devaluation effect. Rice tariffs were reduced from 100% to 11% over the period so the rice price relative to the traditional cereals actually declined (see INTSORMIL Annual Reports 19 and 20). The next round of devaluation would be expected to have a much larger effect on these relative cereal prices, resulting in larger increases in traditional cereal consumption.

In summary, devaluation offers more favorable opportunities to the traditional cereals by increasing the incentives for intensive production (inorganic fertilizers), and removing some of the price distortions that encourage the substitution of imported cereals for the traditional cereals.

Evolution of the Input Markets

One principal effect of the privatization process of structural adjustment programs of the last two decades has been the elimination of public-sector seed production. In some cases, as in Ethiopia, these agencies survive but are instructed to maximize profits and they imitate the private sector. As a consequence, an important barrier to new technology introduction for the traditional cereals is often the availability of sufficient quality seed, especially as the diffusion process accelerates. This was especially clear with introduction of Hageen Dura-1 in the irrigated zones of Sudan in the early '90s. There, 52% of the farmers interviewed (including adopters and non-adopters) said that they either could not get enough seed (21%) or not get as much as they wanted (31%) (Nichola Tennassie and John H. Sanders, "The Seed Industry and the Diffusion of a Sorghum Hybrid," Science, Technology, and Development, 15 (Aug./Dec. 1997), p. 262).

To fill this vacuum, the predominant approach has been to utilize NGOs to undertake community seed production. This approach neglects the skill and quality-control elements needed in the long run for maintaining high-quality seed production. Incentives for new private activities in seed production, trademarking to make producers responsible for quality, and the public-sector production of orphan crops are all alternatives and perhaps complementary operations to improve the performance of the seed sector.

Networking Activities

Support to Students from African Organizations

The main networking of this project is the support of students from African institutions for long-term graduate study. From July 1996 to July 2000, this project and associated funding have always been supporting four or five graduate students. These grad students are selected principally from the agricultural research institutes of their countries and do their thesis research in their own countries. Their research topics are developed in collaboration with their institutes and with other regional and international organizations working in the area. Principal benefits are their degrees and the long-term working relationships with these groups. To date most of our students have gone into international organizations, especially the IARCs, but they are still predominantly working in Africa. Program graduates are presently in Zimbabwe (Rockefeller Foundation), Mali (ICRISAT, IER), Benin (IITA), Ethiopia (ILRI), and Colombia (CIAT). A higher proportion of the next generation of students is expected to return to their national agricultural research institution.

[2] There is a need to intensify traditional cereal (sorghum and millet) production as the soil exhaustion process accelerates in traditional production zones with the breakdown of the fallow system. Rather than increased purchase of inputs to improve soil fertility, the predominant farmer response has been further movement into more marginal zones for crop production. So the nutrient-mining and soil degradation process is being extended into even more marginal soil regions.

[3] Removing the subsidies of developing countries on imported cereals is only half of the process. In developed countries, the predominant form of competing for trade shares is with export subsidies. Having foreign countries subsidize your food consumption is a good thing if you can anticipate how long they will do that and be prepared for the shock when the cereal war is over.

Participation in Networks, Conferences and Other African Activities

During the past four years we have been participating in conferences and workshops. We presented papers from our research in workshops of the West African Sorghum Network, the Millet Network, the University of Hohenheim conference in Niger, IFDC-West Africa, the African Farm Management Association, the seed workshop in Niger, and IFAD. All of the above were held in Africa. Other presentations of our work were made for IFPRI and for the Ambassador-Designate to Burkina Faso and his team (both in Washington, DC), the International Association of Agricultural Economists (Sacramento), the American Agricultural Economists Association (San Antonio), the European Agricultural Economics Association (Edinburgh, Scotland), a conference on Global Agriculture (Iowa), a World Bank-American Society of Agronomy Symposium (Baltimore) and for two Universities in South Africa (in Bloemfontein and Pietermaritzburg).

Research Investigator Exchanges

Sanders spent time in Senegal in training ISRA staff in undertaking impact studies and participating in the Technical Committee's review of the performance of the national research agency, ISRA. Sanders and Jeff Vitale taught a one-week course in Impact Assessment in Ghana. Vitale spent two summers at IER working on his research and doing training programs for them in programming. During much of the fall of 1999 and the winter of 2000, Sanders directed a multi-disciplinary team in a study for IGAD of the potential impact of new technologies in the semiarid regions of six countries in the Horn.

We have continued distributing copies of our 1996 book, The Economics of Agricultural Technology in Semiarid Sub-Saharan Africa, to African professionals. At the present time 243 have been sent.

Publications and Presentations

Journal Article

Ahmed, M.M., J.H. Sanders, and W.T. Nell, 2000. New Sorghum and Millet Cultivar Introduction in Sub-Saharan Africa: Impacts and Research Agenda. Agricultural Systems 64(1):55-65.

Published Proceedings

Sanders, John H., 2000. The Economic Potential of the Agricultural Sector in the Sahel. *In* Energy Supply, Economic Pillars of Rural Sahelian Communities, Need for Revised Development Strategies, proceedings, 12th Danish Sahel Workshop, Jan. 3-5, Hanne Adriansen, Anette Reenberg, and Ivan Nielsen (eds.). Copenhagen, Denmark: SERIEN (Sahel-Sudan Environmental Research Initiative), Occasional paper No. 11, pp. 39-52.

Sanders, John H., and Jeffrey D. Vitale, 1999. Developing Technology for Agriculture in Sub-Saharan Africa: Evolution of Ideas and Some Critical Questions. *In* Farm and Farmer Organisation for Sustainable Agriculture in Africa, proceedings of fourth biennial conference of the African Farm Management Association, Jan. 26-30, 1998, University of Stellenbosch, South Africa, pp. 102-115, Johann Laubscher (ed.) Harare, Zimbabwe, African Farm Management Association (AFMA).

Sanders, John H., 1999. Availability and Adoption of Improved Technologies in the Semiarid and Subhumid Zones of West Africa. *In* Linking Soil Fertility Management to Agricultural Input and Output Market Development: The Key to Sustainable Agriculture in West Africa, Miscellaneous Fertilizer Studies No. 16, Siegfried K. Debrah and Willem G. Koster (eds.). Lomé, Togo: IFDC.

Sanders, John H., and Jeffrey D. Vitale, 1999. Structural Adjustment and Technological Change in West African Cereal Production. *In* Linking Soil Fertility Management to Agricultural Input and Output Market Development: The Key to Sustainable Agriculture in West Africa, Miscellaneous Fertilizer Studies No. 16, Siegfried K. Debrah and Willem G. Koster (eds.). Lomé, Togo: IFDC.

Miscellaneous Publications

Sanders, John H., and Ridley Nelson, 1999. Burkina Faso Agricultural Research Project and Agricultural Services Project, Performance Audit Report, World Bank, Operations Evaluation Dept., June 24.

Sanders, John H., and Mohamed Ahmed, 1999. Developing a Fertilizer Strategy for Sub-Saharan Africa. World Vision Food Security Program Newsletter, Jan.-Apr., 11-16.

Presentations

Sanders, John H., and Mohamed Ahmed, New Sorghum and Millet Cultivar Introduction in Sub-Saharan Africa: Impacts and Research Agenda, presented to the West African Sorghum Network Workshop in Lomé, Togo, April 1999.

Sanders, John H., Burkina Faso Agriculture: Problems and Prospects, presented to the Ambassador-Designate to Burkina Faso and his support staff at the Mission and in the State Department, Washington, DC. August 1999.

Cropping Systems to Optimize Yield, Water and Nutrient Use Efficiency of Pearl Millet

Project UNL-213
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Mr. Pale Siebou, IN.E.R.A., Koudougou, Burkina Faso

Summary

Research in Mali and by the West and Central Africa Pearl Millet Research Network (ROCAFREMI) indicates 3 to 31% grain and stover yields increase to crop rotation with cowpea or peanut across the region, while other production practices appeared to be more site specific. Crop rotation increase of pearl millet stover yields increases the potential for soil maintenance through crop residue management. This research also showed grain yield increases to application of both organic and inorganic fertilizers, but inorganic fertilizer by itself, or preferably in combination with organic fertilizer, was essential to produce the highest grain yields.

Studies on management of profusely tillering, late maturing Maiwa pearl millet in southern Niger indicated that altering the plant population or harvesting tillers at 65 and 85 days after planting had no effect on grain yield. Harvesting tillers at 65 days after planting provides about 250 kg ha^{-1} of quality livestock feed near the beginning of the cropping season when feed is normally in short supply.

Pearl millet shows potential as an alternate grain crop in the dry, short growing season regions of the Great Plains. Planting date studies indicate a recommended date of June 1, but that it has a large window for planting from May 1 until June 17 without large decreases in grain yield, making it a viable alternative for an emergency crop or to use as a double crop. Narrowing row spacing from 76 to 38 cm increases grain yield by 13 to 15% in both eastern and western Nebraska, and increases the crop competitiveness with weeds. Except in very dry years, pearl millet requires approximately 78 kg ha^{-1} nitrogen fertilizer application to produce optimum grain yields.

Since 1996, graduate education has been provided for students from Burkina Faso, Mali, Mexico, Niger and the USA., increasing the human research capital in each country. This has been supplemented with mentoring of former students upon return to their countries, short-term training, and support of the West and Central Africa Pearl Millet Research Network through workshop presentation and active

participation in agronomy research, data analysis, and report/publication preparation.

Project scientists have been active participants in extension/technology transfer in collaborating countries along with national extension programs and NGO/PVOs, especially in Mali and Burkina Faso. This includes adoption of improved cultivars, intercropping practices, fertilizer application, and use of manure. Eight extension bulletins have been released.

Research indicated that plant breeding efforts to produce high yielding grain sorghum genotypes that are tall, or have high vertical leaf area distribution, would result in plants better able to compete with weeds, and be a useful component of integrated weed management programs.

Research also determined that ethylene is essential for early grain sorghum seedling vigor and growth. The genotypes Naga White, CE 145-66, PI 550590, and San Chi San are either tolerant or resistant to temperature stress during germination and emergence, and would be useful in plant breeding programs to improve temperature stress tolerance. An ethylene inhibitor bioassay using 2,5-Norbornadiene was developed that should be a useful genotype screening tool for seedling vigor response to temperature stress.

Objectives, Production and Utilization Constraints

Objectives

- Conduct long-term studies to determine pearl millet/cowpea cropping systems (monoculture, intercropping, rotation) by nitrogen rate interaction effects on grain and stover yields, and nitrogen use efficiency at Cinzana and Koporo, Mali, and Kamboinsé, Burkina Faso.

- Conduct long-term studies to determine the influence of crop residue removal, incorporation, and retaining on the surface on grain and stover yield of pearl millet, and the long-term effects on soil nutrient levels.

- Initiate research on adaptation, production practices, and grain quality for population hybrids in West Africa.

- Actively participate in the West and Central Africa Pearl Millet Research Network (ROCAFREMI) agronomic research and annual meetings in West Africa.

- Develop production practice recommendation for long-season Maiwa pearl millet production for grain yield while harvesting tillers for livestock feed in southern Niger.

- Determine the planting date and row spacing recommendation for dwarf pearl millet hybrid production in eastern and western Nebraska.

- Determine the relative competitive ability of grain sorghum and pearl millet with velvetleaf and the effect of velvetleaf competition on growth of grain sorghum genotypes.

- Determine the role of ethylene in grain sorghum emergence problems under stress inducing temperatures, identify bioassays for emergence under cold and hot temperatures, and identify germplasm useful for plant breeders to use in developing improved cultivars for emergence under cold and hot soil conditions.

- Initiate grain sorghum and maize hybrid comparisons for hybrids from the 1950s, 1970s and 1990s under low and high water holding capacity soils, wide and narrow rows, and dryland and irrigated environments.

- Increase research human capital in West African countries where pearl millet is an important crop through graduate education, short-term training, mentoring former students upon return to their home country, and active participation in the West and Central Africa Pearl Millet Network.

- Collaborate with national extension services and NGO/PVOs in transferring improved pearl millet agronomy practices.

Constraints

This project has focused primarily on crop production systems which increase the probability of obtaining higher pearl millet grain and stover yields. This involves systems which increase nutrient and water availability to growing crops, and produces desired uniform stands. Present efforts emphasize crop rotation, intercropping, inorganic and organic fertilizer, and residue management interactions with traditional and improved cultivars. These cropping systems research efforts require long-term investments of well-trained, interested scientists and stable funding. Education of additional scientists in crop production and continued support of their work after return to their home countries is needed to improve productivity of cropping systems and to maintain the soil/land resource.

Research Approach and Project Output

Pearl millet is usually grown in stressful environments with high temperatures, lack of predictable water supply, fragile soils with low nutrient status, and limited growing season length. Lack of water is usually considered to be the most critical environmental factor controlling growth and limiting yield in Africa, but a source of nitrogen and/or phosphorus often is more critical. This is especially true for intensive cropping systems using improved cultivars on degraded land. Nutrient use and water use efficiencies are closely interwoven with higher yields possible with improved cropping systems utilizing improved cultivars. Since human capital for research and extension activities are very limited for pearl millet producing areas in West Africa, project activities are generally conducted either as graduate education programs for scientists from this region, mentoring collaborative activities upon return of former graduate students, or collaborating with the pearl millet research network (ROCAFREMI). In the U.S. Great Plains, production practice recommendations for high yielding, dwarf hybrids, and development of markets are important to adoption as a grain crop. This complex interaction of water, nitrogen, phosphorus, cultivars and yield enhancing production practices is the focus of Project UNL-213's research efforts. Since grain sorghum is important in many pearl millet grain producing areas, additional research on temperature stress effects on grain sorghum emergence, weed competitiveness, and comparison to potential production of dryland maize has been or is being conducted.

Domestic (Nebraska)

Hybrid and Nitrogen Influence on Pearl Millet Production in Nebraska: Yield, Growth and Nitrogen Uptake and Nitrogen Use Efficiency (Nouri Maman, M.S. Thesis)

Research Methods

A two-year field study was conducted in 1995 and 1996 at Mead, NE with a factorial combination of the pearl millet dwarf hybrids 59022A × 89-0083, 1011A × 086R, and 1361 × 6Rm and nitrogen rates of zero and 78 kg ha^{-1}. Two plants were sampled bi-weekly, partitioned into plant parts, dried, weighed, and analyzed for N and P concentration. From these measurements growth, N and P uptake, and N use efficiency were calculated. In addition, studies were initiated in the Year 2000 to determine the effect of water stress at different growth stages on grain yield and yield components, and to determine dryland nitrogen fertilizer application rate recommendations.

Research Results

Applied nitrogen increased grain yield by 0.4 to 0.5 Mg ha^{-1}, but had only a small effect on dry matter accumulation and partitioning. Hybrid differences were small for grain yield. Pearl millet dry matter accumulation increased cubically in both years, with maximum crop growth rates ranging from 0.48 to 0.57 g m^2 growing degree day in 1995 and 1.9 to 3.1 g m^2 growing degree day in 1996. The relative growth rate among hybrids declined from 0.012 to 0.020 g /g/growing degree day in both years to near zero at physiological maturity. Applied nitrogen decreased the biomass nitrogen use efficiency by 18 to 23 g dry matter/g of nitrogen, and grain nitrogen use efficiency by 7 to 12 g dry matter/g of nitrogen. Environmental variability due to years had a greater effect on pearl millet yield, growth and nitrogen concentrations than did hybrid and applied nitrogen.

Grain Sorghum and Pearl Millet Competitiveness with Velvetleaf, and Effects on Interception of Photosynthetically Active Radiation (PAR) and Growth of Grain Sorghum (Augustin Limon Ortega, M.S. Thesis and Samba Traore, Ph.D. Dissertation Research)

Research Methods

Studies of weed interference in grain sorghum and pearl millet are limited and have focused primarily on proportion of species, spatial arrangement of the crop, and timing of weed removal. Improved knowledge of competitive ability and crop growth in response to weed interference could contribute to selection of cultivars with greater competitiveness with weeds. Competitive ability of pearl millet hybrid 79-2068A/NPM-1 and grain sorghum hybrid DK28 with velvetleaf (*Abutilon theophrasti* Medic.) was studied in 1994 and 1995 at Mead, NE at row spacings of 38 and 76 cm and nitrogen levels of zero and 78 kg ha^{-1}. Differences in grain sorghum hybrid grain yields, growth, and velvetleaf growth and seed production were evaluated in field experiments at Mead and Lincoln in 1996 and 1997. Sorghum hybrids used were FS2 (tall), and DK54 and X260 (medium height). Weed treatments included grain sorghum in monoculture, sorghum kept weed-free for two weeks after emergence, and sorghum and velvetleaf grown in mixture for the entire season.

Research Results

Yield losses of grain sorghum in 1994 and 1995, and pearl millet in 1995 were described by a nonlinear model based on a rectangular hyperbola. As weed biomass approached zero, grain yield reduction of both crops was similar and they were equally competitive. Narrow rows increased yield by 0.8 to 1.1 Mg ha^{-1} over wide rows and increased competitiveness of both crops with weeds. Weed competition decreased all yield components, especially the number of kernels per panicle. Nitrogen fertilizer increased pearl millet grain yield by 1.2 Mg ha^{-1} in 1994, but did not affect yield in the dry 1995 growing season.

Medium height hybrids had greater leaf area indices (LAIs) and leaf area ratios (LARs) throughout the growing season than the tall hybrid, and intercepted more PAR during the early part of the growing season. However, the tall hybrid had a greater carbon exchange rate during the early growing season. Interception of PAR was different among hybrids from anthesis until maturity, likely due to the 30 to 70 cm greater height and 20 to 40 cm higher vertical leaf area distribution of the tall hybrid compensating for the lower LAI (Figure 1). Grain sorghum hybrids intercepted more PAR and produced more biomass in absence of velvetleaf than in mixture, but the reduction in growth in

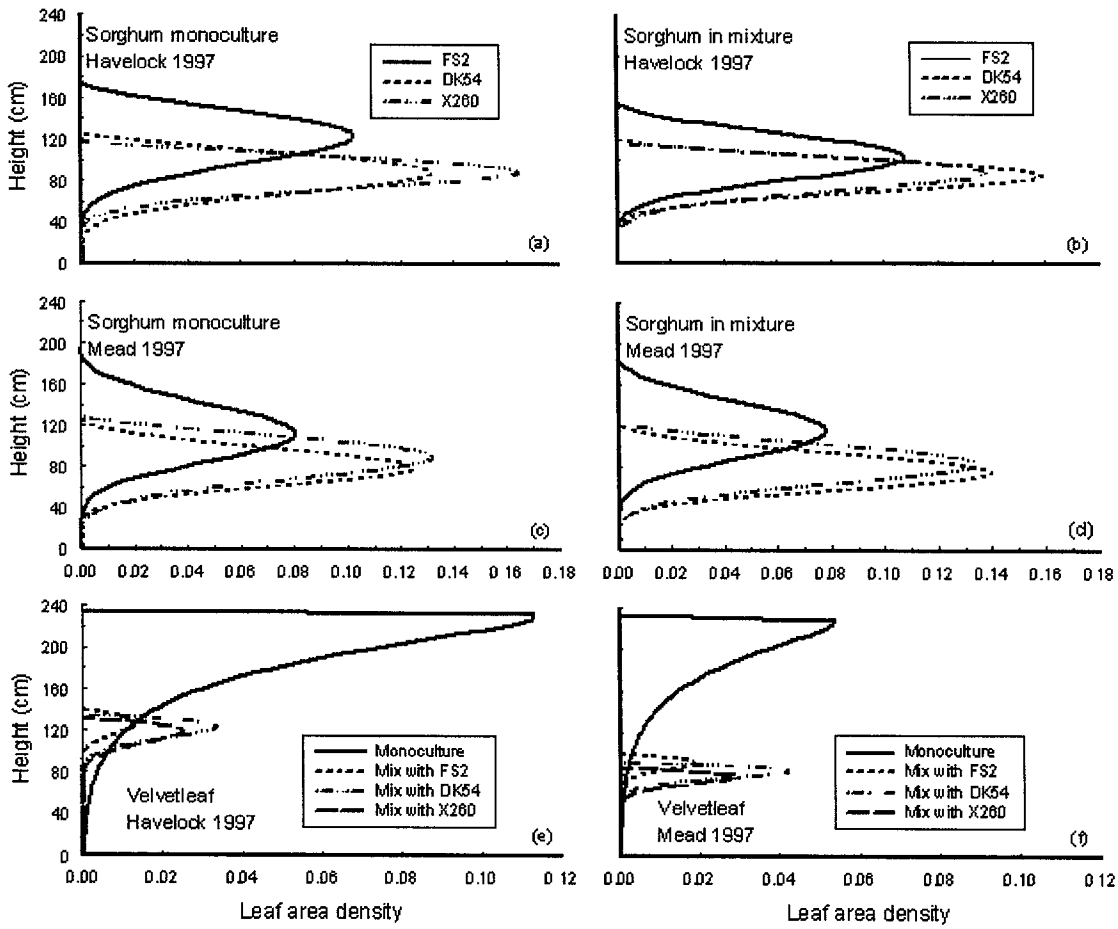

Figure 1. Leaf area densities of grain sorghum and velvetleaf in monoculture and mixture at Mead and Havelock, NE in 1997.

presence of velvetleaf was less for the tall hybrid. Correlation analysis over the growing season indicated that grain sorghum height, LAI, LAR, interception of PAR, relative growth rate and net assimilation rate were highly correlated with dry matter accumulation, but the relationship was complex and changed with growth stage. Correlations between plant height, LAI, relative growth rate and net assimilation rate with dry matter production decreased with progressing growth stage. The tall grain sorghum hybrid had the most stable grain yield and the greatest suppressive effect on velvetleaf growth and seed production. This research indicates that the use of tall grain sorghum hybrids with high vertical leaf area distribution would be a useful component of an integrated weed management program.

Ethylene Involvement in Grain Sorghum Germination and Early Seedling Growth (Roger Stockton, Ph.D. Dissertation)

Research Methods

Grain sorghum is a major feed grain in the USA and a major food grain in much of the world's arid and semi-arid regions. Colder or warmer than optimal soil temperatures often hinder germination and emergence of this crop. The gaseous hormone, ethylene is frequently produced in response to plant stress and has been correlated with germination and release from dormancy in many plant species. The objectives of this research were to: 1) identify heat and/or cold tolerant grain sorghum genotypes for germination and emergence; 2) quantify ethylene and 1-aminocyclopropane

1-carboxylate oxidase (ACCO) production during the first week of seedling growth; and 3) determine if ethylene was necessary for normal germination or early growth. Thirty-five grain sorghum genotypes were screened for percent germination and early seedling growth at 14, 19, 28, and 35°C. Nine selected genotypes were grown in the field at Lincoln, NE in 1996 and 1997 for laboratory tests at 23 and 35°C, and for ethylene inhibitor bioassays using 2,5-Norbornadiene (NBD) in varying concentration to examine ethylene's effect on sorghum seedling growth.

Research Results

Average ethylene production was 0.21, 0.22, and 0.27 pmol/seed/hr at 14, 23, and 35°C, while ACCO activity was 93, 213, and 431 pmol ethylene/seed/hr. ACCO activity correlated negatively R^2 = -0.78) to percent germination at 35°C. Genotypes Naga White, CE 145-66, and PI 550590 had 19% higher germination, 80% better vigor, 14% less ACCO activity, and similar ethylene production as other genotypes, and were thus classified as temperature stress resistant. San Chi San had 28% less ACCO activity, produced 34% less ethylene, had 50% better vigor rating and similar germination than other genotypes, and was thus classified as temperature stress tolerant. These four genotypes should be utilized in future breeding efforts to improve temperature stress response for germination and early seedling growth. Germination was not affected by NBD until the concentration became toxic at 11.8 to 23.7 ml/L. Increasing NBD concentration from 0 to 6 ml/L decreased root and shoot growth, while increasing ethylene production. This bioassay should be a useful tool for screening genotypes for seedling vigor response to temperature stress.

Planting Date and Row Spacing of Pearl Millet in Nebraska (Pale Siebou, M.S. Thesis)

Research Methods

An ongoing study to determine recommended planting date and row spacing for dwarf pearl millet hybrids was continued on sandy soil site in Ogallala and a silty clay loam site in Mead, NE, and expanded to a loam soil in Sidney, NE in 1999. Sidney has low rainfall, short growing season, and efforts are being made to intensify wheat-fallow production systems by incorporating pearl millet as a summer annual crop. The pearl millet hybrids 68A × 89-0083 and 68A × 086R responses to planting date, and narrow (38 to 50 cm) and wide (76 cm) row spacing were compared to the grain sorghum check DK28.

Research Results

Averaged over eight environments (years and location combination), narrowing row spacing increased yield of both pearl millet and grain sorghum by 13 to 15%. Pearl millet produced the higher yield when planted on June 1 until 17 depending on the environment, but yield declines were small with planting as early as May 1 and as late as July 6. Pearl millet produced greater yield than grain sorghum for planting dates after June 17. Grain sorghum had a narrower window for planting. Averaged over environments, grain sorghum produced approximately 0.35 Mg ha^{-1} more grain than pearl millet, but at planting dates after June 17, pearl millet often produced higher yield. Since pearl millet has a lower base temperature than grain sorghum, further study of planting dates in early May is merited. Pearl millet yields produced with late planting dates suggests its adaptation to short growing season, emergency replant crop and/or double crop situations.

Grain Sorghum - Maize Hybrid Comparisons in Dryland and Irrigated Environments (Suzanne Cimino, M.S. Thesis)

Research Methods

A three-year study was initiated in 1999 to determine the importance and physiological basis for shift in dryland sorghum production to maize production in eastern Nebraska. Best hybrids were identified from the 1950s, 1970s and 1990s and produced in four environments each year. The environments are sandy loam and silty clay loam soil types, 76 and 38 cm row spacing, and irrigated and dryland. Grain yield and yield components, dry matter and leaf area, lodging and climatic data are being collected. Path correlation analysis will be used to identify relationships between grain yield and yield components, and stability analysis used to help identify crop/hybrid responses.

Research Results

The seasonal rainfall was very good and lead to high yields of both crops (Table 1). Maize out yielded grain sorghum under both dryland and irrigated conditions, with the grain yield differences being greater for hybrids from the 1970s and 1990s. Large differences in grain yield were found between hybrids from the 1950s and 1970s, but were similar for hybrids from the 1970s and 1990s. Grain sorghum potential yield increase, as indicated by irrigated conditions, was only 0.1 Mg ha^{-1} per decade since the 1950s, while maize increase was 0.4 Mg ha^{-1} with most of this in-

Table 1. Irrigated and dryland yields in 1999 for grain sorghum and maize hybrids developed in different decades.

	Dryland			Irrigated		
Decade	Sorghum	Maize	Difference	Sorghum	Maize	Difference
	Mg/ha					
1950	7.1	8.1	1.0	7.5	10.2	2.7
1970	7.7	10.9	3.2	7.7	11.9	4.2
1990	8.2	11.1	2.9	7.9	12.3	4.4

crease occurring between 1950 and 1970. The lack of water stress in 1999 limits the usefulness of these results, but hopefully the addition of a low soil water holding capacity environment and normal to dry climatic conditions in 2000 and 2001 will provide adequate variation in environments to better understand the basis for producers shifting from dryland grain sorghum to maize.

International

Niger

Influence of Variety and Management Level on Pearl Millet Grain Yield, Dry Matter Accumulation, and N and P Concentration and Accumulation (Nouri Maman, M.S. Thesis)

Research Methods

This study was conducted as a factorial combination of the pearl millet varieties 'Zatib' (improved, tall), '3/4HK' (improved, short), and 'Heini Kirei' (land race, tall) under high and low management levels in 1994 and 1995. Low management levels consisted of 10,000 hills/ha with no fertilizer, and high management of 20,000 hills/ha with manure (5 t ha^{-1}), 18 kg ha^{-1} P, and 23 kg ha^{-1} N. Two plants were sampled bi-weekly, partitioned into plant parts, dried, weighed, and analyzed for N and P concentration. From this measurements growth, N and P uptake, and N use efficiency were calculated.

Research Results

Pearl millet under high management produced 0.5 Mg ha^{-1} more grain yield, 200 to 300 g m^2 more dry matter, and had mean crop growth rates of 4.7 (1995) to 16.5 (1994) g m^2 day than under low management. The shorter 3/4HK variety produced lower yield and dry matter than the other varieties, especially in the dry 1995 growing season. Management level had no effect on N and P concentration of plant parts, but N and P accumulation was greater under high management due to higher dry matter production. Biomass N use efficiency was not influenced by management level. Environment (year) had the greatest effect on pearl millet yield and growth, followed by management level, and variety which had the least effect. This research indicates that pearl millet producers in Niger should increase plant population and apply fertilizer to optimize pearl millet grain and stover yield.

Effect of Plant Population and Tiller Pre-Harvest of Late Maturity Pearl Millet on Grain and Stover Yield, and Feeding Value (Nouri Maman)

Research Methods

A randomized complete block designed experiment was conducted with plant spacing of 1m × 1m and 1.5m × 1m plant spacings with three treatments: plots thinned to 2 plants/hill at 14 days after planting (B_1), B_1 plus tillers harvested 65 days after planting, and B_1 plus tillers harvested 85 days after planting. Tillers were harvested, dried, weighed and analyzed for protein, phosphorus, lignin, fiber, and digestibility. Grain and stover were harvested at the end of the growing season.

Research Results

Plant population and thinning treatments had no effect on pearl millet grain or stover yield in 1998 or 1999. Therefore, it is possible for farmers to harvest tillers for forage without adversely effecting grain yield or stover production. The research indicates that harvested tillers could provide approximately 250 kg ha^{-1} forage which has high protein and phosphorus content (Table 2). Harvesting tillers 65 days after planting resulted in higher protein and phosphorus content was much higher while the fiber content did not change greatly. This was due to the pearl millet tillers harvested at 65 days after harvest having a greater leaf/stem ratio that at 85 days after planting. Harvesting tillers 65 days after planting affords the opportunity to provide high quality livestock feed during the early portion of the growing season when feed is in short supply.

Mali

Cropping System and Residue Management Influence on Pearl Millet Grain Yield and Soil Nutrient Levels (Adama Coulibaly, Minamba Bagayoko and Samba Traore)

Research Methods

Long-term cropping system and crop residue management studies were conducted at Cinzana from 1990 until 1999. The cropping systems study included continuous pearl millet and cowpea, pearl millet-cowpea intercropping, pearl millet-cowpea rotation, and fallow cropping systems with zero, 20, and 40 kg ha^{-1} annual nitrogen fertilizer applications. Grain and stover yields, and soil nutrient levels were collected, and a multi-year analysis was conducted.

The crop residue management system study had a factorial combination of continuous pearl millet and pearl millet-cowpea rotational systems with three residue management treatments. Crop residue management treatments included total removal, incorporation using animal traction, and retaining the residues on the soil surface. Grain

Table 2. Pre-harvest pearl millet tiller yield and feed quality in 1998 in Niger.

Parameter		Days after planting 65	85	Final harvest
		% of Dry matter		
Protein	Leaf	19.0	8.2	4.4
	Stem	13.5	4.3	2.9
Phosphorus	Leaf	0.27	0.17	0.10
	Stem	0.21	0.14	0.09
Lignin	Leaf	5.4	4.1	5.00
	Stem	4.6	4.3	10.1
Neutral detergent fiber (NDF)	Leaf	66.9	63.0	62.1
	Stem	63.7	65.3	69.0
Acid detergent fiber (ADF)	Leaf	34.5	32.6	35.1
	Stem	36.4	37.2	49.0
In vitro dry matter disappearance	Leaf	93.7	93.1	93.6
	Stem	92.2	92.4	92.7
Organic matter	Leaf	87.7	86.1	86.3
	Stem	86.1	87.1	94.4
Harvested tiller dry matter		kg ha^{-1}		
	Leaf	164	123	
	Stem	86	126	
	Total	250	249	10330

and stover yields, and soil nutrient levels were collected, and multi-year analysis was conducted.

Research Results

Nitrogen fertilizer application increased pearl millet grain and stover yield linearly each year, but had no effect on cowpea yield. Rotation with cowpea increased pearl millet grain yield by 142 to 482 kg ha^{-1} (3 to 31%) each year, but had little effect on cowpea grain yield. Rotation increased pearl millet stover yield in a similar manner. Intercropping reduced yield of both crops in each year, but the Land Equivalent Ratio indicated a 14% average increase in land use efficiency. After four years, soil from plots with different cropping systems had similar levels of nutrients, except phosphorus which was highest in continuous cowpea plots. Nitrogen fertilizer application increased yields in the seven years with greatest rainfall, and produced similar yields in the two drier years. Soil from plots with all cropping systems had lower levels of pH, K, Ca, Mg and cation exchange capacity than fallow plots, indicating that all cropping systems were mining the soil of nutrients. This research indicated that nitrogen fertilizer application of at least 40 kg ha^{-1} and crop rotation with cowpea (or other legume) were necessary to optimize pearl millet grain and stover yield in most years.

Crop residue management treatments had no statistically significant influence on pearl millet grain or stover yields from 1991-1999, except for grain yield in 1993 when plots with incorporated crop residues yielded more than those with residues left on the soil surface. However, the nine-year average grain yields for plots with incorporated crop residues was 157 kg ha^{-1} per year (12%) greater than plots with residue removed (significant at $p = 0.07$), and pearl millet stover yield in plots with crop residue incorporated was 130 to 343 kg ha^{-1} per year greater than plots with other crop residue management treatments. These results confirm other studies that in sites with non-degraded soils and/or sites with adequate P levels, crop residue management has only small effects on pearl millet yields. In contrast, either surface crop residue application or incorporation increased cowpea grain yield by 150 to 197 kg ha^{-1} per year (21 to 31%), and cowpea stover yield by 358 to 442 kg ha^{-1} per year (46 to 65%). Rotation with cowpea increased pearl millet grain yields by 138 kg ha^{-1} per year (8%) and stover yields by 691 kg ha^{-1} per year (22%). Retention of crop residues on the soil surface resulted in higher soil P levels than other residue treatments, and incorporating or retaining residues on the soil surface resulted in higher soil K levels than with crop residue removal. The increases in crop and stover yield over time, and the better maintenance of soil nutrient levels, indicated that leaving crop residues in the field and using crop rotation increased sustainability and productivity of pearl millet cropping systems.

Burkina Faso

Long-Term Tillage and Cropping Systems Research (Taonda Sibiri Jean Baptiste)

Research Methods

A five-year study (Table 3) was conducted at Kamboinsé, Burkina Faso on a sandy clay textured soil. The study consisted of a factorial arrangement of soil tillage (flat versus tied ridges), variety (landrace versus improved), fertilizer application (zero versus 2.5 t ha^{-1} manure plus 13 kg ha^{-1} P as rock phosphate), and continuous pearl millet and pearl millet - cowpea rotation cropping systems in a randomized complete block design and three replications. Grain and stover yield of both crops were collected annually, and the soil analyzed at the end of the experiment. Soil analysis are not yet available at time of preparing this report.

Table 3. Pearl millet grain yield as influenced by fertilizer application in Burkina Faso, 1994 - 1999.

Fertilizer	1994	1995	1997	1998	1999	Mean
			kg/ha			
Grain yield:						
Zero	1067	269	669	565	1361	786
2 tha^{-1} manure plus 13 kg ha^{-1} rock phosphate	1320	197	701	636	1635	898
Percent yield increase (%)	24	(27%)	5	13	20	14

Table 4. Effect of soil tillage method on grain and stover yield of pearl millet in Burkina Faso, 1994 - 1999.

Tillage Method	1994	1995	1997	1998	1999	Mean
			kg/ha			
Grain Yield:						
Flat	1137	188	496	363	1674	772
Tied Ridge	1249	276	873	837	1467	940
Stover Yield:						
Flat	6230	2993	2022	1783	2767	3159
Tied Ridge	7022	5063	2180	1416	2623	3661

Research Results

Crop rotation and variety had little influence on pearl millet grain and stover yields. The crop rotation results were in contrast to other studies on sandier soils in West Africa. Tied ridges increased grain yield four years out of five, while it increased stover yield two years out of five (Table 4). Averaged over years, use of tied ridges increased grain yield by 168 kg ha^{-1} per year (22%) and stover yield by 502 kg ha^{-1} per year (16%). Fertilizer application increased grain yield two out of five years and stover yield four out of five years. Averaged over years fertilizer application increased grain yield by 112 kg ha^{-1} per year (14%). Tied ridges and fertilizer application are important for pearl millet grain and stover production on the medium textured soils of Burkina Faso.

ROCAFREMI Agronomy Project

Identification of Principal Constraints and Fertilizer Response Studies

Research Methods

Between 1994 and 1998, the West and Central Africa Pearl Millet Research Network (ROCAFREMI) conducted studies in Burkina Faso, Ivory Coast, Mali, Niger, and Senegal on principal constraints of pearl millet production: tillage, crop rotation, organic and inorganic fertilizer application, crop residue management, and use of improved pearl millet varieties. Regional studies were also conducted on pearl millet grain yield response to application of organic and inorganic fertilizer. Specific treatment levels varied among countries, but could be summarized.

Research Results

The principal constraints research produced inconsistent results for crop residue management and use of improved varieties. Constraints were site specific (year and/or location) except crop rotation with either cowpea or peanut which consistently increased grain yield by 10 to 19% in Ivory Coast, Mali and Niger. However, no yield increase was found on a heavier soil in Burkina Faso. Tied ridges increased pearl millet grain yield by 0.4 Mg ha^{-1} in dry years in heavy textured soils in Burkina Faso, but tillage had no effect on yield at other locations. Both organic and inorganic fertilizers increased pearl millet grain yields with the best yields requiring application of inorganic fertilizers. Although the treatment combinations used did not allow for definitive conclusions, organic and inorganic fertilizers generally increased yields most when applied together.

Technology Transfer in Mali and Burkina Faso

Technology Transfer Methods

During the past decade, IER scientists in Mali collaborating with INTSORMIL Project UNL-213 have interacted with the Malian Agricultural Extension Service (PNVA) and Private Voluntary Organizations to extend improved technologies to producers in the Segou region. In 1997, two farmer adoption surveys were conducted to determine adoption rates of improved technologies. One survey was conducted by PNVA while the other was conducted by IER jointly with ICRISAT. Extension publications have been prepared in both Burkina Faso and Mali.

Technology Transfer Results

In both surveys, the technology adopted to the greatest extent was use of the seed treatment Apron Plus which improves stand establishment and reduces downy mildew problems. In the ICRISAT - IER survey, the communities surveyed were using improved techniques to produce and collect quality animal manure for application to fields. In both surveys, only 16 - 17 % of the farmers indicated use of improved pearl millet cultivars. In Mali, extension bulletins on pearl millet production (Fertilization of Pearl Millet Based Cropping Systems, Date and Density of Legumes in Rotation with Cereals, Pearl Millet Based Cropping Systems, Intercropping Pearl Millet and Cowpea, Intercropping Pearl Millet and Peanut, Intercropping Pearl Millet and Maize, and Cultivars for Pearl Millet Based Cropping Systems) were released in 2000. Also in 2000, the extension bulletin "Improving Pearl Millet Based Cropping Systems" was released in Burkina Faso. Future success in technology adoption would be promoted by proposing a technology package that includes improved cultivars, appropriate management practices, and use of organic and/inorganic fertilizers for specific end-uses.

Networking Activities

Workshops

American Society of Agronomy Meetings. Oct 31-November 4, 1999. Salt Lake City, UT.

ROCAFREMI (West and Central Africa Pearl Millet Research Network) Annual Meeting, 22-24 March 2000, Niamey, Niger.

Kansas/Nebraska Conference, September 1-2, 1999. Lincoln, NE.

Research Investigator Exchange

Visited research collaborators from Burkina Faso, Mali, and Niger during March 15 -24, 2000 trip to West Africa. This included on-site visits of research in Mali and Niger.

Pale Siebou (Burkina Faso), Suzanne Cimino (USA.), and Nouri Maman (Niger) started graduate degree studies in January 2000.

Research Information Exchange

Funds passed through to Burkina Faso, Mali and Niger to assist with collaborative research efforts.

Assisted with the Central America Regional Research Planning Meeting Oct. 4-6, 1999 at Zamorano, Honduras.

Visited INTSORMIL research efforts in El Salvador and Nicaragua June 18 - 23, 2000.

Scientific Liaison Officer to the Centro Internacional de Agricultura Tropical (CIAT) which included visit to CIAT Central America Regional Project June 23 - 29, 2000.

Coordinated the Kansas/Nebraska Sorghum Conference, Sept. 23 - 29, 1999. Lincoln, NE.

Publications and Presentations

Abstracts

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Journal Articles

Maman, N., S.C. Mason and T. Galusha. 1999. Hybrid and nitrogen influence on pearl millet production in Nebraska: yield, growth, and nitrogen uptake and efficiency. Agron. J. 91: 737 - 743.

Maman, N., S.C. Mason and S. Sirifi. 2000. Variety and management level influence on pearl millet production in Niger: I. Grain yield and dry matter accumulation. Afri. Crop. Sci. J. 8: 25 - 34.

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Coulibaly, A., M. Bagayoko, S. Traore and S.C. Mason. 2000. Effect of crop residue management and cropping system on pearl millet and cowpea yield. Afri. Crop Sci. J. 8: (In Press).

Extension Bulletins

Taonda, S.J.B., A. Sohoro and B. Ilboudo. 2000. Amelioration des systèmes de culture a base de mil [Improving pearl millet based cropping systems]. Institut de l'Environnement et de Recherches Agricoles (IN.E.R.A.), Ougadougou, Burkina Faso.

Coulibaly, A., S. Traoré, M. Bagayoko and S.C. Mason. 2000. Fertilisation d'un système de culture à base de mil [Fertilization of pearl millet based cropping systems]. Institut d'Economie Rurale, Bamako, Mali. (In Press).

Coulibaly, A., S. Traoré, M. Bagayoko and S.C. Mason. 2000. Date et densité de semis des légumineuses en rotation avec des céréales [Planting date and density of legumes in rotation wth pearl millet]. Institut d'Economie Rurale, Bamako, Mali. (In Press).

Coulibaly, A., S. Traoré, M. Bagayoko and S.C. Mason. 2000. Système de culture à base de mil [Pearl millet cropping systems]. Institut d'Economie Rurale, Bamako, Mali. (In Press).

Coulibaly, A., S. Traoré, M. Bagayoko and S.C. Mason. 2000. Association mil niébé [Pearl millet - cowpea intercropping]. Institut d'Economie Rurale, Bamako, Mali. (In Press).

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Coulibaly, A., S. Traoré, M. Bagayoko and S.C. Mason. 2000. Association mil maïs [Pearl millet - maize intercropping]. Institut d'Economie Rurale, Bamako, Mali. (In Press).

Coulibaly, A., S. Traoré, M. Bagayoko and S.C. Mason. 2000. Fiche des cultivars utilisables dans les systèmes de culture à base de mil [Cultivars for pearl millet based cropping systems]. Institut d'Economie Rurale, Bamako, Mali. (In Press).

Miscellaneous publications

Bagayoko, M., S.C. Mason, A. Buerkert, N. Maman and A. Coulibaly. 2000. Sustainable pearl millet based cropping systems in West Africa: Crop rotation, residue management and production practices. Invited paper, ROCAFREMI Annual Meeting, March 22 - 24, 2000, Niamey, Niger.

Nutrient Use Efficiency in Sorghum and Pearl Millet

Project UNL-214
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Dr. Damba Traore, Sorghum Agronomist, IER, B.P. 258, Bamako, Mali
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Dr. Samuel Buah, Sorghum Agronomist, SARI, Wa, Ghana
Dr. I.D.K. Atokple Sorghum Breeder, SARI, Tamale, Ghana

Summary

On-farm trials in Niger reconfirmed the advantage of using improved culture to increase yields of sorghum. The incorporation of the new hybrids NAD-1 or NAD-3 in combination with fertilizer and the moisture concerning soil management practice of ridging and/or "tying" the ridges to prevent runoff produced yields, 10 times traditional culture in one location. Farmers of the region are rapidly adopting this improved practice as resources allow. Research in Mali substantiated the practice of sorghum culture in rotation with other crops as a yield enhancement method. The use of the forage legume crop, dolichos, appeared to be the best rotation, and this practice can now be extended to on-farm trials. Trials in Ghana established the advantage of using both N and P fertilizer to increase yields in the Wa region even when sorghum is grown in rotation with a legume. Even though this is a fact accepted in many areas of the world, it still needs to be demonstrated in Ghana as many producers are not willing to use this input which can be economically beneficial to them. On-farm trials are planned for next season to test and demonstrate these improved production practices.

Objectives, Production and Utilization Constraints

Objectives

- Identify sorghum and pearl millet genotypes which are superior in nutrient use efficiency (primarily nitrogen).
- Determine the physiological and morphological mechanisms which allow genotypes to be nutrient use efficient.
- Determine optimum nutrient (particularly nitrogen) management practices for arid and semi-arid environments.
- Conduct on-farm trials to test improved management recommendations for sorghum production.
- Provide long- and short-term training experiences for students and scientists of collaborating institutions, as well as certain technical expertise for collaborative efforts related to overall INTSORMIL objectives.

Constraints

Soil nutrient deficiency stresses.

Lack of adequate nutrient use efficiency in current sorghum and pearl millet cultivars.

Inadequate knowledge of proper management practices to help cope with nutrient stresses.

Lack of technically trained personnel who can devise and carry out sound research programs.

Research Approach and Project Output

International Research

Summary of Research from 1996 in Niger

Upon release of the new hybrid NAD-1, comparative agronomic assessments were continually made of its performance in both research station and on-farm trials. Incorporated into these traits were improved soil preparation methods and use of organic and inorganic fertilizers with emphasis on N. The research station trails conducted at Bengou and Tillakaina locations clearly demonstrated that NAD-1 yield potential is two to six times greater than the local or improved varieties such as IR-204 or SEPON-82. Soil preparation methods, such as furrowing and use of tied ridges which conserve moisture and present runoff, clearly increased yields of all sorghum genotypes. When 2 to 5 t ha^{-1} of manure and 50 kg ha^{-1} N were added as amendments, yields could be increased another 1.5 to 2 fold in some instances.

Based on the results of the research station trials, on-farm studies were initiated. In 1997, from two to four farmer participants at three locations collaborated in trials where the improved culture and genotypes (especially NAD-1) were tested. NAD-1 with improved culture (including fertilizer and tied ridges) yielded an average of 1190 kg ha^{-1} grain compared to 475 kg ha^{-1} when grown in the traditional culture (no fertilizers). In 1998, the performance of NAD-1 with improved culture was less consistent. Collaboration with a World Bank project showed that soil type influenced performance. When comparing "partial factor productivity" to estimate economic return to farmers, it was found that NAD-1 had a higher return from investment in N fertilizer when grown on a loam soil compared to a sandy soil. This was most likely due to greater N availability and less water stress in the loam soil.

It appeared that farmers in these regions are willing and ready to accept the new technology, but there is often a lack of ready capital for the purchase of the inputs necessary.

Results of the 1999 Niger Trials - Seyni -Serifi

On-farm trials were continued in 1999 at two locations, Tillakaina (low rainfall) and Konni (intermediate rainfall). The season was characterized by drought and the normal season was shortened due to lack of rain. In addition, midge problems occurred at Konni which severely affected grain filling.

There was no significant difference between tied ridges, continuous ridges and traditional culture at Konni. Differences in grain yield between NAD-1 and NAD-3 (Table 1) were not significant although NAD-3 was numerically higher (635.5 kg ha^{-1}) than NAD-1 (436.6 kg ha^{-1}). Biomass production for NAD-1 was slightly higher. At Tillakaina, tied ridges were significantly better than continuous ridging, and both were markedly superior to traditional practices (Table 1). Grain yields were improved by 10-fold using NAD-1, tied ridges and fertilizer over the traditional practice in this dry region.

Summary of Research from 1996 in Mali

Yield assessments were made for sorghum response to nitrogen and other amendments in research station and on-farm trials. New experimental lines were tested extensively. In addition, long-term management trials were established to determine which crop rotations/fertilizer combinations are best suited for various locations in Mali.

Several new lines were derived by chemical mutations from popular local and improved sorghums at the University of Katibougou by Dr. Alhousseini Bretoudeau. Mutants derived from CSM388 were generally superior in performance to other mutants. Overall, the average mutant yield was 1313 kg ha^{-1} compared to 1056 kg ha^{-1} for the parents. Added N produced a grain yield increase of 27% at one location. This was primarily due to greater tillering resulting in increased panicle numbers per unit area. Mutants resembled their parents in that they had open panicles and were tall (4 m+) with good grain quality. They were markedly superior for stalk strength which resulted in much less lodging. This is especially important when N fertilizer is added. Sorghum varieties appear to vary in grain yields relative to their N responsiveness depending on the previous crop grown.

A long-term trial was established to test sorghum production when grown in rotation with millet, corn, peanut, cowpea, dolichos (a forage legume) or as the sole crop. In addition, N rates up to 60 kg ha^{-1} farm yard manure, and Malian rock phosphate were used as amendments. Results to

Table 1. Grain and biomass yields and grain: stover ratios of NAD-1 and NAD-3 at Konni, and NAD-1 at Tillakaina in the 1999 season. Treatments were T_1: tied ridges + fertilizer, T_2: continuous ridges + fertilizer, and T_3: traditional culture (no ridging or fertilizer).

Location	Konni						Tillakaina		
Hybrid	NAD-1			NAD-3			NAD-1		
Treatment	Grain	Stover	Ratio	Grain	Stover	Ratio	Grain	Stover	Ratio
	kg ha^{-1}			kg ha^{-1}			kg ha^{-1}		
T_1	490	8950	0.42	333	8200	0.49	1920	6584	0.58
T_2	420	9200	0.43	853	9400	0.54	1116	4079	0.56
T_3	400	7500	0.33	720	6867	0.46	190	1073	0.55
Mean	437	8550	0.39	636	8156	0.50	1075	3912	0.57
LSD	501	3887	0.20	574	947	0.25	665	679	

date show that sorghum following corn had the highest yields and sorghum following sorghum, the lowest. The genotype CSM388 out yielded N'Tenimissa by 449 kg ha^{-1} over all treatments. There was a linear increase in yield up to 60 kg ha^{-1} applied N, and application of rock phosphate increased overall yield by 9%.

The on-farm trials initiated in 1996 were conducted at three locations (six farms) and consisted of five sorghum varieties (local, 3 mutants and CSM388), and N/P fertility amendments compared to traditional culture. Results to date, have shown that grain yields average about 770 kg ha^{-1}. When N and P are added, yields were increased to 896 kg ha^{-1}. Improved genotypes out yielded the local significantly, but local genotypes have large amounts of stover which is a desirable resource for animal feed and construction material. Some farms had very low yields with little fertilizer response. It appears that soil preparation methods such as tied ridges must also be tested similar to the trials in Niger so that water can be conserved resulting in better fertility response.

Results of 1999 Mali Trials - Abdoul Toure

Rotation trials were continued in 1999, comprised of sorghum following the six crops previously listed. Fertilizer treatments included zero fertilizer, 200 kg ha^{-1} rock phosphate (PNT), variable rates of N (0, 20, 40, 60 kg ha^{-1}), and manure at 1000 kg ha^{-1} in alternating years. Two genotypes, CSM388 and N'Tenimissa were used. Results showed that CSM388 performed better than N'Tenimissa regardless of the previous crop, but the magnitude of difference was greatest with peanut, corn, cowpea, and dolichos as the previous crop compared to millet or sorghum. Grain yield of sorghum was not affected by PTN when grown after cowpea, corn or millet. However, when grown after cowpea, dolichos or sorghum, yields were increased by PNT from 40% to over 100%. Nitrogen rates produced a linear increase in yield in sorghum grown after all crops except dolichos, the forage legume. Similar responses were seen for stover production within the treatments. The genotype CSM388 appeared to respond better than N'TENIMISSA to N, especially at the higher rates. The lack of N effect on sorghum grown after dolichos may reflect a greater contribution of that legume crop to soil N compared to other crops in the test. The best rotation effect (determined at zero fertility) was sorghum following dolichos, cowpea, corn, millet, and peanut from highest to lowest dry matter response.

Results of 1999 Ghana trials - Dr. Samuel Buah

Collaborative research with SARI has just been initiated and these are the first results from that research. The first experiment was a comparison of cowpea and sorghum response to P fertilizer with a primary objective to determine if annual applications are necessary to maintain yield. Plots received 0, 30, 60, and 90 kg ha^{-1} P and a uniform 60 kg ha^{-1} N to sorghum only.

The results showed that Pdid not affect sorghum bloom date, early plant growth, or harvest index. However, higher P rates increased dry matter, seeds $head^{-1}$, and plant height (Table 2). Only the 90 kg ha^{-1} P rate increased sorghum yields significantly although there was linear numerical increase with each higher rate. Yield increases were a function of seed number rather than seed size. Similarly, increased P rates numerically increased cowpea yield. Both the 60 and 90 kg ha^{-1} rates were significantly better than zero P. Seed numbers were also the determinate for yield increases. The experiment will continue in the following year with a treatment left unfertilized to observe the residual P effects.

A second experiment was conducted to determine the previous crop effect on sorghum response to N fertilizer. The previous crops tested in rotation are cowpea, soybean, peanut and sorghum. Four N levels tested were 0, 40, 80, and 120 kg ha^{-1} as urea. Plots received a uniform application of 30 kg ha^{-1} P.

Since the experiment was just initiated, the rotation effect cannot be determined. Table 3 shows that grain yield was significantly increased by N application for 40 kg ha^{-1} with no further increase at higher rates. Total dry matter yield followed a similar pattern. Unfertilized sorghum had heavier seeds, but this was most likely due to the inverse relationship that occurs with fewer seeds $panicle^{-1}$. Seed numbers accounted for the total increase in grain yield due to N fertilizer.

Domestic Research

Summary of Research from 1996 in the USA

Most of the research conducted in the USA was oriented to the determination of physiological factors associated with high N use efficiency in sorghum. The majority of this research was conducted by international students working on graduate degrees. Many of these have since become collaborators with project UNL-214.

Field experiments were used to evaluate sorghum genotype differences in N metabolism. Nitrogen uptake, partitioning, nitrate reductase activity (NRA), and N use efficiency were measured. Genotypes used were from West Africa, ICRISAT, and the USA. The results showed that total N uptake and its partitioning varied among genotypes, and that total uptake was dependent on the total biomass produced. The taller African genotypes took up high amounts of N, but failed to partition this to grain compared to more advanced U.S. materials. The high N uptake resulted in African types having high NUE for biomass production. In our studies, NRA was not a factor prominent in obtaining higher yields, and it was not related to a genotype rank for NUE. Another study showed that source of N (either NO_3 or NH_4^+) influenced NUE at maturity. When sorghum was provided 100% N in the NO_3- form, the greatest values for NUE were obtained. As the NH_4^+ concentration was increased, NUE values declined.

Table 2. The effect of P levels on selected sorghum parameters. Wa, Ghana, 1999.

N level	Plant height	100-seed weight	Seeds/head	Dry matter[1]
kg P ha^{-1}	cm	g	no.	kg ha^{-1}
0	217b	2.49a	2.137b	5.094b
30	214b	2.64a	2.272b	6.360ab
60	229a	2.65a	2.108b	6.993a
90	225a	2.65a	2.649a	6.247ab
Mean	221	2.61	2.291	6.173
CV (%)	4.1	6.9	11.2	17.3

[1] Total dry matter (straw) production at physiological maturity.

Table 3. The effect of fertilizer N levels on sorghum yield parameters, Busa 1999.

N level	Dry matter[1]†	100-seed weight	Seeds/head	Grain yield
kg N ha^{-1}	kg ha^{-1}	g	no	kg ha^{-1}
0	918b	2.57a	692b	926b
40	1413a	2.29b	1111a	1565a
80	1413a	2.30b	1277a	1614a
120	1538a	2.36b	1312a	1657a
Mean	1321	2.38	1098	1440
CV (%)	23.8	9.4	26.2	33.8

[1] Dry matter yield at vegetative stage (8-10 leaf growth stage).

Studies on sorghum root systems showed that genotypes developed in Africa, or other areas under stress conditions, had root systems more highly branched than U.S. developed genotypes. Root systems of the African types were also larger, had a greater affinity for NO_3^-, and were capable of extracting N from a lower concentration in the soil solution. It was concluded that this is an adaptive strategy to low or dwindling nutrient supplies.

Two lines from China, identified in collaboration with Kansas State University, were found to have 25% or more higher NUE than traditional U.S. breeding lines. These were studied to determine the physiological/biochemical factors responsible for high NUE in sorghum. Our investigations indicated that these lines maintain high photosynthesis rates under moderate to extreme N deficiencies. Further studies showed that the mechanism responsible was one of the CO_2 fixing enzymes, PEP carboxylase. By maintaining the integrity and activity of this enzyme under extreme N stress, genotypes could continue to grow and accumulate biomass and grain. This resulted in very high NUE values in these China lines, China 17 and San Chi San.

Results of 1999 Domestic trials - Teshome Regasse

A field experiment was conducted in 1999 to compare the response of two sorghum cultivars to a combined effect of moisture and N. Two cultivars, San Chi San and CK 60, with contrasting moisture and N requirements, were planted under two moisture conditions and four N levels in a split split-plot design.

Moisture treatments were applied by covering plots with clear plastic to drain away incoming rain to avoid moisture after treatment application, so that the crop will exhaust moisture in the soil, resulting in moisture stress as the crop season progressed. The part of the treatment, which was not covered by plastics, had continuos moisture input as rain, so remained in a non-stressed condition. The method created a good contrasting moisture gradient for the time it was applied. For those plots where plastic was applied, significant difference in soil moisture was detected as determined by gravimetric moisture. Our observation from this experiment showed that moisture deficit can be created, with reasonable precision in this manner, to study the interaction of moisture and N under field conditions. Table 4 shows the main effects of the three treatments on measured crop parameters at two growth stages.

No significant effect of moisture was observed. However, the method established a trend for some of the important parameters such as dry matter, grain yield, and N use efficiency. Statistically significant ($p \leq 0.001$) differences were observed between the two cultivars for most of the important parameters measured. Chlorophyll (measured using Minolta SPAD-52 meter) was higher for CK-60 at both growth stages. This is in agreement to leaf N content of CK-60, which was significantly higher for this cultivar at both growth stages. Female N was, however, lower for CK-60 at heading while grain N was higher. Dry matter and grain yield was significantly higher for San Chi San, which may be a reflection of its high N use efficiency. This variety had the highest N use efficiency both in terms of biomass or grain. Higher N concentration was in the leaves of CK-60 than San Shi San, and it remained high at both measured growth stages. San Chi San had comparable N in all plant parts to that of CK-60 at heading, but there was a complete shift in the relative amount to N percent in the panicle at the expense of leaf N. This was reflected in the difference in N use efficiency between the two cultivars at maturity. All measured parameters increased up to a maximum in response to added N, and then dropped off with a further increase of added N. Increased N, in general, reduced N use efficiency.

Table 4. Chlorophyll, dry matter, grain yield, plant part nitrogen content and nitrogen use efficiencies of two sorghum cultivars at two growth stages.

Cultivar	Heading						Maturity							
	Chlor.	Total DM (g/plant)	Nitrogen (%) Leaf	Stem	Head	NUE1	Chlor.	Total DM (g/plant)	Grain yield (g/plant)	Nitrogen (%) Leaf	Stem	Grain	NUE1	NUE2
CK-60	51.43	72.58	2.85	0.89	1.77	13.16	54.28	95.55	39.04	2.46	0.77	1.70	19.42	7.93
San Chi San	44.56	76.68	2.76	10.84	1.85	14.08	45.97	126.40	69.54	1.89	0.50	1.52	32.36	17.80
	***	ns	ns	ns	***		***	***	***	***	***	***		
Moisture														
Stress	48.22	73.56	2.78	0.88	1.85	13.42	50.53	111.18	53.50	2.19	0.66	1.62	24.88	11.97
No stress	47.78	75.70	2.82	0.85	1.81	13.81	49.72	110.77	55.08	2.16	0.61	1.59	25.42	12.64
Nitrogen (kg/ha)														
0	44.81	74.44	2.42	0.70	1.72	15.37	46.06	104.09	48.96	1.95	0.53	1.60	25.51	12.00
40	48.38	73.29	2.82	0.84	1.85	13.30	50.31	110.82	54.82	2.19	0.62	1.61	25.07	12.40
80	49.88	75.98	2.95	0.95	1.84	13.24	52.44	116.60	59.89	2.21	0.66	1.60	26.13	13.42
120	48.94	74.80	3.02	0.97	1.84	12.82	51.69	112.38	53.18	2.35	0.72	1.62	23.97	11.41
	***	ns	***	***	***		***	ns	ns	***	***	ns		

***Significant at $P \leq 0.001$
ns Statistically nonsignificant a $P \leq 0.05$

No statistically significant interactions were observed, mainly, because the moisture treatments were not imposed soon enough. Significant N by variety interaction was found for N concentration in the panicle and total plant N. The interaction (Figure 1) showed that CK-60 accumulated N as the N rate was increased. San Chi San increased N accumulation up to a certain point, and additional application of N did not increase accumulation of N in either panicle or other parts. This resulted in the difference in N use efficiency observed between the cultivars.

Networking Activities

Project UNL-214 is continuing collaboration with Dr. R.K. Pandey, formerly of the World Bank, who is currently in Dehli, India writing manuscripts from collaborative studies in Niger. Maranville will travel to India in September 2000 to complete manuscripts in progress and review ICRISAT research.

Funds were transferred to Ghana to initiate the collaborative research from the recently established MOU with SARI. Funds were also expended in Niger to enhance the on-farm research/demonstration trials on improved management systems.

Collaboration with World Vision International is still in progress. The UNL-214 PI is expediting the roles of the collaborating NARS scientists in Niger, Mali and Ghana with WVI personnel in the field in these countries.

Publications

Maranville, J.W. and S. Madhavan. 2000. Physiological adaptations for nitrogen use efficiency in sorghum. Plant and Soil (in press). Invitational paper presented at International Workshop on "Food Security in Nutrient-Stressed Environments: Exploiting Plants Genetic Capabilities". 27-30 Sept. 1999, ICRISAT - Patancheru, India.

Regassa, T.H. and J.W. Maranville. 2000. Morphological performance of two contrasting sorghum cultivars under moisture and N stress. Agron. Abstr. (poster at ASA meetings).

Regassa, T.H. and J.W. Maranville. 2000. Traditional sorghum management practices to mitigate moisture stress. Agron. Abstr. (special oral presentation representing CRSPs at ASA meetings).

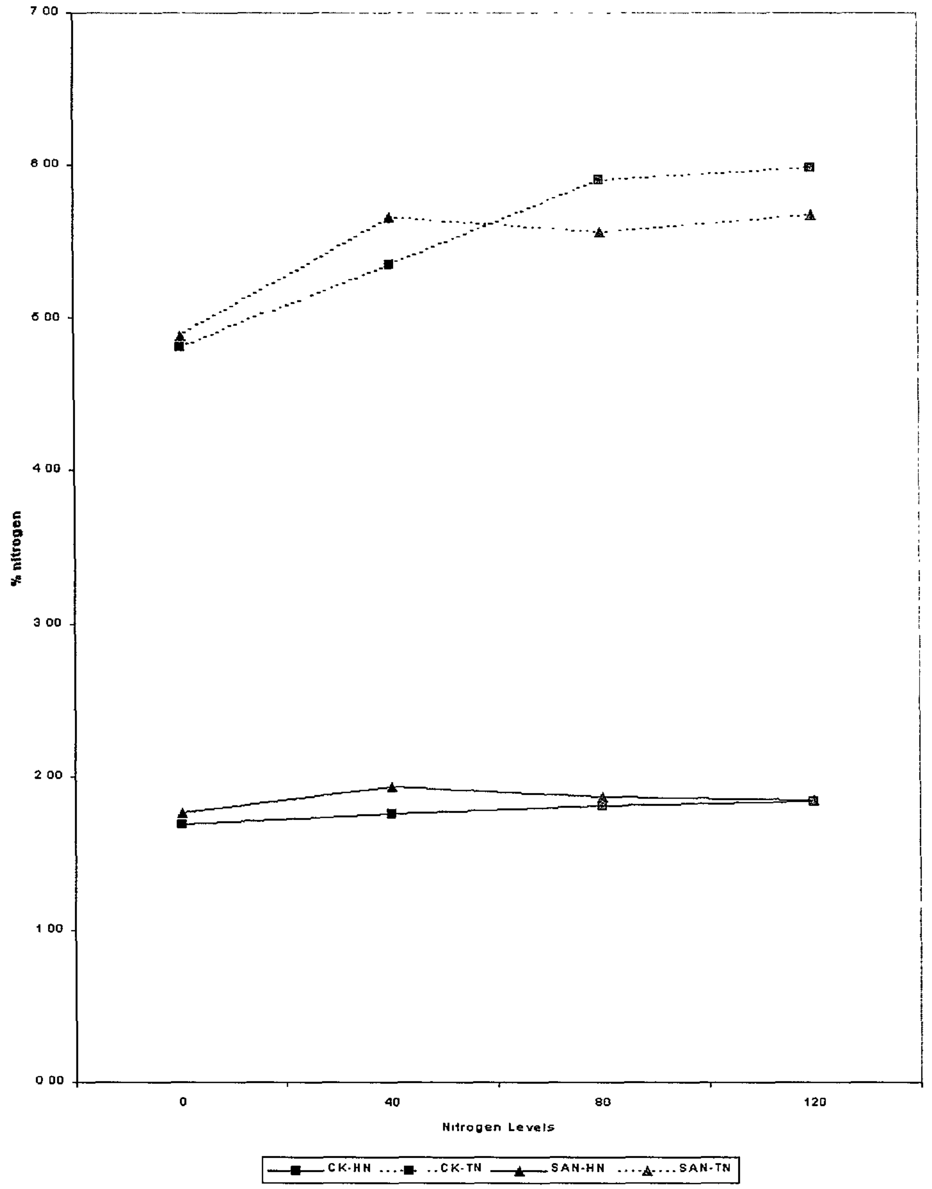

Figure 1. Effect of Nitrogen on biomass and head % nitrogen of two cultivars.

Germplasm Enhancement and Conservation

Breeding Pearl Millet with Improved Performance and Stability

Project ARS 204
Wayne W. Hanna
USDA/ARS/ Tifton, GA

Principal Investigator

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Collaborating Scientists

Moussa Sonogo, Millet Breeder, Cinzana Agricultural Experiment Station, B.P. 214, Segou, MalI
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Hamadou Mossi, INRAN/KOLO, B.P. 60, Kollo, Niger
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Summary

Cooperators were identified in Niger, Mali, Nigeria, and Burkina Faso for testing and evaluation of pearl millet hybrids. Two sites in each Niger and Mali and one site in Burkina Faso were identified for a regional study (in cooperation with project UNL- 213) to compare a landrace and population hybrid at two fertility levels. Seeds were sent to all cooperators.

The major accomplishment at this time is the development of a regional experiment across Nigeria, Niger, Mali, and Burkina Faso.

Objectives

West Africa

- Improve the productivity and stability of pearl millet cultivars in West Africa.
- provide short- and long-term training for pearl millet breeders.

USA

- Use West African germplasm to improve germplasm and productivity of U.S. hybrids.

Research Approach and Project Output

This project started January 1, 2000 and this report covers only the first six months of the project.

Key land races from West Africa have been assembled and grown under quarantine. Land races were intercrossed and also used to pollinate pearl millet inbreds with two standard cytoplasms and seven new experimental cytoplasms.

Networking Activities

Attended the ROCAFREMI meetings in Niger- March 22-24, 2000

Met with scientists in Niger, Mali, and Burkina Faso to discuss cooperative research, March 15-24, 2000.

Received pearl millet landraces and inbreds from Niger and Nigeria.

Sent 13 population hybrids each to Mali, Niger and Nigeria.

Sent 99 crosses resulting from 8 cytoplasms × 7 land races and 4 inbreds to Niger.

Plans have been made to bring Moussa Sonogo, pearl millet breeder in Mali, to work for six weeks in the Tifton,GA program.

Received germplasm from David Andrews.

Other cooperating scientists

Bruce Hamaker, Department of Food Science,
Purdue University, West Lafayette, IN
K.N. Rai, ICRISAT, India
Botorou Ouendeba, ROCAFREMI Coordinator,
ICRISAT Sahelian Center, Niamey, Niger

Breeding Sorghum for Increased Nutritional Value

Project PRF-203
John D. Axtell
Purdue University

Principal Investigator

Dr. John D. Axtell, Department of Agronomy, Purdue University, West Lafayette, IN 47906

Collaborating Scientists:

Dr. Gebisa Ejeta, Sorghum Breeder, Department of Agronomy, Purdue University, West Lafayette, IN 47907
Dr. Lee House, Sorghum Breeder, Rt. 2, Box 136A-1, Bakersville, NC 28705
Dr. Issoufou Kapran, INRAN/INTSORMIL Coordinator for Niger, Sorghum Breeder, INRAN, B.P. 429, Niamey, Niger
Dr. Bruce Hamaker, Cereal Chemistry, Food Science, Purdue University, West Lafayette, IN 47905
Mr. Adam Aboubacar, Cereal Chemist, Postdoc, Food Science, Purdue University, West Lafayette, IN47905
Dr. Ouendeba Botorou, Millet Coordinator, ROCAFREMI, Niamey, Niger
Dr. Jeff Bennetzen, Biological Sciences, Purdue University, West Lafayette, IN
Dr. Wayne Hanna, Millet Breeder, USDA/ARS, Tifton, GA 31793

Summary

Seed Production of NAD-1 in Niger

Sorghum hybrids being produced by participatory seed producers on small farms in Niger increases yield by 40 to 65% compared to the best local varieties. The sorghum hybrid, NAD-1, was released in Niger in 1992. The hybrid was developed from collaborative research between the Nigerien sorghum breeders and INTSORMIL breeders at Purdue University. In Niger, the hybrid was involved in on-farm demonstrations where it raised excitement among farmers. In 1995, INRAN (Institut National de Recherches Agronomiques du Niger) and INTSORMIL-Purdue (International Sorghum and Millet CRSP) expressed interest in using this hybrid to launch a seed production and marketing activity in the private sector. Seed production in the private sector is now widely accepted in Niger.

Testing indicated a 40 to 65% increase in yield compared to the best local varieties. Yield results from on-farm demonstrations have ranged from 3000 to 4500 kg ha^{-1} with adequate moisture to 1200 to 1500 kg ha^{-1} on dryland (the national average is around 270 kg ha^{-1}). Farmer enthusiasm and interest is strong.

Production and marketing of seed in the private sector is not new in Niger. Rice seed used in the country is produced by a Co-op. Seed of onions is privately produced and marketed. A private company, Agrimex, markets vegetable seed through a well organized marketing program and their seed comes from Holland. ICRISAT expects to have hybrid pearl millet ready for seed production in 1999. They currently are involved with experimental seed production. There is some use of hybrid maize seed coming from Nigeria, but hybrid maize is currently being developed in Niger, some of this being done privately. Pearl millet is grown on over 3 million hectares and sorghum on over 1.5 million hectares in the country, providing ample marketing opportunity. The successful establishment of a seed industry in Niger would stimulate the establishment of industries in other West African countries, particularly Mali and Burkina Faso.

Brown Midrib (BMR) Sorghum-Sudangrass

This is a value-added trait, introduced through Purdue/INTSORMIL research, which currently provides $40-45 million U.S. dollars additional value to U.S. dairy and beef producers, with the potential to provide over $100 million U.S. dollars annually to animal producers. Several years ago, Purdue/INTSORMIL produced several brown midrib mutants in sorghum by chemical mutagenesis. These mutants were evaluated for their reduction in lignin content and for improved dry matter digestibility. Three of these mutants were fully characterized and released to the seed industry for incorporation into commercial forage varieties. Several companies have backcrossed the low lignin genes into sudangrass so that sorghum sudangrass hybrids can be produced. Sorghum sudangrass hybrids are a very high-yielding forage grown on several million acres in the United States alone. The forage yields are very high, but the forage quality is generally lower than other forage grass species. This can now be remedied by the incorporation of the brown midrib gene in sorghum sudangrass hybrids. They are also extensively utilized in Asian countries as a forage crop.

Several seed companies are now producing seed of brown midrib sorghum sudangrass commercially. Re-

sponse of livestock producers has been excellent due to improved digestibility and significantly improved palatability. Dairy farmers are the first to see the benefits of the improved nutritional quality in increased milk production. There are approximately five million acres of sorghum sudangrass in the United States at the present time, compared with nine million acres of hybrid sorghum for grain production. The potential of brown midrib sorghum sudangrass in West Africa is being explored through collaboration with Dr. Issoufou Kapran. The value of forage in West Africa is high and there is a chronic shortage of good quality forage which, we believe, can be partially alleviated by brown midrib sorghum sudangrass hybrids. At this point in time, there has been extensive cultivation of brown midrib sorghum hybrids in Pakistan and in some Asian countries. The potential value in India has been recognized since India is now the largest milk producer in the world and they are heavily investing in research on brown midrib forage cereals.

Objectives, Production and Utilization Constraints

Objectives

- 1) Collaboration with Issoufou Kapran to develop the hybrid seed production potential in Niger so that this well adapted and well accepted sorghum hybrid NAD-1 can be produced for utilization in Niger.
- 2) Collaborate with Bruce Hamaker to develop rapid screening techniques for breeders to assess the new high digestibility trait recently discovered by Dr. Hamaker in germplasm from our program.
- 3) To determine the inheritance of the recently discovered sorghum cultivars with very high digestibility and to incorporate this trait into improved African and U.S. sorghum germplasm.
- 4) Improve forage quality of sorghum stover for better ruminant animal nutrition.
- 5) Train LDC and U.S. scientists in plant breeding and genetics with special emphasis on exposure of graduate students to the U.S. seed industry. All graduate training at Purdue involves active involvement for every graduate student in plant breeding with hands-on experience with new technologies, including sorghum transformation and molecular marker studies through collaboration of PRF-203A with other Purdue University scientists.

Constraints

Sorghum and millet production in West Africa is limited by the lack of high yielding cultivars with superior grain quality for utilization as a subsistence cereal by people in West Africa. This project addresses improvement of sorghum yield potential through utilization of elite sorghum lines and hybrids with good food grain quality. An additional constraint addressed is the lack of a viable private seed industry in West Africa, which would allow the exploitation of heterosis or hybrid vigor for the benefit of agriculture in West Africa. Experience in the rest of the world has shown that pure lines have a significant role to play, but also that there are opportunities for utilization of hybrid cultivars of sorghum and millet with benefits for both increased stress tolerance and high yield potential under appropriate management. Both sorghum and pearl millet are usually grown under stress conditions (particularly moisture and temperature) in semi-arid environments. Most cereal breeders acknowledge the benefits of heterosis in providing superior performance of hybrids when grown under stress conditions (see Axtell review article in CIMMYT heterosis symposium published in 1999 by the Crop Science Society of America).

Utilization of sorghum grain has been limited by poor protein digestibility in humans and other monogastric animals. Sorghum germplasm with protein digestibility as high, or higher than maize, or other staple cereals has been identified through Purdue/INTSORMIL research. Studies on the genetics of this trait indicate that it is a simply inherited trait which can be transferred to other genotypes for utilization in sorghum producing regions throughout the world. One limitation, which has now been substantially overcome, is the food grain quality of these highly digestible cultivars. New research demonstrates that vitreous kernels with good food grain and processing properties have been identified and are now available for breeding programs.

Research Approach and Project Output

Objective 1 - Sorghum hybrids in Niger. The following update will demonstrate significant progress in the production of NAD-1 seed. First, a private seed company has purchased the government seed farm at Lossa. Dr. Salifou, who was trained at Mississippi State in seed technology several years ago, is leading the development of a private sector seed industry for Niger. INRAN and the Government of Niger are supportive of this private seed sector activity. NAD-1 will be the first hybrid seed produced and marketed by this company. Second, several hybrid sorghum seed producers in Niger have formed a seed producers association. This association recognizes INRAN as an honorary member, but is intent on controlling the seed association outside of the formal structure of the government. We think this is an encouraging development which we will nurture. Third, the demand for hybrid seed far exceeds the supply even though the seed is sold at approximately eight times the price of grain. The important distinction between seed and grain is now recognized in Niger. We estimate that 60 tons of hybrid seed will be produced this year in Niger. A great deal of this seed production will be on small farms. One important observation should be noted which has made this a successful enterprise. The male parent of the hybrid is ,in itself, a very popular variety among farmers in Niger. MR732 has good grain quality, excellent forage quality, and good yield potential which appropriate management. This allows the small farmers to buffer their hybrid production fields with an ample quantity of the male parent so that isolation from local varieties can be achieved, even though these are small production units of less than 1 hectare. This is important because the farmers don't hesitate to get adequate isolation for pure hybrid seed by using wide borders of the male parent, which in fact they like very much as a variety. This may seem a small point, but it is important in a situation where many small farmer seed producers are involved.

Objective 2 - Develop rapid screening techniques for breeders to assess the new high digestibility trait recently discovered in germplasm from our program. A new rapid screening technique, which measures disappearance of alpha kafirin in sorghum grain, has been developed by Bruce Hamaker and Adam Aboubacar. The test is rapid and readily distinguishes between normal sorghum and the highly digestible sorghum cultivars. Lex Nduulu has tested this technique across several environments and found that it is accurate and yet simple enough to be applied to large populations of breeding materials.

The endosperm of a sorghum mutant cultivar, with high in vitro uncooked and cooked protein digestibilities, was examined by transmission electron microscopy and α-, β-, and γ-kafirins (storage proteins) were localized within its protein bodies. Transmission electron microscopy micrographs revealed that these protein bodies had a unique microstructure related to high protein digestibility. They were irregular in shape and had numerous invaginations, often reaching to the central area of the protein body. Protein bodies from normal cultivars, such as P721N studied here, with much lower uncooked and cooked digestibilities are spherical and contain no invaginations. Immunocytochemistry results showed that the relative location of α- and β-kafirins within the protein bodies of the highly digestible genotype were similar to the normal cultivar, P721N. However, γ-Kafirin was concentrated in dark staining regions at the base of the folds instead of at the protein body periphery, as is typical of normal cultivars. The resulting easy accessibility of digestive enzymes to α-kafirin, the major storage protein, in addition to the increased surface area of the protein bodies of the highly digestible cultivar, appear to account for its high in vitro protein digestibility.

Objective 3 - Identification of molecular markers linked to high protein digestibility and/or high lysine in high lysine sorghum lines. Sorghum genotypes with high protein digestibility and others with hard kernels have been reported. A population derived from a cross between P851171 and P721N has been used to construct a genetic map and evaluate phenotypic traits. P851171 is high in protein digestibility and has soft kernel endosperm, whereas, P721N is low in protein digestibility and has hard kernel endosperm. P851171 × P721N crosses were made in the Mexico winter nursery in February 1998. A total of 5 to 10 crosses were made. F_1 plants were grown and selfed at the PU-ARC at West Lafayette in the summer of 1998. The F_2 seeds were bulked and sent to the Mexico winter nursery to be grown. Five hundred randomly selected F_2 plants were self-pollinated and harvested when mature to produce F_2 derived F_3 families. Out of the 500 selected F_3 families, 80 to 300 will be used for QTL analyses depending on the heritability results. Data for protein digestibility and kernel hardness will be collected on the F_3 seeds of all the selected F_2 plants, including their parents to determine heritability of the digestibility trait.

Polymorphic markers will be selected using SSR techniques. The frequency of high protein digestibility (HPD) and kernel hardness (KH) alleles for each family will be calculated and a distribution obtained. The observed polymorphic markers will be used to construct a linkage map using Mapmaker. Map distances will be estimated according to Kosambi function.

Objective 4 - Improve forage quality of sorghum stover for better ruminant animal nutrition. Chemically induced brown midrib (bmr) mutants of sorghum [Sorghum bicolor (L.) Moench] were characterized with regard to phenotype, fiber composition, and in vitro dry matter disappearance (IVDMD) several years ago. The recessive bmr genes produced brown pigmentation in the leaf midrib and stem of mature plants. Pigmentation varied among mutants in intensity, time of appearance, and degree of fading as plants matured. Ten of the 13 mutants had significantly less stem lignin than their normal counterparts. Reductions in lignin ranged from 5 to 51% in stems and from 5 to 25% in leaves. Increases in IVDMD and IVCWCD of as much as 33 and 43%, respectively, were associated with the presence of bmr genes. Seed company researchers have now incorporated one of our low lignin brown midrib genes (bmr-6) into both parents of a sorghum × sudangrass hybrid. Results on improved palatability and performance of the brown midrib cultivar have been excellent and commercial studies have shown the brown midrib hybrid seed is producible on a commercial scale. Currently, in vivo studies confirm the higher digestibility for dairy and beef animals that were seen in our earlier studies using in vitro tests. Pacific Seeds, a subsidiary of Zeneca, has an extensive research program on brown midrib for forage quality in Argentina, Australia, and India. Pakistan has now widely adopted the brown midrib trait in their dairy operations and is reporting gains of 8 to 10 pounds of milk per day per cow. In the USA there are currently five million acres of sorghum sudangrass compared to 9 million acres of hybrid grain sorghum. So the forage component of sorghum research is frequently underestimated and will play an increasing role in the world as we approach the next era which many call "the meat revolution".

Many important forage grasses used in Africa have poor forage digestibility. A new technique, from biotechnology studies by Purdue/INTSORMIL scientists, has presented an opportunity to identify and tag the brown midrib genes from sorghum and insert them into the genomes of other tropical forage grasses. The technique involves utilization of a molecular characterization of a mutable pigmentation phenotype and isolation of the first active transposable element from Sorghum bicolor. Accumulation of red phlobaphene pigments in sorghum grain pericarp is under the control of the Y gene. A mutable allele of Y, designated as *y-cs* (*y-candystripe*), produces a variegated pericarp phenotype. Using probes from the maize *p1* gene that cross-hybridize with the sorghum Y gene, we isolated the *y-cs* allele containing a large insertion element. Our results show that the Y gene is a member of the *MYB*-transcription factor family. The insertion element, named Candystripe1 (*Cs1*), is present in the second intron of the *Y* gene and shares features of the CACTA superfamily of transposons. *Cs1* is 23,018 bp in size and is bordered by 20-bp terminal inverted repeat sequences. It generated a 3-bp target site duplication upon insertion within the *Y* gene and excised from *y-cs*, leaving a 2-bp footprint in two cases analyzed. Reinsertion of the excised copy of *Cs1* was identified by Southern hybridization in the genome of each of seven red pericarp revertant lines tested. *Cs1* is the first active transposable element isolated from sorghum. Our analysis suggests that *Cs1*-homologous sequences are present in low copy number in sorghum and other grasses, including sudangrass, maize, rice, teosinte, and sugarcane. The low copy number and high transposition frequency of *Cs1* imply that this transposon could prove to be an efficient gene isolation tool in sorghum.

Agrobacterium-mediated Transformation of Sorghum and other Tropical Grasses. Utilization of the identified and cloned bmr genes requires that a transformation system be available for sorghum and other tropical grasses. Plant biotechnology has become a powerful tool to complement the traditional methods of plant improvement. Several methodologies have been developed to identify and clone agronomically important genes and to transfer genes from any living organism to plants. This report includes the development of a protocol for sorghum transformation via *Agrobacterium tumefaciens*. It demonstrates that *Agrobacterium*-mediated transformation is a feasible technique for the genetic transformation of sorghum. Sorghum transgenic plants were produced via *Agrobacterium tumefaciens*, and the transformation evidenced by Southern blot analysis of T_0 and T_1 plants, detection of GUS activity, and production of T_1 plants resistant to hygromycin. Immature embryos of sorghum were very sensitive to *Agrobacterium*, and embryo death after co-cultivation was considered the limiting step to increase the transformation efficiency. Key factors were the co-cultivation medium, the use of a genotype and an explant with good tissue culture response, and the addition of Pluronic F-68 to the inoculation medium. Sorghum transformation via *Agrobacterium* is still not a routine technique, but it seems to have good potential once the protocol is further refined and improved. The significance of this research means that sorghum can now benefit from the rapid advances in crop molecular biology utilized by other cereal grains. A significant part of this research is that the selectable marker used was not a herbicide. The selectable marker used was the antibiotic hygromycin, which worked very well and is a feasible marker to select transformed plants. This has great advantages over the use of a herbicide resistance marker, which runs the risk of spreading herbicide resistance among weedy sorghum relatives. In our estimation, this research means that sorghum can join the new biology in terms of opportunities for improving sorghum in the future.

Objective 5 - Train LDC and U.S. scientists in plant breeding and genetics with special emphasis on exposure of graduate students to the U.S. seed industry. Graduate student education continues to be an important and vital activity of our INTSORMIL program. A partial list of graduate students who have completed degrees with Purdue/INTSORMIL is presented by category of employment.

***Academic Appointments* (6 students)**

Dr. Mitch Tuinstra, Sorghum Breeder, Kansas State University
Dr. Gebisa Ejeta, Sorghum Breeding/Genetics, Purdue University
Dr. Bruce Hamaker, Cereal Chemist, Purdue University
Dr. Nora Mason, Popcorn Breeder, University of Nebraska
Mr. Tom Tyler, Urban Gardening, Washington, D.C.
Dr. Robert Bacon, Wheat Breeder, Arkansas State University

***National Program Scientists* (17 students)**

Dr. Osman Ibrahim, Sorghum Breeder, Sudan National Research Program (ARC)
Dr. Joe Mushonga, Sorghum Breeder, Zimbabwe National Crops Research Program
Dr. Carlos Carvalho, Sorghum Molecular, Biologist, EMBRAPA, Corn and Sorghum Research Center, Brazil
Dr. Ouendeba Botorou, Millet Breeder, Niger National Program (INRAN)
Dr. Issoufou Kapran, Sorghum Breeder, Niger National Program (INRAN)
Dr. Yahia Ibrahim, Sorghum Breeder, Sudan National Research Program (ARC)
Dr. John Clark, Sorghum Breeder, Niger National Program (INRAN, Retired)
Dr. Moussa Adamou, Sorghum Breeder, Niger National Program (INRAN, Retired)
Dr. Lexington Ndulu, Sorghum Breeder, Kenya National Program (KARI)
Mr. Tadesse Mulatu, Sorghum Breeder, Ethiopian National Program (deceased)
Dr. Rameshwar Singh, Sorghum Breeder, Pantnagar University, India
Dr. Robert Schaffert, Sorghum Breeder, EMBRAPA, Brazil
Dr. Chris Nwasike, Millet Breeder, Nigeria (deceased)

Dr. Lichuan Tu, Sorghum/Sesame Breeder, People's Republic of China
Dr. Adam Aboubacar, Sorghum Biochemist, Niger National Cereal Program (INRAN)
Dr. Laila Monawar, Sorghum Food Chemist, Sudan National Program (ARC)
Mr. Zenon Kabiro, Sorghum Breeder, Burundi National Program

***Seed Industry Scientists* (13 students)**

Dr. Ed Grote, Corn Breeder, Pioneer Hybrid International
Dr. Kay Porter, Sorghum Director, Pioneer Hybrid International
Dr. Yilma Kebede, Sorghum Breeder, Pioneer Hybrid International
Dr. Joe Keaschall, Corn Breeder, Pioneer Hybrid International
Dr. Paul Christensen, International Division, DeKalb
Dr. Tom Prest, Corn Breeder, Northrup King Seed company (Novartis)
Dr. D.P. Mohan, Sorghum Breeder, Pioneer Hybrid, Sudan (Retired)
Dr. Gloria Cagampang, Sorghum Biochemist, Kellogg Cereal Company
Dr. Billy Woodruff, Corn Breeder, DeKalb
Ms. Rebecca Hartigan, Corn Breeder, Becks Seed Co. (Private Business)
Dr. Paul Peter, Owner/Manager, Garden Classics, Landscape Tree Nursery (Private Business)
Dr. Kevin Cavanaugh, Corn Breeder, Becks Seed Company
Mr. Xiaokun Yang, Corn Biotechnician, Asgrow Seed Company

***International Center Scientists* (9 students)**

Dr. Emmanuel Monyo, Millet Breeder, SADC/ICRISAT Sorghum and Millet Improvement Program
Dr. Sam Mukuru, Sorghum Breeder, ICRISAT (Retired)
Dr. Dallas Oswalt, Chief Training Officer, ICRISAT (Retired)
Dr. Dale Hess, Sorghum/Striga Breeder, ICRISAT Mali Program
Dr. Vartan Guiragossian, Sorghum Breeder, ICRISAT (deceased)
Dr. R. Jambunathan, Sorghum Biochemist, ICRISAT (Retired)
Dr. Bantayehue Gelaw, Corn Breeder, CIMMYT, Maize Program, Zimbabwe
Dr. Ronald Cantrell, Director General, IRRI (International Rice Research Institute)
Dr. Laurie Kitch, Cowpea Breeder, FAO UN Food-Agric Organization

Networking Activities

Workshops

A Hybrid Seed Workshop for West Africa, was held in Niamey, Niger September 28 through October 2, 1998. The purpose of the workshop was to acquaint West African sorghum and millet research scientists about the benefits of hybrid seed for West Africa. Speakers discussed relevant hybrid seed experiences in their own developing countries, including India, Zambia, Sudan, and Brazil. The goal was to explore opportunities for development of sorghum and pearl millet hybrids for West Africa and to assist the development of a private sector seed industry which brings many benefits to farmers in West Africa.

The workshop consisted of approximately 150 participants from 14 countries including: United States, Niger, Ghana, Mali, Cote d'Ivoire, India, Burkina Faso, Kenya, Chad, Egypt, Senegal, France, Nigeria, Zimbabwe, and Zambia. The following organizations participated:

Winrock International (Senegal/Mali)
PROCELOS-CILSS (Burkina Faso)
World Bank
ONAHA (Niamey)
USAID/Washington
ITRA (Chad)
INTSORMIL
ARC/FCRI (Egypt)
INRAN
CIRAD-CA (France)
IER/Mali
ISRA (Senegal)
WCASNR/ROCARS (Mali)
DDEIA/CUN (Niamey)
IDESSA (Cote d'Ivoire)
Premier Seed Nigeria Ltd. (Nigeria)
Mahyco Seed Ltd. (India)
ICRISAT Sahelian Center/Niger
C.TRA.P.A. (Burkina Faso)
ICRISAT/WCA (Nigeria)
ROCAFREMI (Niger)
Ministry of Food and Agriculture (Ghana)
Mahindra Hybrid Seed Co. (India)
PASP (Niamey)
IN.E.R.A. (Burkina Faso)
Ministry of Agriculture (Namibia)
Care Intl. (Niamey)
SADC/ICRISAT/SMIP (Bulawayo)
World Vision Int. (Ghana, Mali)
AGRIMEX (Niamey)
Rockefeller Foundation (Kenya)
USAID/REDSO/ESA (Nairobi)

A second workshop activity during 1999 was a training program conducted at the ICRISAT Sahelian Center in the spring of 1999 by Lee House and Issoufou Kapran. Training was on elements of hybrid seed production for INRAN and

World Bank technicians in Niger. This activity was very useful and productive during the growing season and will definitely be repeated in the spring of 2000. A practical training manual on hybrid seed production in Niger was prepared in English and French.

Research Investigator Exchanges

A number of sorghum scientists from the USA and throughout the world were involved in exchanges during 1996-2000. Dr. Robert Schaffert from the EMBRAPA program in Brazil spent a one-year sabbatical leave as a visiting professor at Purdue University. Support was provided by EMBRAPA, INTSORMIL, IPIA and the Department of Agronomy. Main activities included a conference, on the development of sorghum hybrids which are tolerant to the acid high aluminum savannas in Brazil, which was held during the spring of 1998. A major topic of discussion was how to transfer the very successful experience in Brazil to many problem soil areas in Africa, including Niger.

Many other scientists participated in the INTSORMIL Plant Breeding Workshop and visited Purdue while in the USA. One exchange occurred with the new Director General of ICRISAT, Dr. Shawki Barghouti, to discuss West African sorghum research. Dr. M.V. Rao who was, according to Dr. Norman Borlaug, the most influential wheat breeder during the Green Revolution Days in India, spent a week with our faculty and graduate students on the sorghum project in 1997.

Germplasm and Research Information Exchange

Numerous requests for germplasm and information were received and distributed to collaborators in Africa, South Asia, and Latin America. Former students are constantly in contact to receive germplasm which they learned about while graduate students in the Purdue/INTSORMIL sorghum project. Cultivars with improved protein quality have been widely distributed throughout the world as lines and populations. The brown midrib mutant genes for improved forage quality have been distributed throughout the world over the past four years to researchers interested in improved forage quality. Collaborating scientists have requested basic supplies from the project including pollinating bags, staplers, marking pencils, etc. Many of these researchers work in areas where even the basic supplies are not available and so we provide them until they can identify a domestic source in their own country. A training manual on hybrid seed production in English and French has been widely distributed in West Africa. This manual is used to conduct short-term training courses for technicians and scientists, many of whom are with PVOs and NGOs.

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Development and Enhancement of Sorghum Germplasm with Sustained Tolerance to Biotic and Abiotic Stress

Project PRF-207
Gebisa Ejeta
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Principal Investigator

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Dr. Kay Porter, Pioneer HiBred International, Plainview, TX

Summary

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 PRF-207 attempt 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 the last four years, research efforts in PRF-207 have focused on a selected core of constraints that limit the productivity and utilization of the sorghum crop. We conducted specific studies in attempting to understand the genetic and physiologic basis of drought tolerance using a mix of both traditional and molecular approaches. We also conducted several studies in elucidating the basis of grain mold resistance in low and high tannin sorghums. Specific studies were undertaken in determining the role of physical and chemical kernel properties associated with mold resistance, and in assessing the nature of specific phenolic compounds that contribute to grain mold resistance. We also conducted a major study in assessing genetic diversity using molecular markers. The results of several of these experiments are summarized in our Year 21 report for PRF-207.

Objectives, Production and Utilization Constraints

Objectives

Research

- To study the inheritance of traits associated with resistance to biotic and abiotic stesses in sorghum and/or millets.

- To elucidate mechanisms of resistance to these stresses in sorghum and/or millets.

- To evaluate and adapt new biotechnological techniques and approaches in addressing sorghum and millet constraints for which conventional approaches have not been successful.

Germplasm Development, Conservation, and Diversity

- To develop sorghum varieties and hybrids with improved yield potential and broader environmental adaptation.

- To develop and enhance sorghum germplasm with increased levels of resistance to drought, cold, diseases, and improved grain quality characteristics.

- To assemble unique sorghum germplasm, and to encourage and facilitate free exchange of germplasm between U.S. and LDC scientists and institutions.

- To assess applicability of various statistical and DNA fingerprinting technologies for evaluating genomic similarity, or for discerning genetic diversity of sorghum and millet germplasm pools.

Training, Networking, and Institutional Development

- To provide graduate and non-graduate education of U.S. and LDC scientists in the area of plant breeding and genetics.

- To develop liaison and facilitate effective collaboration between LDC and U.S. sorghum and millet scientists.

- To encourage and facilitate positive institutional changes in research, extension and seed programs of collaborating countries involved in sorghum and millet research and development.

Research Approach and Project Output

Research Methods

The research efforts of PRF-207 are entirely interdisciplinary. The on-campus research at Purdue is in close collaboration with colleagues in several departments. We undertake basic research in the areas of biotic and abiotic stresses where a concerted effort is underway in elucidating the biochemical and genetic mechanism of resistance to these constraints. Field and laboratory evaluations of sorghum and millet germplasm are coordinated, the results from one often complimenting the other. In addition, there have been collaborative research efforts with colleagues in Africa where field evaluation of joint experiments are conducted.

Our germplasm development and enhancement program utilizes the wealth of sorghum and millet germplasm we have accumulated in the program. Intercrosses are made in specific combinations and populations generated via conventional hybridization techniques, through mutagenesis, or through tissue culture in vitro. Conventional progenies derived from these populations are evaluated both in the laboratory and in the field at West Lafayette, Indiana for an array of traits, including high yield potential, grain quality, as well as certain chemical constituents that we have found to correlate well with field resistance to pests and diseases. We, also, evaluate our germplasm for tropical adaptation and disease resistance during the off-season at the USDA Tropical Agricultural Research Center at Isabella, Puerto Rico. Selected progenies from relevant populations are then sampled for evaluation of specific adaptation and usefulness to collaborative programs in Sudan, Niger, and more recently Mali. Evaluation of the drought tolerance of our breeding materials have been conducted at Lubbock, Texas in collaboration with Dr. Darrell Rosenow, in a winter nursery at Puerto Vallarta, Mexico, as well as the University of Arizona Dryland Station at Yuma, Arizona. Over the years, assistance in field evaluation of nurseries has also been provided by industry colleagues particularly at Pioneer HiBred and DeKalb Genetics.

The training, networking and institutional development efforts of PRF-207 have been provided through graduate education, organization of special workshops, and symposia as well as direct and closer interaction with research scientists and program leaders of NARS and associated programs. Much of the effort in this area has been primarily in Sudan and Niger, with limited activity in Mali, and some in Southern Africa through SADC/ICRISAT.

Research Findings

In the last five years, research in PRF-207 has focused in the following three major areas, namely drought tolerance, grain mold resistance, and assessment of genetic diversity using a mix of biotechnological approaches:

Using an empirical plant breeding approach, we made slow but significant progress in breeding of sorghum for drought tolerance by breaking the trait of drought tolerance into specific phenological stages. Our approach has been to breakdown the complex trait of drought tolerance into simpler components by studying drought stress expressions at specific stages of plant development. We have been particularly interested in midseason (pre-flowering) and late-season (post-flowering) drought expressions in sorghum germplasm. Our rationale is that if individual components associated with a complex trait can be identified, we can measure the contribution of each of the factors or mechanisms independently without the confounding effect of other factors. Using this approach, we have identified sorghum germplasm that are uniquely pre-flowering or post-flowering drought tolerant and few that combine tolerance at both stages. We have developed new improved drought tolerant sorghum lines in diverse and elite germplasm background. Some of these lines have been officially released and distributed to both public and private sorghum research concerns. Several more await release and distribution following further characterization and cataloguing to facilitate specific mode of utility. Our breeding and selection effort was based on reliable phenotypic markers associated with morphological and yield related symptoms that occur at pre-flowering and post-flowering stages of crop development. Some of these marker traits are simply inherited, and others appear quantitative rendering them amenable to QTL marker analysis and introgression. The development of molecular genetic markers and the use of these markers in quantitative trait loci (QTL) analysis is, increasingly, becoming a common approach for evaluating the inheritance, and evaluating the feasibility of accelerating gains from selection for complex quantitative traits in crop plants. Drought tolerance is one such trait for which QTL analysis holds great promise. The genetic and physiological mechanisms that condition the expression of drought tolerance in crops are poorly understood. Controlled by many genes and dependent on the timing and severity of moisture stress, drought is one of the more difficult traits to study and characterize. Sorghum is one of the most drought tolerant grain crops and its rich genetic diversity for stress tolerance makes it an excellent crop model and choice for studying the genetic and physiologic mechanisms of drought tolerance. Nonetheless, even in sorghum, direct selection for drought tolerance using conventional approaches has been slow and difficult. A number of physiological and biochemical traits have been implicated to enhance drought tolerance. Yet, only a few of these mechanisms has been demonstrated to be causally related to the expression of tolerance to drought under field conditions. We believe the use of molecular markers and QTL analysis, based on carefully managed replicated tests, has the potential to alleviate the problems associated with inconsistent and unpredictable onset of moisture stress or the confounding effect of other stresses such as heat. To this end, we conducted several experiments on both phenotypic selection for drought tolerance as well as QTL analysis of drought tolerance in sorghum.

Grain mold resistance in sorghum is a fairly complex trait that is affected by a number of genes that control physiological and morphological characteristics in the crop. Physical kernel hardiness, maturity of the genotype, morphology of the inflorescence and chemical compounds, accumulated in the inflorescence of the plant, all control susceptibility to mold. We conducted several studies to assess the role of physical and chemical kernel characteristics as well as evaluating selection strategies for mold resistance in sorghum. High concentration of certain phenolic compounds, particularly flavan-4-ols, have been found to correlate strongly with grain mold resistance. We confirmed this strong association, in another study, by screening 240 diverse sorghum land races from a collection of sorghum germplasm maintained at Purdue University. However, whereas there is a strong association between mold resistance and levels of flavan-4-ols, certain genotypes have high levels of flavan-4-ols but are susceptible to grain mold, and some are low in flavan-4-ols yet resistant to grain mold. This discrepancy suggested that other mechanisms are the basis for grain mold resistance in those genotypes, or that the concentration of flavan-4-ols at certain stages of kernel development is more critical, or that flavan-4-ols are merely indicators of other chemical factors that better determine genetic resistance to grain mold infection. We conducted a study to assess changes in concentration of major phenolic compounds during seed development, and to determine if these changes are associated with shifts in fungal population ,or if a decline in flavan-4-ols concentration in certain genotypes during seed development renders them susceptible to grain mold infection. Ten sorghum genotypes with differences in phenolic compound concentration and grain mold resistance were evaluated over three crop seasons to make these assessments. Samples were collected for nine weeks at seven-day intervals starting seven days after anthesis. Acidified methanol extracts of the seeds were assayed to determine concentrations of 3-deoxyanthocyanidins, flavan-4-ols, and proanthocyanidins.

Analysis of the extent and distribution of genetic variation in a crop are essential in understanding the evolutionary relationships between accessions and to sample genetic resources in a more systematic fashion for breeding and conservation purposes. Traditionally, genetic resources in sorghum are classified by taxonomists based on morphological markers. However, these morphologica traits, used in classification of sorghum to different races, are conditioned by a relatively small number of genes. On the other hand, important traits which are related to habitat adaptation and exhibit enormous variability among sorghum germplasm are complex and quantitatively inherited. Hence, classifying germplasm accessions, based solely on a few discrete morphological characters, may not provide an accurate indication of the genetic divergence among the cultivated genotypes of sorghum. We hypothesize that both natural and human selection efforts have contributed to current genetic differences in sorghum, and, hence, land races of the same race grown in different habitats may have greater genetic dissimilarity than those of different races from the same habitat.

The results of each of the above three studies will be summarized in the following series of enumerated research findings:

Identification of Quantitative Trait Loci Associated with Pre-Flowering Drought Tolerance in Sorghum (Ref. Crop Science 1996.Vol 36: 1337-1344)

Drought tolerance is an important agronomic trait, but the genetic and physiological mechanisms that condition its expression are poorly understood. Molecular genetics and quantitative trait loci analysis provide a new and powerful approach to understand better the inheritance and expression of this trait. The purpose of this study was to use molecular markers to identify genetic loci associated with the expression of pre-flowering drought tolerance in sorghum [*Sorghum bicolor* (L.) Moench]. Two genotypes with contrasting drought reactions, TX7078 (pre-flowering tolerant, post-flowering susceptible) and B35 (pre-flowering susceptible, post-flowering tolerant), were selected as parents for a sample of recombinant inbred (RI) lines. Ninety-eight RI lines were evaluated in two different years under conditions of pre-flowering drought and full irrigation. This information was used to quantify the drought tolerance of each line. The population was also genotyped with 150 RAPD and 20 RFLP markers that mapped to 17 linkage groups. By means of these markers, six regions of the genome were found to be specifically associated with pre-flowering drought tolerance. Eight additional regions were more generally associated with yield or yield components under fully irrigated conditions. Several loci were associated with the expression of drought tolerance under both mild and severe drought stress conditions.

Genetic Analysis of Post-flowering Drought Tolerance and Components of Grain Development in Sorghum bicolor (L.) Moench (Reg. Molecular Breeding 1997. Vol. 3: 439-448)

Drought is a serious agronomic problem and the single greatest factor contributing to crop yield loss in the world today. This problem may be alleviated by developing crops that are well adapted to dry-land environments. Sorghum [*Sorghum bicolor* (L.) Moench] is one of the most drought-tolerant grain crops and is an excellent crop model for evaluating mechanisms of drought tolerance. In this study, a set of 98 recombinant inbred (RI) sorghum lines was developed from a cross between two genotypes with contrasting drought reactions, TX7078 (pre-flowering- tolerant, post-flowering susceptible) and B35 (pre-flowering susceptible, post-flowering-tolerant). The RI population was characterized under drought and non-drought conditions for the inheritance of traits associated with post-flowering drought tolerance and for potentially related components of grain development. Quantitative trait loci (QTL) analysis identified 13 regions of the genome associated with one or more measures of post-flowering drought tolerance. Two QTLs were identified with major effects on yield and 'stay green' under post-flowering drought. These loci were also associated with yield under fully irrigated conditions suggesting that these tolerance loci have pleiotropic effects on yield under non-drought conditions. Loci associated with rate and/or duration of grain development were also identified. QTL analysis indicated many loci that were associated with both rate and duration of grain development. High rate and short duration of grain development were generally associated with larger seed size, but only two of these loci were associated with differences in stability of performance under drought.

Heterogeneous Inbred Family (HIF) Analysis: a Method for Developing Near-isogenic Lines that Differ at Quantitative Trait Loci (Ref. Theor. App. Genetic 1997. Vol. 95: 1005-1011)

Analysis of near-isogenic lines (NILs) that differ at quantitative trait loci (QTL) can be an effective approach for the detailed mapping and characterization of individual loci. Although NILs are useful for genetic and physiological studies, the time and effort required to develop these lines have limited their use. Here we describe a procedure to identify NILs for any region of the genome that can be analyzed with molecular or other genetic markers. The procedure utilizes molecular markers to identify heterogenous inbred families (HIFs) that segregate for a genomic region of interest. Each HIF is isogenic at the majority of loci in the genome, but NILs differing for markers linked to QTL of interest can be extracted from segregating families. The application of this procedure is described for two QTLs associated with seed weight in sorghum. A population of 98 HIFs was screened with two RAPD markers from different linkage groups that were associated with seed weight. Three segregating families were identified for each marker. The progeny of these HIFs were characterized for the segregation of seed weight and other yield components, and for markers flanking each QTL. NILs derived from each HIF had significantly different seed weights confirming the presence of at least two loci that influence seed weight in sorghum.

Evaluation of Near-Isogenic Sorghum Lines Contrasting for QTL Markers Associated with Drought Tolerance (Reg. Crop Science 1998. Vol. 38 : 835-842)

Drought is the most important constraint on crop production in the world today. Although selection for genotypes with increased productivity in drought environments has been an important aspect of many plant breeding programs, the biological basis for drought tolerance is still poorly understood. We have been conducting a genetic research program directed at developing a better understanding of drought tolerance in sorghum [*Sorghum bicolor* (L.) Moench]. Several quantitative trait loci (QTL) associated with pre-flowering and post-flowering drought tolerance were previously identified in a recombinant inbred mapping population. The process of identifying linkage between markers and traits in a mapping population followed by test of marker effects in NILs can be powerful and useful to resolve several issues. First, marker linkage to a QTL can be confirmed by examining the phenotype on NILs that only differ for individual QTL. Initial QTL analysis indicates regions of the genome that may contain QTL but the particular phenotypic effects of these loci need to be confirmed. Second, NILs can be used for fine mapping of QTL. Evaluation of a series of NILs that contrast at a specific locus can be used to narrow the genetic interval known to contain the QTL. Third, NILs that differ at a QTL can be used to characterize the expression and function of a specific locus. In our case, we reasoned that NILs differing for QTL associated with drought tolerance can be used to identify the specific mechanism of drought tolerance controlled by each QTL. We focused on the analysis of NILs contrasting at three loci and evaluated differences in the size of the genomic region differentiating each set of NILs by testing markers flanking each target QTL. In the current study, near-isogenic lines (NILs) were developed and used to test the phenotypic effects of three different genomic regions associated with various measures of agronomic performance in drought and/or non-drought environments. In most cases, NILs contrasting for a specific locu differed in phenotype as predicted by QTL analysis. Nils contrasting at QTL marker *tM5/75* indicated large differences in yield across a range of environments. Further analysis indicated that differences in agronomic performance may be associated with a drought tolerance mechanism that also influences heat tolerance. NILs contrasting at QTL marker *tH19/50* also differed in yield under drought and non-drought conditions. The analysis of these NILs indicated that these differences may be influenced by a drought tolerance mechanism that conditions plant water status and the expression of stay green. NILs contrasting at QTL marker *t329/132* differed in yield and seed weight. These differences appear to be the result of two QTL that are closely linked in repulsion. These findings can further be corroborated with careful physiological studies that can be more readily undertaken using NILs than random and nonrelated genotypes. We plan to conduct these studies to identify and define the specific mechanisms of drought tolerance mediated by these loci. We believe that the approach of narrowly focusing on specific genomic regions associated with drought tolerance holds promise for developing a clearer understanding of the specific biological basis of this complex trait.

Physical and Chemical Kernel Properties Associated with Resistance to Grain Mold in Sorghum (Ref. Cereal Chemistry 1996. Vol. 73 (5): 613-617)

Identification of kernel properties associated with resistance to grain mold would be useful in screening germplasm in a breeding program. We screened and characterized a large and diverse collection of sorghum (*Sorghum bicolor* (L.) Moench) accessions for physical and chemical kernel properties, as well as for resistance to grain mold in the filed. We identified sorghum accessions with a high level of grain mold resistance originating from diverse geographical areas and belonging to different botanical races. We found that resistance to grain mold in these sorghums was strongly associated with high concentration of phenolic compounds (apigeninidin, flavan-4-ols, and tannin), kernel hardness, and pericarp color. Each of these kernel properties contributed to grain mold resistance differently in white, red, and brown pericarp sorghum accessions. We developed a numerical index effectively differentiated resistant and susceptible sorghum genotypes.

Fungal Invasion of Kernels and Grain Mold Damage Assessment in Diverse Sorghum Germplasm (Ref. Plant Disease 1996. Vol. 80: 1399-1402)

Use of resistant cultivars in the most feasible way to minimize crop damage from grain mold when sorghum (*Sorghum bicolor*) is grown in a climate conducive to fungal invasion. An experiment was conducted to assess relative contribution of fungal species to grain mold damage and to evaluate extent of variation in sorghum for resistance to grain mold. A large and diverse set of land races were evaluated for grain mold resistance at different stages of grain maturity. Fungal species infecting sorghum kernels were isolated and counted. Significant differences in the percentage and severity of kernel infection were observed among accessions at all stages of kernel development. The predominant fungal species, isolated from sorghum kernels collected from field-grown panicles, did not change across different sampling dates and years. Although visual rating identified highly susceptible accessions as early as 40 days after flowering, rating a few weeks after physiological maturity more reliably identified genotypes with higher levels of resistance to kernel damage. A multiple regression model, involving all the fungal species isolated from sorghum kernels accounted for 64% of the variation in the final visual grain mold damage rating. *Gibberella zeae* and *Fusarium moniliforme* each accounted for 46 and 16%, respectively, of the variation in the final visual grain mold damage rating. Sorghum accessions free from colonization by one or more fungal species across three sampling dates were identified. Thus, it should be possible to establish differentials for each fungus or group of fungi to facilitate screening of germplasm for resistance to grain mold.

Grain Mold Resistance and Polyphenol Accumulation in Sorghum (Ref. 1996. Vol. 44: 2428-2434)

Ten sorghum [*Sorghum bicolor* (L) Moench] genotypes with differences in phenolic compound concentrations and grain mold resistance were evaluated at West Lafayette, IN, over three crop seasons (1989, 1990, and 1992) to assess changes in phenolic compounds during seed development and how these changes influence grain molding. Samples were collected for nine weeks at seven-day intervals starting seven days after anthesis. Acidified methanol extracts of the seeds were assayed to determine concentrations of 3-deoxyanthocyanidins, flavan-4-ols, and proanthocyanidins. Seeds were also plated on biological media to observe the level of seed infection by mold-causing fungi. Flavan-4-ol concentrations were high and similar for both the mold-resistant and mold-susceptible genotypes at early stages of seed development. In susceptible genotypes, the flavan-4-ol concentration dropped by 67% between the third and the last sampling dates compared with a 20% decline for the resistant genotypes in the same period. In addition, the resistant genotypes (P954255, P932062, IS15346, IS7822, PO13931) had high concentrations of proanthocyanidins throughout the season compared with susceptible lines, which lacked or had negligible amounts of this material. Although significant differences occurred among genotypes for 3-deoxyantho- cyanidins, the presence of these pigments did not differentiate mold-resistant and mold-susceptible genotypes. The results also showed that the highest incidence of seed infection by fungi occurred between 25 and 35 days after anthesis. *Alternaria, Fusarium* (especially *F. moniliforme), Cladosporium,* and *Epicoccum* species were the major fungi isolated from the seeds.

RAPD Based Assessment of Genetic Diversity in Cultivated Races of Sorghum (Ref. Crop Science 1997. Vol. 37 : 564-569)

Analysis of the extent and distribution of genetic diversity in crop plants is essential for optimizing sampling and breeding strategies. We used random amplified polymorphic DNA (RAPD) markers to assess genetic diversity and taxonomic relationships in 190 accessions sampled to represent the cultivated races of sorghum [*Sorghum bicolor* (L.) Moench]. A high level of variation was detected among cultivated genotypes. Partitioning the genetic variation in cultivated sorghum with Shannon's diversity index revealed that 86% of the total genetic variation occurred among accessions and 14% among races. We also examined the degree of association of accessions with their geographic areas of origin by using Shannon's diversity index. The results indicated that only 13% of the total genetic variation was attributable to divergence among regions. Further tests using principal component analysis also failed to show separation of accessions into discrete racial or geographic groups. Despite such limited differentiation among races or regions, RAPD markers successfully identified races and regions with maximum genetic diversity. For example, accessions within races bicolor and guinea had greater genetic diversity than accessions from race kafir. Accessions from Southern Africa had a lower level of genetic diversity than accessions from Far and Middle East, Central and Eastern Africa, and Western Africa. Thus, use of RAPD markers may optimize sampling of genetically divergent accessions for introgression into breeding pools.

Networking Activities

Workshop and Program Reviews

Year 18

Served as a member of the organizing committee of both INTSORMIL Principal Investigators Conference and the International Sorghum and Millet Genetics Symposium held at Lubbock, Texas, September 1996. Presented joint papers with several colleagues at these meetings.

Presented a paper at the Sixth International Parasitic Weed Symposium, Cordoba, Spain, April 1996.

Served as Visiting Faculty, University of Wisconsin, Summer Institute for African Agricultural Research, June 1997.

Participated in African Dissertation Internship Award selection, Rockefeller Foundation, November 1996 and April 1997.

Attended the American Society of Agronomy national meetings, Indianapolis, IN, November 1996.

Year 19

Traveled to Eastern Africa to visit NARS in the region with INTSORMIL Director, Dr. John Yohe and held discussions leading to the establishment of an INTSORMIL Regional Collaborative Research Program in the Horn of Africa, June 1997.

Served as chair of the organizing committee of an INTSORMIL/Horn of Africa Traveling Workshop. The week long traveling workshop was attended by three scientists from Kenya, two from Eritrea, one from Uganda, scientists from the Ethiopian Institute of Agricultural Research, four INTSORMIL principal investigators, and the associate program director.

Attended and participated in the 1997 World Food Prize Symposium, 16-17 October 1997, Des Moines, Iowa.

Served as Visiting Faculty, University of Wisconsin, Summer Institute for African Agricultural Research, June 1998.

Participated in African Dissertation Internship Awards Selection, Rockefeller Foundation, November 1997, and April 1998.

Attended the American Society of Agronomy National Meetings, Anaheim, California, October 1997.

Participated in Pioneer HI-Bred In-house Review of Public/Private Plant Breeding Programs, April 1997, Des Moines, Iowa.

Year 20

Participated in African Dissertation Internship Awards selection, Rockefeller Foundation, 18 May 1998, New York.

Evaluated and harvested sorghum winter nursery, NC+ Research Farm, 17-22 March 1998, Ponce, Puerto Rico.

Attended the INTSORMIL International Impact Assessment Workshop, Corpus Christi, Texas, 20-24 June 1998.

Attended the Sorghum Ergot Conference, Corpus Christi, Texas, 24-26 June 1998.

Participated in Summer Institute for African Agricultural Research. June 14-19, 1998 University of Wisconsin, Madison.

Participated in Regional Collaborative Research and provided technical guidance to sorghum research efforts in Ethiopia, 19-26 September 1998.

Attended and participated in the International Hybrid Sorghum Seed Workshop, Niamey, Niger, 27 Sept.-2 October 1998.

Participated in review and evaluation of INTSORMIL Horn of Africa program, 2-10 October 1998.

Attended the American Society of Agronomy National Meetings, 18-22 October 1998, Baltimore, Maryland.

Participated in African Dissertation Internship Awards selection, Rockefeller Foundation, New York, 11-12 December 1998.

Participated in a meeting of Board Members for the Essential Electronic Agricultural Library, Rockefeller Foundation, New York, 16-17 December 1998.

Year 21

Participated in the development of a Food Security project for the Amhara Region in Ethiopia at the invitation of USAID/Ethiopia, 22nd of February to the 5th of March 1999, Addis Ababa, Ethiopia.

Negotiated a contract for an INTSORMIL project to undertake a study on the development and diffusion of drought tolerant crops in Eastern Africa with the Inter-Governmental Agency for Development, 7-13 March 1999, Djibouti.

Participated in African Dissertation Internship Awards selection, Rockefeller Foundation, 4-5th May 1999, New York.

Participated in Summer Institute for African Agricultural Research, June 13-17, 1999, University of Wisconsin, Madison.

Participated in Workshop on Molecular Approaches for the Genetic Improvement of Cereals for Stable Production in Water Limited Environments, 21-25 June 1999, CIMMYT, Mexico.

Participated in Workshop on Breeding for *Striga* Resistance in Cereals and Molecular Application in Crop Improvement, 14-21 August 1999, IITA, Nigeria.

Participated in the Review and Evaluation of INTSORMIL programs by the External Evaluation Panel, West Lafayette, IN 22-24 September 1999.

Attended the American Society of Agronomy national meetings, 30th of October to 5th of November 1999.

Attended the American Seed Trade Association Meeting, Chicago, IL, 8-9 December 1999.

Research Investigator Exchange

Interactions with public, private, and international sorghum research scientists continues to be an important function of PRF-207. The following individuals visited our program or worked in our laboratory during the last four years:

Dr. Paula Bramel-Cox, Director, Genetic Resources, ICRISAT, February 1996 , June 1997, and June 1999.

Dr. Jill Lenne, Principal Plant Pathologist, ICRISAT, July 1996.

Dr. Aberra Debello, Sorghum Breeder and Program Leader, Ethiopian Sorghum Improvement Project, September, 1996, May 1998 and June 2000.

Dr. Abdel Gabar Babiker, Sudan National Coordinator for Sorghum and Millets, September 1996.

Dr. Abdel Moneim Bashir El Ahmadi, Director, National Seed Industry, Sudan, September 1996.

A large number of sorghum scientists from the USA and around the world visited our sorghum research program, field, and laboratory facilities, on the way to and from the International Sorghum and Millet Genetic Conference in September 1997.

We were also visited by the then new Director General of ICRISAT, Dr. Shawki Barghouti, where current state of ICRISAT and future collaborative possibilities with Purdue were discussed.

Dr. Yilma Kebede, Sorghum Breeder, Pioneer HiBred, November 1996, September 1997, and November 1999.

Dr. Brian Hare, Advanta, Pacific Seeds, Australia, October, 1999.

Germplasm Exchange

We continue to provide an array of sorghum germplasm from our breeding program to national research programs in developing countries. Our germplasm is provided in either a formally organized nursery that is uniformly distributed to all collaborators that show interest, or upon request by a national program of specific germplasm entries or groups from our germplasm pool. Germplasm was distributed to cooperators in 25 countries in 1996, 15 countries in 1997, 10 countries in 1998, and 7 countries in 1999.

Publications

Refereed Papers

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King, D., M.Z. Fan, , G. Ejeta, A. Asem, and O. Adeola. 2000. The effects of tannins on nutrient utilization in the White Pekin duck. British Poultry Science (In Press).

Conference Proceedings

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Ejeta, G., M. Tuinstra, E. Grote, and P. Goldsbrough. 1999. Genetic Analysis of pre-flowering and post-flowering drought tolerance in sorghum. *In* Proc. Workshop on Molecular Approaches for the Genetic Improvement of Cereals for Stable Production in Water Limited Environments, 21-25 June, 1999, CIMMYT, El Batan, Mexico.

Mickelbart, M., G. Ejeta, D. Rhodes, R. Jolly, and P.Goldsbrough. 1999. Assessing the contribution of glycinebetaine, to environmental stress tolerance in sorghum. *In* Proc. Workshop on Molecular Approaches for the Genetic Improvement of Cereals for Stable Production in Water Limited Environments, 21-25 June, 1999, CIMMYT, El Batan, Mexico.

Ejeta, G., A. Mohammed, P. Rich, A. Melakeberhan, T. Housley, and D. Hess. 1999. Selection for specific mechanisms of resistance to *Striga* in sorghum. *In* Proc. Workshop on Breeding for *Striga* Resistance in Cereals, Ibadan, Nigeria.

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Ejeta, G. 1999. Breeding for *Striga* Resistance in Sorghum. *In* Proc. Workshop on Breeding for *Striga* Resistance in Cereals, Ibadan, Nigeria.

Ejeta, G. 1999. Solving Agricultural Problems Through Crop Science. *In* Proc. Symp on Diversity: A Source of Strength for the Tri-Societies, American Society of Agronomy Annual Meeting, Salt Lake City, Utah.

Published Abstracts

Ejeta, G., P. Goldsbrough, M. Tuinstra, E. Grote, and M. Mickelbart. 1999. Drought Tolerance in Sorghum: Mapping of QTL and Analysis of Near- Isogenic Lines, p. 242. Agronomy Abstracts. ASA Madison, WI

Mickelbart, M., R. Jolly, D. Rhodes, P. Goldsbrough, and G. Ejeta. 1999. Development of near-isogenic lines of sorghum accumulating different concentration of glycinebetaine, p. 120. Plant Phys. Abstracts.

Invited Research Lectures

Ejeta, G. 1997. Strategies in breeding sorghum for stress tolerance. Presented at the Summer Institute for Agricultural Research. June 8-14. Univ. of Wisconsin; Madison.

Ejeta, G. 1997. Interdisciplinary collaborative research in sorghum and millets. Presented at the Greater Horn of Africa-INTSORMIL Traveling Workshop. Sept, 22-Oct 5, Nazret, Ethiopia.

Ejeta, G. 1997. Response to the Sasakawa Global 2000 Program Presentation. Presented at the 1997 World Food Prize Symposium, Food Security and the Future of Sub-Saharan Africa. Oct. 17-18. DeMoines, Iowa.

Ejeta, G. 1997. Agricultural Research, Population, and Global Food Production. Presented at the HOBY World Leadership Congress. July 21, Purdue University, West Lafayette, Indiana.

Ejeta, G. 1997. Breeding for *Striga* Resistance in Sorghum. Special Seminar. Purdue University. Dec. 11, Purdue University, West Lafayette, Indiana.

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Ejeta, G. 1999. Challenges to African Human Resource Development. Presented at Workshop on Agricultural Development Challenges Facing African Scientists, Summer Institute for African Agricultural Research,. 16 June, University of Wisconsin, Madison.

Ejeta, G. 1999. Solving Agricultural Problems Through Crop Science. Presented at the Symposium on Diversity: A Source of Strength, American Society of Agronomy Annual Meeting at Salt Lake City, Utah.

Germplasm Enhancement for Resistance to Pathogens and Drought and Increased Genetic Diversity

Project TAM-222
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Ing. Laureano Pineda, INTA, Nicaragua

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Summary

The principal objectives of TAM-222 are to identify and develop disease resistant and drought resistant sorghum germplasm 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 program continued to develop germplasm for use in the USA and host countries. Twenty-seven new fully converted exotic lines and 70 partially converted lines from the cooperative TAMU-TAES/USDA-ARS Sorghum Conversion Program were identified for release in 2000 and 20 more for late 2000.

Seed of over 2,000 entries of Malian indigenous sorghums from the Mali Sorghum Collection were assembled, grown out in Mali, and introduced into the USA. A portion was prepared at NSSL and grown out under quarantine in St. Croix in the winter of 1999-2000, with the growout of the remainder scheduled for winter 2000-2001.

Performance of stay green hybrids under severe post-flowering moisture stress has shown that the stay green trait dramatically reduced lodging and produced higher yields than non-stay green hybrids, and also provides resistance to charcoal rot.

Sterilization of a large number of new B-lines is essentially completed, and most show lodging resistance and pre- and/or post-flowering drought resistance.

Selected breeding progenies looked very good in the Southern Africa region, combining drought resistance,

grain quality, sugarcane aphid resistance, and high yield. Many Macia derivative lines looked excellent.

GAM, the largest baker and marketer of bread and cookies in the Bamako area is now marketing cookies using a blend of wheat and sorghum (N'Tenimissa) flour.

The white-seeded, tan-plant, guinea type breeding cultivar named N'Tenimissa continued to look promising for yield and adaptation in on-farm trials in Mali. Grain quality evaluations indicate that the grain has good food quality traits for various commercial food products. Several new N'Tenimissa derivatives looked outstanding in 1999 and did not show the stem breakage problem of N'Tenimissa. These lines should be useful in Mali and West Africa as an improved guineense type sorghum with grain that has improved quality for use in value-added commercial food products.

Objectives, Production and Utilization Constraints

Year 21 Project Objectives

USA

- Develop agronomically improved disease and drought resistant lines and germplasm and identify new genetic sources of desirable traits. Select for drought resistance with molecular markers. Evaluate new germplasm and introgress useful traits into useable lines or germplasm.

Mali/West Africa

- Assist breeders in developing agronomically acceptable white-seeded, tan-plant Guinea type sorghum cultivars, to enhance the commercial value and demand for improved value, high quality sorghum grain.

- Characterize and describe the indigenous Mali origin sorghum collection and evaluate for useful traits and breeding potential, and introduce into the USA.

- Identify and assist in developing new germplasm with resistance to grain mold, drought, headbug, anthracnose, and *Striga*.

- Identify molecular markers for head bug resistance to develop improved sorghums for West Africa.

Central America

- Enhance germplasm base with sources of resistance to grain mold, foliar diseases and drought, and food type sorghums, and lines for adapted commercial hybrids.

Horn of Africa and SADC Region

- Enhance drought resistance and disease resistance with the development of improved high yielding, adapted germplasm and elite lines.

Constraints

Drought is the major constraint to sorghum and millet production around the world. west Texas has a semi-arid environment ideal for large scale field screening for both pre- and post-flowering drought response, and breeding for improved resistance to drought.

Diseases are important worldwide and most internationally important diseases are present and are also serious constraints in Texas, especially downy mildew, charcoal rot, grain mold/weathering, head smut, and head blight. The Texas environment, particularly south Texas, is ideal for screening and breeding sorghums with high levels of resistance to most internationally important diseases.

Poor grain quality is a major problem in Mali and much of West Africa and is, primarily, due to the head bug/grain mold complex. Head bugs are a major constraint to the use of improved high yielding nonguineense type sorghums in much of West Africa with head bug damage often compounded by grain mold resulting in a soft, discolored endosperm, which is unfit for decortication and traditional food products. Early maturity of introduced types also increases the grain deterioration problem. In southern Mali, late maturing, photoperiod sensitive sorghums are needed to assure grain maturity after the rainy season.

Mali and Niger, especially the more northern areas, are both drought prone areas where drought tolerance is important. Foliar diseases, such as anthracnose and sooty stripe, are important in the central and southern parts of Mali and in certain areas of Southern Africa. In Sudan, and much of East Africa, the major constraint is drought, and related production problems. Moisture-stress related charcoal rot and subsequent lodging are serious problems. *Striga* is a major constraint in Mali, Niger, and Sudan.

In Central America, diseases and grain quality are major constraints, with drought also important in the drier portions of the region. Improvement in the photoperiod sensitive, food-type maicillos criollos grown in association with maize on small, hillside farms is a unique challenge.

There is a constant need in both host countries and the USA to conserve genetic diversity and utilize new diverse germplasm sources with resistance to pests, diseases, and environmental stress. Many developing countries are an important source of diverse germplasm in sorghum and millet. The collection, preservation and utilization of genetic diversity in sorghum is important to long-term, sustainable sorghum improvement programs needed to insure sufficient food for increasing populations of the future.

Research Approach and Project Output

Research Methods

Introductions from various countries with drought or disease resistance, or specific desirable grain or plant traits, are crossed in Texas to appropriate elite U.S. lines or elite breeding materials. Seed of the early generations are sent to host countries for selection of appropriate traits and adaptation. Technical assistance is provided, as time and travel permits, in the selection, evaluation, and use of such breeding material in the host country.

Disease resistant breeding material is generated from crosses among various disease resistant sources, agronomically elite lines, and new sources of resistance. Initial screening is primarily in large disease screening nurseries utilizing natural infection in south Texas. Selected advanced materials are sent to host countries, as appropriate, for evaluation and are, also, incorporated into various standard replicated trials for extensive evaluation at several locations in Texas and host countries.

Breeding crosses, involving sources of drought resistance, are selected under field conditions for pre- and post flowering drought resistance, yield, and adaptation at several locations in west Texas. Molecular markers for the stay green trait are used in a marker assisted selection program. Selected advanced materials are incorporated into standard replicated trials for evaluation at several locations in Texas and sent to host countries for evaluation and use.

Converted and partially converted lines from the Sorghum Conversion Program, exotic lines, new introductions, and breeding materials are screened and evaluated in Texas for new sources of resistance to internationally important diseases and resistance to drought.

New sorghum germplasm is assembled or collected as opportunities exist, introduced into the USA through the quarantine greenhouse or the USDA Plant Quarantine Station in St. Croix, and evaluated in Puerto Rico and Texas for useful traits. Selected photoperiod sensitive cultivars are entered into the cooperative TAES-USDA Sorghum Conversion Program. Cooperative work with NARS assures their country's indigenous sorghum cultivars are preserved in long-term permanent storage, as well as evaluated and used in germplasm enhancement programs. Growouts of entire collections have been grown in their country of origin for characterization, seed increase, and evaluation prior to introduction into the USA. Assistance is provided in developing smaller working or core collections for the NARS to actively maintain and use in their improvement programs.

Research Findings

Twenty-seven new fully converted exotic lines and 71 partially converted lines are in preparation for release from the cooperative TAMU-TAES/USDA-ARS Sorghum Conversion Program. An additional 20 fully converted lines from the 1999 increase will be ready for release in late 2000, which will bring the total released fully converted lines to 700 since the inception of the program. That will include 117 during the last four years. Five new female parental lines (A1, A2-2(b), A35, A803, and A807 are being prepared for release. Several other A-B pairs and R lines have been selected for release as germplasm stocks. These lines contain various desirable traits, including resistance to downy mildew, head smut, grain mold/weathering, anthracnose, charcoal rot, both pre- and post-flowering drought resistance, food type grain quality, and lodging resistance.

A large group of new B lines, many developed cooperatively with Dr. L.E. Clark (retired) at Chillicothe/Vernon, are in the final stages of sterilization, with many to have their first evaluation in hybrid combination in 2000. Some are white-seeded, tan-plant lines and some have waxy endosperm. Most have good resistance to lodging, and many have some stay green (post-flowering drought resistance), and/or pre-flowering drought resistance. Most show wide adaptation as lines from Puerto Rico to west Texas, with some having good head smut resistance and good foliage disease resistance. Some also show improved grain mold resistance and thresh easily and clean. A few have shown excellent potential in hybrids in Niger. Plans are to release this set primarily as germplasm stocks, but a few may be released as parental lines. Pedigrees represented include (B1*BTx635), (BTx635*B4), (B1*B9501), (B35*B9501), (B2-1*B9501), (B1*Segaolane), and (B.BON34*B9502), where B9501=(B7904*(SC748*SC630)) and B9502=(BTx3042*(BTx625*B35)).

Some grain quality analyses by Dr. Lloyd Rooney of new white, tan-plant, waxy endosperm B-lines indicated that they were superior to existing B-line waxy endosperm lines in decortication yield and density (Table 1). These new lines may produce waxy endosperm hybrids with improved grain density, weathering resistance, and grain yield.

Breeding, selection, and screening for drought resistance and disease resistance continued using disease screening field nurseries in south Texas and field drought screening nurseries at Lubbock, Halfway, Lamesa, and Chillicothe. The growing seasons vary over years, due to rainfall, but good pre-flowering drought stress was obtained in 1999 at Lubbock, Lamesa, and Chillicothe with some post-flowering stress under limited irrigation at Lubbock and Halfway. Severe late season moisture stress develops sometimes in south Texas, as it did in 1998 and 1999. Pre-flowering stress was also severe in south Texas in 1998. The evaluation of the photoperiod insensitive sorghums from Sudan was completed, with several identified as promising sources of drought (mostly pre-flowering) resistance (Table 2). Breeding derivatives of the stay green line, B35, have continued to show good stay green and outstanding lodging resistance over the years. Major diseases involved in the disease resistance breeding were charcoal rot, grain

Table 1. Grain quality analysis of new white, tan plant, waxy endosperm B-lines.

Pedigree	Pericarp color	Plant color	Endo-sperm	TKW[1]	Decort.[2] Yield	Density[3]
(BTx630*B9502)-HD8	white	tan	wx	22.50	82.83	1.387
(BTx630*B9502)-HD37*	red	tan	wx	23.63	77.17	1.373
(B.BON34*B9502)-BE11	white	tan	wx	22.13	76.75	1.384
(B.BON34*B9502)-LD6	white	tan	wx	26.38	75.90	1.374
BTxARG1	white	tan	wx	27.00	70.69	1.366
RTx2907	white	tan	wx	31.50	56.98	1.357
RTx430	white	purp	non-wx	37.63	70.86	1.393
Sureno	white	tan	non-wx	26.75	83.25	1.412

1 Thousand kernel weight (grams)
2 Decorticated yield (100 minus % removed) (higher is best)
3 Density of grain (g/cc) (higher is more dense)

* Outstanding milling yields and color of decorticated grain.

Table 2. Photoperiod insensitive sorghums from the Sudan Sorghum Collection with drought resistance.

1993 Sudan (SU) number	IS number	Race	Type of drought resistance[1]
3	921	C	Pr
78	2322	CD	Pr
92	2337	CK	Pr
96	2344	CD	Pr
147	3467	C	Pr
166	3489	CD	Pr
170	3493	C	Pr
171	3494	C	Pr
173	3496	CD	Pr
181	3507	C	Pr
262	3744	C	Pr
279	6906	CK	Pr
439	8688	CK	Pr & Po
445	8786	C	Pr
448	8799	B	Pr
451	9227	K	Pr
496	9643	CD	Pr
544	9693	C	Pr
577	9729	C	Pr
578	9730	C	Pr
581	9733	C	Pr
583	9735	C	Pr
599	9751	C	Pr
600	9752	C	Pr
601	9753	C	Pr
602	9754	C	Pr
609	9762	C	Pr
629	9782	C	Po
661	9817	C	Pr
689	9747	C	Pr
716	9877	C	Pr
779	9951	C	Pr
809	9987	C	Pr
831	12459	C	Pr
847	12725	D	Pr
957	19075	C	Pr
1008	19126	D	Pr
1084	19203	CD	Pr
1149	19269	C	Pr
1192	19312	C	Pr
1355	19561	C	Pr
1556	20855	CD	Pr
1671	22363	C	Pr
1672	22364	C	Pr & Po
1677	22369	C	Pr
1862	22557	C	Pr
2508	—	C	Pr
2510	—	C	Pr
2603	—	—	Pr
2724	—	—	Pr
2739	—	—	Pr
2802	—	—	Pr
2858	—	—	Pr

1 Pr=Pre-flowering; Po = Post-flowering.

mold/weathering, downy mildew, head smut, anthracnose, and foliage diseases such as rust, zonate, and leaf blight. Grain mold/weathering was especially severe in south Texas in 1999.

The stay green trait is an extremely useful drought resistant trait under post-flowering moisture stress and results in significantly higher grain yield, while also yielding well when under non-stressed conditions. Hybrids involving a stay green parent performed well in south Texas under moisture stress where they showed good stay green ratings, no lodging, and good yields.

Molecular analysis using RFLP markers, along with drought evaluation, was continued on F_9 recombinant inbred lines (RILs) of (B35*Tx430) and (B35*Tx7000). Five QTLs were identified for the stay green trait in the cross (B35*Tx7000) with two or three appearing to be the most important. In the cross (B35*Tx430), three of the same QTLs were identified for stay green along with two others. Two hundred different RILs, each from two populations, B35*Tx7000 and SC56*Tx7000, were evaluated for drought and lodging and DNA analyzed to map QTLs for lodging resistance. BC6 near isogenic lines (NILs) have been developed involving QTL1, QTL2, and QTL3 to do fine mapping and study the role and function of these QTLs. Crosses and backcrosses were made using marker assisted selection (MAS) for stay green and greenbug resistance. Also, the advanced backcross technique is being used with selected exotic lines to identify QTLs for yield and heterosis.

Several breeding progeny from crosses generated for Host County and the USA have looked very good agronomically in Southern Africa. Some showed excellent sooty stripe resistance, especially progeny of Macia, ICSV1089BF, Dorado, and SRN39. Various progenies showed excellent drought resistance, grain quality, and sugarcane aphid resistance, combined with excellent yield potential. The cross, Macia*Dorado, was especially outstanding. Many Macia derivatives look excellent. Other lines giving good progeny included 87EO366, WSV387, TAM428, SRN39, ICSV1089BF, Sureño, Dorado, and 90EON328.

The Mali Sorghum Collection Growout in Mali was very successful and has been processed at NSSL. The late group was grown out, seed increased, and characterized in St. Croix in the winter 1999-2000.. There was much more diversity in the Collection than expected, especially among the Durra derivative cultivars. Several potential new candidates for the Sorghum Conversion Program were identified. The remainder of the Mali Collection is planned for growing in St. Croix in the winter of 2000-2001.

The guinea-type, white-seeded, tan-plant sorghum cultivar "N'Tenimissa", developed at IER, continued to perform well in IER and World Vision InterCRSP on-farm trials in Mali. It was also included in the ROCARS (Sorghum Regional Network) regional trials. It's head bug resistance is slightly inferior to the local guinea cultivars, but appears to have an acceptable level under on-farm conditions. Farmers seemed happy with it grain quality wise, and also for yield, but it exhibits significant peduncle breakage under some conditions.

Several new tan-plant N'Tenimissa derivative guinea type breeding lines looked outstanding in Mali in 1999, showing less stalk breakage, and better head bug resistance than N'Tenimissa. Also, some new, shorter N'Tenimissa derivative F_3 and F_4 lines showed real promise. Selection also continued among non-guinea type, tan-plant breeding lines with improved levels of head bug tolerance and grain mold resistance. N'Tenimissa grain was increased for use in various food quality and food product trials. Grain quality evaluations consistently show N'Tenimissa as being superior to non-guinea breeding materials, but not quite as good as local guinea cultivars in decortication yield, a measure of hardness of endosperm. The quality of food products however, is excellent.

GAM, the largest producer of bread and cookies in the Bamako area, has announced that it is now marketing cookies with a blend of sorghum and wheat flower, using sorghum flour from the N'Tenimissa increase. There recently was a big public announcement by the Mali government regarding this development.

Excellent segregation for headbug resistance occurred in the F_3 progenies of the cross (Malisor 84-7*S34). However, Dr. Aboubacar Toure, in his Post-Doc research, failed to identify any QTLs for head bug resistance, as there was a problem with low polymorphism in the cross as well as some problems with variability in one parent. CIRAD scientists have also done some DNA analysis of the same cross, and hopefully some QTLs for resistance will be identified.

Networking Activities

Workshops/Conferences

Participated in the INTSORMIL Central America Planning Conference, October 4-6, 1999 at EAP, Zamorano, Honduras.

Participated in the 2000 Sorghum Industry Conference, February 20-22, 2000, Corpus Christi, TX.

Participated in the Annual Texas Seed Trade Association Research Conference, January 31-February 1, 2000, Dallas, TX.

Research Investigator Exchanges

Traveled to Montpellier, France October 11-13, 1999, along with Dr. Aboubacar Toure, to visit CIRAD scientists Dr. J.C. Chantereau and others working on sorghum, especially those working in West Africa.

Traveled to Mali October 14-25, 1999 to evaluate and plan INTSORMIL/IER collaborative research. Procured and brought to the USA additional seed of 102 Mali Sorghum Collection items from ICRISAT that were missing from the Cinzana growout.

Traveled to Honduras, October 4-6, 1999 to interact with scientists from Honduras, El Salvador, and Nicaragua to plan future collaborative research projects in Central America.

Traveled to Indianapolis, IN July 27-28, 1999 to the INTSORMIL/IGAD Horn of Africa drought project planning meeting.

Traveled to El Salvador, January 6-8, 2000 to the CENTA/INTSORMIL MOU signing ceremony and to meet and discuss sorghum research with CENTA scientists.

Participated in and presented poster paper at the Annual American Society of Agronomy Meetings, October 31-November 4, 1999 at Salt Lake City, UT.

Assisted in and participated in the INTSORMIL EEP reviews at Corpus Christi (July 18-20), College Station (July 21-22), and Lubbock (September 20-21, 1999).

Participated in the Sorghum Crop Germplasm Committee (SGC) as AdHoc member, February 20, 2000, Corpus Christi, TX.

Participated in INTSORMIL Technical Committee (TC) meetings, April 18-20, 2000 at Kansas City, Missouri.

Continued coordination of the introduction of the Mali Sorghum Collection into the USA with the planting of the late group of the Collection under quarantine in St. Croix the winter of 1999-2000, with characterization and harvest May 23-27, 2000 along with Aboubacar Toure, Jeff Dahlberg, and John Erpelding. Initiated plans for the growout of the remainder in the winter of 2000-2001.

Coordinated the visit and hosted Dr. Andrew Borrell, sorghum stress physiologist from Queensland, Australia, at Lubbock, Texas, June 28-July 2, 1999.

Coordinated and hosted the short-term training of Mr. Sibene Dena, sorghum pathology technician, IER, Mali, August 12-September 18, 1999, with training visits to Texas A&M, College Station (Dr. Frederiksen), Kansas State, Manhattan (Dr. Claflin), and Lubbock, Texas.

Coordinated the training (B.S. to lead into M.S.) for Mr. Niaba Teme, sorghum breeding technician from Mali, at Texas Tech University and TAES at Lubbock, beginning August, 1995.

Toured the sorghum research plots of Dr. Mitch Tuinstra, Sorghum Breeder, Kansas State University September 24, 1999.

Germplasm and Research Information Exchange

Germplasm Conservation and Use

Continued the coordination of the work with the Mali Sorghum Collection, including plans for planting, seed increase, and completion of characterization of the late group of the Collection in St. Croix the winter of 1999-2000. Identified, along with Aboubacar Toure, candidates for the Working Collection. Made plans for the quarantine growout of the remainder of the Mali Collection in St. Croix in the winter of 2000-2001.

Seed of 102 additional Mali Sorghum Collection lines (ones that had no plants or no seed in the Cinzana growout) was obtained from ICRISAT in Mali (from their duplicate growout at Samanko) and introduced into the USA.

Evaluated a large Ethiopian Sorghum Collection (2,200 in 1998-99 and 2,900 in 1999-2000) in Puerto Rico and identified candidates for entry into the Sorghum Conversion Program. Several had very large seed and high yield potential.

Thirty-five new sorghum breeding lines from IER, Mali were introduced into the USA. These included white-seeded, tan-plant, good food quality guinea derivative and non-guinea types.

Several photoperiod insensitive sorghum cultivars from the Sudan Collection were identified as promising sources of drought resistance.

Twenty-seven new fully converted exotic lines from the cooperative TAMU-TAES/USDA-ARS Sorghum Conversion Program were selected for release and are being prepared for release along with 70 partially converted lines. Twenty additional new fully converted exotic lines were selected for release later in 2000.

Seed Production and Distribution

Several sets of released fully converted lines and partially converted bulks from the cooperative TAMU-TAES/USDA-ARS Sorghum Conversion Program were distributed. A large number of sorghum breeding and germplasm lines, from early to advanced generation progeny, A, B, and R lines, converted lines, and experimental hybrids were increased and distributed to international and domestic collaborators. These contained sources of desirable traits such as resistance to downy mildew, anthracnose, sooty stripe, leaf blight, rust, and charcoal rot, pre- and post-flowering drought resistance, grain mold and weathering resistance, and lodging resistance. Seed was increased and many sets of standard replicated trials containing elite germplasm and source lines were packaged and distributed in the USA and internationally. These include the ADIN (All Disease and Insect Nursery), IDIN (International Disease and Insect Nursery), GWT (Grain Weathering Test), DLT (Drought Line Test), DHT (Drought Hybrid Test), and the UHSN (Uniform Head Smut Nursery). Countries to which large numbers of germplasm items were distributed include Mali, Niger, Zimbabwe, Botswana, Zambia, Ethiopia, Guatemala, Honduras, El Salvador, Nicaragua, and Mexico.

Assistance Given

Joint evaluation of germplasm and nursery and test entry decisions was done collaboratively with national scientists in Mali. Training on disease and drought breeding methodology, as well as information on sources of new useful germplasm and sources of desirable traits, was provided to several visitors. Pollinating bags, coin envelopes, and breeding supplies were provided to the Mali breeding program.

Other Collaborating/Cooperating Scientists

Cooperation or collaboration with the following scientists, in addition to the collaborating scientists previously listed, was important to the activities and achievements of Project TAM-222.

Dr. Issoufou Kapran, Sorghum Breeder, INRAN, Maradi, Niger.

Dr. Fred Rattunde, Sorghum Breeder, ICRISAT, Bamako, Mali.

Dr. Inoussa Akintayo, WCASRN Coordinator, WCASRN, ICRISAT, Bamako, Mali

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Dr. L.E. Claflin, Pathologist, KSU-108, Kansas State University, Manhattan, KS.

Prof. D.J. Andrews, Sorghum/Millet Breeder, UNL-115, University of Nebraska, Lincoln, NE.

Dr. J.D. Eastin, Physiologist, University of Nebraska, Lincoln, NE.

Dr. Jeff Dahlberg, Research Director, National Grain Sorghum Producers Association, Lubbock, TX.

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Germplasm Enhancement for Resistance to Insects and Improved Efficiency for Sustainable Agriculture Systems

Project TAM-223
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Summary

This project is the breeding for resistance to insects component of the integrated Texas A&M University sorghum improvement program. Project objectives are to identify, characterize and utilize the genetic diversity of grain sorghum to develop improved cultivars, germplasm, or parental lines resistant to selected stresses. Research is conducted to determine the genetic factors responsible for resistance and their associated mechanisms. Insect pests receiving major emphasis are the sorghum midge (*Stenodiplosis sorghicola*), biotype E and I greenbug (*Schizaphis graminum*), and sugarcane aphid (*Melanaphis sacchari*). Some research is conducted on resistance to yellow sugarcane aphid (*Sipha flava*). Breeding and selection activities primarily use conventional methodology. Collaborative molecular biology research projects map genes for resistance to greenbug biotypes, and use molecular markers to concurrently select for greenbug and stay-green (post-flowering drought resistance).

A primary research objective has been to develop sorghum lines resistant to sorghum midge that are suitable for use as hybrid parents. In addition to pest resistance, the lines should produce excellent grain yield potential under high pest density, acceptable yield with the pest absent, and contain other needed traits including adaptation, foliar quality, etc. In 1997, the Texas Agricultural Experiment Station released sorghum inbred line pairs A-/B-Tx639, Tx640, and Tx641. The lines will produce hybrids with excellent grain yield in the presence of sorghum midge. When sorghum midge are absent at anthesis hybrids with these lines as the hybrid seed parent will yield 10 to 15% less than the best susceptible hybrids. These lines give U.S. seed companies the capability of producing sorghum-midge resistant hybrids for use if insecticides to control sorghum midge are not available.

Molecular markers diagnostic for resistance to the sorghum greenbug biotypes C, E, I and K have been identified. Nine markers on eight linkage groups were determined to condition resistance. Greenbug resistance sources used in the research were: Tx2737 (resistance from SA7536-1), Tx2783 (resistance from Capbam), and PI550607. Only two

loci were biotype specific and most acted in an additive or incompletely dominant way. Digenic interactions accounted for a greater portion of the resistance phenotype than did independently acting loci. Unfortunately, low levels of DNA polymorphism in existing populations made high-resolution mapping impossible. New populations are being developed for high-resolution mapping of the QTLs conferring GB resistance. Results from the mapping are being used in a marker-assisted selection (MAS) study to combine greenbug resistance with stay green (post-flowering drought tolerance). The research is using molecular probes to combine the two traits, and to study the efficiency of MAS versus traditional selection methodology.

Objectives, Production and Utilization Constraints

Objectives

- Obtain and evaluate germplasm for resistance to arthropod pests. Determine the resistance source or mechanisms most useful to sorghum improvement.
- Determine the inheritance of insect resistance.
- Develop and release high yielding, agronomically improved sorghums resistant to selected insects.
- Utilize molecular biology to increase understanding of the genetics of plant resistance traits.
- Identify and define sorghum genotypes with varying levels or tolerance to drought and chemical stress of Sahelian soils.

Constraints

Sorghum production and yield stability is constrained by many biotic and abiotic stresses including insects, diseases and drought. Insects pose a risk in all areas of sorghum production with damage depending on the insect and local environment. To reduce stress impact, sorghum cultivars with enhanced environmental fitness suitable for use in more sustainable production systems are needed. Cultivars experience stress concurrently or sequentially and genetic resistance to multiple stresses will result in reduced environmental risk and contribute to improved productivity. This is especially important as production ecosystems experience induced change due to cultivars and/or technology, the natural balance between cultivars and biotic stresses also changing and insect damage becoming increasingly severe.

Genetic resistance may be utilized at no additional cost to the producer to meet the demands of increased food production in an economically profitable, environmentally sustainable production system. This requires a multi-disciplinary research program to integrate resistant hybrids into the management system. Cultivars resistant to insects readily integrate with other required inputs as part of an integrated, ecologically sound production and stress control strategy with large potential benefits in subsistence and mechanized agriculture. Host plant resistance to insects is a continual effort in response to a dynamic evolving production agroecosystem.

Sorghum midge, *Stenodiplosis sorghicola*, is the only ubiquitous sorghum insect pest and may be the *Sorghum* species most destructive pest. As LDC programs introduce exotic germplasm with improved agronomic traits into sorghum improvement programs, cultivars with less photoperiod sensitivity will be developed and sorghum midge damage will become increasingly severe. Depending on the environment, other insect pests (including aphids, head bugs and borers) will damage grain sorghum. For all of the insect pests, genetic resistance exists and can be integrated into the production system in an ecologically safe, economically inexpensive, and environmentally sustainable manner.

Research Approach and Project Output

Research Methods

Collaborative research is conducted in LDCs on specific problems. LDC research is supported through graduate education, germplasm exchange and evaluation, site visits, and research at nursery locations in Texas. This project supports collaborative research in three ecogeographic sites - West Africa (Mali), Southern Africa, and Central America. Research efforts in Mali are being reallocated to other sites, with current activity directed primarily at graduate education and support of a Ph.D. student. Research in Southern Africa is directed at incorporating resistance to sugarcane aphid into adapted cultivars. Activity in Nicaragua provides the opportunity for additional research on sorghum midge (the most important production constraint in Nicaragua), drought, disease, and adaptation. For the United States, sorghum midge, biotype E, I, and K greenbug and yellow sugarcane aphid resistant sources have been identified and used in developing elite resistant sorghums. Through collaborative ties with other projects genetic inheritance and resistance mechanisms are determined. Molecular biology is used to map genes for greenbug resistance and conduct marker-assisted selection research.

Germplasm is evaluated for resistance to economically important insects in the collaborative breeding/entomology program in field nurseries or greenhouse facilities, depending on the insect mode of infestation. Sources of germplasm for evaluation are introductions from other programs (including ICRISAT), exotic lines, and partially or fully converted exotic genotypes from the sorghum conversion program. New resistance sources are crossed to elite resistant germplasm, and to other germplasm lines with superior trait(s). Although the primary selection criteria is for insect resistance, the geographical diversity of Texas nursery locations provides the opportunity to select for wide adaptation, resistance to specific diseases, drought resistance, and weathering resistance. Studies to determine the genetics of resistance and resistance mechanism(s) are conducted when possible. Based on data analysis and phenotypic evaluation, crosses are made among elite lines to produce additional germplasm for subsequent evaluation. The overall objective is to combine as many stress resistance genes as possible into a single high yielding genotype.

For insects important in LDC's but not in the U.S., germplasm is provided to the LDC cooperator. The germplasm is evaluated for resistance to the specific insect under the local production system (fertilizer, tillage, plant population, etc.) and agronomic and yield data collected. Based upon experimental results, crosses are made to produce populations for inheritance and entomological studies. These populations are provided to the cooperator for evaluation. When possible, the populations are grown in the USA and selected for adaptation. Molecular biology has been used to study head bug resistance in Mali and the USA.

Research Findings

Research to broaden the genetic base of the sorghum midge resistance breeding program, to incorporate additional sources of resistance into elite lines, and to identify new superior A- or R-lines continued. Significant progress to improve agronomic traits and grain yield potential of sorghum midge resistant germplasm has been achieved.

Breeding lines and hybrids were evaluated for sorghum midge resistance at two locations in the USA under high (Corpus Christi) and moderate (College Station) population density. The midge line test was also grown at the INTA research station near Managua, Nicaragua. Diverse locations to screen for sorghum midge resistance are needed since lines and hybrids that perform well under moderate/low midge density may not perform well under high sorghum midge density. At maturity, the entries receive a midge damage rating (MDR) and agronomic evaluation. The MDR is a subjective rating on a scale of 1 = 0-10% aborted kernels, 2 = 11-21% aborted kernels, up to 9 = 91-100% kernels.

Sorghum midges were present at anthesis in high numbers in both the Corpus Christi (MDR=4.84) and College Station (MDR=4.81) Midge Line Test (Table 1). The test included three susceptible checks, 13 resistant checks, 69 experimental entries, and 12 introductions from Southern Africa. The susceptible check RTx430 sustained high damage at both locations (MDR = 7 at Corpus Christi and 6.3 at College Station). Most resistant checks and experimental

Table 1. Midge damage rating (MDR) of selected entries in the 1999 Midge Line Test at College Station and Corpus Christi, TX.

Pedigree/Designation	Midge Damage Rating[1]	
	CC[2]	CS
97M1/(PM12713*Tx2766)/7BRON134	2	3.7
(MR127-92M5*MR114-90M11)-SM17-SM2-CM1-SMBK	2	3.3
IS6919C/SC846-14E	2.3	3.3
MR114-90M11	2.3	4.3
B8PR1021/MB116C-	2.3	3.7
94ML68/((SC228-14*Tx2767)*Tx2876)	2.3	3
PM12713	2.7	3.3
Rep(MR118-der*Tx2882)-	2.7	3.3
7BRON159/7MLT69/(PM12713*Tx2882)-CM3-CM2	2.7	2.3
(MR127-92M5*MR114-90M11)-SM2-CM2-SM1-CMBK	2.7	3
Tx2880	3	3
Tx2782	3	3.7
B94-7	3	4.7
Rep/((SC228-14*Tx2767)*Tx2876)	3	3
7BRON145/7MLT58/(MB108B/P.G.*MB110-49-der)	3	4.7
(Tx2880*SC170-6-17)-SM15-CM1-	3	2
(Tx2882*SRN39)-CM3-SM2-SM2-SM2-SMBK-CMK	3	3.3
BTx640	3.3	4
B8PR1015/MB124B-	3.3	4.3
97M14/(Tx2882*6EO374)/7BRON153	3.3	3.7
Rep/((SC62-14*Tx2782)*Tx2878)	3.3	4
(((SC572-14*SC62-14)-C12-)*Tx2767)-CM19-	3.3	6.3
(Tx2882*SRN39)-CM3-SM2-SM2-CM1-CMBK-CMBK	3.3	3.3
((MB120C-BM5-)*MB108B/P.G.)-SM5-CM1-CM2-CM1-	3.3	3.7
((MB120C-BM5-)*MB108B/P.G.)-SM5-CM1-CM2-CM2-	3.3	3.7
((MB126E-BM3-)*MB108B/P.G.)-CM9-CM2-	3.3	3.3
(MR112B-92M2*Tx2880)-SM17-CM2-CM2-CMBK	3.3	5
(MR127-92M5*MR114-90M11)-SM2-SM1-SM1-CMBK	3.3	5.3
(Tx631*(MB126E-BM6-)-SM21-CM1-	3.3	3.3
(BVar*MB102-3)-CM5-SM2-	3.3	6
(BArg34*(MB120C-BM5))-SM3-CM2-	3.3	4
(MR112B-92M2*Tx2880)-SM3-SM1-SM2	3.3	5
B8PR1013/MB120A-	3.7	3
((MB126E-BM3-BM2)*MB108B/P.G.)-SM5-CM2-	3.7	3.3
(MB110-21-der*Tx623)-CM11-LMBK-SM2-	3.7	7
(BVar*MB102-3)-CM5-SM2-	3.7	5

Table 1 - Continued

Pedigree/Designation	Midge Damage Rating[1]	
	CC[2]	CS
Tx2882	4	4.7
B8PR1011/MB120A-	4	3
97M9/(Tx2882*7EO366)/7BRON146	4	5.3
97M16/(MR112-90M5*87EO366)/7BRON156	4	3.3
97M17/(PM12713*Tx2880)/7BRON156	4	4
(Tx2782*MB108B/P.G.)-CM10-SM1-	4	4
B8PR1017/MB124B-	4.3	3.3
7BRON155/7MLT61/(Tx2767*(SC572-14*SC62-14))	4.3	5.3
(88B885/(Tx623*CS3541)*Tx2782)-BM8-LMBK-	4.3	4.7
BTx639	4.7	4.7
B94-15	4.7	4.7
B8PR1019/MB131B-	4.7	5.3
97M13/(Tx2882*6EO374)/7BRON152	4.7	3.3
Rep/((SC62-14*Tx2782)*Tx2878)	4.7	3 7
((MB120C-BM5-)*MB108B/P.G.)-SM10-CM1-	4.7	3.7
BTx2755	5	4.7
Tx2767	5	5
(PM12713*Tx2882)-CM7-CM1-CM2-CM1-SMBK-CMBK	5	3.7
((MB120C-BM5-)*MB108B/P.G.)-SM10-CM1-	5	6
B94-17	5.3	4
BTx641	5.7	4
MB108B/P.G.	6	.3
TAM2566	6	4.3
Rep/(MB110-der*Tx623)	6	5.7
((MB126E-BM3-)*MB108B/P.G.)-SM5-CM2-	6	5.7
(Tx631*(MB126E-BM6-)-SM4-CM1-	6.3	6
(B1*(MB126E-BM6))-CM4-CM2-	6.3	5.3
BTx623	6.7	3.3
RTx430	7	6.3
Macia	7	7
BTx378	7 3	6.3
WM#322	7 7	5.3
CE151	8	6.7
EPSON 2-40/E#15/SADC	8	5.7
Segaolane	8	9
Town	8	5
SV1	8.3	8
ICSV745	8.7	8.7
A964	8.7	7.7
WM#177	9	8
FGYQ336	9	9
Marupantse	9	9
Mean	4.8	4.8
LSD .05	1.2	1.4

[1] Midge Damage Rating based on a scale of 1 = 1-10% aborted kernels, 2 = 11-20% aborted kernels, ..., 9 = 91-100% aborted kernels.
[2] CC = Corpus Christi, CS = College Station

lines were significantly less damaged than the susceptible checks. Several experimental entries sustained no more damage than the most resistant checks. Two new seed parents (A-/B-lines), designated 8PR1011 and 8PR1013, exhibited excellent resistance. The Southern Africa introductions - Macia, WM#322, CE151, EPSON 2-40/E#15/SADC, Segaolane, Town, SV1, ICSV745, A964, WM#177, FGYQ336, and Marupantse - were very susceptible to sorghum midge damage. MDR for the introductions ranged from 5 to 9 with most entries rated at 8 or 9.

The primary sorghum midge resistance source is TAM2566 (SC175-9) a partially converted zerazera (IS12666) from Ethiopia. Major research emphasis for several years has been to use other resistance sources to 1) diversify the genetic base of the program for resistance, and 2) attempt to improve the level of resistance. Several midge line test entries derive resistance from two or three different sources. These resistance sources include IS3390C (SC572-14E), IS12572C (SC62-14E), IS2579C (SC423-14E), IS2549C (SC228-14E), and two lines from ICRISAT (PM11344 and PM12713). Utilization of these lines enables a broader resistance genetic base and selection for other useful traits including tan plant, improved foliar quality, and larger kernel size.

Combining ability for yield potential and sorghum midge resistance was evaluated to identify breeding lines suitable for use as hybrid parents. The major constraint to use of sorghum midge resistant hybrids has been the lack of parental lines which possess excellent resistance and grain yield po-

Table 2. Mean grain yield and midge damage rating for entries in the 1999 Midge Hybrid Test at Corpus Christi and College Station, TX.

Hybrid	Class[1]	Kg/ha-1	Kg/ha-1 CC¶	Kg/ha-1 CS	MDR[2]	MDR[3] CC	MDR[3] CS
A8PR1013*Tx2880	R*R	3290	3097	3482	3	2.3	3.7
A8PR1019*Tx2880	R*R	2536	2887	2185	3.8	3	4.7
ATx641*97M9	R*R	2667	2694	2639	3.2	2.7	3.7
A8PR1011*Tx2882	R*R	3113	2529	3697	3.7	4	3.3
ATx640*94ML68	R*R	2476	2525	2426	3.3	3.3	3.3
A8PR1011*Tx2767	R*R	2879	2411	3348	4	4	4
A8PR1017*Tx2767	R*R	2249	2363	2135	3.8	4	3.7
ATx640*97M9	R*R	2282	2360	2203	3.7	3.7	3.7
ATx640*94ML66	R*R	2407	2343	2472	3.5	3.7	3.3
A8PR1013*Tx2767	R*R	2464	2263	2665	4	4	4
ATx640*Tx2880	R*R	2389	2252	2526	3.5	3.3	3.7
ATx641*94ML66	R*R	2256	2234	2278	4	4.3	3.7
A8PR1019*Tx2882	R*R	2364	2195	2533	4.7	4.7	4.7
A94-15*Tx2880	R*R	1752	2191	1313	5.3	4.3	6.3
ATx640*97M16	R*R	2258	2156	2360	3.3	3	3.7
ATx2755*97M17	R*R	2426	2142	2709	4.5	4.7	4.3
ATx640*Tx2882	R*R-CK	2347	2108	2586	3.3	3.3	3.3
A8PR1021*Tx2880	R*R	1998	2102	1894	4.8	5	4.7
A8PR1021*Tx2882	R*R	2357	2032	2683	3.5	3.3	3.7
A94-15*Tx2767	R*R	2422	2021	2822	4.3	4.3	4.3
A8PR1017*Tx2882	R*R	1890	1843	1936	3.5	3.7	3.3
ATx640*97M18	R*R	2069	1758	2380	3.3	3	3.7
ATx641*97M16	R*R	2152	1730	2575	4.7	5	3.3
ATx2755*97M16	R*R	2230	1696	765	4.5	5	4
A94-14*Tx2767	R*R	1919	1688	2149	5	5	5
ATx641*Tx2882	R*R-CK	1988	1673	2302	4.3	4.7	4
ATx641*97M1	R*R	1902	1636	2169	4.5	4.7	4.3
ATx640*97M10	R*R	1988	1636	340	4	5	3
A94-17*Tx2880	R*R	1546	1569	1524	6	6	6
ATx641*Tx2880	R*R-CK	1763	1558	1968	4.7	5	4.3
ATx641*97M17	R*R	1843	1558	2127	4.3	4.3	4.3
ATx640*97M17	R*R	1602	1553	1651	4	4.3	3.7
A8PR1017*Tx2880	R*R	2081	1537	2625	4.7	5.3	4
ATx640*97M1	R*R	1836	1528	2143	4.3	5	3.7
ATx641*97M10	R*R	1858	1521	2195	4.7	5	4.3
ATx641*97M18	R*R	1953	1520	2386	4.7	5.3	4
ATx2755*Tx2880	R*R-CK	1861	1481	2241	4.8	5	4.7
ATx2755*97M10	R*R	1718	1413	2024	5.5	5.7	5.3
A8PR1021*Tx2767	R*R	2059	1382	2737	4.8	5.3	4.3
ATx641*94ML68	R*R	1697	1313	2081	4.7	5.7	3.7
ATx2755*Tx2767	R*R-CK	1704	1020	2390	5.3	6.3	4.3
ATx2755*Tx2882	R*R-CK	1433	904	1962	6	6.7	5.3
ATx2755*97M9	R*R	1477	802	2151	6	6.7	5.3
A94-17*Tx2882	R*R	814	741	886	6.8	6.7	7
A8PR1015*Tx2882	R*R	1377	728	2026	6.5	7.7	5.3
A94-7*Tx2882	R*R	964	630	1299	6.3	7	5.7
A8PR1015*Tx2880	R*R	870	532	1209	6.7	7.7	5.7
A8PR1011*Tx2880	R*R	1653	506	2800	6.2	8	4.3
A8PR1015*Tx2767	R*R	492	328	657	7.3	8.3	6.3
ATx399*RTx430	S*S-CK	67	72	62	9	9	9
ATx2752*RTx430	S*S-CK	83	41	126	8.8	8.7	9
A94-6*Tx2767	R*R	45	21	70	8.8	9	8.7
A35*RTx430	S*S-CK	108	14	203	9	9	9
A94-6*Tx2882	R*R	28	9	48	9	9	9
94-6*Tx2880	R*R	49	6	92	8.8	9	8.7
35*Tx2783	S*S-CK	47	4	90	9	9	9
A1*Tx2862	S*S-CK	60	2	118	9	9	9
MEAN		1722	1489	1955	5.2	5.4	5
LSD .05		500	463	588	0.8	0.9	0.9

[1] Classification: R = resistant, S = susceptible, Ck = check.
[2] Midge Damage Rating based on a scale of 1 = 1-10% aborted kernels, 2 = 11-20% aborted kernels, ..., 9 = 91-100% aborted kernels.
[3] CC = Corpus Christi; CS = College Station.

tential under pest infestation, and excellent grain yield potential in the absence of the pest.

Grain yield and midge damage rating for entries in the Midge Hybrid Test at Corpus Christi (CC) and College Station (CS) are shown in Table 2. The standard resistant check is ATx2755*Tx2767 (MDR=6.3 (CC) and 4.3 (CS), grain yield=1020 (CC) and 2390 (CS) kg ha^{-1}) and the standard susceptible check is ATx2752*RTx430 (MDR=8.7 (CC) and 9.0 (CS), grain yield=41 (CC) and 126 (CS) kg ha^{-1}). Most experimental hybrids produced significantly more grain than the susceptible checks. At both locations, many experimental hybrids produced significantly more grain than ATx2755*Tx2767 and several produced more grain than the most resistant hybrid, ATx 640*Tx2880. Based on grain yield data, MDR and agronomic evaluation as hybrid parents, and midge line test MDR two new A-lines were identified as potentially useful. The lines, designated 8PR1011 and 8PR1013, have large open panicles with white grain and possess excellent resistance as lines. Both lines were selected for inclusion in the PROFIT (Productive Rotations On Farms In Texas) hybrid seed project. Hybrids with each line as the seed parent (female) will be produced in the summer of 2000 for wide area evaluation in 2001.

Selections to develop germplasm resistant to biotype E, I, and K greenbug were made in many populations. The primary sources of resistance to biotype I and K are PI550607 and PI550610. Both sources are used in developing R-lines, and PI550610 is used in B-line development. Screening against biotypes E and I greenbug identified genotypes that contain moderate resistance to both biotypes. Resistance to the biotypes is conditioned by different genes and a moderate level of resistance to both biotypes is emphasized in the selection criteria. Crosses to introgress resistance gene(s) into other germplasm were made.

New R-lines resistant to biotype E and/or I produced excellent hybrids. The lines represent a range of plant types including tan plant, white pericarp and tan plant, red pericarp. New tan plant, red grain biotype E resistant A-lines were evaluated in hybrid combination. The tan plant, red grain hybrids were resistant to either biotype E or biotype E/I greenbug, depending on the male parent. The hybrids expressed excellent grain yield potential, wide adaptation and resistance to several diseases. Based on 1999 performance, one A-line, 8PR1059, and two restorer lines, 5BRON139 (resistant to biotype E) and LG35 (resistant to biotype E/I) were selected for inclusion in the PROFIT hybrid program. Hybrid seed will be available in 2001 for wide area testing of tan plant, red grain, greenbug and disease resistant hybrids.

Marker-assisted selection research to combine greenbug resistance and stay green (post-flowering drought tolerance) into a single genotype continued. The research is a collaborative project between TAM-223, TAM-222, and the molecular biology laboratory of Dr. Henry Nguyen (Texas Tech University). Mr. Sidi Bekaye Coulibaly (Mali) is conducting Ph.D. research in this project to compare the efficiency of marker-assisted selection versus traditional selection methodology. Three greenbug resistance sources are used: Capbam through Tx2783, PI550607, and PI550610. The source of post-flowering drought tolerance is the cross B35*Tx7000. Backcrossing is continuing to introgress the needed genes into elite genetic backgrounds. To evaluate the efficiency of marker-assisted selection versus traditional selection methodology 347 total F_4 progeny from four populations were selected for analysis. Each of the lines was analyzed for presence of greenbug resistant or stay green genes using probes diagnostic for the genes of interest. Phenotypic ratings for stay green were collected on field plantings and for greenbug resistance in seedling stage greenhouse trials. Molecular analysis identified 78 lines with stay green (3 to 5 QTLs) and 46 lines with greenbug resistance (1 to 4 QTLs). Phenotypic ratings identified 102 lines with stay green and for greenbug 78 lines resistant to biotype E, 50 lines resistant to biotype I, and 19 lines resistant to E and I. Molecular or phenotype data identified 22 and 24 lines, respectively, with stay green and greenbug resistant QTLs. Seventeen lines were identified as greenbug resistant with both molecular and phenotypic data, and 27 lines were similarly identified for stay green. Hybrids using the selections as the pollen parent have been made to evaluate resistance gene performance in hybrids.

The program to develop resistance to sugarcane aphid entered the second year. The research is in collaboration with TAM-222, TAM-228, and TAM-225. Resistance sources including TAM428, CE151, WM#177, Sima (IS23250), SDSL89426, FGYQ336 have been intercrossed or crossed to locally adapted cultivars to develop a range of populations. Exotic cultivars used include Segaolane, Marupantse, Macia, Town, SV1, and A964. The lines were crossed to elite TAM-223 germplasm to introduce additional favorable traits including foliar disease resistance and backcrosses of selected F_1s to adapted cultivars were made. The germplasm was planted at Corpus Christi and Lubbock, Texas for initial selection.

A 50-entry test for sugarcane aphid resistance was developed and sent to Southern Africa. The test was evaluated for resistance to sugarcane aphid in a greenhouse screening at the ARC, Potchefstroom, South Africa (Table 3). Eleven experimental entries sustained no more damage than the most resistant checks (WM#322, Ent. 62/SADC, FGYQ353, TAM428). Sugarcane aphid resistant breeding materials are being developed for the program and several experimental lines were entered in the test. Several lines exhibited resistance equal to or not significantly different from the resistant checks. The lines may also contain resistance to other stresses including sorghum midge. Selection will continue in Texas and seed will be provided to collaborators in Southern Africa for evaluation in the local environment. The lines should contain wide adaptation, sugarcane aphid resistance, and disease resistance (primarily sooty stripe and anthracnose), and other favorable traits. Traits needed

Table 3. Sugarcane aphid damage and abundance on entries in the 1999 Sugarcane Aphid Test, Potchefstroom, SA.

Pedigree/Designation	Aphid Damage[1]	Aphid Abundance[2]
WM#322	1	1
Ent. 62/SADC	1	1.5
FGYQ353	1	1
PRGC/E#222879	1	1.5
PRGC/E#69414	1	1.5
TAM428	1	1
(Macia*TAM428)-LL2	1	1 5
(Macia*TAM428)-LL7	1	1
(CE151*BDM499)-LD17-BE2	1	1
(Macia*TAM428)-LL9	1	1
GR128-92M12/(GR105*(R5646*SC326-6))	1	1
(Tx2783*VG15/M50009)-LG9-	1	2
(Tx436*GR108-90M24)-LG8	1	1
(Tx2883*(Tx2864*(Tx436*(Tx2864*PI550607))))-PC1-	1	1
(Tx2883*(Tx2880*(GR108-90M24*(Tx2862*(Tx430*(Tx2862*PI550607))))))-PR3-	1	1
(Tx430*Sima/IS23250)-LG5-	1	2
(6OB128/(Tx2862*6EO361)*CE151)-LG19-	1	1
FGYQ336	1.5	1
PRGC/E#222878	1.5	1.5
SDSL89426	1.5	2
(Macia*TAM428)-HD1	1.5	1.5
(87EO366*TAM428)-HF2 (F6)	1.5	1
6OB124/(GR104*((Tx432*CS3541)*SC326-6))	1.5	1.5
GR127-90M39/(GR105*((Tx432*CS3541)*SC326-6))	1.5	1.5
MB108B	1.5	1.5
(Tx2883*(Tx2864*(Tx436*(Tx2864*PI550607))))-PC2-	1.5	2.5
(Tx2883*(Tx2880*(GR108-90M24*(Tx2862*(Tx430*(Tx2862*PI550607))))))-PR2-	1.5	2.5
(SDSL89426*6OB124/GR134B-LG56)-LG5-	1.5	1
(6OBS124/GR134-LG56-*WM#177)-LG2-	1.5	1.5
CE151	2	1
WM#177	2	1
Macia	2	3
(CE151*BDM499)-LD17-BE1	2	1.5
(TAM428*SV1)-HD10	2	2
(87EO361*Macia)-HL25	2	2
(Tx2783*(Tx2737*(Tx436*(Tx2783*PI550607))))-PC4	2	2 5
(Sima/IS23250*5BRON131/(80C2241*GR108-30)-LG1-	2	2
(SV1*Sima/IS23250)-LG6-	2	2.5
(87EO366*TAM428)-HF4 (F6)	2.5	2
(91BE7414/(R8505*(R5646*SC326-6))	2.5	2
(87EO366*GR134A-90M50)-LG6-	2.5	1
(EPSON2-40/E#15/SADC*A964)-LG6-	2.5	2
Segaolane	3	2
Sima (IS23250)	3	1
Kuyuma	3	2.5
Tx2882*SRN39)-CM3-	3	2
(5BRON154/(87BH8606-14*GR107-90M46)*EPSON2-40/E#15/SADC)	3	2
(Macia*Dorado)-HD4	3.5	3
(PM12713*Tx2880)-CM3-	3.5	2.5
(Sima/IS23250*6OBS129/(Tx2862*6EO361)-LG1-	4	3
Test Mean	1.8	1.6
LSD .05	1.5	1.2

[1] Rated on a scale of 1 = no damage up to 4 = plant death.
[2] Rated on a scale of 1 = few aphids up to 3 = high infestation.

to enhance potential use include tan plant, white pericarp, and appropriate height and maturity.

Networking Activities

Research Investigator Exchanges

Honduras and El Salvador - August 29 to September 2, 1999. In Honduras, met with officials of EAP, DICTA, and USAID to discuss potential for continued INTSORMIL activity in the country. Planned the regional planning meeting scheduled for October 4-5 and the EEP Review scheduled for October 5 and 6. In El Salvador met with officials and scientists of CENTA to discuss mutual interest in initiating collaborative research on sorghum. Discussed the regional planning meeting with scientists and how the new regional program will operate.

Honduras and Nicaragua - October 2-9, 1999. In Honduras, participated in the INTSORMIL sponsored regional planning meeting to review sorghum research in Central America and plan research projects for the new regional program activity. Participated in the EEP review of INTSORMIL activity in Honduras. In Nicaragua, met with officials of INTA to discuss collaborative activity and plan future research. Met with representatives of UNA (Managua) and UNAN-Leon to sign MOUs between the respective universities and INTSORMIL.

El Salvador - January 6-8, 2000. Participated in formal signing ceremony of the MOU between CENTA and INTSORMIL. Met with CENTA scientists to discuss research proposals.

South Africa, Botswana, Mozambique, and Zambia - April 2-15, 2000. The trip had three objectives: 1) Meet with scientists and administrators as the in-coming INTSORMIL Regional Coordinator (all countries); 2) Continue research on sugarcane aphid resistance (South Africa, Botswana, Zambia); 3) Discuss INTSORMIL participation in the inter-CRSP Mozambique training program (Mozambique).

Germplasm and Research Information Exchange

Germplasm Conservation and Use

Accessions from the sorghum conversion program were grown for increase and evaluation. Releases from the sorghum conversion program were deposited in the National Seed Storage Laboratory. Germplasm was distributed to private companies as requested and to the following countries, including but not limited to: Mali, Botswana, Niger, Guatemala, Nicaragua, South Africa, Botswana, Zimbabwe, and Zambia. Entries in the All Disease and Insect Nursery (ADIN) were evaluated at many locations domestically and internationally.

Seed Production

The following experimental lines developed by TAM-223 were increased in the 2000 Puerto Rico winter nursery for use as hybrid seed parents in the summer of 2000: Sorghum midge resistant: Tx2880, Tx2882, A8PR1011, A8PR1013; Biotype E greenbug resistant: 5BRON139, A8PR1059, Biotype E/I greenbug resistant: LG35. Seed was provided under contract to a private seed company to produce hybrid seed for wide area testing in 2001 as part of the PROFIT initiative.

Impacts

Germplasm previously developed and released by this project is widely used by commercial seed companies in hybrid production. Biotype E greenbug resistant R-lines from this project are widely used in the production of greenbug resistant hybrids.

Assistance Given

Trained Malian IER breeding collaborators in the use of computer software.

Other Cooperators

Collaboration with the following scientists was important in the activities of TAM-223:

Dr. R.A. Frederiksen, Dep. of Plant Pathology and Microbiology, Texas A&M University, College Station, TX 77843 (TAM-224).

Dr. L. W. Rooney, Cereal Chemistry, Dep. of Soil and Crop Sciences, Texas A&M University, College Station, TX 77843 (TAM-226).

Dr. R. D. Waniska, Cereal Chemistry, Dep. of Soil and Crop Sciences, Texas A&M University, College Station, TX 77843.

Dr. W.L. Rooney, Sorghum Breeding, Dep. of Soil and Crop Sciences, Texas A&M University, College Station, TX 77843.

Dr. T.L. Archer, Entomology, Texas A&M University Agricultural Research and Extension Center, Route 3 Box 219, Lubbock, TX 79401-9757.

Dr. R.G. Henzell, Sorghum Breeding, Hermitage Research Station, via Warwick, QLD 4370, Australia.

Dr. M.D. Doumbia, Soil Chemistry, IER, Sotuba, B.P. 438, Bamako, Mali.

Dr. Y. Doumbia, Entomology, IER, Sotuba, B.P. 438, Bamako, Mali.

Publications and Presentations

Presentations

Peterson, G.C. 2000. Using molecular biology to understand greenbug resistance. Texas Seed Trade Association Production and Research Conference. January 30 - February 1, 2000. Dallas, TX.

Peterson, G.C. 2000. PROFIT - A New Research and Education Paradigm for Sorghum. Texas Seed Trade Association Production and Research Conference. January 30 - February 1, 2000. Dallas, TX.

Refereed Journal

Katsar, C.S., A.H. Paterson, G.L. Teetes, and G.C. Peterson. 2001. Molecular analysis of sorghum resistance to the greenbug, *Schizaphis graminum* Rondani (Homoptera:Aphididae). J. of Econ. Entomol. (submitted).

Katsar, C.S., G.C. Peterson, Y.R. Linn, G.L. Teetes, and A.H. Paterson. 2001. Correspondence among greenbug resistance loci suggest the need for "gene rotation" as a new dimension of integrated pest management. Proc. Nat. Acad. Sci. (submitted).

Breeding Pearl Millet and Sorghum for Stability of Performance Using Tropical Germplasm

Project UNL-218
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Dr. Tunde Obilana, Sorghum Breeder and Emmanuel Monyo, Millet Breeder, ICRISAT/SMIP Program, Matopos, Zimbabwe
Drs. T. Hash and K.N. Rai, Millet Breeders, and Dr. Paula Cox, Genetic Resources, ICRISAT, Patancheru P.O. AP 502 325, India
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Summary

Sorghum and pearl millet are the major traditional cereal crops on which millions of people are dependent in extensive drought prone areas of low-resource agriculture in Africa and the Indian sub-continent. These two cereals are the best adapted to most reliably produced food in the unpredictable conditions of erratic rainfall, low soil fertility, and numerous pests and diseases. In such conditions, agronomic interventions, such as the use of chemical fertilizers, have dramatic effects but their costs and the risks involved are still too high for most low resource farmers. Seed of new cultivars is a highly cost effective technology even without agronomic support, but they are more effective with and encourage the use of other agronomic interventions. Where production increases have been obtained in low resource conditions, they have always been dependent on new cultivars. Plant breeding is therefore the key, and the catalyst to improving food production in Africa, and has already done so in India.

Sorghum is widely used as a grain feed in intensive agriculture, in North and South America, southern Europe, South Africa and Australia, with consequent high levels of breeding research, some results of which can be modified and used in research in developing countries. The situation is different for pearl millet, which so far has only been utilized in intensive agriculture as a forage crop. However, pearl millet has a more nutritious grain than sorghum, and has the potential to become a high yielding feed grain with a somewhat different adaptation pattern than sorghum. It has frequently been shown in India that pearl millet hybrids can produce five tons of grain/ha in three months, and the same yield has been obtained on a field scale in Kansas.

The goals of this project are several: to develop parental material of higher yielding ability that can be used in collaborative breeding programs in developing countries; in the USA. to increase the genetic diversity available to sorghum breeders and to produce the adapted plant type needed to grow pearl millet as a combine feed crop; to identify sources

of useful traits and to develop methods to consistently select for them; and to provide students thesis topics from the on-going research which are relevant to the problems they will face in their research programs at home.

Collaborative breeding with pearl millet to make hybrids with the best varieties was continued in Mali and Namibia and initiated (1998) in Zambia, the latter two with the assistance of the SADC/ICRISAT Sorghum and Millet Improvement Program at Matopos, Zimbabwe. Collaborative breeding in sorghum in Botswana was completed with the participation of the SADC/ICRISAT/SMIP program. Breeding material and information, mostly on pearl millet, is routinely exchanged with the ICRISAT programs in India and the West African Center in Niger. Sorghum germplasm and pearl millet germplasm has been sent to many developing countries.

In the USA., both applied and basic research is conducted on both crops. Good progress was made in developing and releasing pearl millet hybrid parents (1997) which give high levels of heterosis, lodging resistance and early maturity. Basic research on the new A_4 cytoplasmic male sterility (CMS) system, and recently, in collaboration with ICRISAT, the A_5 system, was continued. Research showed these offer significant advantages in breeding and producing hybrid seed both in the USA. and tropical areas. Studies with the same (isonuclear) pearl millet hybrids with A_1, A_4 or normal cytoplasm, showed indications of cytoplasm/nuclear interaction, which could vary according to cytoplasm, and nuclear genotype. Some hybrids made in sterile cytoplasm appeared better than in normal cytoplasm. If this cytoplasmic contribution to heterosis is substantiated, it would have important implications to all crops with CMS hybrids. The development of isonuclear stocks of three further CMS systems, A_5, A_{av} and A_{egp} continued. The main thrust of the sorghum program is to introgress new high yielding tropically bred food sorghums into U.S. grain sorghums and use some of the resulting early generation segregating populations for selection in Botswana and other countries. This introgression continues to provide new genetic diversity for early and full season grain hybrids in the USA including white grain-tan plant food quality hybrids. In the report period, 303 parental lines and germplasms were released. Screening methods were developed to identify and investigate sources of genetic resistance either to low and high temperatures at germination and initial stages of seedling growth.

Objectives, Production and Utilization Constraints

Objectives

- For both crops to build and improve a diverse range of breeding germplasm from crosses between U.S. adapted lines and proven tropical breeder stocks. Such diversity is used in collaborative country projects, in deriving parent lines for the USA, and in genetic and breeding methods research.
- To train LDC personnel in genetics and plant breeding.

Specifically in Pearl Millet

- To determine relative values of alternative cytoplasmic male sterility (CMS) systems for breeding hybrids and their seed and grain production.
- To produce A_4 top cross hybrids from adapted parents through collaborative breeding in Namibia, Zambia and Mali.
- To produce and release parental lines, both in A_1 and A_4 CMS systems, for making early maturing, high yielding lodging resistant grain hybrids for the USA.
- To investigate and utilize genetic variability for special attributes; emergence from cool soils, white grain, zenia (direct effect of pollen genotype) and recovery from seedling damage.

For Sorghum

- Study methods of early generation selection for combining ability.
- Continue to produce and evaluate hybrid parent lines for Botswana (in collaboration with ICRISAT/SMIP/ Zimbabwe) and supply relevant germplasm to other countries.
- To produce and release parental lines for food quality hybrids for the USA.
- To develop screening methods, and separately study genetic ability to emerge from cool soils, and inheritance of seedling heat tolerance.

Constraints

Pearl millet and sorghum are major food crops in low resource semi-arid (LRSA) subsistance farming in Africa and Asia. LRSA production is limited by both agronomic and nonagronomic factors (negligible capital, small and fragile markets, competing imported cereal grain prices and social constraints). Principal agronomic constraints are lack of plant nutrients, moisture (drought), timely operations, and occurrence of pests, diseases and weeds. When these constraints to plant growth exist, local varieties often perform relatively well, and give stable but low yields. Improving production conditions in LRSA agriculture has proved difficult mainly because of cost and risk involved to the individual farmer and because of the inability of many developing countries to provide support to LRSA farmers. In this context, higher yielding cultivars developed through plant breeding are the most viable low cost route (seed costs are much lower than fertilizer, etc.) to a valuable increase in food production. Also, new cultivars are always essential prerequisites for any successful agronomic package.

Improved varieties, where seed can be self increased (in contrast to hybrids, for which new seed must be obtained for each crop) can and have been successfully bred for LRSA agriculture. However, progress in variety breeding is relatively slow (even in developed countries) and variety multiplication requires continued government support because varieties do not normally attract private enterprise investment in developing countries. Hybrids however do attract private enterprise and this results in providing farmers with quality seed. In the last few years, attitudes have changed in regard to the utility of hybrids in developing countries and local production of hybrid seed and sale to farmers is now viewed as desirable and possible (e.g., Nigeria).

Hybrids in both sorghum and pearl millet, use growth resources most efficiently, particularly when they are in short supply, and generally give 20% more yield than equivalent varieties. While varieties in pearl millet are internally heterotic, higher yields are still given by F_1 hybrids, even those where the best variety is used as a parent in top cross hybrids. Increased yields at the small farmer level, often at low productivity levels without other inputs, has been the reason why sorghum and pearl millet hybrids have been successful in Asia. If the hybrids are of a stable and durable type, they can also perform in low resource agriculture in Africa. Therefore, the project, with this in mind, has been examining aspects of top cross hybrid development and production in pearl millet with conventional CMS or protogyny seed parents.

Thus, the underlying theme of genetic research and germplasm development in both crops in this report period has been the utilization of heterosis, through selection for the relative combining ability of male and female parents, and in pearl millet, exploring new CMS systems that can improve hybrid development and performance.

The need of all plant breeders, especially in developing countries, where research resources are limited, is knowledge of the most effective selection procedures (methods) to use to gain their objectives. Thus, our research [Chibwe Chungu, (M.S.) from Zambia followed by Fabien Jeutong (Ph.D.) from Cameroon] in sorghum first investigated methods of selecting for combining ability, which is fundamental to breeding superior hybrids. Cytoplasmic male sterility (CMS), needed in both crops (although protogyny, as shown by previous research, provides a very useful alternative in pearl millet) to produce hybrids, can add substantial limitations to breeding parental lines. The availability of two (now five) independent effective CMS systems in pearl millet provided a valuable opportunity to analyze the constraints imposed on parental development and hybrid performance by different CMS systems. This research was partly conducted by Dr. K. N. Rai of ICRISAT, who was a Visiting Scientist 1998-99, Fabien Jeutong (Post Doc) and Dr. John Rajewski (Project Manager).

Traits related to seedling establishment are important, particularly in stressful environments. Peter Setimela in his Ph.D., from Botswana, evaluated easy to use methods, and genetic effects of sorghum seedling emergence and establishment at high soil temperatures, shown to be a major constraint in the tropics. Iskender Tiryaki (M.S.) from Turkey using sorghum looked at the contrast, methods of measuring genetic differences in lines and their hybrids for emergence from cool soils, advantageous for tropically derived crops seeded into soils emerging from temperate winters. Continuing with this theme Mr. S. A. Ipinge, Visiting Scientist from Namibia, began research on the direct effect (Zenia) of pollen genotype on size of seed borne by seed parents, and in cross pollination between genetically contrasting hybrids. Currently, Mr. M. Mogorosi, Pearl Millet Scientist, from Northern Botswana, is studying pearl millet breeding, variety and hybrid seed production techniques for five months as a visiting scientist on the project.

Research Approach and Project Output

Research Methods

The general approach for both crops is to create new genetic diversity for selection by crossing high yielding U.S. stocks with new germplasm from developing countries or ICRISAT (and in the case of sorghum, from the Kansas State Introgression Program). This diversity is then used in collaborative breeding projects in host countries to select for per se adaptation, and also in the USA to release lines with new trait combinations. In both crops the principal breeding method is pedigree selection combined with test crosses and hybrid evaluation to select for the parental lines that make the best hybrids. Winter nurseries are used to expedite the selection process. In sorghum some selection for host countries is for varieties also. Seed parents are produced in A_1 cytoplasmic male sterile (CMS) system in sorghum but both A_1 (Tift $23A_1$ cytoplasm) and A_4 (monodii cytoplasm) and now A_5 CMS are being used in pearl millet. A_4 male sterility has been transferred into lines derived from a Senegalese long headed dwarf pearl millet variety, IBMV 8401. These can then be used to detect existing or introduced A_4 genes in adapted varieties in Senegal and elsewhere with the eventual aim of producing top cross hybrids made with R_4 derivatives or R_4 versions of the best varieties as male parents. A similar approach is being used in collaborative projects in Namibia and Zambia (see Southern Africa region report) and Mali. Using a phenotypic marker, studies have commenced in pearl millet on direct effects of pollen (male genotype) on seed growth. Field screening is conducted to identify germination cool tolerance in pearl millet, where like sorghum, earlier planting has advantages.

Several types of testers were evaluated by Fabien Jeutong in his Ph.D. study on early generation selection for combining ability. Iskender Tiryaki (M.S.) studied germination cool tolerance. The inheritance of seedling heat tolerance in sorghum using a simplified lab screening technique was studied by Peter Setimela for his Ph.D. dissertation. A food quality B-line sorghum population based on genetic male sterility gene ms_7 has been produced by random mating 26 elite lines.

Research Findings

The findings reported here are a synthesis, with interpretations as to their impact, of project research conducted last year, and the previous three, as detailed in the INTSORMIL Annual Reports of 1997 (pp. 104-109), 1998 (pp. 106-112) and 1999 (pp. 101-108).

Pearl millet

Research based on the A_4 CMS system expended greatly in this funding phase, as its attributes were explored and utilized. In respect to breeding parental lines, compared to the A_1 system, the A_4 system was found to give access to a much wider range of diversity and facilitate rapid development of both seed and (see below) pollen parents, based on clearer inheritance and less environmental interaction on the expression of male sterility and restored male fertility. A_4 sterile cytoplasm has not been noted to revert (mutate) back to fertile (normal) cytoplasm as occurs with A_1 - a cause of impurity in hybrid seed. Though R_4 genes in adapted germplasm initially were scarce, a method was developed of selecting restorers in A_4 sterile cytoplasm (by their pollen shed plants are then essentially indicating their male fertility restoration potential) which enables any line to be rapidly converted to an R_4 restorer by a dominant backcross procedure.

The A_4 CMS system in pearl millet, since most germplasms are A_4 maintainers (though any line can be converted to an R_4 restorer) unlike the A_1 system, allows virtually unlimited selection for heterotic performance, thus making conversion of the parental lines to A_4 CMS parents a secondary economical and assured process. Thus, as long as A_4 had no negative effects on seed production or hybrid performance, its' use would confer substantial advantages in breeding higher yielding hybrids.

The effect of cytoplasm type on hybrid performance was tested by first breeding iso-nuclear A_1 and A_4 seed parents (both being maintained by the same B line), and male parents found to restore fertility on both systems, thus the difference between hybrids $A_1 \times R$; $A_4 \times R$ and $B \times R$ is only cytoplasm [A_1 (male sterile), A_4 (male sterile) and B (normal), respectively]. In 1998, field tests were conducted between three sets of seed parents and three different male parents i.e., three cytoplasms were compared across nine sets of iso-nuclear hybrids. In 1999, this was expanded to six seed parents with three restorers (18 sets of iso-nuclear hybrids) (Table 1). There were several important results. There was a significant difference in flowering due to cytoplasm. Most A_4 hybrids commenced flowering two to four days earlier than A_1 hybrids and one to two days earlier than B hybrids. A_1 hybrids had a longer (by about 1 day) protogyny period between stigma emergence and pollen shed on any given head and pollen quantity was low on some A_1 hybrids. These factors lead to low or imperfect selfed seed set in many A_1 hybrids under head bags (a test used as an indicator for susceptibility to adverse environmental conditions which reduces seed set in fields of a single hybrid). In contrast, most A_4 hybrids had good seed set, and many equaled their $B \times R$ hybrids, where male fertility and seed set is not affected by CMS cytoplasm.

In general, A_1 and A_4 hybrids yielded similarly but at the individual hybrid level either the A_1 or A_4 version may be slightly better, which is explainable if cytoplasm/nuclear interactions contribute to heterosis. The indication that there may be a CMS/nuclear genotype interaction component in heterosis is of great importance, with implications for all crop species where CMS is used for hybrid production. This area needs further exploration.

In a separate experiment an A_4 hybrid was found to shed viable pollen at 8°C. Many A_1 hybrids go male sterile if overnight temperatures fall even to 15°C. In limited segregation tests, male fertility in the A_4 CMS system was controlled by a single dominant gene, but there is a possibility as yet unresolved, of duplicate genes for fertility restoration. However, segregation for male fertility/male sterility was clear, unlike the A_1 system where there is a large segregating and unusable class of partial sterile/ fertiles.

Though some individual hybrids may be best made in A_1 CMS and others in A_4, overall there appears to be no yield disadvantage with A_4 hybrids. There were two distinct A_4 advantages - earlier flowering and better seed set. We conclude that equally high yielding hybrids can be bred in the A_4 system, with more tolerance to conditions that stress seed set in A_1 hybrids, and thus there seems to be no limitation to using the substantial breeding advantages conferred by the A_4 CMS system.

Realizing the potential of the A_4 CMS system, the project has developed and released parental lines (NM-1 through NM-7, 1998) and germplasm (NPM-3), and initiated collaborative research in Namibia, Zambia and Mali to develop adapted A_4 top cross hybrids with high yielding varieties. This builds ICRISAT on research in West Africa and India which shows a) higher yielding varieties make better top cross hybrids and b) varieties can easily be converted to parents (R_4) for the A_4 CMS system, whereas this can never be satisfactorily done for the A_1 system.

The project first released in 1993 an early maturing R_4 population (NPM-3, providing opportunities to select different R_4 lines), then in 1998 five seed parents (NM-1 through NM-5), each in A_1 and A_4 with two male parents, NM-6 R_1 and NM-7 R_1R_5. Recipients of these parental lines and germplasm can now develop their own A_1 or A_4 hybrid combinations. Further CMS systems have been identified; A_5 (K. N. Rai - ICRISAT), A_v (ORSTOM) and A_{egp} (ICRISAT) - and several others have been detected (Hanna - USDA, Tifton, GA). To enable critical comparisons to be

Table 1. Hybrid grain yields (kg ha^{-1}) of pearl millet iso-nuclear hybrid sets in A_1 A_4 and B cytoplasms. Mead, NE 1999.

Seed Parents/ cytoplasm	Male Parents 16 R	58012 R	086 R	Seed parent/ cytoplasm mean effect
293 A_1	6100	5960	6090	6050
A_4	6540	5970	5990	6167
B	6340	5890	6690	6307
	6327	**5940**	**6257**	
413 A_1	4640	5130	4630	4800
A_4	5930	4840	5130	5300
B	5350	4480	4290	4707
	5307	**4817**	**4683**	
378 A_1	4480	4880	3330	4230
A_4	3660	4030	3810	3833
B	4240	3860	3590	3897
	4127	**4257**	**3577**	
59052 A_1	5170	5800	5720	5563
A_4	4760	4930	5270	4987
B	5880	5100	5450	5744
	5270	**5277**	**5480**	
57135 A_1	5970	6380	6740	6363
A_4	6590	6260	5780	6210
B	6670	5920	6510	6367
	6410	**6187**	**6343**	
59668 A_1	4720	5340	4770	4943
A_4	4520	4510	4830	4620
B	4460	4950	4580	4663
	4570	**4933**	**4727**	
Male parent mean effect	5335	5235	5167	
Mean cytoplasm effects	A_1	5325)		SE (within seed parents) ± 630
	A_4	5186)	SE ± 578	
	B	5236)		

made between the five CMS systems known to exhibit effective male sterility (A_1, A_4, A_5, A_v and A_{egp}), we are nearing completion of iso-nuclear seed parent sets for these five systems on two seed different parents (NM-1 and NM-3). We have already identified one line, NM-7R, that restores male fertility on all systems, except R_4, which is being backcrossed in.

Another research area of general interest are the various effects that pollen genotype can have on seed growth and composition on the female parent (known as zenia, or direct pollen effect). This is known to occur in maize and sorghum and can affect many traits, including seed size, color, protein and oil content. Increase in seed size can produce more yield per head, and give better seedling vigor. Zenia effects on grain weight and head threshing percentage were investigated in pearl millet using pollen carrying a dominant grain color marker, white, from white seeded male parents, to show which grains were cross pollinated on a grey seeded female line. Seed from 100% sibbed female heads (possible in pearl millet), heads with 100% hybrid seed, and heads with a mixture of hybrid and sibbed seeds were compared. With the two inbreds used, hybrid (white) seed weight, relative to sibbed (grey) seed weights, increased 15% in mixed heads and 19% on heads bearing 100% hybrid seed. Head threshing percentage was 11% higher on heads bearing 100% hybrid seed, relative to heads with 100% sibbed seed. Thus, in hybrid seed production, seed weight on the female parent is heavier, and seed yields increased, by the heterotic effect of male parent pollen. The degree to which this occurs is probably genotype specific, but larger hybrid seed confers advantages like increased seedling size and growth.

To see if the effect could also occur between hybrids (which might result in a slight increase in grain yield just through growing a mixture of two hybrids of equal yield), similar crosses were made between two genetically different hybrids, one homozygous white seeded, the other grey. Differences were not significant. However cross pollinated seed on heads bearing both hybrid and sibbed seed was 3% heavier and 6% heavier on 100% cross pollinated heads, which also showed a 5% increase in head threshing percentage. More experimentation is needed to check these indications..

Two other areas were investigated in pearl millet - seed germination/seedling cold tolerance, and response to seedling damage. Three years of early planting in cool soils, about 15°C in April/early May at Lincoln, detected strong and consistent differences among pearl millet lines. This is of interest because pearl millet is thought of as more cold susceptible than sorghum, however our findings show, with the right hybrid, pearl millet could be planted at least as early as sorghum, with many consequent advantages.

A mowing experiment, planted both early and late simulating seedling/young plant damage as might be sustained for a variety of causes, grazing, insects, heat, sand blasting, or hail was conducted with hybrids of different phenotypes. All but one, the earliest maturing, recovered well from mowing 25 day old seedlings to 10 cm. The two latest maturing hybrids actually responded with significantly higher yields, due to increased tillering. Pearl millet shows remarkable tolerance to early defoliation.

Support for the breeding of locally adapted hybrids in Namibia, Zambia and Mali was continued. Activities for Namibia and Zambia are contained in the Southern African Regional report. Breeding for Mali consisted of providing a CMS option of producing hybrid CIVAREX 9106 × Trombedie, currently being made by the use of protogyny. Initial crosses and backcrosses were made to convert CVX 9106 into an A_4 seed parent and Trombedie to an R_4 restorer. Seed of these crosses was sent to the pearl millet breeding program at Cinzana, Mali so the original adapted parent populations can be used to complete the backcrossing.

Sorghum

Fabien Jeutong's Ph.D. thesis work tested whether any difference in combining ability could be detected among early generation (F_4 - F_5) B-lines (potential A_1 seed parents) using progressively broader based R_1 restorer pool testers. If differences could be detected, lines with poor combining ability could then be dropped at an early stage and only good lines converted to male sterile seed parents, thereby increasing the efficiency of this time consuming activity. Four unrelated R_1 testers (made male sterile in the A_2 CMS system), three resulting two-way testers and one four-way tester (possibly using a combination of genetic and A_2 male sterility) made from the 4 individual testers, and an unrelated ms_3 population, were used to evaluate 14 B lines over three environments in two years. Similarly 16 potential R lines were evaluated with different male sterile tester types. The results were inconclusive, but did provide indications. One tester known to have more general combining ability and one 2-way would be better for initial screening than a single tester. More complex testers provided no obvious advantage. However, there were differences (expected) between single testers, and the repeated use of only one tester with a narrow range of combining ability would, therefore, bias the type of seed parent selected. If only a single tester can be used for the first screening of new lines, it is important that it has a wide range of combining ability, which is known to occur, also lines selected by that should subsequently be evaluated by several more different testers. The conversion of these to A_2 CMS, or to genetic male sterility, will provide an effective way of testing B lines prior to conversion to A lines.

Counting seed germination percentages at an early time (eight days) in petri dishes kept at a constant 15°C was the best simple way to measure germination tolerance related to planting in cool soils. Large genotype differences were detected. Germination cold tolerance in male parents (in the set of 12 lines used) had little effect on hybrid performance indicating recessive inheritance in male parents. However, seed parents had large consistent effects, both negative and positive on rate of germination of hybrids in cool conditions. Even where the male parent showed good tolerance, the use of a cold tolerant seed parent could produce hybrid seed with better cold tolerance than either parent.

Seedling recovery growth between plexiglass plates measured 32 hours after a heat shock of 10 minutes exposure to 50°C in a water bath gave the best separation between genotypes for seedling heat tolerance. Soil surface temperatures often exceed 50°C after planting in the tropics and in a few hours this can greatly reduce emerging plant populations. Plexiglass plates allowed rapid recording (by photocopying) repeated over time. Generation means analysis of crosses between relatively heat tolerant and heat susceptible genotypes showed additive and dominance effects contributed to coleoptile elongation under normal conditions, but only additive effects were significant in recovery growth. Epistatic effects were present in both conditions. General combining ability effects for recovery were highly significant under all conditions but specific combining ability effects were negligible. These results show that sorghum can be improved by breeding in tropical areas where poor emergence or high seedling mortality is due to hot soils.

In 1999, new parental lines and partly inbred seed parent and restorer germplasms from the most recent crosses in the long term program of introgression of elite tropical food quality stocks were evaluated. Some were tested in hybrid yield trials (Table 2) and the whole breeding nursery (since 1999 was the final season of this project) was subject to a peer review separately by 10 professional breeders. This led to the identification and release of 90 parental lines and 149 partially inbred germplasms in February 2000. This release, together with 64 parental lines released in 1998 represent a wide range of diversity made available for midwest/high plains environments. As shown in Table 2, it has been possible to combine food grain quality with high yield in early maturing hybrids. Breeding parents used over the years have come from tropical breeding programs in India, China, Cameroon, Nigeria, Senegal, Botswana, South Africa, Zambia, Zimbabwe, and Latin America. Accessions from Russia have also been used because of earliness, cold tolerance and green bug resistance. Segregating populations from these crosses have been used in INTSORMIL collabo-

Table 2. Early maturing grain sorghum hybrid trial 99-41, Mead, NE. Days to bloom (days from planting) plant height (cm), lodging score[4] and grain yield (kg ha^{-1}) of 11 of 23 hybrids in test.

Hybrid[1]	Bloom	Plant height	Lodging[4]	Grain yield
N250A x N514R[2]	66	94	2.0	9360
N250A x N511R	64	115	3.0	8630
N250A x N530R	59	104	2.0	8150
N250A x N533R[2]	63	103	1.5	8080
N250A x N516R[2]	62	104	1.0	7920
N250A x 35028-1	66	114	1.5	7730
N250A x N513R[2]	60	100	1.5	7480
N250A x N249R[2,3]	61	111	3.5	7460
N250A x N524R	65	103	2.0	7330
DeKalb 28[3]	58	96	2.5	6750
Pioneer 8925[3]	55	110	5.0	5490
Mean (23 entries)	**61.5**	**102**	**2.1**	**7230**
LSD = 0.05	4.4	10.9	1.9	1190

[1] Parental lines N249R, N250A/B among project UNL-218 releases April 1998; germplasm restorer lines N511R through N533R among project UNL-218 releases 2-24-2000.
[2] Tan plant white/cream seeded food quality hybrids.
[3] Check hybrids.
[4] Lodging, 1= least, 5 = worst, recorded on border plants 1 month after harvest.

rative research in some of these countries in Africa. Segregating germplasm and appropriate lines have been supplied to Botswana, South Africa, Zimbabwe, Kenya, Niger, Senegal, Egypt, Mexico, Australia and Argentina. Most U.S. sorghum seed companies have taken parts or all the releases made from this project.

Networking Activities

Workshops

Genetic Improvement of Sorghum and Pearl Millet, Lubbock, Texas, September 1996.

Farmer participatory breeding and farmer based multiplication systems workshop, March, Okashana, Namibia, 1997.

West African Sorghum and Pearl Millet Hybrid Seed Workshop, Niger, September 1998.

Research Investigator Exchanges

Mr. S. A. Ipinge, Namibia, Visiting Scientist, millet breeding, May-Nov., 1997.

Dr. K. N. Rai, ICRISAT Staff Deployment, millet research, Jan.-Dec., 1998.

Dr. Mary Mgonga, Zimbabwe, Co-ordinator SMINET Network/ICRISAT SMIP Southern Africa, March, 1999.

Mr. M. Mogorosi, Botswana, Visiting Scientist, millet breeding June - (Nov.) 2000.

Fifteen other scientists from Argentina, Australia, Brazil, Egypt, India, Kenya, Mexico, Niger, Senegal, Zambia and Zimbabwe visited the project.

PI visited Botswana (four times), Mali, Namibia (three times), Niger, Uganda, Zimbabwe (four times), South Africa, Mexico (winter nursery five times), India and ICRISAT (twice).

Germplasm

Pearl Millet

1996-1999 - Two hundred nineteen samples of pearl millet exchanged with ICRISAT (India, Niger and Zimbabwe), Brazil, Mali, Namibia, Nigeria, Senegal.

Seed parents (A_4) and male parents (R_4) under conversion, separately for Namibia, Zambia and Mali, 1997 through 1999.

Fifteen A_4 and R_4 parental lines ICRISAT Niger and Nigeria, 1997.

Fifty-four Breeding germplasms to Dr. Wayne Hanna Project ARS 205, Tifton, GA.

Twenty-three Breeding germplasms to DPI Qld Australia.

Five A_1 and A_4 seed parent sets, NM-1 to NM-5; two male parents, NM-6R to NM-7R, released 1997.

Sorghum

1996-1999 - Sixty-four samples of sorghum exchanged with ICRISAT (India, Niger and Zimbabwe), Botswana, Egypt, Ethiopia, India, Niger, Senegal, South Africa, Zambia, Zimbabwe.

Forty-three lines to DAR Botswana.

Eleven seed and restorer parents to INRAN, Niger.

Sixty-two seed parents and two restorers, N248 - N311, released April 1998.

Two hundred thirty-nine seed parents, restorer parents and germplasms, N341-N579, released February 2000.

Impacts

Methodology research and demonstration of existence and effects of genetic variability for critical traits e.g., seedling tolerance to heat or cold, early assessment of combining ability, characterization of CMS systems, etc., are of global importance to breeding programs especially in developing countries where limited resources must be used with focused efficiency.

Germplasm and parental line releases in the USA will contribute to new and better quality sorghum hybrids. Pearl millet grain hybrids provide a new feed crop for better use of certain production conditions not covered by sorghum or maize.

Collaborative research with Namibia, Zambia and Mali will convert parents of existing successful experimental hybrids, to a CMS basis - essential for large scale commercial production.

Germplasm supplied to other countries, and other US programs, including all major seed companies, increases breeding opportunities for the ultimate benefit of the farmer.

Assistance Given

Almaco plot belt thresher supplied to pearl millet breeding program MAWRD Okashama, Namibia.

Almaco single head thresher supplied to pearl millet breeding program, Department of Crops and Soils Research, Kaoma, Zambia.

Pearl millet pollinating bags (20,000) supplied each to breeding programs in Botswana, Namibia and Zambia.

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Tiryaki, I. and D.J. Andrews. 1999. Methods for measuring germination and seedling cold tolerance in sorghum. Agron. Abstr. p. 119.

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Crop Utilization

and Marketing

Chemical and Physical Aspects of Food and Nutritional Quality of Sorghum and Millet

Project PRF-212
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Summary

In the past four years, our work has concentrated mainly in two areas: sorghum and millet couscous processing (including a range of agglomerated particle sizes) and nutritional quality of sorghum grain. In conjunction with the setting up of a couscous processing unit at INRAN/Niger, graduate student studies have been conducted at Purdue to identify grain and flour factors that determine couscous quality. The objective of these studies was to identify ways to produce the highest and most consistent quality couscous products possible for eventual commercialization. A couscous preference study was done in Niger showing, while consumers accept couscous of different colors, there is a clear preference for light colored products. A decortication study showed that, for some cultivars, 20% kernel removal gave a product near in appearance to bought wheat couscous. In off-color grain, up to 40% removal was necessary to obtain an acceptable appearing product. Studies on the origin of stickiness in cooked couscous revealed that starch damage during grain milling, and concomitant fragmentation of the largest starch molecules, is highly correlated to sticky couscous. Addition of oil to the cooking (rehydration) water substantially reduced stickiness, particularly among those sorghum cultivars producing the stickiest products. Tempering (adding moisture) to grain would produce flour with less starch damage and, accordingly, would give less sticky couscous. Notably, it was generally found that harder grains produced stickier couscous with more damaged starch and fragmented starch molecules. Therefore, in choosing cultivars for quality couscous processing, intermediate textured grains would be best.

In Niger, we are collaborating closely with sorghum breeders (I. Kapran and J. Axtell) to use new sorghum hybrids released from their program. Processing of agglomerated hybrid products or high quality flours for commercial markets would create an outlet for the high production of hybrids, and could act as a driving force for their adoption. Equally important, cereal processors require a consistent supply of good quality grain, with preference given to a single grain sources, such as a hybrid would provide. At this writing, a large scale two phase market study has begun in Niamey using the sorghum hybrid NAD-1. In home surveys will provide information on product acceptability and market potential, and in-store market evaluation will show actual commercial potential. In the future, we would like to place one or more entreprenuerial-scale processing units outside of the institute and collaborate with an NGO to stimulate commercial processing of sorghum and millet products.

In studies on digestibility of sorghum protein, much of our work has followed our previous discovery of a sorghum mutant with high protein digestibility. We had found that this cultivar has high protein digestibility because protein bodies, that contain the kafirin storage protein, were abnormally formed. While normal protein bodies have a hard-to-digest outer protein, γ-kafirin, the mutant protein bodies are highly invaginated with this protein located at the base of folds. As a result, the main storage protein, α-kafirin, is exposed to digestive enzymes, and, accordingly, digests very rapidly. In this reporting period, our major achievement was the development of a simple, rapid screening assay for identification of sorghum lines with

high protein digestibility. This work was done with financial assistance of the Texas Grain Sorghum Board. A reliable turbidity-based assay was one of three developed, and is now being used by Axtell's breeding program at Purdue to select for highly digestible segregants. The assay entails a rapid digestion of flour, followed by extraction of the undigested proteins, and subsequent precipitation of extracted proteins into a stable suspension. Low turbidity read at 520 nm signifies highly digestible lines. The assay was scaled down to use 96-well microtiter plates, and currently has a throughput of 100 samples/day with replicates. The written procedure is available on request.

Also notable was the identification and selection of high protein digestibility sorghum lines with increasing amounts of internal "core" vitreous (hard) kernel texture. Improved modified lines are sought in the breeding program. This unique type of kernel endosperm texture contains densely packed starch granules without a continuous protein matrix that is typical of vitreous endosperm. A study has been initiated to examine whether high protein digestibility has a positive effect on starch digestibility in raw grain and cooked flours for livestock and humans, respectively.

Objectives, Production and Utilization Constraints

Objectives

- Develop an understanding of traditional village sorghum and millet food processing and preparation procedures and determine the grain characteristics that influence the functional and organoleptic properties of traditional food products.
- Determine the relationships among the physical, structural, and chemical components of the grain that affect the food and nutritional quality of sorghum and millet.
- Determine the biochemical basis for the relatively poor protein and starch digestibility of sorghum grain and many cooked sorghum products.
- Develop laboratory screening methods for use in developing country breeding programs to evaluate and improve the food quality characteristics of sorghum and millet grain.

Constraints

Research on the food and nutritional quality of sorghum and millet grains is of major importance in developing countries. Factors affecting milling qualities, food quality, and nutritional value critically affect other efforts to improve the crop. If the grain is not acceptable to consumers, then grain yield and other agronomic improvements to the crop are lost. In addition, breeding grains that have superior quality traits will more likely give rise to processed food products that can be successfully and competitively marketed. This is especially true for sorghum which is perceived in some areas to have poor quality characteristics. The overall goal of this project is to improve food and nutritional quality of sorghum and millet through a better understanding of the structural and chemical components of the grain that affect quality. This knowledge will be applied to develop useful methodologies for screening germplasm for end-use quality, develop techniques to make the grain more nutritious, and improve grain utilization through processing.

Research Approach and Project Output

Sorghum and Millet Couscous Processing

Sorghum and millet pre-cooked agglomerated products, such as couscous, are traditional foods of the Sahelian West African countries. However, outside of Senegal, there are no examples of mechanized units to process these products for sale to urban consumers. In the last four years, INTSORMIL PRF-212 has been involved in two activities related to sorghum and millet processing in West Africa. First, a entrepreneurial-scale couscous and flour processing unit was installed at INRAN/Niger with the goal to optimize processing conditions to produce a consistently high quality product and, through demonstration and testing, to stimulate entrepreneurs to invest in commercial units. In this project, a close linkage has been established with breeders I. Kapran/Niger and J. Axtell/Purdue with the objective of ultimately stimulating demand for sorghum hybrids through processed products sold in the marketplace. The advantage of the hybrid to a processor would be a ready supply of pure source grain, which is a prerequisite to processing high quality commercial products. Secondly, we have been engaged in fundamental studies at Purdue to describe grain properties necessary to produce a high quality commercial couscous and to elucidate the basis of couscous stickiness, an undesirable property in sorghum and millet-based agglomerated products.

In the West African region, there are currently a number of new activities in the food processing area (e.g., ROCAFREMI millet processing project, ITA/EU project in Dakar, PROCELOS/Ouagadougou, the new IFAD/CIRAD Sorghum/Millet Processing Initiative, INTSORMIL, and others) that have the common objective of creating new urban markets for products made from locally grown grain and increasing entrepreneurial-level processing businesses. NARS, such as INRAN/Niger, can play a key role in stimulating processors, by providing technological expertise and creating models that show promise in the West African urban setting.

Couscous Processing Unit in Niger

The core of an entrepreneurial-scale couscous unit was installed at INRAN/Niger in late 1995; consisting of a central mechanized agglomerator designed and fabricated at

CIRAD, France by J. Faure, a mixer for flour wetting, a couscousierre (steamer), and a small solar drier with through ventilation powered by a solar cell (fabricated in Niamey by ONERSOL), and a sealer for packaging. The initial unit was funded through the then functioning Niger InterCRSP project. Since that time, a much larger passive solar drying unit was built at INRAN to dry approximately 500 kg couscous every 2 days. As high quality flours are essential to make quality couscous, a small-scale commercial grain decorticator (dehuller) and hammer mill (Urpata Sahel, Dakar) were recently procured through PRF-212 to complete the unit. This last addition has also permitting INRAN cereal technologists to begin work on production of high quality sorghum and millet flours and other products made from them. An identical decortication and hammer mill unit will soon be sent to the sorghum utilization group at EARO/Ethiopia.

A number of activities involving the couscous processing unit have concentrated on optimization of couscous processing procedures to achieve a high quality commercializable sorghum or millet couscous product. All processing steps were optimized, including water content relating to agglomeration size, throughput/day (to approximately 100 kg/day), decortication rate related to product quality, (70-80% decortication rate optimum – also see below) depending on cultivar used, flour particles size, and drying temperature and time. Couscous yield, as measured by the amount of couscous obtained in one pass through the agglomerator, was increased from about 70% to about 95%. Optimization tests have been conducted on local and new sorghum cultivars, including the sorghum hybrid NAD-1, and local and ICRISAT millet cultivars. Regarding the hybrid NAD-1, it was determined, that the first sorghum crop grown following the rainy season crop, produced seed of good quality for commercial couscous processing. Through the West and Central African Millet Network (ROCAFREMI), collaborators on millet processing (A. N'Doye of ITA/Dakar and I. Nizar, an entrepreneur who processes millet for the Dakar market) have assisted in contributing the practicality of studies related to the marketplace. In 1998, the couscous unit was demonstrated and product produced were exhibited at a regional agricultural research exposition in Ouagadougou, Burkina Faso by M. Oumarou and M. Moussa of INRAN. At the Regional Hybrid Sorghum and Pearl Millet Seed Workshop held in Niamey, September 28 – October 2, 1998, the participants were invited to the Cereal Quality Laboratory at INRAN and couscous prepared using the mechanized unit was served. In 1998, a local food processor group was established and meetings have been held between INRAN scientists/technologists and entrepreneurs to discuss new technologies and to obtain feedback on INRAN processing projects.

At the time of this writing, a large-scale market study has begun, to test sorghum NAD-1 couscous and flour marketability. This test is in collaboration with C. Nelson (UIUC-205) and J. Ndjeunga (ICRISAT/Mali) who have aided in the project design and implementation. The study will involve two parts and tests four products made from NAD-1; two couscous products of different particle size (fine and intermediate) that are traditionally made in Niger, *degue*, a large agglomerated, precooked product usually mixed with milk for breakfast, and a high quality decorticated flour. The first study will involve an in-home survey of product acceptability and potential in the marketplace. The second part is the actual market test, involving placement of products in three market niches, and subsequent monitoring of sales and feedback. Depending on the outcome of the market test, the project may expand in the future to place one or more processing units outside the research institute, and work in cooperation with an NGO to provide technical expertise for processing and marketing high quality sorghum and millet products.

Couscous Preference Test

In August 1996, a sensory study on five sorghum cultivars (IRAT-204, Mota Maradi, NAD-1, SC283-10, and SEPON) was conducted by A. Aboubacar (doctoral student) in Niamey, Niger. Couscous was produced using the couscous processing equipment installed at INRAN. A commercial durum wheat couscous bought at a local store was included for comparison. Thirty INRAN employees participated in the sensory test. Couscous was evaluated for color, taste, stickiness, and hardness. Results indicated that although the sensory panel accepted a wide range of couscous color, there was a clear preference for light-colored couscous. Wheat couscous had the highest color score followed by SEPON, NAD-1 and IRAT-204 couscous. Couscous from Mota Maradi and SC283-10 had brown and pink color, respectively. Differences in couscous taste, hardness, and stickiness were noted among the cultivars. The panel judged all the sorghum couscous as harder than durum wheat couscous. As for stickiness, members of the panel reported some of the sorghum couscous as less sticky and some significantly more than wheat couscous. Overall, consumers liked the uniformity in couscous granular size obtained with the mechanized agglomerator. It was noted that the manner of couscous consumption were dependent upon granules size. For example, couscous of fine granules (1-1.5 mm) called *dambu* can be consumed with milk, vegetables, or sauce, whereas couscous of intermediate granules known as *burabusko* (1.5-2 mm) is eaten with either milk or sauce. A third type of couscous of coarse granules (> 2 mm) called *degue* is often mixed with spice and consumed with milk. A desirable feature of the couscous agglomerator is that it can be used to produce all three types of couscous simultaneously, which can be marketed as separate products.

Effect of Grain Decortication Rate on Sorghum Couscous Color and Yield

From the above study, consumers were found to accept a wide range of couscous color, although there was a clear preference for light-colored couscous. A study was undertaken at Purdue to determine the effect of extent of kernel decortication, or dehulling, on couscous color and granule size distribution.

Grain samples from seven sorghum cultivars (IRAT-204, SEPON, NAD-1, SC283-10, P721N, P721Q, Mota Maradi) were decorticated with a tangential abrasive dehulling device (TADD) to remove 10, 20, 30 and 40 % of the kernel, and ground into flour. Flour ash and protein content decreased with increased percent kernel removal. Also, an increase in flour lightness and a decrease in flour red color was observed as decortication rate increased. Couscous was prepared from the flours using a laboratory procedure. Processing flour into couscous decreased the lightness and increased red and yellow color in couscous at all decortication rates. These changes in color became obvious upon water addition to flour and were accentuated during steaming. For all the cultivars, couscous lightness increased with increased decortication rate. The best couscous in terms of lightness were obtained with IRAT-204, SEPON, NAD-1 and SC283-10, while the worst couscous were derived from Mota Maradi, P721N, and P721Q. Couscous from IRAT-204 and SEPON were the best in yellow color and resembled the color of durum wheat couscous. Red color in flour was found to be the most important parameter that influenced final couscous color. This study showed that, for some sorghum cultivars, substantial improvement in couscous color can be achieved through appropriate decortication, though for the poorest colored grain had to be decorticated to 30-40% kernel removed to achieve good color.

Decortication rate also affected couscous granule size distribution. For all the cultivars, high proportion of fine (< 1mm) couscous granules was obtained at 10% kernel removal. As percent kernel removed increased, the proportion of fine (< 1mm) granules decreased and that of intermediate (1-2 mm) and coarse (> 2mm) granules increased gradually. We observed that couscous granules prepared with flour from 10% decorticated grain tended to break easily when dried, whereas couscous from 40% decorticated grain gelatinized quickly during steaming and produced high proportion of large chunks of granules that were very hard after drying. The best couscous granules were obtained when flours from 20 and 30% kernel removed were used.

Grain or Processing Factors Related to Couscous Quality (Stickiness)

Although most sorghum and millet cultivars can be made into couscous, there is wide variation in product quality. Stickiness, one of the critical textural characteristics of couscous, is viewed as an undesirable factor. Good quality cooked couscous is a soft, fluffy product that easily falls apart on the plate. In testing eight sorghum varieties, six of which are used in Niger, a wide difference in couscous stickiness was measured. A study was conducted to identify the causative agent for couscous stickiness, its origin, and methods to control stickiness or to select cultivars with low degree of stickiness.

Earlier studies in our laboratory indicated that the component responsible for couscous stickiness was in its water-soluble extracts. Water-soluble materials contained considerable amounts (40 to 90%) of carbohydrates which alone correlated with stickiness. Native starch is comprised of two major molecules, the very large branched amylopectin and the comparably small more linear amylose. A chromatographic separation of these carbohydrates indicated that they were composed of two major components: an intermediate-to-low molecular weight component that was identified as fragmented amylopectin and a low molecular component that was composed of small sugars. The stickiness of couscous was positively correlated to the amount of the fragmented amylopectin fraction in couscous ($r = 0.86$, $P<0.01$) and to the amount of starch damage in the flour ($r = 0.89$, $P< 0.01$). A marked decrease in stickiness was noted when soybean oil was added to couscous cooking water; an effect pronounced in sorghum cultivars with high proportion of fragmented amylopectin. It was concluded that the decrease in stickiness observed after oil addition was due to carbohydrate-lipid interactions.

To determine whether the branched starch fraction originated from the flour, water-soluble extracts from sorghum flour and couscous were compared. High performance size exclusion chromatography (HPSEC) revealed that flour contained the carbohydrate fraction previously correlated to couscous stickiness. Fragmented amylopectin found in couscous solubles originated in flour, however, the molecular makeup of fragmented starch from couscous and flour were found to be different; the couscous solubles containing more linear starch fragments than the flour.

Milling experiments were conducted to test whether the origin of the fragmented amylopectin fraction correlated to couscous stickiness was because of milling damage. Chromatograms of water-soluble extracts of sorghum flours pin-milled to obtain 3.6% and 6.1% damaged starch showed that more material was solubilized from flour with higher damaged starch. When couscous was made from flour with 6.1% damaged starch, more fragmented starch with molecular weight below 400,000 Da was extracted. Ball-milling decorticated sorghum kernels intensified damaged starch to 20.6% and increased the amount of solubilized intermediate molecular weight fragmented amylopectin, as well as smaller amylopectin fragments.

Experiments were also conducted to determine the contribution of enzymatic degradation of starch molecules during couscous processing on product stickiness. Overall, enzymatic starch degradation did not substantially change the water-solubles elution profiles. It was concluded that flour milling is the major cause of starch fragmentation that leads to a sticky couscous product. Tempering (increasing moisture content) of grain would reduce starch damage and concomitant generation of fragmented starch that causes couscous stickiness.

Fragmented Starch and Porridge Stickiness

Starch damage and fragmented amylopectin were also found correlated to sorghum porridge stickiness. Water-soluble extracts of sorghum and maize starches with increasing proportions of damaged starch were separated through a HPSEC system with refractive index detection. Chromatograms were typical of fragmented starch, with a distinct peak containing fragmented amylopectin eluting in the amylose elution range (Figure 1). Maize starch damaged to various levels resulted in chromatograms with less intense fragmented amylopectin peaks, than sorghum starch with corresponding levels of damaged starch. The lower amounts of water-soluble carbohydrates eluted in maize explain why maize starch gels had lower stickiness than sorghum starch gels with similar percent damaged starch. The logarithm of the area under the fragmented starch fraction in the chromatogram highly correlated with starch gel stickiness. When freeze-dried water-soluble fragmented starch was added sorghum porridge, its stickiness increased. This confirmed the role of flour water-soluble components on the stickiness of sorghum food products.

A Three-way Complex Involving Starch, Free Fatty Acids, and Protein Affects Paste (Porridge) Properties

Following liberation of free fatty acids from flour during a relatively short storage period, sorghum porridge quality changed because of the formation of a three component complex involving amylose, free fatty acid, and soluble protein. In this study whole grain sorghum was ground to flour and stored under ambient conditions to examine the effect of flour storage on pasting properties of porridges. Paste viscosity profiles, as measured by a Rapid ViscoAnalyzer, were measured, as well as production of free fatty acids caused by enzymatic breakdown of triglycerides (the native form in oil). Large increases in cooling paste viscosities (at about 50°C) were observed when free fatty acids were liberated from triglycerides at around month two of storage. Stored sorghum flour showed breakdown of triglycerides to free fatty acids at a much faster rate than comparable stored maize flour. The reason for this difference is unclear.

The three component interaction was defined using a model system consisting of isolated sorghum starch, free

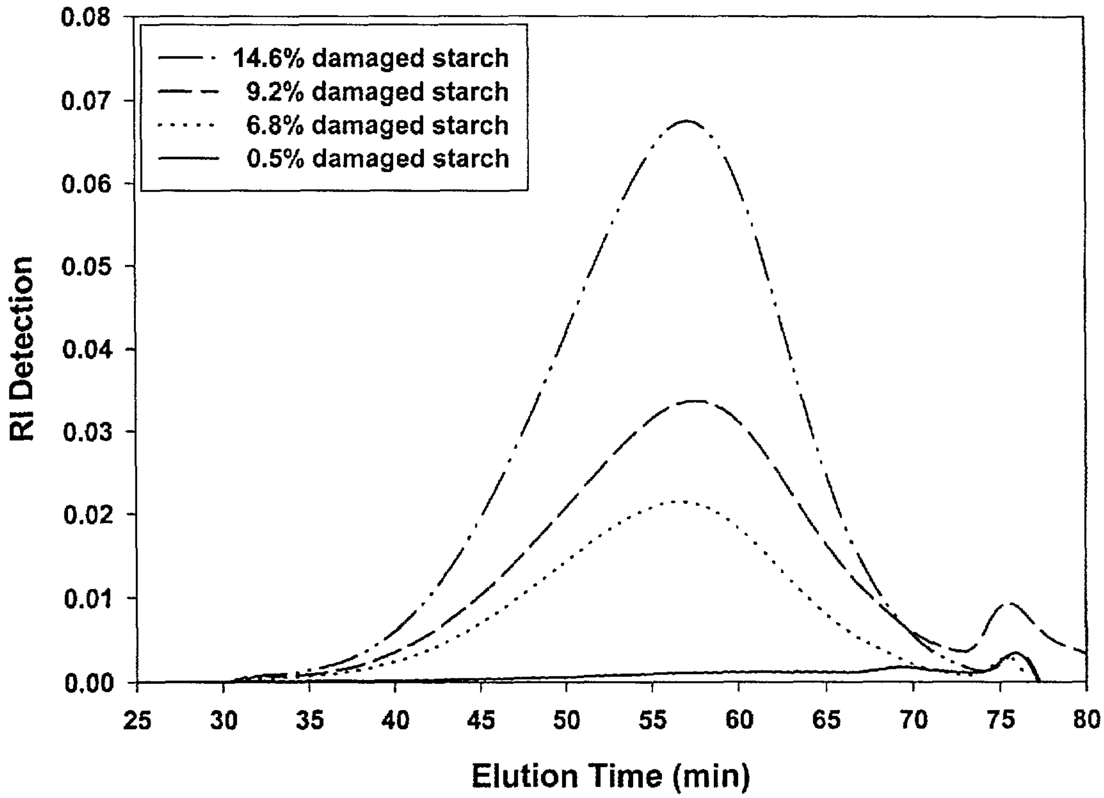

Figure 1. Size-exclusion chromatograms of water-soluble extracts from sorghum starch damaged to different degrees through ball-milling. Increasing peaks indicate higher amounts of fragmented starch molecules that were shown to correlate to couscous stickiness. Flow rate was 1.5 ml/min.

fatty acids both made in the laboratory and purchased, and soluble whey protein. All three components were required to develop the large increase in cooling stage (50°C) paste viscosity. The complex itself was isolated by HPSEC and was verified by a combination of RI, UV, and carbohydrate (phenol-sulfuric acid) detections. This large soluble complex (~1 million Da) was disrupted by salt, lowering of pH to 5, addition of a reducing agent. This is the first evidence of a three component complex occurring in food preparation. Large changes in viscosity can produce unacceptable sorghum porridges. This study reveals fundamental information on the changes that occur in pastes.

Sorghum with High Protein Digestibility

Previous to this four year period (1994-96 INTSORMIL annual reports), we reported on the identification of sorghum lines within J. Axtell's high lysine population with markedly higher uncooked and cooked protein digestibility levels compared to normal types. Biochemical and microstructural studies in our laboratory showed that higher digestibility was due to altered morphology (folded structure) of the kafirin-containing protein bodies, resulting in a more rapid digestion of the main storage protein of sorghum, α-kafirin (see inset in Figure 2). α-kafirin alone comprises over half of the total whole grain proteins of sorghum. These protein bodies were distinctly different from the spherically shaped protein bodies of normal sorghum cultivars (inset). Immunocytochemistry investigation showed similarities in localization of α- and β-kafirins within the protein bodies of highly digestible and normal cultivars. However, in the highly digestible cultivars, γ-kafirin, the high cysteine-containing protein, was found located at the base of the folds of the protein bodies instead of at the periphery as is characteristic of normal cultivars. Consequently, α-kafirin in the highly digestible cultivars is more exposed and is more easily accessible to digestive enzymes. This, along with the large surface area exhibited by the invaginated protein bodies of highly digestible cultivars is thought to account for their high in vitro protein digestibility. The discovery of these highly digestible sorghum cultivars generated interest in incorporating them into breeding programs. This, in turn, prompted the need to develop quick, inexpensive and simple assays to screen breeders' lines for protein digestibility. The following report of assay development work was funded by the Texas Grain Sorghum Board.

Rapid Screening Assays for High Protein Digestibility Sorghum

Prior to this work, there were two in vitro (laboratory) procedures used to predict sorghum protein digestibility. Mertz et al (1984) developed an in vitro pepsin digestion method specifically for sorghum proteins, that approximated data obtained from human feeding trials. Although

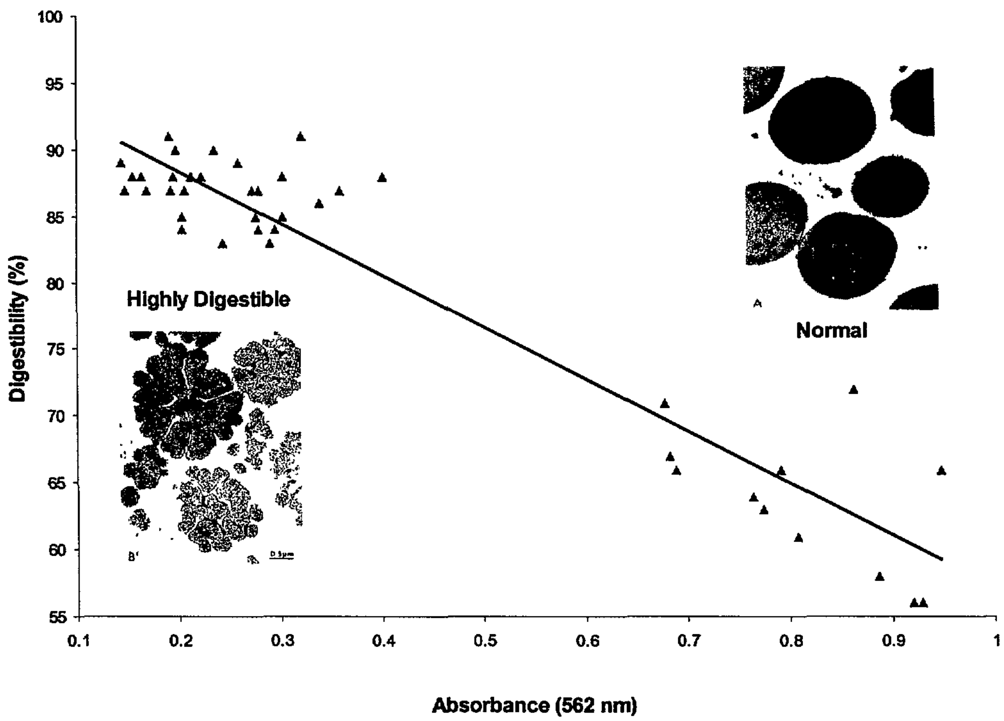

Figure 2 Comparison of values from the new high throughput turbidity-based protein digestibility assay and the standard pepsin digestibility assay. The two distinct populations show the ease in using the assay to distinguish the high protein digestibility and normal sorghum types. Insets show transmission electron micrographs of protein bodies of developing endosperms.

very effective in differentiating for digestibility among sorghum cultivars, this method is very lengthy and cumbersome and allows for only few samples to be analyzed at a time. Alternatively, the pH-stat procedure, provisionally recommended by FAO/WHO, has been used by some investigators as a more rapid method to measure sorghum protein digestibility. In spite of the relatively short analysis time used, the pH-stat procedure also has limited practical use when screening hundreds to thousands of breeders' lines. Only about 16 samples can be analyzed in a day using this procedure, and the operator must be present at all times.

Protein digestibility in sorghum cultivars were determined using the standard pepsin digestibility procedure and compared to newly developed, rapid assays. The new assays were based on the rate of α-kafirin disappearance after pepsin digestion. In the new assays, samples were first digested with pepsin for 1 hour and undigested proteins were quantified using different methods. In the first method, undigested proteins were extracted with a buffer and analyzed by sodium dodecyl sulfate-polyacrylamide gel electrophoresis (SDS-PAGE). The intensities of the undigested α-kafirin bands were then measured. Higher band intensity indicated lower protein digestibility. For qualitative analysis to simply separate highly digestible from normal genotypes, the SDS-PAGE method can be used with visual scoring (+ or -). In the second method, proteins remaining after one hour pepsin digestion of sorghum flours were extracted and quantified by a colorimetric assay using bicinchoninic acid (BCA). The lower the amount of remaining protein indicated the more digestible the cultivar. Values from both assays highly correlated to the values from the standard pepsin assay. The third method, described below, is currently used in our collaborative research program.

Turbidity Assay

Two versions of the turbidity assay were developed, based on relative turbidity of suspensions of undigested proteins. Extracted undigested proteins were precipitated with 72% trichloroacetic acid and the absorbance of the turbid solution was read at 520 nm. The first version uses 1.5 ml microcentrifuge tubes to digest and extract samples, and precipitate proteins. The second version is a scaled-down procedure using 96-well microtiter plates and ELISA plate reader to increase throughput and decrease sample size. In this procedure, flour samples are digested in microcentrifuge tubes and extracts (1% SDS, 0.5% 2-mercaptoethanol, borate buffer, pH 10) of undigested proteins are placed in microtiter plate wells. Plates were read on an ELISA plate reader. Addition of TCA to the protein solutions resulted in a quick turbidity development that reached a plateau at about five min for highly digestible cultivars and 10 min for normal cultivars. In both cases, the turbid solutions were stable for at least one hour. Comparison tests with the standard assay showed high correlation and discrimination between the normal and highly digestible lines (Figure 2). These results indicate that by using the turbidity assay, considerable amount of time can be saved, more samples analyzed, and use of costly chemical reagents avoided. A comparison between the BCA, turbidity, and electrophoresis-based assays indicated that the turbidity assay is more efficient than the BCA assay in distinguishing highly digestible from normal cultivars. A linear relationship with a correlation coefficient of $r = 0.995$ was obtained when a standard curve prepared using kafirin was developed for the turbidity assay. This indicates that the amount of kafirin remaining after digestion can be quantified using the turbidity assay.

Axtell's group conducted further validation tests on the turbidity assay and found it to have good repeatability and low source of experimental error. Currently, 100 sorghum lines are evaluated per day by one operator. It is possible to further increase sample throughput, perhaps to 200 samples/day, by adding microcentrifuges. Procedure write-ups are available on request.

Modification of Floury to Hard Endosperm High Protein Digestibility Types

Modified, hard endosperm phenotypes have been found that contain the high protein digestibility trait, as well as the high lysine trait. These, however, are not normal vitreous (translucent), hard endosperm types, but have a unique endosperm structure where vitreous endosperm is found surrounding a floury core of the kernel with a dense floury endosperm radiating from the vitreous portion out to the grain periphery (Figure 3). Scanning electron micrographs suggest that Instead of having starch granules packed compactly into a continuous protein matrix, the modified kernel type has starch granules densely packed into a discontinuous protein matrix.

In a recent study on grain development, we showed peripheral layers (about 2 cells deep) contain small starch granules, suggesting a shutting off of starch synthesis in the later stages of development. Light micrographs, using a protein stain, clearly show that the modified vitreous core contains starch granules that are not surrounded by a protein matrix. Proteins, both within and outside protein bodies, were found accumulated near the cell periphery. The core vitreous endosperm appears to arise simply out of densely packed starch granules.

Highly digestible lines have been recently selected by Axtell's group that have much improved vitreousity. However, there still appear to be environmental affects on the degree of modification. Also, observations made in Mexico suggest that grain within the panicle of these modified types is not of uniform vitreousness; grain from the bottom of the panicle had a higher percentage of central vitreous endosperm than at the top of the panicle. Environmental effect on modification is currently being studies by Axtell's group.

Modified highly digestible lines were evaluated for milling performance and cooked porridge texture. Milling evaluation showed that the modification of kernels to a central

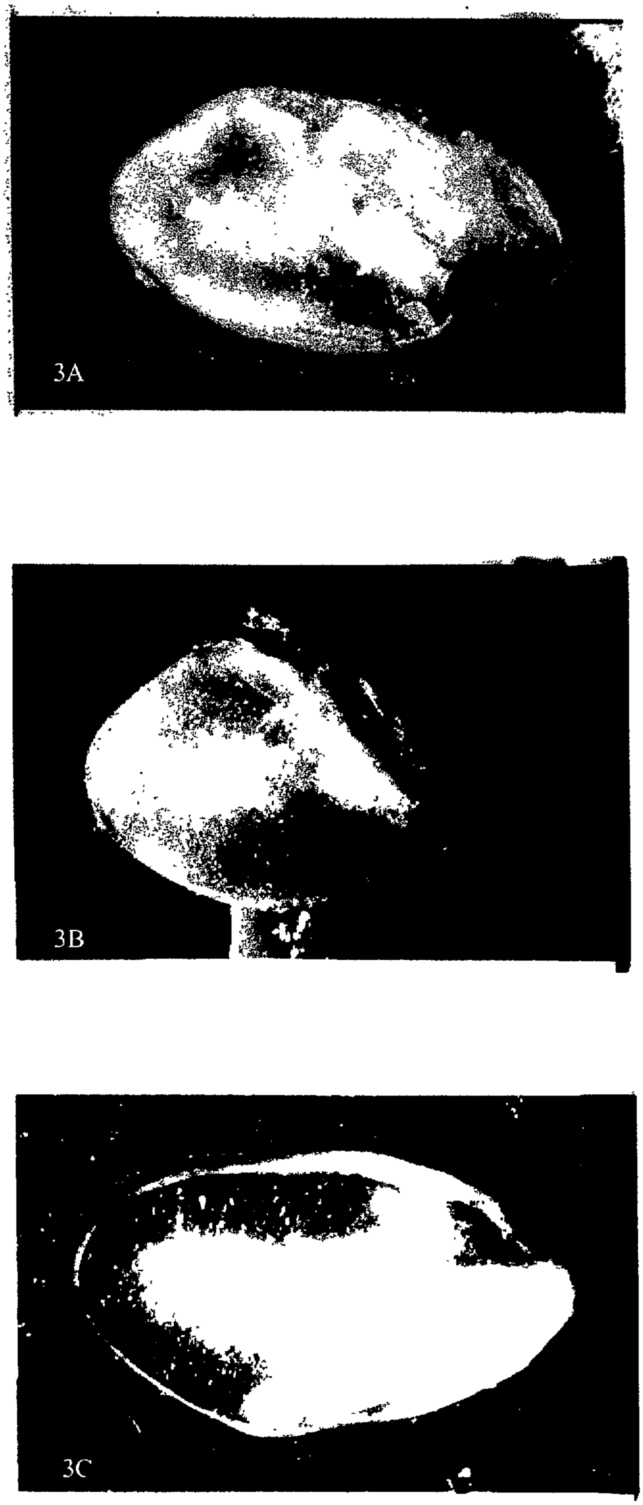

Figure 3. Photos of longitudinal cross-sections of high protein digestibility modified vitreous "core" kernel sorghum types (A and B), and normal vitreous sorghum (C).

vitreous endosperm confers a harder, more dense grain that can mill nearly as well as a normal vitreous grain. Abrasive hardness index (AHI) values, defined as the time in sec required to remove 1% of the kernel, which are a reliable indicator of grain milling quality, placed the modified kernel group (AHI range, 4.0 to 5.7) in proximity to the normal vitreous group (AHI range, 6.3 to 8.3), and well above the floury group (AHI range, 3.0 to 3.7). Kernel density values for the modified group (range, 1.30 to 1.34 g/cc) were even closer to the normal group (range, 1.34 to 1.38 g/cc), and further from the floury group (range, 1.23 to 1.27 g/cc). The correlation coefficient between AHI and kernel density was significant at r=0.87, indicating that density could be used as a fairly good predictor of milling quality.

Cooked flour gel properties produced at three different flour:water ratios showed the modified, highly digestible lines were softer (measured as the modulus of elasticity) than gels made from either the normal vitreous lines or all but one of the floury lines. Stickiness values (measured as the work required to pull the compressed gel from between a plate and probe) of the modified grain group were similar, though slightly stickier, to the normal or floury groups. Differences in gel properties, particularly firmness, exhibited within the modified group may be the result of changes in the starch component - amylose:amylopectin ratio or molecular fine structure. This needs to be investigated further.

Protein Digestibility of Normal Sorghum

In our studies on protein digestibility of sorghum grain, we found variations in digestibility occurring over years and during grain drydown. It appears that environment has a significant effect on protein, and possibly starch, digestibilities, and may be rooted in changes in susceptibility of sorghum protein bodies to digestion.

Year-to-Year Variation

A fairly large variation in in vitro protein digestibility was found within a sorghum cultivar (P721N) monitored over 7 years. Uncooked digestibility values ranged from 69.2 to 89.1% and cooked values ranged from 47.2 to 72.9%. Year-to-year protein digestibility differences were not related to amounts of protein disulfide isomerase, a non-kafirin high molecular weight putative heat shock protein that we identified at the periphery of the protein body, or amounts of the individual α, β, or γ-kafirins. However, in sequential extractions of kafirins in incrementally increasing concentrations of reducing agent (to cleave disulfide bonds), there was a negative correlation (r=0.88) noted between amount of crosslinked γ-kafirin extractable in 0.001% reducing agent (2-mercaptoethanol) and digestibility. This finding may indicate that digestibility in normal sorghum cultivars is related to the amount of disulfide-bound γ-kafirin. It is notable that the highly digestible cultivar was not significantly affected by year, probably due to the fact that γ-kafirin is not found at the periphery of its protein bodies, but at the base of folds in its structure.

Effect of Drydown on Protein Digestibility

We showed previously that sorghum protein digestibility decreases during development. This decrease coincides with the formation of disulfide bonds in γ-kafirin, a sorghum protein body protein, and possibly other related proteins. Sorghum reaches physiological maturity at approximately 40 days after half bloom (DAHB), but it dries in the field until approximately 90 DAHB (moisture content to about 14%). The formation of disulfide bonds has been speculated to be due to oxidation during dry-down. In this experiment, sorghum samples (45 DAHB, moisture content = 31%) were dried under varying environmental conditions. Samples were freeze-dried immediately after harvest or allowed to air-dry at room temperature (18 da). Additionally, several samples were dried under artificial environments. To investigate the effect of oxygen during drying, sorghum was dried at 0, 21 (ambient), and 42% oxygen; nitrogen made up the balance of the atmosphere. The digestibilities of all samples dried at 45 DAHB under the various environments had higher digestibility (approximately 92%) than samples harvested at 90 DAHB following field drying (77%). These results indicate that dry-down alone is not the cause of disulfide bond formation during development. Another factor, possibly an enzyme, may facilitate the formation of these bonds.

Starch Digestibility of Cooked Sorghum Flour

Sorghum starch is somewhat less digestible (available) than starches from other cereals. This is true both in animal feed, where processed sorghum has on average about 5% less nutritional value compared to maize, and in human food, where studies on children showed 21% of energy consumed from a sorghum diet was excreted in the feces. We reported on the study below four years ago, and have just recently started another study designed to identify ways to increase starch digestibility for animals and humans. We are particularly interested in the effect of the rapidly digesting proteins of the highly digestible mutant, and differences in starches and protein matrices among normal sorghums.

Our in vitro experiments using α-amylase as the digestive enzyme showed that starch from cooked sorghum flour pastes was about 20% less digestible than a maize flour paste. Isolated starches, however, were about equal in digestibility, with sorghum starch even slightly more digestible than maize. Pepsin pretreatment markedly increased the starch digestibilities of sorghum cultivars, while little affecting maize. Also, cooking sorghum flours in the presence of a reducing agent, sodium metabisulfite, increased starch digestibilities. Pepsin treatment after cooking did not increase starch digestibility. These results support a view that sorghum protein reduces starch digestibility in cooked flours. This hypothetically could be through an interaction with starch after gelatinization or by restricting gelatinization, which would retard its digestion. Under the conditions used, we found, using differential scanning calorimetry, that starch was fully gelatinized. This leads us to believe there may be an interaction that reduces digestibility. Uncovering the mechanism accounting for the lower starch digestibility of cooked flour will allow for methods to be developed to increase digestibility in cooked human foods

Improving the Function of Prolamin Storage Proteins in Breadmaking

In this study, prolamins, the storage proteins of sorghum (kafirins) and maize (zeins), were made to contribute to dough strength and loaf volume of sorghum-wheat composite breads. It is generally accepted that wheat gluten proteins alone can form viscoelastic fibrils during dough mixing that contain carbon dioxide to produce a leavened bread product. Storage prolamin proteins are the predominate proteins of sorghum (~80% in decorticated flour), maize (~70% in maize grits), and millet. They are encapsulated in protein body structures, where they are synthesized and packaged, and, therefore, normally do not function in the breadmaking process. However, in the highly digestible sorghum mutant, with altered protein body structure, or in the form of an ingredient, proteins could be made functional. This study provides fundamental information regarding the potential of using native or added sorghum kafirins or maize zeins in breadmaking. The overall objective is to find ways to increase the substitution rate of sorghum or millet flour in composite dough systems for breadmaking.

Addition of sorghum flour to wheat flour produces marked negative effects on rheological properties of dough and loaf volume. Although there are notable differences in the chemical composition of sorghum proteins, kafirins, compared to wheat gluten that might imply poor functionality in bread making systems, a larger constraint may be the unavailability of kafirins due to encapsulation in protein bodies. zein, the analogous maize prolamin to kafirin, was used to determine the potential effects of protein body-free prolamins on dough rheology and baking quality of wheat-sorghum composite flour. Mixograms ran at 35°C (above the glass transition temperature of zein) were significantly ($p<0.01$) improved with addition of zein. Mixogram peak heights increased while mixing time decreased uniformly with addition of zein. Dough extensibility studies showed an increase in maximum tensile stress while baking studies showed an increase in loaf volume with increasing amounts of added zein (Figure 4). These data are supported by a previous study, showing that in a model system zein mixed with starch can form viscoelastic networks, and suggest that kafirin, if made available, could contribute to dough formation.

Confocal laser scanning microscopy was used to observe the structure of zein fibrils and the interaction between zein and gluten proteins in the composite dough and bread systems. Autofluorescence and immunolocalization techniques were used to locate wheat gluten and maize zein, respectively. Optical sections were collected every 0.4 µm through the samples and digitally processed to produce reconstructed three-dimensional images. Results showed that zein fibrils form an outer layer that intermittently coats the gluten networks, thereby strengthening them. This type of microstructure is able to withstand the pressure exerted by gas cell expansion during yeast fermentation to increase loaf volume.

A Highly Reactive Protease (likely fungal) in Sorghum Grain

A protease was found in sorghum pericarp (bran) that is active in highly denaturing extraction solvents and interfers with protein analysis. The protease was highly active in a solvent containing SDS and 2-mercaptoethanol at alkaline pH of 10, and was inhibited using 15 mM PMSF. The protease effectively hydrolyzed sorghum protein and resulted in marked loss of protein bands on SDS-PAGE and lower ELISA readings. Moreover, the protease was active under electrophoresis conditions, as it created a clear zone on a casein-impregnated gel from migration at the top of the separating gel to its band formation at about 45 kDa. In those cultivars most highly affected (e.g., SRN39), proteolysis during alkaline-detergent extraction for 1 hr removed over 80% of sorghum proteins normally seen in an SDS-PAGE banding pattern. Grain of sorghum cultivar SRN39 that was separated visually for weathered (darkened to any extent) versus clean grain showed high and no proteolytic activity, respectively, following a 2 hr alkaline-detergent extraction. Interference can be avoided by decorticating grain or by adding a protease inhibitor. Preliminary experiments suggest that the presence of the protease is not detrimental to quality of sorghum foods.

Networking Activities

Workshops

Over the four year period, B. Hamaker has participated in the annual planning and evaluation meetings for the P5 project Millet Promotion Through Improvement of Processing Technologies of the ROCAFREMI network. These have been held in Accra, Ghana (February 1997); Niamey, Niger (March 1998); Dakar, Senegal (March 1999), and a P5 meeting followed by a general workshop of all ROCAFREMI projects in Niamey, Niger (March 2000). The focus of the project is on processing of locally grown millet to products for sale to urban consumers. This project has to date been quite successful in coordinating millet processing projects in the region; has significant output in opti-

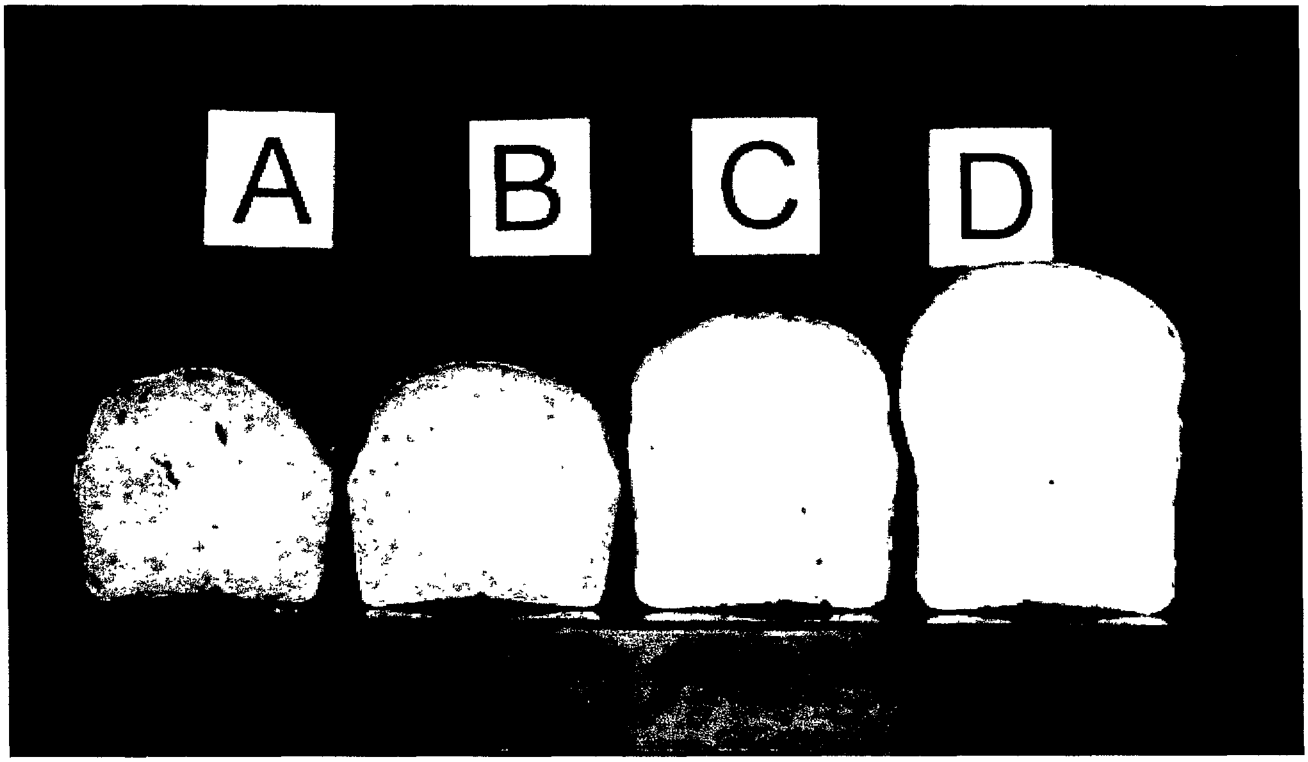

Figure 4. Breads made from 20/80% sorghum/wheat composite flours with 0, 5, 10, and 20% added zein protein, mixed in dough at 35°C.

mizing the design of a destoner, its placement in key research institutes, conducting regional surveys on methodology and processing technologies; and was recently rated by an external review panel one of the most effective in ROCAFREMI.

B. Hamaker participated in an East Africa regional workshop held in Nazret, Ethiopia in September 1997. Collaborative projects were planned with S. Yetneberk of IAR, Ethiopia and plans were finalized for B. Bugusu of KARI, Kenya to come to Purdue for her M.S. studies. Ms. Bugusu arrived in January 1998 to begin her program.

B. Hamaker and A. Aboubacar participated in the West African Regional Hybrid Sorghum and Pearl Millet Seed Workshop held in Niamey, Niger in September 1998. B. Hamaker moderated a panel discussion on commercial utilization of hybrids in processed foods and animal feed utilization, and A. Aboubacar gave an introductory talk on potential commercializable products in West Africa. In the afternoon, workshop participants traveled to the Cereal Quality Laboratory to observe a demonstration of the couscous processing unit and try sorghum and millet couscous products prepared by the INRAN staff.

B. Hamaker has made four visits (as part of above trips) to INRAN/Niger to consult with collaborators in couscous/flour processing – M. Oumarou, M. Moussa, and S. Kaka. Plans were made for final optimization and completion of the couscous processing unit, meetings were held with local processors and NGOs, and design of the market study was made with INRAN technologists/scientists, C. Nelson, and J. Ngeunga.

B. Hamaker participated in the biennial Congress on Maize and Sorghum held in Uberlandia, Brazil in May 2000, and presented talks on sorghum grain nutritional quality and current regulatory issues concerning GMOs in the USA. He also visited the EMBRAPA center on maize and sorghum improvement in Sete Lagoas and met with scientists on potential areas of future collaboration.

Research Investigator Exchange

A. Aboubacar (doctoral student) traveled in August 1996 to CIRAD/Montpellier, France to be trained on use of the couscous agglomerator, and on to INRAN/Niger to set up the couscous processing unit, B. Hamaker traveled to Niamey in February to work with M. Oumarou and R. Seydou in setting up plans for the unit. A protocol was developed to optimize processing conditions for sorghum and millet couscous production, followed by sensory testing, and market trials. Two food technologists (one each for sorghum and millet) were later hired on a short term basis to carry out the planned work.

A. Aboubacar traveled to INRAN/Niger in September-October 1997 to conduct sensory studies on sorghum couscous produced using the new couscous processing unit, and to meet with local entrepreneurs and an NGO active in processing of locally grown crops.

B. Hamaker has traveled to India twice in September 1997 and November 1999 to initiate and follow-up on a project funded by the Mahyco Research Foundation (Mumbai) designed to study the potential of introducing the high protein digestibility sorghum into Indian germplasm. On the first trip, he visited B.R. Barwale, chairman of Mahyco Ltd. and Drs. Usha and Brent Zehr of same company, Dr. Rana of the All India Sorghum Program, and A. Chandrashekar (collaborator) of the Central Food Technology Research Institute, Mysore. On the second trip, he visited co-PI A. Chandrashekar at CFTRI/Mysore, V.S. Murty at Mahyco Co./Hyderabad, F. Bidinger at ICRISAT/Hyderabad, and Drs. Usha and Brent Zehr at Mahyco research headquarters/Jalna.

Dr. Arun Chandrashekar traveled from CFTRI in Mysore, India to Purdue University in September 1998 for 6 weeks for short-term research, training, and planning for a new project funded by the Mahyco Research Foundation (Mumbai) designed to study the potential of introducing the high protein digestibility sorghum identified through INTSORMIL PRF-212 into Indian germplasm.

B. Hamaker traveled to CIMMYT, Mexico in April 1998 to explore further the possibility of setting up a nutritional impact study on Quality Protein Maize.

An information pamphlet was designed and printed by A. Aboubacar to promote couscous processing for commercial markets. The pamphlet was carried to INRAN/Niger and was distributed within the Niamey area and at a regional exposition in Burkina Faso. An entrepreneurial-scale decorticator and hammer mill are in the process of being purchased for the INRAN/Niger and IAR/Ethiopia laboratories.

Purdue staff working on INTSORMIL-related projects (see accompanying list of abstracts) attended and presented research findings at four annual American Association of Cereal Chemists meetings in: Baltimore, Maryland in September, 1996; in San Diego, California in October 1997; Minneapolis, MN in October 1998; and Seattle, WA in November 1999. A presentation was made at the annual Institute of Food Technologists meeting in Chicago, Illinois in July 1999.

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Food and Nutritional Quality of Sorghum and Millet

Project TAM-226
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Summary

This project has made significant contributions to the development of new markets for value-enhanced white food sorghums promoted by the U.S. Grains Council. Value-enhanced white food sorghums positively impressed the Japanese food industry as an ingredient in extruded snacks and related products. Sorghum flour was demonstrated effective in nearly 20 traditional Japanese foods in Tokyo. Its extrusion properties were better than rice. The bland flavor and light color extrudates were excellent flavor carrier. Additional industrial food processing trials sponsored in part by the U.S. Grains Council are underway in Japan.

In Central America, white food sorghums are used in cookies and other products as a substitute for wheat or maize. Personnel in Honduras successfully conducted baking trials demonstrating the value of white food sorghums. A new snack from white sorghum was marketed in the United States. Several mills are producing sorghum flour for niche markets .

Special sorghums with high levels of phenols and antioxidants produce excellent chips and baked products. The antioxidant level in brown sorghum bran is higher than that of blue berries.

New commercial sorghum hybrids with tan plant red and white pericarp color are nearing release from commercial hybrid seed companies and TAES. Several parental sorghum lines released from the program are used in commercial hybrids grown in Mexico and the United States. ATx 635 hybrids have outstanding milling properties.

The principles defined by Ms. M. Leon-Chapa's thesis on Mexican cookies made from sorghum flour was used to make excellent rosquettes (cookies) and rosquillos which are dry salty cookies made from nixtamalized maize or sorghum in Honduras. Sureño, a white food sorghum grown in Honduras, and two new improved Maicillo varieties were useful. Several white tan plant sorghum varieties in El Salvador are used as a substitute for wheat flour in sweet breads.

Our long term research on improving sorghum milling properties include these observations:

- The milling properties of sorghum are affected by hybrid and environmental conditions.
- Sorghums with purple or red plant color produce highly-colored, stained grits when the grain weathers during and after maturation; tan plant color reduces discoloration.

- The food sorghums released have about the same grit yields as cream hybrids, but the grit color is much better, especially when weathering occurs.

- The tan plant red sorghum hybrids produced about the same yields of grits; however, the grit color was much improved.

- ATx635 hybrids all had significantly improved yields of grits with excellent color. The density and test weights were highest for ATx635 grains at all locations.

- In Mali, 20% flour from N'Tenimissa, a white food sorghum, was used successfully in biscuits by a large industrial processor. The bland flavor and light color of white food type sorghums were superior to maize in composite baked products. However, identity preserved grains of consistent quality must be obtained for processing. This is a major constraint.

- Antifungal proteins are related to grain mold resistance in sorghum. A molecular linkage map for sorghum kernel characteristics, milling properties and mold resistance is nearing completion.

- Near infrared equipment and a single kernel hardness tester were calibrated and used for whole grain composition analysis and hardness, kernel size and kernel weight successfully for sorghum.

- Eight Ph.D., 8 M.S. and four B.S. students completed their studies and joined the food industry or went on to graduate school during the past four years.

Objectives, Production, and Utilization Constraints

Objectives

- Develop new food products from sorghum and millet using technology appropriate for use in less developed areas.

- Determine physical, chemical, and structural factors that affect the food and nutritional quality of sorghum; seek ways of modifying its properties or improving methods of processing.

- Develop simple, practical laboratory methods for use in breeding programs to assess important grain quality characteristics.

- Determine the factors that affect resistance to grain molds and field deterioration in sorghum and devise laboratory procedures to detect genotypes with resistance.

Constraints

Factors affecting food quality, processing properties, and nutritional value of sorghum and millet are critically important. If the grain cannot be processed and consumed for food or feed, then the agronomic and breeding research has been wasted. This project relates quality to measurable characteristics that can be used to select for sorghum and millet with acceptable traditional and industrial utilization attributes. It has defined quality attributes and incorporates those desirable properties into new cultivars at early stages in the breeding and improvement programs. The project also seeks to find more efficient ways of processing sorghums and millets into new foods with better acceptability that can generate income for farmers and entrepreneurs.

The major constraint to development of profitable sorghum and millet foods is the lack of a consistent supply of good quality grain. Until a source of identity-preserved, good quality grain can be produced, sorghum and millet products will continue to be inferior. It is imperative that plant improvement programs develop cultivars with good quality for value-added processing at the local level. Systems for marketing identity-preserved grains as value-added products for urban consumers are critically important.

Grain molds cause staining and significantly reduce the quality of sorghum for food and feeds. Information on the factors that affect mold damage of sorghum and methods to develop mold resistant sorghums is needed. This project addresses those critical issues.

Research Approach and Project Output

Sorghum and millet grains grown locally and from various areas of the world were analyzed for physical, chemical, structural, and processing properties. Various food and feed products were prepared to test the quality of the different grain samples. Some of these findings are summarized below.

Significant Accomplishment - Application of Technology to Marketing

This project has led the way in developing and stimulating interest in the U.S. sorghum industry to produce value-enhanced white food type sorghums using identity preserved systems with subsequent market development in several areas of the world. Recently, the U.S. Grains Council completed successful marketing efforts in Japan to sell white identity preserved white sorghum for food applications. Lloyd W. Rooney provided continuing technical information and was a major participant in these market activities utilizing information obtained over the years in TAM-226. Figure 1 shows the market development team presenting information to Japanese millers and food processors in a milling company that has developed a small scale milling plant for sorghum. The products in the photo pro-

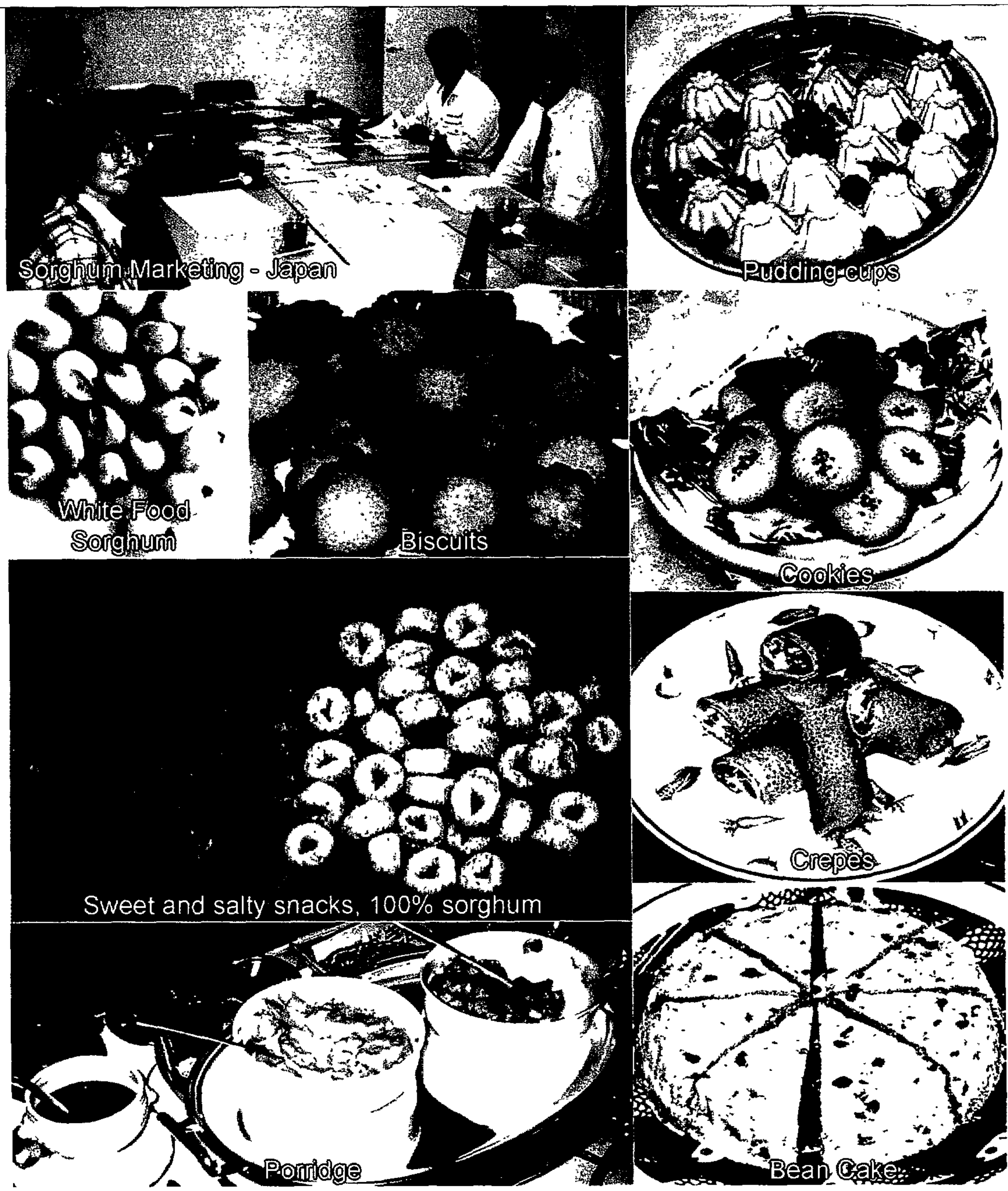

Figure 1. United States Grains Council market development activities in Japan (top right) have utilized information and technologies generated to promote identity preserved value-enhanced sorghum for Japanese food processors. The products shown were produced in Japan. Identity preserved white sorghum is being sent to Japan for processing. The white sorghum flour produces bland, white products compatible with Japanese food systems.

duced by Japanese food companies and a dietician were exhibited and consumed by 45 or more participants in a U.S. Grains Council sorghum products seminar in Tokyo in June 2000. The products were given high ratings and were the capstone for the seminar. Lloyd Rooney presented a two-hour lecture on use of sorghum in food products which was based on research conducted as part of this project.

An extruded salty snack and sweet chocolate coated snack was made by a Japanese food company from sorghum flour using twin screw extruders following our suggestions. The extrusion properties of sorghum flour and meal were judged outstanding by these Japanese industrial food scientists which confirmed what we had told them in their visit to our laboratory in 1999. They found that the white sorghum produced bland flavor, light color products that extruded into "O"-like products with better properties than rice at reduced cost.

Two containers of identity preserved food sorghums were shipped to Japan for further evaluations. The Japanese are interested in buying white sorghum and sales could occur this next year if all goes well and increase after that.

POPUMS, a commercial new product based on a special white food hybrid sorghum, was marketed by a west coast company in the United States. These new food hybrids are also marketed as flour and meal to ethnic and celiac sprue afflicted people by several small companies.

Our long-term efforts to improve sorghum quality through breeding and demonstration of its use in prototype food products have finally begun to pay dividends by assisting farmers to produce and market value-enhanced sorghum hybrids. The long term financial support of INTSORMIL, the TAES and our tenacity in persevering allowed this to happen.

Applications in Honduras and El Salvador

Our research on sorghum has been applied in Honduras and El Salvador. The variety, Sureño and others with white tan plant color, are used in Central America for tortillas, rosquillos, and rosquettes which are major baked products. Figure 2 shows some of the products produced near

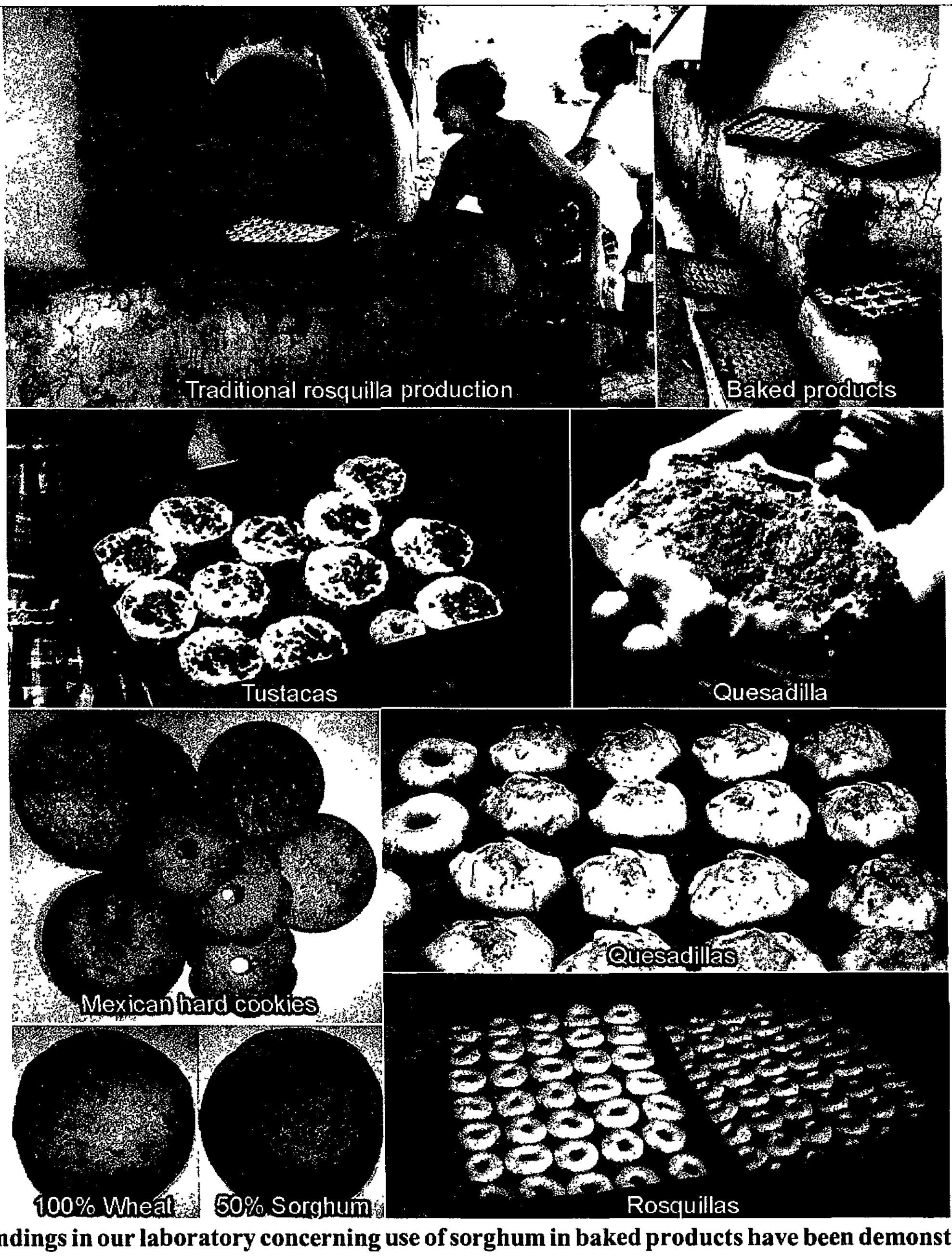

Figure 2. Findings in our laboratory concerning use of sorghum in baked products have been demonstrated in products in Honduras by EAP personnel. The products shown contain white food type sorghum with little or no change in their characteristics over the usual wheat or maize products.

Choluteca, Honduras by small bakeries and housewives. They utilize nixtamalized Sureño to produce the rosquillos. The color is slightly darker for sorghum rosquillos but they are more acceptable than corn products since the slightly darker color signifies to the consumer that more cream, cheese, and other high-value ingredients have been used. In El Salvador, sorghum flours are used in small bakeries to produce rosquettes, rosquillos and other variations of these products.

Applications of Technology in Mali

Work in Mali continues to demonstrate the value of new, white, tan plant sorghum varieties in food systems. Major constraints continues to be lack of an effective identity preserved production scheme integrated into processing into value added flour and meal. The General Foods Company of Mali has found up to 20% white sorghum flour acceptable in production of biscuits. The key constraint now is to secure adequate production of the tan plant sorghum varieties. Also, new improved tan plant white sorghums are needed to improve production levels. Farmers growing the white tans remark that they prefer them to those made from the tan plant grains. This is a similar situation to farmers in Honduras and El Salvador who like tortillas made from white tan plant sorghum varieties.

Work continues in Mali by the IER and Novartis to demonstrate the application of sorghum or millet malt in production of improved weaning foods made with a combination of cowpeas and millet. We have worked on this technology in the past to show that millet or sorghum malt can be used to produce caloric dense weaning foods from pearl millet or sorghum and cowpea blends. Progress is being made in Malian villages to use home-made children's foods with high caloric density and reduced viscosity. The millet malt reduces the viscosity of the cooked gruels significantly.

Sorghum Phenols and Catechins as Anti-oxidants

Some sorghum varieties contain tannins and other phenols concentrated in the bran; they could provide a natural source of antioxidants for foods. Our objective was to isolate sorghum fractions with the highest levels of tannins and phenols and determine their antioxidant capacities. Twenty-three sorghum varieties grown in Texas in 1999 were analyzed for tannins (Vanillin-HCl) and phenols (Folin-Ciocalteu). Four varieties with different characteristics -Early Sumac (Br1) and ATx623*SC103 (Br2), type III high tannin sorghums; Tx430 (Bk1), a black variety high in anthocyanins; and ATx631*RTx436 (white), a food type sorghum - were selected and abrasively milled to remove successive bran fractions. Phenol contents (mg/100 mg gallic acid equivalent, GAE) in whole grains ranged from 0.07 to 2.45, and bran 0.43 to 6.01; blueberries had 2.57 and wheat bran 0.30 on a dry matter basis. Tannin levels (mg/100 mg catechin equivalent, CE) ranged from 0 to 5.6 in the whole grains. Br1 and Br2 brans had values of 13.9 and 17.5. The brans had an ORAC (oxygen radical absorbance capacity) value (U mol Trolox equivalent, TE/g) range of 23 to 410, compared to blue berries with values of 63 to 282 on a dry matter basis. Sorghum brans high in tannins, anthocyanins, and phenols have excellent potential as antioxidants and they are excellent sources of insoluble dietary fiber.

Effects of Sorghum Brans on Bread Quality

Adding sorghum brans to baked goods can produce nutraceutical products. Since addition of bran to breads may diminish bread quality, effects of white sorghum, early sumac, and black sorghum brans on bread quality were evaluated. Breads were formulated according to AACC method 10-10B, with addition of 17 or 23% bran. Controls were formulated with the addition of wheat bran. Brans were analyzed for tannins, phenols, and Oxygen Radical Absorbance Capacity (ORAC) values, as well as dietary fiber and other components. A maximum of 23% bran (for all brans except black sorghum, which exhibited a maximum usage level of 17%) yielded high-quality loaves with excellent sensory characteristics. Use of sorghum brans also added significant dietary fiber and higher amounts of phenolic compounds compared to wheat bran. Addition of 23% early sumac bran or 17% black sorghum bran gave breads with appearance, texture, color and specific volume (cm3/g) similar to commercial specialty or dark rye breads.

The Effect of Grain Color and pH on Sorghum Tortilla Chips

The effect of grain color and pH on sorghum chip properties was evaluated. Masas prepared from hard-endosperm, white-pericarp, food-type (white- ATX631 × RTX436) and soft-endosperm, tannin-containing, red-pericarp (brown-ATX623 × SC103-12-E) sorghums were adjusted to pH levels of 5, 7 (control) and 11 and processed into tortillas and tortilla chips. Color components were measured. Grain color and pH levels had a significant effect on sorghum chip properties. Chips produced from brown sorghum were dark brown at high pH and reddish tan at low pH. White sorghum chips were yellowish at high pH and pinkish tan at low pH. Both types of sorghum chips increased in hardness at a high pH. White sorghum chips were softer than those from brown sorghum at every pH. Brown and white chips at neutral and low pH were similar in texture. For both varieties, chips prepared at high pH levels developed peak viscosity in a shorter time and the peak viscosities were higher than those of chips at low pH. Chips produced from brown and white sorghum had acceptable flavor at neutral and high pH.

Sorghum Starch, Malting and Brewing Studies

Brewing Adjuncts and Sweet Worts from Waxy Sorghums

Four different sorghum genotypes, white normal (WNO), white waxy (WWX), white heterowaxy (WHWX), and brown normal (BNO), were decorticated in a PRL mill and then roller-milled into brewing grits. Grain hardness values determined with the TADD mill indicated that the BNO sorghum had the softest endosperm and yielded the lowest amount of decorticated kernels. Decorticated kernels had lower protein, crude fiber, ash, and color scores and higher starch contents than their respective whole kernels. The yield of brewing adjuncts from decorticated WNO, WWX, WHWX, and BNO were 87.4, 89.9, 90.0, and 81%, respectively. Worts produced from WWX brewing adjuncts filtered faster than the heterowaxy and normal counterparts. All sorghum worts, standardized to 14° Plato, had in practical terms similar pH, viscosity, alpha amino nitrogen and color scores. The fermentable carbohydrate content of the BNO sorghum wort was slightly lower when compared with all the white sorghum worts. White sorghums with hard, waxy endosperms were the most suitable for use as brewing adjuncts.

Dr. Serna-Saldivar, ITESM, Monterrey, Mexico, is continuing to investigate brewing and starch properties of sorghum with our collaboration. He has two more students initiating research in this area presently. New food type sorghum hybrids are being grown in Mexico where sorghum is the second leading cereal crop; these new varieties should be successfully utilized by the brewing industry.

Effect of Sorghum Flour and Gelatinized Starch on the Structure and Texture of Cookies

Cookies were prepared from 100% sorghum flour (SF), a combination of 50:50 wheat/SF, and 95:5 SF/gelatinized corn starch, using 100% wheat flour as a control, to determine what effect the flours had on cookie texture and structure. Fragility of the 100% sorghum cookie and low values for peak force (texture) was because of reduced starchy continuous phase and no gluten network to hold the crumb together. The flour particles in the crumb appeared to be held together by little more than the fat in the mixture. The 50:50 wheat/SF cookie had a stronger crumb, higher peak force value, and similar appearance to control; a continuous phase/gluten network was present, but was thin and insufficient to hold the crumb together. The cookie prepared with 95:5 SF/ gelatinized corn starch was harder in texture than the 100% SF cookie and was similar in appearance to the controls. The pre-gelatinized starch provided enough starchy continuous phase matrix to hold the sorghum flour particles in the cookie together and provide strength to the crumb. The SF/gelatinized corn starch cookies were as acceptable in appearance and texture as the control cookies. Increased production of sorghum in Mexico creates long-term opportunities to use sorghum as an alternative flour source. White food type sorghums are high quality grains with bland taste that can be easily incorporated into many foods. The grittiness of the sorghum flour can be reduced by process changes.

Sorghum flour (SF) can be substituted for wheat flour in a variety of cookies. A 50:50 blend can be used with little reduction in cookie quality. It is possible to produce cookies without wheat flour, but a binder is needed to strengthen the crumb. The addition of 5% pregelatinized corn starch to 95% SF made the dough easier to handle, held the cookie structure together, and improved the handling properties of the cookies. However, over time, this treatment tended to be more fragile than the wheat control. The bland flavor and light color of sorghum flour makes it advantageous to use in flour substitution, but the grittiness of the particles must be controlled.

Sorghum Flour in Biscuits and Cookies in Central America and Mexico

Ms. Leon Chapa completed her M.S. thesis on the utilization of sorghum flour as a substitute for wheat flour in Mexican dry, sandy, cookies. She found that up to 50% sorghum flour could be substituted for wheat flour without affecting organoleptic and other properties. The same type of cookies called roskettes in Honduras and El Salvador are used. Ms. P Carrillo, B.S. student and Ms. C. Villadares, Food Scientist at EAP in Zamorano, Honduras assisted by Mr. Bueso, Ph.D. graduate student in our Cereal Quality Laboratory, have applied her information in Honduras. They found that sorghum can be used extensively in rosquette production provided it is a white sorghum flour. They conducted experiments in local households near Choluteca in southern Honduras demonstrating that rosquettes containing sorghum are of excellent quality and can provide an outlet for improved sorghum grains (Figure 2).

Ms. Herrera, working with CENTA in El Salvador, has conducted many trials in local bakeries showing that sorghum can be used effectively in baking of roskettes, sweet breads, and other products as well. We have initiated a program in El Salvador to work with her to assist in sorghum flour production from the improved white, tan plant food sorghums that are available in El Salvador. This work along with the breeding program in El Salvador and Nicaragua will continue to improve sorghum quality for use in foods.

The production of sorghum flour by small operators is a major constraint to more widespread use of sorghum by the small holders in the region. We are trying to blend together existing expertise in the region to put the technologies to work.

Rosquillos, made by small local processors, are a type of dry, salty, cookie made from nixtamalized maize in Central America (Figure 2). They are, after tortillas, the second most important use of nixtamalized maize. Field experiments in Choluteca, Honduras by the EAP, accompanied by Mr. Bueso, showed clearly that the rosquillos made from white sorghum (Sureño) had equal to or better acceptance than those made with a white corn. The slightly darker color of the sorghum rosquillos was an advantage because darker means that greater amounts of cream, cheese, and other ingredients were used in production of the product and, hence, the improved quality is perceived. The taste of the rosquillos from sorghum and corn were the same in the trials. Ms. Herrera, CENTA has industrial experience in this area as well. Rosquillos and rosquettes are made by small bakers and sold in the local cities and towns.

These findings are discussed in detail in the Central American report. Our experience with tortilla processing from sorghum has direct relevance to rosquillo production as well. This affords an opportunity to utilize sorghum in popular food items where it has an advantage over maize. As we work to enhance utilization at the entrepreneur level, the combination of cereals and legumes to produce value-added foods is critically important. Acquisition of good quality raw grains and legumes is the limiting economic factor in many cases.

Our emphasis will be to work with personnel in Central America to assist them in stimulating production of foods from these grains in an economic and practical manner. We can provide training on technology that will be useful in El Salvador and Honduras. Proper milling technology and identity preserved food sorghums can be used to produce a wide array of products including rice substitutes.

The price of rice is such that locally grown sorghums could compete for markets in certain snacks, ready to eat breakfast cereals, and composite flours for baking.

Tan Plant Food Type Hybrid Performance and Quality Trials

A new replicated food sorghum test consisting of 18 commercial hybrids submitted by 9 seed companies, plus 5 Texas Agricultural Experiment Station food hybrids, and 2 commercial red sorghum hybrids was grown at Corpus Christi, College Station, Halfway, and Dumas, Texas. The objective was to obtain uniform agronomic and quality data to permit a better understanding of our current food sorghum hybrids and their properties. Data from the Halfway, Texas location was abandoned due to excessive midge damage. The Corpus Christi and College Station locations had some grain molds and weathering while Dumas, Texas grain was optimum quality. Typical red and cream commercial sorghum hybrids were included as well as open pedigree food hybrids for comparisons.

The agronomic data showed that the tan plant hybrids were competitive with comparable traditional purple plant hybrids. The availability of short season tan plant hybrids is limited. More of them are required to extend the food sorghum production into drier, shorter season environments. In 1999, College Station and Corpus Christi had significant weathering and discoloration of the early hybrids. The later maturing hybrids avoided weathering. The test at Dumas had excellent clear grain and gave a real accurate comparison of relative grain quality traits. Grain weathering and molds are definitely limiting factors affecting food sorghum production. Fortunately, the red tan plant hybrids avoided weathering; some had excellent grain yields and processing qualities. They are an obvious choice for planting in more humid areas, i.e., Corpus Christi and College Station, Texas.

Several white tan plant hybrids out yielded the red commercial sorghum hybrids and are being grown in some locations in west Texas. Surprisingly, the grain yields of some white tan plant hybrids was tops in many of the Kansas State University sorghum yield trials. The grain quality traits of the hybrids were good to excellent except for the early maturing hybrids that stayed too long in the field prior to harvesting at College Station and Corpus Christi. Next year, tan plant performance trials will be located in Kansas as well.

The objective to evaluate commercial food-type hybrids was achieved. These trials originated by Bill Rooney, Sorghum Breeder, TAES, and sponsored by the Grain Sorghum Producers Association, and a special TAES fund called PROFIT, provide information required to develop markets for value-enhanced food sorghums. Identity preserved white food sorghums are now available to service these markets. They are the direct results of the significant long term research done in this project and others within INTSORMIL in conjunction with other funding sources. The white food and tan plant red sorghums had superior milling properties consistently and can be used for production of light color, bland flavor food ingredients, and consumer products.

In Japan, commercial food companies have successfully developed prototype snacks and other products from white sorghums. They report that the extrudates are excellent and carry flavor and color additives better than extruded rice flour snacks. A new product made from 100% white food sorghum called POPUMS, introduced by a company in Washington State, is made from a specific commercial food grade white sorghum hybrid that has excellent yield and hard grain.

We continue to evaluate grain from international food quality nurseries and hybrid trials to monitor new materials in the pipeline and to encourage private seed companies to develop new improved value-enhanced hybrids. The grain industry in the U.S. is rapidly changing to a value-enhanced identity preserved marketing system which fits into our long term goal of improving sorghum quality for food and feeds. Sufficient quantities of value-enhanced sorghums exist to allow for market development.

Yield, Agronomics and Quality Attributes of Commercial White Tan Food Sorghum Hybrids

Commercial sorghums and value-enhanced white food sorghum grown on farmers' fields and exported from Gulf Coast elevators in 1999 were analyzed for composition, physical, and milling properties. The milling properties of value-enhanced food-type sorghum hybrids grown under commercial production were compared with commercial export samples of sorghums. The white food grains had slightly higher test weight, true density, reduced floaters, and slightly higher yields of decorticated grain than the red sorghum. However, the major difference was in color, which was significantly lighter and brighter for the food-type sorghums. The red pericarp contributes significant color to the flour which would have been worse if the grain had been weathered slightly. This information was used in the U.S. Grain Councils value-enhanced grains - 2000 summary of quality for grain importers.

We evaluated the International Food Sorghum Trials grown in several locations in Texas during 1990 to 1999 for kernel properties and milling properties. Based on abrasive milling techniques on samples from these extensive multi-location, multi-year trials we have the following conclusions:

- The milling properties of sorghum are affected by hybrid and environmental conditions.

- Sorghums with purple or red plant color produce highly-colored, stained grits when the grain weathers during and after maturation; tan plant color reduces discoloration.

- The food sorghums released have about the same grit yields as cream hybrids, but the grit color is consistently improved because they do not stain during light weathering. When hot, humid conditions exist all sorghums will eventually deteriorate.

- The tan plant red sorghum hybrids produced about the same yields of grits as grains from red grain with purple plant color; the grit color was much improved. These hybrids should be grown in hot, humid areas such as the Gulf Coast region. They also produce grain that causes reduced specking in eviscerated broilers which allows sorghum feeding during final days prior to slaughter.

- ATx635 hybrids all had significantly improved yields of grits with excellent color. The density and test weights were highest for ATx635 grains at all locations.

- Some commercial tan plant hybrids have improved milling and processing properties that relate to ATx 635. ATx 635 is used as a parent in several commercial food hybrids. It produces excellent quality grain; hybrids based on it are being produced in Mexico.

Improved Methods of Analysis

Near infrared equipment to analyze whole grain for chemical composition and physical properties have been calibrated for whole and ground sorghum samples. This will allow rapid analysis of sorghum for many of its components. The instrument can be utilized for millet as well, but calibration equations must be developed for its effective application.

A single kernel characterization tester used for wheat kernel hardness was applied to sorghum kernel hardness measurement. The instrument in our laboratory has been renovated to more efficiently work with sorghum. We use it to characterize sorghum kernels from our replicated white tan plant and other sorghum tests in 2000. Preliminary information looks promising with a high correlation between hardness scores, milling properties, and other characteristics.

Funds to improve these methods were received from a special research program on sorghum from the Texas Legislature.

Role of AFP in Minimizing Grain Molding of Sorghum

Grain deterioration caused by molding is the major disease problem for sorghum utilization in many regions of the world. Grain deterioration is common when sorghum is grown in warm, humid environments. We are continuing to determine mechanisms of mold resistance involving proteins with antifungal activity (AFP). Previously, we reported several AFPs (sormatin, chitinases, β-1,3-glucanase, and ribosomal inactivating proteins (RIP)) are present in pericarp, germ and endosperm; and these AFPs are inhibitory to grain mold fungal species.

We assisted Drs. Bill Rooney and Raul Rodriguez to determine the levels of AFPs in the grain of sorghums grown in eight environments over three years. Levels of four AFPs were determined in mature caryopses (40-45 days after anthesis) of eight grain mold resistant (GMR) and eight susceptible (GMS) sorghum lines using the immunoblot technique. These 16 lines came from the same cross and were selected for high and low grain mold resistance. The GMR lines had less grain molding in seven environments with grain mold incidence, as expected. There was very little grain deterioration or molding in any cultivar in the grain-mold-free environment.

In the seven environments with grain mold incidence, higher levels of sormatin, chitinases, and ribosomal inactivating proteins (RIP) were observed in the GMR lines compared to the GMS lines (Figure 3). Values of β-1,3-glucanase for the GMR lines were higher in three of seven and were similar in four of seven environments with grain mold incidence. Also, levels of chitinase, sormatin, and RIP in the GMR lines were higher in the environments with grain mold than in the mold-free environment. AFPs correlated among themselves and with grain mold resistance.

In the grain mold-free environment (Halfway, Texas in 1996), grain mold ratings were similar and low for GMR

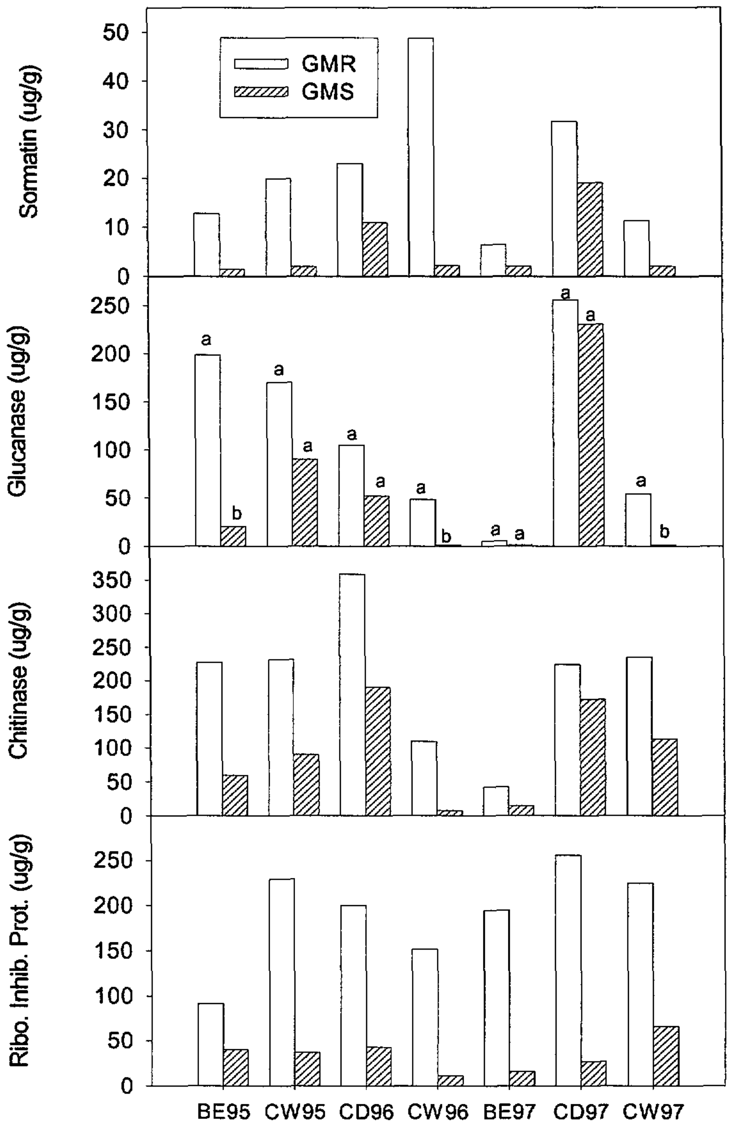

Figure 3. Antifungal protein levels (μg/g) in mature caryopses of eight grain mold resistant (GMR) and eight susceptible (GMS) lines grown at seven environments. Resistant lines have more AFP than susceptible lines except for glucanase. For glucanase, means followed by the same letter are not significantly different (within environments). Legend: BE - Beeville, CD - College Station, dry (furrow irrigated), CW - College Station,

and GMS lines. The GMR lines had higher RIP and lower β-1,3-glucanase levels than those in the GMS lines. Sormatin and chitinase contents were not significantly different between GMR and GMS lines. AFPs did not correlate with grain mold resistance since no grain molding was observed in this environment.

Grain mold infection pressure caused GMR lines to induce and/or retain more AFPs compared to GMS lines. The co-induction or retention of AFPs may be a necessary prerequisite for resistance to grain mold in sorghums without a pigmented testa, even though some AFPs may be constitutively expressed.

We are continuing this research with Dr. Bill Rooney, David Wooton (a Ph.D. student of Dr. Bill Rooney) and Dr. Robert Klein (USDA). We are currently sampling and will evaluate AFPs in 200 lines from Dr. Rodriguez's study to establish molecular markers for antifungal proteins.

We are also assisting Dr. Luis Prom (USDA) to evaluate AFPs in eight lines from Dr. Rodriguez's study that have been stressed at anthesis with fungal pathogens. This is needed to verify previous results from Javier Bueso's thesis research that suggested resistant cultivars responded to stress by retaining more AFPs than susceptible cultivars.

These data were presented by Dr. Ralph Waniska to the "Consultative Group Meeting on Technical and Institutional Options for Sorghum Grain Mold Management" held at ICRISAT on May 18-19, 2000. The goal of the meeting was to increase the value of the grain by 1) increased resistance to grain deterioration (molding) during development and post maturation; and 2) increased utilization (demand) of the grain for food and non-food uses. All of the recent data on AFP research was provided by Dr. Waniska. These data were instrumental in the formulation of the work plans of the conference. We decided the target should be "warm-humid environment, white pericarp, high yield, bold grain, short duration, medium hardness, thin pericarp, and increased gama-prolamins." We decided that a marker assisted selection process should be utilized to increase AFPs in improved cultivars. The conference report will soon be complete and used by ICRISAT in a strategy to increase grain mold resistance in sorghum.

Sorghum Improvement Research

This project cooperates closely with other members of the sorghum program to incorporate the best quality characteristics into new cultivars and parents of new hybrids. Several inbreds that produce white, tan-plant sorghum hybrids with excellent food and feed processing quality have been released. These sorghums produce excellent quality grain when grown under dry conditions. Because of reduced anthocyanin pigments, the grain can withstand some humidity during and after maturation. However, these sorghums need more resistance to molds and weathering to be grown in hot, humid areas, e.g., the Coastal Bend of Texas and Tamalipas in Mexico. The need to understand sorghum molding and weathering is critical. If markers can be found that confer mold resistance, we will be able to make better progress since field screening is difficult.

Networking Activities

Southern Africa

Graduate students in the Food Science Department at the University of Pretoria are from many other African countries. Many of them are participating in the Regional Master of Science program which consists of joint programs between CSIR and the University of Pretoria. Thus, interactions with this program informs many future African food industry leaders on the potential role of sorghum and millets as food and industrial ingredients. INTSORMIL can provide assistance to the region by involvement in these programs where possible.

Several graduate students are conducting research on aspects of sorghum utilization with professor Taylor. Dr Trust Beta completed her Ph.D. on processing sorghum with high levels of polyphenols into foods. She has published several manuscripts related to dry milling, malting and brewing applications of local Zimbabwean sorghum cultivars. Her work has been cooperative with the Matopos grain quality lab in Zimbabwe. She has worked on starch properties at the University of Hong Kong with Professor Harold Corke and is a faculty member at the University of Zimbabwe in the food science area. Lloyd Rooney served on her committee and was a thesis examiner.

Ms. Leda Hugo, Mozambique, is a Ph.D. student at the University of Pretoria working on the effect of malting sorghum on its use in composite breads. She is a professor at the University of Eduardo Mondlane University and completed her M.S. at Texas A&M University. Lloyd Rooney serves on her Ph D. committee.

Lloyd Rooney served as external examiner for the M.S. program of Mr. Joseph Wambugo, Kenya, who completed a thesis on weaning foods from sorghum. Ms. S Yetneberk, Ethiopia, is initiating her Ph D. program and L. Rooney will serve on her committee as well. Her project will be related to determination of the factors affecting the quality of injera from sorghum.

Mr. J. Awika,Kenya, is a M.S. candidate in the Cereal Quality Lab nearing completion of his degree. He will continue on to a Ph.D. in food science and technology.

Honduras, Mexico and South America

L.W. Rooney traveled to Honduras to assist Mr. Javier Bueso with research and teaching activities at EAP. Nixtamalization of sorghum from advanced breeding nurseries was accomplished in the CITESGRAN laboratory.

The EAP CITESGRAN program has increased activities in food science teaching, research, and out reach in Central America. Mr. Javier Bueso made two trips to EAP in the spring of 2000 to assist in conducting research on baking quality of sorghum. He is working on a Ph.D. in our lab. Nolvia Zelaya, M.S. Student from Honduras, is working on tortillas in our laboratory and is available for these activities. They are partially funded through INTSORMIL.

L.W. Rooney has a cooperative project with Dr. S. Serna-Saldivar, Professor and Head, Food Science, Instituto Tecnologico y de Estudios Superiores de Monterrey (ITESM), Monterrey, Mexico, to evaluate the usefulness of the new improved food sorghum hybrids in wet and dry milling and as adjuncts in brewing. We provided samples of sorghum for planting and for analysis in addition to the use of our laboratory for a few analytical tests, i.e., reducing sugars, rapid viscosity analyses, color, and texture. His Ph.D. and subsequent experience was funded from INTSORMIL. We have a graduate student from Mexico partially funded on this project.

Mali

N'Tenimissa (a new white, tan plant, locally adapted photosensitive sorghum cultivar specifically designed for value-added processing in Mali) is liked by farmers for its improved tô quality. N'Tenimissa's panicle breaks off after grain fill and causes harvesting problems. Sister selections and other advanced breeding materials offer promise to eliminate that problem. N'Tenimissa has high yields with slightly softer grain than local cultivars so some adjustments in milling time are required. It consistently has a lighter color, provided it is not contaminated with off types.

Production of identity-preserved grain in sufficient quantities for value-added processing has proven difficult to achieve. Ms. Berthe and others in the IER Food Technology laboratory have demonstrated the improved value of N'Tenimissa in food products. The real key is to produce large enough quantities of identity preserved grain for value-added processing on an economically sound basis. This is a very significant problem that limits adaptation of technology for processed food products from sorghum and millet.

Our information on weaning foods with increased caloric density using sorghum or millet malt is being tested in villages by the IER Food Lab through a grant from the Novartis Foundation. These activities are pursued by Dr. Scheuring of the Novartis Company in Basil, Switzerland. It looks promising. In the past, a small company produced MILEG, a weaning food from cowpea and millet, but could not maintain profitability. It failed for a number of reasons, including the lack of good quality millet and cowpeas for processing. The current effort is focused in villages that consume millet and sorghums. Once successful, the technology can be applied in urban areas.

North America

Several papers were presented at the annual American Association of Cereal Chemists conference in Seattle, WA and at the Institute of Food Technologists Food Exposition in Dallas. L.W. Rooney presented sorghum quality/utilization discussions to Texas Sorghum Producers Board Members and panels. L.W. Rooney was appointed to the National Sorghum Producers associations committee challenged to market sorghums for the food industry in value-enhanced products/ingredients. L.W. Rooney was awarded funds (100K+) from the Texas Advanced Technology Competitive Research program for a two-year effort to evaluate special sorghums for anti-oxidant potential and use in nutraceuticals. Sorghum bran fractions contained from 20-400+ ORAC units compared to 80-200+ ORAC units for blue berries which are considered excellent sources of antioxidants.

Numerous presentations were made to sorghum production conferences in Texas to U.S. Grain Council market development teams from Japan, Mexico, Central America, Taiwan, and to visitors from Australia, Mali, Niger, Botswana, Honduras, Guatemala, El Salvador, and China.

Our laboratory conducted annual short courses on practical snack foods production for private industry in which sorghum utilization was part of the program.

Sorghum Market Development Activities

The Grain Sorghum Producers Association has market development activities to capitalize on value-enhanced sorghums for use in value-added products in Japan, Taiwan, Mexico, Central and South America. Our research activities on development of food type sorghums, milling properties, composite flours, tortillas, snacks, and other prototype food products from sorghum was presented at the U.S. Grain Council sponsored value-enhanced market development workshops in the United States (three times), Japan, Mexico (three times), Guatemala and to trade teams from several countries.

The concept of identity-preserved production and marketing of grains is expanding significantly in value-added corns. Our development of white food-type, waxy, heterowaxy, and nonwaxy sorghums fits into these marketing schemes.

Training, Education and Human Resource Development

Monterrey Institute of Technology: our collaboration with Dr. Serna-Saldivar, Head, Food Science Dept., ITESM, Monterey, Mexico has lead to completion of six Master of Science degrees. These young scientists have positions in the Mexican food industry. Thus, knowledge of sorghum utilization potential has been transferred.

Mr. Javier Bueso, Assistant Professor, CITESGRAN, Escuela Agricola Panamericana, Tegucigalpa, Honduras joined our laboratory in January 2000 to complete his Ph.D. in food science and technology. He has completed two short term assignments to Honduras to work with his successor to continue collaborative research on sorghum processing into baked products. Three B.S. students were provided partial scholarships from INTSORMIL to complete their senior thesis research on baking and extrusion of sorghum. Three graduate students currently work on INTSORMIL related research, with partial financial support.

Eight Ph.D., eight M.S. and four B.S. graduates were educated as part of this project over the past four years. Several joined the food industry in their home countries.

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Strategic Marketing of Sorghum and Pearl Millet Food Products in Western and Southern Africa

Project UIUC-205
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Summary

The project completed a study on valuing the attributes of millet in the preparation of tô and couscous in Niger. A survey was prepared and began to be administered in June, 1999. Five millet varieties were identified for inclusion in the test. The attributes that consumers value were developed in consultation with food scientists at INRAN. Data were collected through a structured survey administered at four sites. Variety and attribute preferences were collected for three products: couscous, tuo, and fermented tuo. Conjoint analysis was used to quantify the relative value of cooking and consumption attributes. Results show a strong preference for the local landrace, Hainikire, with one modern variety, MTDO92, coming close in overall consumer preference. The modern varieties ZATIB, Souna III, and CTO-V were all found to be significantly inferior in overall consumer preference. The analysis of the basis of varietal preference revealed that color, cohesiveness, and chewiness were the most important product attributes contributing to overall consumer preference. Given consumer preference for the local landrace, adoption of modern varieties is likely to be slow or non-existent if the varieties do not exhibit some of the consumption attributes preferred by households.

The research in Southern Africa is addressing constraints on coordinated marketing of processed sorghum food products. Current research is studying constraints on the supply of quality grain for the production of processed products. The study is concentrating on supply to sorghum millers in Botswana because these millers have a good market for their processed products. Consumer demand for products is not a constraint for these processors. The constraint on growth and profitability is caused by their inability to procure reliable supplies of quality grain. So, the research is concentrating on factors that are constraining farmers from producing and marketing sorghum for the thriving processed sorghum market in Botswana. Two research projects are underway to investigate the constraints on supply. First, a household survey is being conducted to gain an understanding of the potential for a domestic commercial supply of sorghum. The survey instrument has been constructed and the survey area, Baralong , has been pre-surveyed. Second, a country level equilibrium analysis will be performed to analyze the economic impacts of sorghum processing in Botswana, and the differential impacts of domestic sorghum supply versus imports. Preliminary data collection for the equilibrium analysis was completed.

Objectives, Production and Utilization Constraints

All principal investigator work in 1999-2000 was conducted from the United States, because of familial constraints on travel. This caused some delays in research progress because long-distance communication and organization moves more slowly than on-sight communication and organization. As a result, the primary work that was completed was economic analysis of recently collected data, and revision and refinement of a survey instrument that was pre-tested in Botswana. These results have furthered the accomplishment of the research objectives on production and utilization constraints.

Objectives

The overall objectives are :

- To identify the elements needed to create a successful coordinated marketing channel from farm to processor to consumer.
- To develop strategies to overcome the constraints on these elements.

The sub-objectives that contribute to the identification of constraints and the development of solutions address three areas:

- The adoption of varieties by farmers
- The demand for characteristics by consumers
- Coordinated supply of identity preserved grain from farmers to processors.

The research in West Africa made progress in understanding the demand for characteristics. And the research on demand for attributes established a research methodology that can be applied to other products by NARS scientists in other countries. There are current plans to conduct a similar study on sorghum varieties in Mali. The research in Botswana is directed at identifying how to sustain the growth of sorghum processing. The most immanent threat to sustained growth is supply interruption. So the research plan is constructed to identify the full range of feasible supply alternatives and their economic welfare implications.

Research Approach and Project Output

Valuing Attributes of Pearl Millet in the Preparation of Tô and Couscous

The research method is founded in the hedonic theory of consumer demand, which explains demand for consumer goods as a demand for the bundle of properties that the goods deliver. It is the properties that are the ultimate source of value for consumers. This model of consumer demand provides the ability to derive implicit relative prices of properties that are valued by consumers. Closely related is the technique of conjoint analysis, which is used in new product research. This research differs from traditional new product research because the packaging of attributes is not under the control of researchers. The consumer goods, which package attributes, are the different varieties of pearl millet.

This research is also related to ongoing chemical analyses of pearl millet and sorghum varieties that are being conducted by the NARS in the region. One of the stated aims of the chemical analyses is to identify varieties of value to processors. The research has found the relative value of consumption attributes that determine consumer preference for varieties. This provides the understanding necessary to gauge consumer acceptance of new varieties by means of taste tests of the varieties.

Constraints on Sorghum Supply for Food Processors in Botswana

The research question concerns the incentives necessary to cause small farmers in Botswana to view sorghum production as a commercial enterprise tied to the value added processing carried out by small-scale millers. A region of Botswana – Baralong – has been chosen for a survey because it contains commercial and subsistence farmers. The research method employs agricultural household models to identify the key components of resource allocation decisions that influence willingness to engage in commercial contracting. The economic model of agricultural households emphasizes the interrelation between production, marketing, consumption, savings, and investment decisions. When households live in risky environments, as in Botswana, risk balancing of the components of the household portfolio is central.

Thus, the survey is being constructed to collect information about key components of the household portfolio and the decisions that are made to manage risky contingencies. Commercial and subsistence households will be sampled in order to learn the significant differences in the constraints and incentives facing these households.

A rapid reconnaissance rural appraisal conducted in March, 1999 revealed that agricultural programs of the Botswana government have a large impact on farmer planting intentions. The appraisal supports information that can be extracted from aggregate production statistics for Botswana – sorghum planting and harvesting has declined significantly in the last two years. Thus, an additional objective of the survey research is to understand the incentives and constraints that limit planting and harvesting of sorghum. Two components are being given primary attention: agricultural incentive programs; and off-farm income .The data collected from the survey will be analyzed with econometric techniques based on the economic models of agricultural households.

Given the current reliance of sorghum processors on imported sorghum supplies, the additional research plan is to evaluate the economic welfare impacts of imported versus domestic sorghum supply. The research method is derived from computable general equilibrium models. The equilibrium framework allows the direct and feedback effects of alternative input supply sources to be analyzed. It also allows for the quantification of the distributional impact on identified economic groups, such as processors and rural households.

Networking Activities

These activities were restricted to strengthening existing working relationships, given the constraints on principal investigator travel for the majority of the year.

Publications and Presentations

Presentation

Ndejunga, J. and C.H. Nelson. "Toward Understanding Household Preference for Millet Varieties in the West African Semi-Arid Tropics", selected paper, annual meeting of American Agricultural Economics Association, Tampa, FL. July, 2000.

Host Country

Program Enhancement

Central America Regional Program

Stephen C. Mason
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Collaborative Program

Institutions

Collaboration between 1996 and 1999 was primarily with the Pan-American Agricultural School, Zamorano (EAP), Honduras; Dirección de Ciencía y Técnologia Agrícola (DICTA),Honduras; Instituto Nicaraguense de Técnologia (INTA) ,Nicaragua; Texas A & M University; and Mississippi State University. In 1999 - 2000, the Centro de Technologia de Agricola, El Salvador: Universidad Nacional Agraria (UNA), Nicaragua; Universidad Autonoma de Nicaragua (UNAN), Nicaragua; Kansas State University and the University of Nebraska became collaborating institutions.

Organization and Management

From 1996 through 1999, the INTSORMIL Central American Regional Program was based at the Panamerican Agricultural School (EAP), Zamorano, Honduras. This location provided the opportunity to conduct sorghum research in Honduras, to evaluate new technologies throughout Central America through outreach and networking, interact with private seed industry, and identify EAP students for degree training. The EAP has excellent faculty and students, and provided an ideal location from which to conduct research and training. The Direccion de Ciencia y Tecnologia Agricola (DICTA) provided Government of Honduras research support by use of the LaLujosa Experimental Station located near Choluteca. Nurseries and trials were planted at Zamorano and Choluteca. The program was managed by Dr. Raúl Espinal in collaboration with Hector Sierra and Rafael Mateo, and had extensive ties with private seed industry resulting in development of the first multi-location Central American region sorghum performance test to provide unbiased hybrid performance data across environments in the region. Texas A&M University developed collaboration with Christiani Burkard (Guatemala), the largest regional seed company in Central America.

The major goal of the program between 1996 - 1997 was to develop high yielding photoperiod sensitive sorghums. Much of the breeding activity has been on improvement of indigenous land race varieties unique to Central America, called maicillos criollos in Honduras and millón in Nicaragua. These sorghums are widely planted in the semi-arid regions of Central America and used as a maize substitute for making tortillas. Research has been conducted in sorghum breeding, entomology, plant pathology and cereal quality. Primary support for the breeding, plant pathology and cereal quality program was from Texas A&M University and entomology research from Mississippi State University. Entomology research has dealt primarily with insect complexes in the maicillos, but research on sorghum midge (*Stenodiplosis sorghicola*) in Nicaragua was initiated in 1998.

INTSORMIL through the CLAIS network has strengthened sorghum research in Central American countries. This collaboration has had several aspects - training, publication of research results, and germplasm exchange. The Grain Sorghum Performance Trial publication offers sorghum producers an evaluation of the cultivars available in Central America as well as their performance across diverse locations. Private companies use this trial to evaluate their hybrids, and thereby, help their breeding programs develop better hybrids adapted to tropical conditions.

Three types of grain sorghum are grown in Central America. Maicillos criollos are grown on hillsides and are used primarily by very small producers in a maize intercropping system. The primary production region for the maicillos is the steep hillsides of the Pacific regions of Honduras, Nicaragua, Guatemala, and El Salvador. INTSORMIL maicillo research has been conducted in Honduras, but the El Salvador and Nicaragua national programs have also conducted such research. Small to medium producers in the region frequently produce photoperiod insensitive varieties, with such research conducted in El Salvador and Nicaragua. Large producers grow hybrids developed by private seed companies for use in mechanized systems.

In 1999, a major change in program occurred due to increasing opportunities for sorghum research in El Salvador and Nicaragua, a shift in priorities at EAP, and reduced support by the Honduran government for the national sorghum research program. The program emphasis shifted from Honduras to El Salvador and Nicaragua, with collaborative projects developed in plant breeding, utilization, plant protection (entomology and plant pathology), and agronomy. The INTSORMIL program will now focus on the needs of the two largest sorghum producing countries in Central America, who also have the most comprehensive sorghum research programs, and will broaden discipline involvement.

Financial Inputs

Primary financial support for the program is from the INTSORMIL Central America Regional Program budget. The regional budget has been approximately $80,000 per year. Between 1996 - 1997 approximately 67% of the funds have been transferred to EAP for program operation. The funds supported all phases of the research program including supplies, general operations, and salary. Two partial scholarships for fourth year EAP students to conduct thesis research on sorghum production were included in the budget. The remaining Central American Regional funds were kept at the Management Entity and used for travel, supplies, equipment, repairs, and maintenance of the regional program. INTSORMIL collaborated with the Soil Management CRSP in research on the steeplands of southwestern Honduras, the primary maicillo growing region. The Soil Management CRSP transferred $17,000 to Honduras to support research activities. Funds also were generated through operation of the PCCMCA sorghum performance trial, a fee entry trial was initiated and organized by this program with approximately six locations per year. EAP supported the research through facilities, land, financial management and general supervision of the program operations. DICTA supported the research by providing land and facilities at the LaLujosa Experimental Station, Choluteca. Starting in 2000, $16,000 of budgeted funds will be allocated to each discipline-based project (plant breeding, utilization, plant protection, and agronomy), with the balance maintained at the INTSORMIL Management Entity to support regional research activities.

Collaboration

The program has collaborated with many organizations and served as a catalyst for Central American sorghum research. Seed was provided to the USAID funded LUPE (Land Use Productivity Enhancement) project for several years. Collaboration with other organizations includes but is not limited to: Associates in Rural Development (ARD-USAID), Center for Agricultural Development (CEDA-Japan/GOH), Consolidated Agrarian Reform in the South (CORASUR- Belgium/GOH), Integrated Rural Development (DRI-Yoro-Swiss/GOH), Escuela Nacional de Agricultura (ENA-GOH), Friederich Ebert Foundation (F.E. Foundation - W. German Social Democrats), Luis Landa Ag. School, Rural small business development program (PER-INFOP-Dutch), COSUDE Cooperación Suiza al desarrollo (Swiss), Lempira Rural Development Project (FAO), Rural Development Program (GTZ), Evangelist Committee on National Emergency (CEDEN-PVO), Mennonite Social Action Commission (PVO), World Vision (PVO), Choluteca Support Project (PROAPACH-UN), San José Obrero (PVO), and World Neighbors (PVO). In 1998-99, seed of DMV-198 (161 kg) and Sureño (276 kg) was distributed in Honduras and Nicaragua through DICTA, World Vision, Paz y Desarrollo, and to small farmers. Seed (100 kg) of Sureño was provided to the PROMESA project in Nicaragua for increase following the destruction caused by Hurricane Mitch. Collaboration with the Soil Management CRSP Program measured the effect of soil conservation techniques on sorghum productivity on steepland areas of southern Honduras.

A MOU with the Instituto Nicarguense de Technologia Agropecuaria in Nicaragua was signed in May, 1998 and with the Universidad Nacional Agraria (Managua), and the Universidad Nacional Autonoma de Nicaragua (Leon) in 1999. Initial research activity in Nicaragua centered on an entomology graduate student research project on sorghum midge. Additionally, several germplasm tests from Texas A&M University were sent to INTA for evaluation and selection. A MOU was signed with Centro de Technologia de Agricola in El Salvador in January, 2000. The new operating structure will open opportunities for new collaborative relationships in the future.

Production/Utilization Constraints and Research Findings

Introduction

Sorghum is the third most important crop in Central America (El Salvador, Guatemala, Honduras, and Nicaragua) after maize and beans. The area devoted to sorghum in 1997 was 302,738 ha^{-1} with an average grain yield of 1.2 Mg ha^{-1} (FAO, 1998). During the last decade sorghum grain yield in Central America increased due to improved technology (including improved cultivars and hybrids, herbicides, insecticides, planting date, minimum tillage, seed treatments and fertilizer) available to producers.

Small-scale Central American farmers are burdened with low productivity and limited land resources. Intercropping provides a means to increase total productivity per unit land area and reduce the risk of monocrop dependence. The dominant cropping system is maize intercropped with maicillos criollos. These tropical sorghums are three to four meters tall, drought tolerant, and photoperiod sensitive. The grain is used as human food and livestock feed grain, and the stover for livestock forage. Although maicillos produce low yields, they are planted on 235,000 ha^{-1}, or 67%, of the sorghum hectarage in Central America. Maicillos are cultivated along the Pacific side of the Isthmus, from southeastern Guatemala through El Salvador and southern Honduras and south to Lake Nicaragua. Maicillo is the last remnant of tall, photoperiod sensitive sorghums brought to the New World during the colonial period. Although of African descent, maicillos possess unique traits for adaptation to traditional maize intercropping systems and local food processing customs. These changes have come about through allopatric differentiation and artificial selection by small farmers in Central America. As the need to boost sorghum productivity in Central America increases, maicillos are slowly being replaced by higher yielding, uniform cultivars.

The limited grain yield response of maicillos to management practices is a primary constraint to increased production. Soil and water conservation, improved soil fertility and increased genetic potential of cultivars is essential to obtain economical yield increases. To date increased sorghum yield and area is due primarily to utilization of improved cultivars (hybrids and varieties), which are increasing Central American sorghum production.

Maicillo is an old world crop adapted to neotropical slash and burn agroecosystems. More than 60 percent of the sorghum planted in Central America is maicillos intercropped with early maturing maize. While maize is the preferred staple, it is often intercropped with sorghum by small farmers in hot, erratic rainfall areas as a hedge against drought. Maicillo's sensitivity to photoperiod and its ability to withstand shading are essential for its adaptation to traditional maize intercropping systems. Maicillos have an acute sensitivity to photoperiod and day lengths of 12 hours or less are required for floral initiation. In Central America, floral initiation occurs during the first fortnight of October regardless of planting date. The photoperiod response prevents maicillos from spreading beyond their defined agroclimatological range. For maicillos to produce good quality edible grain, dry conditions during maturity are required. High precipitation areas with different distribution patterns need high yield potential sorghum cultivars with good disease resistance to produce high yields.

The traditional farming system of clearing the forest, intense grazing during the dry season, and residue burning prior to planting have all contributed to severe erosion and runoff from the steeplands in Central America. This severe erosion reduces crop productivity by decreasing the amount of nutrients available for plant growth and soil water holding capacity. Land use pressure on hillsides has increased with population growth. Some farmers have adopted soil conservation techniques, but the majority still practice traditional agriculture. Research on planting improved maicillos on steepland areas with soil conservation techniques has shown dramatically increased sorghum yield.

Alternative uses for sorghum grain need to be developed to encourage sustainable economic growth in semi-arid areas in Central America. White grain, tan plant colored sorghum cultivars are well adapted to Central American human food and livestock feed systems. Innovative processing systems, like extrusion and flaking, are needed to increase starch digestibility and maximize net energy intake for livestock feed. Human consumption needs to be promoted, especially in tortilla related products, extruded snacks and flour substitution through use of superior grain quality sorghum cultivars. Use of sorghum cultivars for forage, or dual use for both grain and forage are important to small producers.

Plant Breeding Research - Hybrids

Each year sorghum hybrid tests have been conducted in five to seven countries in Central America. This testing program has helped seed companies evaluate hybrids across different environments, and producers select the best hybrids. Five companies have participated in the tests: Asgrow, Cargill, Cristiani Burkard, DeKalb and Pioneer. Results were published and distributed among sorghum scientists and collaborators during the PCCMCA meeting held annually. Sixteen hybrids were evaluated in 1999 at locations in Guatemala (1), Honduras (2), Nicaragua (2), Panama (1), and Dominican Republic (1). Average grain yield over locations was 4.56 Mg ha^{-1} (Table 1). The hybrids AS7327, DKX-9811 and DK 69 produced average grain yields over 5.0 Mg ha^{-1} (Table 2).

The Texas A&M University INTSORMIL sorghum breeding program provided the All Disease and Insect Nursery (ADIN), Grain Weathering Test (GWT), International Food Sorghum Adaptation Trial (IFSAT), Drought

Table 1. Location means for 16 sorghum hybrids in PCCMCA performance trial in 1999.

Location	Grain Yield	Days to Flowering	Plant Height	Panicle Exertion
	— Mg ha^{-1} —		cm	cm
Azua, Dominicana	2.01	51	134	10
Tiquizate, Guatemala	5.56	62	177	19
Zamorano, Honduras	5.33	69	151	21
Sta. Inés, Honduras	5.50	64	133	13
Rivas, Nicaragua	5.03	62	160	16
Managua, Nicaragua	5.18	62	169	17
Río Hato, Panamá	3.31	59	92	13

Table 2. Sorghum hybrid mean yield and other characteristics averaged over seven locations in 1999.

Hybrid	Grain Color	Grain Yield	Days to Flowering	Plant Height	Panicle Exertion
		— Mg ha^{-1} —		cm	cm
AS 82247	White	5.06	63	148	15
AS 82327	White	4.87	60	140	12
AS 92277	White	4.89	60	156	15
AS 7327	Red	5.16	59	146	14
AS 82137	Red	4.67	59	151	16
MERCURIO	Red	4.20	56	155	18
MARTE-85	Red	4.53	61	154	20
CB-8996	Red	4.63	66	145	16
CB-8971	Red	4.90	65	138	15
CB-2966	White	4.09	64	155	14
CB-887V1	Red	4.41	62	157	19
DKX-9811	Red	5.11	62	161	19
DK-46	Red	3.83	53	129	13
DK-69	White	5.14	64	155	17
DK-50A	Red	4.33	60	147	14
X-852	Red	3.63	68	122	11

Hybrid Test (DHT), and the Drought Line Test (DLT) for evaluation by Cristiani Burkard, Guatemala. Also the Midge Line Test (MLT), All Disease and Insect Nursery (ADIN), Drought Line Test (DLT), Grain Weathering Test (GWT), and food type introductions from Southern Africa were evaluated by INTA in Nicaragua.

Although plant breeding efforts have focused on developing improved maicillo photoperiod sensitive varieties, some effort has been made to develop improved hybrids. The hybrid ZAM-ROJO has been released along with three broomcorn hybrids. This latter has had a positive economic effect on the artisanal broomcorn manufacturers in Nicaragua.

Enhanced Maicillos

Enhanced maicillos are sorghum lines obtained from crossing photoperiod-sensitive land races (maicillos criollos) with elite sorghum lines from ICRISAT and Texas A&M University that have adaptation to the maize/maicillo intercropping system. Nurseries of enhanced maicillos were planted annually at Zamorano and LaLujosa. Advanced materials were then evaluated in the International Improved Maicillo Trial (EIME). This has resulted in the release of three improved maicillo varieties (Tortillero, Catracho and Sureño) which are widely used in southwestern Honduras.

With the program shift from Honduras to El Salvador and Nicaragua, the nursery was planted and increased in 1999 - 2000 at Zamorano and evaluated by René Clará. A set of the nursery germplasm was left at Zamorano, and a set transferred to CENTA, El Salvador and to Texas A&M University.

Entomology Research

Thelepidopterous complex *Spodoptera* frugiperda, *Spodoptera latisfacia*, *Mocis latipes* and *Metaponpneumata rogenhoferi* have been identified as the major insect pests of sorghum in southern Honduras. Control of the insects has been studied the past several years using an integrated pest management approach. Results showed that farmers increased sorghum yield by 20% and maize by 35% using the recommended production practices that included delayed planting, weed control after crop emergence and seed treatment with insecticides. Natural enemies of some species in the lepidopterous complex have been identified in relatively high numbers, especially larval and pupal parasitoids. Twenty-six species of larval and pupal parasitoids of *Spodoptera* frugiperda have been identified in Honduras. Zamorano published a technical bulletin about this lepidopterous complex on sorghum and maize which highlights collaborative research accomplishments in dealing with these insect pests in Honduras.

Sorghum midge remains the most serious insect pest on large scale, mechanized farms in Nicaragua. A graduate student from MSU has studied the dynamics of the sorghum midge population and means of control. An extension bulletin on sorghum midge biology, and cultural and chemical control was published by INTA based on this research. Future research will include identification and management of insect pests in the maicillo intercropping systems in Nicaragua.

Grain Quality Research

The Central America program has historically concentrated on improving the grain yield and processing characteristics of sorghum for use in tortillas and related products. This includes the improved maicillos criollos. Beginning in January 1998, enhanced maicillos (named dwarf maicillo varieties or DMV) that showed good agronomic traits in the EIME trials were evaluated for grain quality, nutritional composition, and masa and tortilla quality at Zamorano. This research was in close collaboration with the Texas A&M University Cereal Quality Laboratory where the evaluations had been done previously. Sixteen DMVs from the 1997 EIME were evaluated for grain quality traits along with two high-yielding commercial white-tan sorghum hybrids (MX7124 and DK69). Standard checks were Lerdo Ligero, a maicillo, and Sureño, a photoperiod-insensitive food-type sorghum released by INTSORMIL Sureño was selected as the standard because of its wide acceptance for making tortillas.

Nixtamilized Sureño flour was found to be more desirable than maize for making rosquillos in the Choluteca, Honduras area. CENTA research in El Salvador has led to much interest to a 50% substitution of sorghum flour for wheat flour in baking sweet breads, rosquettes and rosquillos. The production of Sureño allows sorghum flour production of good enough quality for use in cookies and rosquillos. Future research and technology transfer in El Salvador will focus on the substitution of sorghum flour for wheat flour in baked products.

Optimum quality grain sorghum for tortillas must have a white pericarp, tan glumes and tan plant color. The anthocyanin pigments of the purple maicillos criollos produce dark colored tortillas that are not accepted by farmers once they have used Sureño. The kernel should have a high density (>1.3 g/cc), thousand kernel weight of at least 25 g and intermediate to high hardness indices (<30% TADD decorticating and 30-70% floaters). A yield of 1.6-1.8 kg of masa/kg of corn or sorghum at 13% humidity is considered optimum. All DMVs and two hybrids tested had excellent quality traits and was found to be suitable for food processing. Variability among DMVs was very low, averaging a true density of 1.38 g/cc and a 1000-kernel weight of 25g. Hardness of most DMVs was high, except for DMV 222 and 223. These results show that the screening process for grain quality traits in the breeding nurseries has been successful.

Every sorghum cultivar was tested in comparison with white corn (Hybrid H-29) for tortilla quality traits such as appearance (color), taste, aroma, texture (mouthfeel), and rollability (Table 4) by a taste panel. The quality of tortillas made with DMV 218 and DMV 210 was statistically equal to the ones made with corn and Sureño. Farmers emphasize whiter tortilla color and good rollability when selecting a sorghum variety. Thus DMV 198, a purple-colored glume line, is not suited for tortilla making despite good field performance.

Masa yields of sorghums was in general significantly higher than the yields of masa of corn. Except for DMV 198 (1.33 kg/ kg grain) and DMV 221 (1.24 kg/kg grain), all improved maicillos yielded over 1.6 kg of masa/kg of grain. Such similarity among DMVs in masa yield was expected since their grain quality traits are fairly similar. Sureño was the highest yielding of all sorghums evaluated (2.06 kg of masa/kg of grain). Sorghum (DMV 218)/corn masa combinations were tested at four levels:100:0, 75:25, 50:50, 25:75; with 100% corn as the control. Respondents preferred corn tortillas and could differentiate them from tortillas made with as low as 25% DMV 218 masa. However, even tortillas made with 100% DMV 218 received acceptable grades on all quality traits evaluated. Further in situ evaluations of agronomic performance and tortilla quality of DMV 218 and DMV210 with farmers from Choluteca are required to elucidate if these cultivars are suited for release. Testing of these cultivars in Nicaragua and El Salvador will be suggested to PCCMCA collaborators in those countries. DMV 210 is the best choice since it combines high grain yield with good tortilla quality.

Tortillas made with 100% DMV 219 staled at a similar rate to tortillas made with Sureño but slower than ATx631*RTx436. Staled tortillas become tougher with time and require more force (N) to be bent. Tortillas with reduced peak viscosity measured with the Rapid Visco Analizer contain more retrograded starch, which is an indication of higher degree of staling of the tortilla. Some farmers report that sorghum tortillas tend to stale faster than corn tortillas. This was confirmed subjectively during evaluation of the improved maicillos. Further research at Texas A & M University will focus on the factors that accelerate the staling of sorghum tortillas compared to corn tortillas.

Preliminary tests on sorghum's ability to substitute for corn in an extruded pellet for fish and in a expanded breakfast cereal made in combination with soybean were preformed. The Insta-Pro 600 Jr. Extruder available in Zamorano did not produce expanded snacks, but produced sorghum pellets with 40 to 50% floatability even though water supply to the barrel was done manually. Delays in the installation of a water pump to the extruder have postponed the conclusion of these studies until next year.

In 1999, this research was expanded to include the potential of sorghum for making nixtamalized (rosquillas) and non-nixtamalized (rosquetes) cookies or biscuits. Preliminary tests on sorghum's ability to substitute corn in an extruded pellet for fish and in a expanded breakfast cereal made in combination with soybean were performed. The Insta-Pro 600 Jr. extruder available in Zamorano appears not to be suited to produce expanded snacks but produced sorghum pellets with 40-50% floatability even though water supply to the barrel was done manually. Delays in the installation of a water pump to the extruder have postponed the conclusion of these two studies for next year.

Sorghum is used in the Honduran southern region to make sweet cookies called "polvorones" (sandies) or "rosquetes" at the household level. These rosquetes are rod-shaped and made with decorticated sorghum flour, unlike the also rod-shaped but salty "rosquillas", which are made with nixtamalized masa and cheese. Cookies in Honduras are mostly consumed soaked in coffee and these polvorones tend to fall apart almost immediately . Partial or total substitution of wheat flour by sorghum in the production of a sugar cookie at industrial level was evaluated. Dry-milled sorghum grits (Sureño) produced at Texas A&M University were hammer-milled and sifted in Zamorano to produce a coarse flour (through US # 40 mesh). A descriptive trained panel evaluated the sensory properties of the cookies.

Overall, 100% sorghum cookies showed acceptable smell and taste but bad texture and a darker appearance than 100% wheat (Table 3). Grittiness and poor cohesiveness (cookies crumbled easily when soaked in coffee) were the most important complaints raised by the descriptive panel. Improved dry milling and sifting procedures for producing a finer and whiter sorghum flour would reduce the grittiness and poor appearance of 100% sorghum cookies. Further studies will focus on improving the cohesiveness of sorghum cookies by adding pregelatinized corn starch or gums (CMC, Xanthan).

Table 3. Sensory properties of cookies made with different levels of addition of sorghum flour.

% Sorghum Flour	External Appearance	Internal Appearance	Texture	Smell	Taste[1]
0	3.61a	3.67a	3.44a	3.44a	3.78a
25	3.44a	3.56a	3.17a	3.89a	3.67ab
50	3.44a	3.44a	3.78a	3.56a	3.78a
75	3.17ab	3.28a	2.89ab	3.72a	3.61ab
100	2.17b	2.28b	2.00b	3.06a	2.94b
HSD[2] (0.05)	1.16	0.84	0.92	1.12	0.77

[1] Rating scale: 1 = poor, 2 = bad, 3 = neither good or bad, 4 = good, 5 = excellent.
[2] Highly significant difference

Addition of up to 50% sorghum flour did not significantly reduce sensory properties of the cookie compared to the wheat control (p=0.05). Even 75% sorghum cookies showed similar appearance, smell and taste than 100% wheat cookies, although grittiness increased and cohesiveness was reduced. These data agree with the findings of Leon and Rooney (1999) that sorghum flour can be used effectively in a wide variety of cookies substituting for up to 50% of the wheat flour and that with special formulations higher levels can be used.

Corn rosquillas are rod-shaped , very dry, crunchy salty cookies that are the second most popular nixtamalized product in Honduras, behind tortillas. They are also consumed soaked in coffee. Production of rosquillas is , like tortillas, mostly a home-based business and there is no data available on their shelf stability. There is only one snack industry ("Alimentos Dixie", located in San Pedro Sula, Northern Honduras) that produces corn rosquillas at the commercial level, but the product is of fair to good quality. An industrial cooking and baking procedure for making sorghum rosquillas was developed.

Extensive research was conducted in the communities of Santa Elena and Namasigue (Choluteca region) where sorghum rosquillas are made, to gather information on variations in formulations and cooking and baking procedures. Different ingredient levels and processing conditions were evaluated in Zamorano to determine the best formulation according to a trained descriptive panel (Table 4).

Product quality and shelf stability of sorghums vs. corn rosquillas are currently being evaluated. Sureño ,the best food-type sorghum available in Honduras, and an improved maicillo (DMV-228) are being evaluated for rosquilla making. Preliminary data from evaluations performed with a trained panel and with consumers indicate that sorghum rosquillas are as good as corn rosquillas. The slightly darker color of sorghum rosquillas appears not to be a burden for acceptability. This is because, unlike tortillas, consumers associate a slightly dark yellow-brownish color with product quality (the higher the cheese content the darker the product). Early shelf-stability tests show that sorghum rosquillas stale at a rate similar to corn rosquillas. In both cases, the products retained their crunchiness and taste for at least 15 days, when stored at room temperature in polyethylene bags.

Table 4. Formulations and process conditions evaluated in Zamorano for sorghum rosquilla production at an industrial level.

Ingredients	Levels (%)[1]
Lime[2]	1, 2 ,3, 4
Water	300, 350
Fresh Cheese (Cuajada)	50, 65
Salt	0.5, 1.0, 1.5, 2.0, 2.5
Cream	7, 10, 12
Shortening	10, 12, 20, 25
Process Conditions	**Levels**
Cooking time	40, 45, 50, 55 min
Baking temperature	300, 350, 400 °C
Baking time	12, 18, 24, 40, 55 min

[1] Expressed as % of the amount of dry grain (lime and water), nixtamal (cheese) or masa (salt, cream and shortening).
[2] Low quality, nonpurified lime.

Future research will focus on developing an alkaline cooking procedure for the best improved maicillos (DMV-210, DMV-218), a 100% sorghum cookie for coffee with improved cohesiveness and elaboration of pellets for Tilapia with whole sorghum instead of corn meal. Samples of grain from the best three DMVs and Sureño were brought to Texas A&M University to continue evaluations of sorghum tortilla staling vs. corn. Seed samples of 10 DMVs were also imported to be increased in Weslaco, TX for use in future studies. Use of sorghum for making other traditional products (popped sorghum in "alborotos" and pearled sorghum as a substitute for "Marmaon" pasta) will be explored.

Mutual Research Benefits

Many production constraints are similar between Central America and the U. S. including drought, diseases, insects, and adaptation. U.S. based scientists can provide germplasm that could at least partially alleviate the effect of some of these constraints. The maicillo criollos are a unique type of sorghum and can potentially contribute useful food quality traits to U.S. germplasm, and several lines are presently in the Texas A & M University /USDA-ARS Sorghum Conversion Program. Germplasm exchange will contribute to development of novel genetic combinations with multiple stress resistance, wide adaptation, and improved food quality. Entomology and plant pathology research includes pests that affect sorghum both in Central America and in the U.S., such as sorghum midge and ergot.

Institution Building

Equipment and other support

INTSORMIL purchased a Jeep Grand Cherokee for use in Nicaragua by graduate students and INTA personnel in conducting research in different regions of the country. The Ford pickup, John Deere tractor and planter were transferred from EAP, Honduras to CENTA, to support sorghum research in El Salvador.

Training and education

During the past four years numerous half-tuition scholarships were awarded to EAP students to conduct research on sorghum plant breeding, pest management and grain processing. In 1999, the project awarded four Zamorano students a half-tuition scholarship to conduct research on soil erosion on steepland areas in southern Honduras, and on substitution of sorghum for wheat flour in sugar cookies and evaluation of maicillos for tortillas (Belen Prado, Honduras). In 2000, Paola Carrillo (Ecuador) started research to compare quality and shelf stability of corn versus sorghum rosquillas.

Mr. Javier Bueso (Honduras), Assistant Professor, EAP has joined the Grain Quality Lab at Texas A & M University to complete a Ph.D. degree with part of the dissertation research conducted in the EAP CITESGRAN laboratory in Honduras. Mario Carrillo (Nicaragua) is completing a M.S. degree in entomology at Mississippi State University with thesis research on insect management strategies in traditional and improved sorghum and maize production systems in flat and gently sloping fields in southern Honduras. Johnson Zeledon (Nicaragua) is completing a M.S. degree at Mississippi State University with thesis research on the biology and management of sorghum midge on sorghum in Nicaragua, and will continue studies for a Ph.D. degree with dissertation research on sorghum insect pest management in Nicaragua. Short-term training has been planned at Kansas State University for sorghum plant pathologists from El Salvador and Nicaragua in 2000.

Travel and Networking

A Central America Sorghum Research Planning meeting was held at Zamorano, Honduras in October 1999. This meeting was attended by scientists from El Salvador, Honduras, Nicaragua and the United States. INTSORMIL was represented by Drs. John Yohe, Gary Peterson, Steve Mason, Lloyd Rooney, Darrell Rosenow, and Larry Claflin. External Evaluation Panel (EEP) members were also present for part of the meeting.

Drs. John Yohe, Gary Peterson, Lloyd Rooney, Darrell Rosenow and Larry Claflin attended the MOU signing ceremony with CENTA, El Salvador in January 2000.

Dr. Henry Pitre evaluated research in Honduras and Nicaragua in November, 1999 and June, 2000.

René Clará represented INTSORMIL at the PCCMCA meeting in Puerto Rico in May, 2000. Laureano Pineda represented INTA (Nicaragua) at this meeting.

Drs. Larry Claflin and Stephen Mason visited INTSORMIL collaborative research in El Salvador and Nicaragua in June 2000.

Mr. Javier Bueso, graduate student at Texas A & M University, traveled to Honduras in March and June 2000 to assist with sorghum rosquilla research.

Networking

Strong collaboration has developed between the INTSORMIL sorghum program and other organizations in Honduras to implement programs to improve the sustainability of steepland agricultural production. A partial list of collaborators during the life of the project was listed previously in the report. Collaboration has been established with NARS/ICRISAT/CIAT to evaluate sorghum and millet for tolerance to acid soils in Honduras, and collaboration is being established with the CIAT Hillside project reference sites in Yorito (Honduras) and San Dionisio (Nicaragua). Increased collaboration with programs located in El Salvador and Nicaragua are expected as the INTSORMIL program expands in these two countries.

Research Results

- Released three food type cultivars (Tortillero, Catracho, Sureño), a sorghum-sudangrass hybrid (AT x 623 * Tx2784), the hybrid Zam-Rojo, and three broomcorn hybrids.

- Developed improved maicillo germplasm (yield potential, grain quality, processing traits) for use in national plant breeding programs.

- Developed and extended control strategies of delayed planting, weed control and seed treatment for the lepidopterous ("langosta") complex that increases sorghum grain yield by 20% and maize yield by 35%.

- Characterized the severity of sorghum midge infestation, and released an extension circular about this insect and its control.

- Sorghum grain can produce tortillas of comparable quality to maize, especially white grain, tan plant types of improved maicillos.

- Sorghum flour can substitute up to 50% for wheat flour in cookies, rosquillos and sweet breads, affording the opportunity to increase sorghum production and reduce wheat imports.

- Sureño production in Honduras continues to increase due to its good agronomic properties, unique properties for use in white tortilla preparations, and the sweet, juicy stalk gives good forage quality. In addition, Sureño grain has the potential for use in rosquillos and rosquetas.

A more detailed list of research accomplishments up to 1998 can be found in the INTSORMIL 1988 Annual Report.

Publications and Presentations

Journal Articles

Clará, René. 2000. Grain sorghum performance test for the PCCMCA. (In Spanish). Tech. Rep. No. (In Press). Escuela Agricola Panamericana, El Zamorano, Honduras.

Horn of Africa

Gebisa Ejeta
Purdue University

Coordinators

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Peter Esele, Uganda Country Coordinator, Serere Agricultural and Animal Production Research Institute, Serere, P.O., Soroti, Uganda

Collaborative Program

INTSORMIL/Horn of Africa is a new initiative proposed to regionalize our collaborative research efforts in Eastern Africa. Before the start of the current regional effort, INTSORMIL had a productive collaborative program with the Agricultural Research Corporation (ARC) in Sudan. This collaboration has resulted in an array of technical developments that have impacted on sorghum agriculture in Sudan. Sudanese scientists have been trained in INTSORMIL institutions. U.S. scientists have traveled extensively in Sudan and worked alongside their Sudanese counterparts. Joint workshops and conferences were organized and attended. Results of joint research efforts have been published and distributed widely. Extensive raw and improved germplasm have been identified, assembled, and catalogued for the benefit of U.S. and Sudanese agriculture.

Under the INTSORMIL Horn of Africa initiative, new memoranda of agreements have been signed with NARS in Ethiopia, Eritrea, Kenya, and Uganda to go with the existing relationship with the Agricultural Research Corporation of Sudan. With these MOAs, INTSORMIL now has collaborative relationships with five countries in the Horn of Africa region. A two-tier program has been under development in the Horn of Africa. With each national program, we have initiated a traditional collaborative program between a NARS scientist and a U.S. principal investigator(s) on a topic of common concern and interest with at least one disciplinary project identified in each country. A scope of work is jointly developed and submitted for review and approval by the NARS country coordinator, NARS research director and the Horn of Africa program coordinator before being approved as an INTSORMIL/Host Country workplan. Each workplan has its own funding. Funds are forwarded directly from Purdue University or the INTSORMIL Management Entity at the University of Nebraska, and are then disbursed in-country to each collaborating scientist to carry out the research project. With limited funds available to the INTSORMIL/Horn of Africa, it has not been possible to initiate a full range of collaborative projects with each of the NARS in the region. Instead, the intent has been to establish a full complement of collaborative partnerships with the Institute of Agricultural Research in Ethiopia and to use this program as a hub from which to network with the other member countries of the Horn. A line item for networking has been built into the budget of the INTSORMIL/Horn of Africa program to catalyze exchange of information and ideas among member NARS and INTSORMIL scientists. A major initiative that has been under consideration is the identification of major regional constraints upon which considerable research may have been undertaken by one or more of the NARS in the region. There has been great interest among scientists in the region to identify such research projects and undertake regional evaluation and verification with the hope of generating technologies that could have regional application. We continue to have dialogue on the feasibility of implementing such a regional initiative. Once agreed upon, collaborative research projects among NARS in the region will be developed, in consultance with appropriate INTSORMIL scientists, on a priority research agenda of regional importance. Inputs from concerned scientists in the region will be solicited in developing the research agenda as well as in refining the research protocol on a timely basis. Collaborative scientists will be encouraged to meet regularly (preferably once a year) to exchange ideas and to sharpen the focus of the regional research agenda.

Annual field/laboratory touring workshops will be organized alternately at a site in one of the host countries in the region. Participation in the tour will be based on interest and the topic of the workshop for that year. These tours will provide INTSORMIL PIs opportunities for interaction with very many scientists in the region. Scientists from the region will also have opportunity to pick up useful germplasm, research techniques, or potentially transferable technologies that they may come across during these tours.

Opportunities for collaboration with other organizations such as ASARECA, ICRISAT/East Africa, World Vision International, Sasakawa Global 2000, and the IPM CRSP have been good and there are initiatives under development with each of these organizations. Discussions have also been underway to determine possibilities of buy-ins from USAID Missions in the various countries in the Horn of Africa. Contacts have also been made with the new USAID initiative, the Greater Horn of Africa program as well as REDSO/East to check for possible financial assistance to INTSORMIL/Horn of Africa program.

Research Disciplines and Collaborators

Sudan

Cooperative Sorghum Breeding and Genetic Evaluation - Osman I. Ibrahim, ARC; Gebisa Ejeta, Darrell Rosenow, INTSORMIL.

Cooperative Millet Breeding - El Haj Abu El Gasim, ARC; David Andrews, INTSORMIL.

Plant Pathology Program - El Hilu Omer, ARC; Richard Frederiksen, INTSORMIL.

Entomology Program - N. Sharif Eldin, ARC; Henry Pitre, INTSORMIL.

Food Quality Program - Paul Bureng, ARC; Bruce Hamaker, INTSORMIL.

Economics Program - Hamid Faki, Abdel Moneim Taha, ARC; John Sanders, INTSORMIL.

Striga Research – A.G. T. Babiker, ARC; Gebisa Ejeta, INTSORMIL

Ethiopia

Agronomy – Kidane Georgis, EARO; Jerry Maranville, INTSORMIL.

Striga Management – Gebremedhin Wolde Wahid, EARO, Wondemu Bayu, MOA; Gebisa Ejeta, INTSORMIL.

Entomology – Tsedeke Abate, EARO; Henry Pitre, INTSORMIL.

Agricultural Economics – Yeshi Chiche, EARO; John Sanders, INTSORMIL.

Sorghum Utilization – Senait Yetneberk, Aberra Debelo, EARO; Lloyd Rooney, Bruce Hamaker and Gebisa Ejeta, INTSORMIL.

Research Extension – Beyene Seboka, Aberra Deressa, EARO; Gebisa Ejeta, INTSORMIL.

Pathology – Girma Tegegne, IAR; Larry Claflin, INTSORMIL.

Kenya

Sorghum Breeding – C. K. Kamau, KARI; Gebisa Ejeta, INTSORMIL.

Food Quality – Betty Bugusu, KARI; Bruce Hamaker and John Axtell, INTSORMIL.

Uganda

Sorghum and Millet Pathology – Peter Esele, NARO; Richard Frederiksen, INTSORMIL.

Striga Management – Joseph Oryokot, NARO; Gebisa Ejeta, INTSORMIL.

Eritrea

Sorghum Breeding – Tesfamichael Abraha, DARE; Gebisa Ejeta, INTSORMIL.

Entomology – Asmelash Woldai, DARE; Henry Pitre, INTSORMIL.

Striga Management – Asmelash Woldai, DARE; Gebisa Ejeta, INTSORMIL.

Sorghum/Millet Constraints Researched

Sorghum and millet are important crops in all of the countries in the Horn of Africa (Table 1) ranking first or second in cultivated area among the major cereal crops of the region. Sudan and Ethiopia are the indisputable centers of origin for sorghum and are major centers of genetic diversity for both crops. In addition, a wealth of improved sorghum and millet germplasm has been made available in both of these countries as a result of association with INTSORMIL and ICRISAT. Collaborative research between Sudan and INTSORMIL has also resulted in research and production technologies that can be shared by other members of the Horn of Africa.

According to the sorghum and millet scientists in the Horn of Africa region, "the major sorghum and millet production and utilization constraints are generally common to all countries (Table 2).

These constraints include lack of improved germplasm, drought, *Striga*, insects and diseases (anthracnose, leaf

Table 1. Sorghum and millet production.

Countries	Sorghum			Millet		
	Area 1000 ha	Yield Kg ha^{-1}	Production 1000 mts	Area 1000 ha	Yield Kg ha^{-1}	Production 1000 mts
Eritrea	60	842	51	15	546	8
Ethiopia	890	1236	100	280	1000	280
Kenya	120	745	90	85	682	58
Sudan	4684	785	2386	1150	192	221
Uganda	255	1498	382	407	1602	652

Table 2. Production constraints of sorghum and millet across eastern Africa countries.

	Eritrea	Ethiopia	Kenya	Sudan	Uganda
Varietal Development	x	x		x	x
Striga	x	x	x	x	x
Crop Protection					
Pest	x	x	x	x	x
Diseases	x	x	x	x	x
Drought	x	x	x	x	x
Production	x	x	x	x	x
Technology Transfer	x	x	x	x	x
Training - Long-term	x	x	x		x
- Short-term	x	x	x	x	x
Socioeconomics				x	
Utilization	x	x	x		x
Information Exchange					x
Germplasm Introduction	x	x	x	x	x
Soil/Water Conservation	x		x		
Seed Production and Marketing	x	x	x	x	x

blight, grain molds, smuts, ergot in sorghum, blast, downy mildew, and ergot in pearl millet). Other problems in the region include lack of adoption of new production and utilization technologies by farmers, soil/water management techniques, as well as the infrastructure and technology for production and marketing of seeds and other essential inputs.

Agronomic research on soil and water conservation techniques have not been extensively evaluated in any of the countries in the region. Lack of moisture and soil nutrients and poor husbandry are primary constraints of sorghum and millet production. Breeding efforts currently in use to incorporate drought tolerance traits to genotypes with high yield potential are limited by lack of a field screening procedure and lack of knowledge of sources of appropriate germplasm with useful traits. The lack of absolute definition of good food quality parameters and good screening methods for food quality to some extent also limit the utilization of high yielding sorghum and millet varieties. Very little research has also gone in developing germplasm with resistance to the major insect pests and diseases. *Striga*, a major parasitic weed of sorghum and millet, constitutes a major constraint to the production of these crops. There is very little sorghum and millet germplasm with resistance to *Striga* and the mechanisms that render resistance to *Striga* are not well understood. Knowledge about inheritance of many of these traits is also lacking. In many of these areas, the crop/bush fallow system of production has traditionally been used to provide enough nutrients and possibly some moisture for a period of crop years (5-10 years fallow/2-4 years cropping). In some areas, other crops are often grown in an intercropping system with millet and sorghum to maximize production. Over the last two to three decades, rainfall in the Horn of Africa region has declined, thus reducing the soil recovery rate during fallow. Fallow periods have also decreased due to higher human and animal pressure on plant cover, resulting in further reduction of sorghum and millet yields in the region. Research on all of these aspects is needed to improve sorghum and millet production and utilization in the Horn of Africa.

Research Methods

Research conducted by participating scientists of NARS in the Horn of Africa is primarily applied research. In each of the NARS, research scientists appear to be closely in tune with crop production, protection, and utilization constraints encountered by farmers and farm communities in the sorghum and millet growing areas. There are established protocols for assessing and prioritizing research constraints on a regular basis, often annually in conjunction with a national research and/or extension conference organized to take stock of emerging technologies and to publicize developments in research. Such fora have also been used to exchange ideas and concerns across disciplinary lines, and tend to lead to development of interdisciplinary initiatives. Collaborative projects that have been agreed upon by participating NARS and INTSORMIL scientists would be presented to a national committee that would evaluate the merit and relevance of the research before formal approval and local research support is granted. Field research facilities at most of the NARS are excellent. Machinery and equipment have not been always adequate or appropriate. Technical support and capabilities vary from country to country. ARC, Sudan and IAR, Ethiopia have been the strongest sorghum and millet research programs in the area with a full complement of technical assistance particularly in field research. As a newly independent nation, the Eritrean national program needs further strengthening in human capital at all levels. Wet-lab facilities are very modest in all NARS of the region, with technical expertise most limiting. In general, sufficient effort is committed to summarizing research results for subsequent sharing of information with production agencies and extension services.

Research Progress

In the last four years collaborative regional research on sorghum and millet has been carried out between scientists at INTSORMIL institutions and their collaborators at NARS in the Horn of Africa. Collaboration with the Agricultural Research Corporation of the Sudan has been suspended as a result of cooled relations between the governments of Sudan and the United States. Hence, the following examples of research progress in our collaborative efforts in each of the countries in the region will not include a report from Sudan.

Ethiopia

Selection for *Striga* Resistant Sorghum Cultivars

Significant progress has been made in our collaborative efforts in the area of selection for *Striga* resistance. Activities included demonstration and testing of elite *Striga* resistant sorghum cultivars in farmers' fields, introduction of new breeding lines from INTSORMIL and testing them in *Striga*-sick plots, and initiating a breeding program to incorporate genes for *Striga* resistance into Ethiopian highland sorghums.

Eight *Striga* resistant sorghum lines developed at Purdue were released for wide distribution in 1994. In Ethiopia, a collaborative program between EARO, INTSORMIL, and Sasakawa Global-2000 undertook testing, demonstration, and diffusion of these varieties in *Striga* endemic areas of the country. Based on the results of testing of these eight varieties over the last four years, two of the cultivars, P9401 and P9403 were recommended for wide commercial cultivation by the Ethiopian National Variety Release Committee at the end of the 1999 crop season. In addition to *Striga* resistance, these varieties were preferred because of their superior productivity, adaptation, grain quality and resistance to drought and diseases. These varieties were also found to possess acceptable food quality characteristics.

As a second tier, field tests of a pool of sorghum lines developed at Purdue University have been conducted in several *Striga* endemic locations in Ethiopia. Genotypic differences in *Striga* resistance, productivity, and grain quality were taken into consideration in advancing selected entries through the testing program. Some 21 entries were selected as showing superior performance and will be evaluated further for adaptation and tolerance to local production constraints.

The *Striga* problem in Ethiopia is progressing into the highlands where the local sorghums do not possess resistance to *Striga* and lowland *Striga* resistant selections are not well adapted. To address this problem, a new breeding program has been initiated to introduce genes for *Striga* resistance into selected land races from the highlands of Ethiopia.

Introduction and Testing of Food Grain Sorghum Hybrids

There is great potential to introduce adapted sorghum hybrids to many of the sorghum growing environments in Ethiopia. In the 1970s and 1980s considerable progress was made in introducing a large array of parental germplasm as well as in synthesizing and testing experimental hybrids, but there has been some loss of momentum in recent years. As part of our collaborative effort, we have resumed scheduled introduction and testing of INTSORMIL germplasm for potential adaptation in Ethiopia. In the last four years, several hundred experimental hybrids have been introduced. In 1999, for instance, a total of 419 experimental hybrids were introduced from Purdue university and evaluated at Melkassa and Mieso test sites. Based on visual evaluation of these hybrids at these locations, 158 hybrids were advanced for further evaluation and selection. These hybrids will be resynthesized and evaluated in a multilocation trial.

In addition to experimental hybrids, effort has also been exerted in introducing seed parents (A and B lines) and restorer (R) lines. Several hundred R lines and sets of seed parents have been introduced and evaluated in the last four years. With the interest in hybrids by sorghum breeders in Ethiopia and availability of a relatively good logistics for winter nursery activities, the opportunity for expanded undertaking of hybrid sorghum work in Ethiopia looks good. Germplasm and expertise at the various INTSORMIL institutions will be tapped.

Management Study on Sorghum Smuts

We studied the efficacy of traditional management practices that are routinely employed by subsistence farmers in Ethiopia for the control of sorghum smuts. These studies have been carried out since 1996 and were conducted both at research stations and on farmers' fields. Preparations made from plant and animal products have been evaluated in comparison with the commercially available seed treatment chemicals, Thiram and Apron plus. Application of a powder form of the plant preparations as seed treatment at the rate of 33g/kg and soaking sorghum seeds for 20 minutes in livestock urine that is diluted with water at a ratio of 1:1 V/V effectively controlled covered smut incidence. The efficacy of the traditional treatment was as good as commercial seed treatment chemicals. We also found that seed treatment with the natural products had no adverse effect on seed germination and emergence in experiments conducted under both greenhouse and field conditions. Different rates, on a volume basis, were evaluated and no significant differences were observed, suggesting that rate determination may require knowledge of active compounds involved in the actual control of smut pathogens in these preparations. While our past experiments involved only one plant product, more recently, we have identified several plants that have potential antifungal properties. In the 1999-2000 crop season, we tested natural products from two plant species and found significant reduction in infection by both covered and loose smuts even at very low rates. We also conducted a laboratory bioassay on the mode of action of these products and observed that our natural plant extracts caused deformation of teliospore germ tubes and inhibition of mycelial growth of other pathogens. Further indepth studies are required to elucidate the specific mode of action as well as to identify the specific active ingredients involved in the control of sorghum smut pathogens.

Uganda

Screening Sorghum Germplasm for Anthracnose Resistance

Sorghum anthracnose caused by *Colletotrichum graminicola* is the most important foliar disease of sorghum in Uganda. The disease has been reported in all parts of the country but is more prevalent in the humid areas of Eastern, Central, and Western Uganda. The disease infects most parts of the plant including leaves, stalks, peduncles, and panicles, as well as the grain. However, leaf infection is the most prevalent in Uganda. The disease has been responsible for the elimination of the 2 KX series of sorghums from the Serere collection. We have emphasized research into the management of this disease because of its importance and impact in the economy of sorghum production in the country.

As a collaborative effort with INTSORMIL, a project was launched to screen all of the sorghum germplasm available at SAARI for resistance to sorghum anthracnose. The objective was to identify resistance sources for utilization in the breeding program. It was also expected that this study would go further into investigating the possibility of the existence of variability in the Ugandan pathogen. A total of 857 sorghum entries in 14 experiments were screened in 1999 at two locations, Soroti and Ngetta. Soroti is the main sorghum research station with an altitude of 1100m and average annual rainfall of 1320mm. Ngetta is a sub-station of SAARI located in Lira district in Northern Uganda with an altitude of 1000m and an average annual rainfall of 1200mm. All entries were planted in September in single row plots of 5m length. Data on infection levels were collected on leaves, stalks and panicles at 50% flowering and at maturity. A score of 1-5, where 1= resistant, disease inconspicuous or present on occasional plant, and 5= highly susceptible with death of leaves or plants, was used. Generally, foliar anthracnose was found to be the most prevalent at both locations. Stalk and panicle infection also occurred but were generally insignificant. A large number of entries were found to have good level of resistance to anthracnose. The number of susceptible entries among elite introductions was low. Most of the susceptible entries were in the world collection. Plans are underway to repeat this experiment with artificial inoculation with the pathogen to ensure uniformity of infection.

Striga Management for Small Scale Sorghum Farmers

Sorghum production in Uganda is threatened by *Striga* which has become the leading biological constraint in its production. It is now present in all the major sorghum producing areas of the country. In two districts of Uganda for example, *Striga* was found in up to 83% of fields surveyed, causing yield losses estimated at 60 to 85%. Several strategies have been proposed to manage *Striga* infestation in the field. These have included growing of resistant sorghum varieties, and cultural control measures such as improving soil fertility through fertilizer application or intercropping with legumes and rotation with trap crops. Resistant varieties have been either not adapted or possessed undesirable agronomic characteristics. Research done indicates that nitrogenous fertilizers can reduce the level of *Striga* infestation. Late season hand weeding has also been shown to reduce *Striga* seed return to the soil or even increase yields . A farmer strategy in Uganda, in the past, was to interplant sorghum with *Celosia argentea,* its efficacy has not been, however quantified. Several other crops and plants have also been reported to be trap crops. Intercropping or interplanting sorghum with these crops increases yields and reduces *Striga* emergence.

To put effective management strategies in the hands of the small-scale producers, simple and effective measures that are socio-economically and locally adaptable need to be developed. This project therefore was to develop farmer friendly *Striga* management options that minimize crop losses due to *Striga* infestation are economically viable.

The trial was planted in five farmers' fields in Kacaboi, Kumi district. Farmers fields were selected on the basis of a history of high *Striga* infestation. Individual farmers formed the replicates. Plot size was 12.0 m x 9.0 m and treatments were located in the most *Striga* sick area of the field. Treatments were randomly allocated to plots in each field. Seed of *Celosia argentea* were interplanted with sorghum seed at the proportion of 1.0 g to 500 g of sorghum seed. This was a guestimate but estimated to prevent it from becoming a weed itself. The *Celosia argentea* seed was mixed with soil as a filler to allow for broadcasting or row planting. Sorghum was planted at 60 cm x 20 cm, as recommended except in farmer management treatments, where it was broadcast. Seed of *Celosia argentea* in filler were interplanted between the sorghum rows and thinned to two plants per metre row. Emerged *Striga* plants were counted three times; early season (5-7 sorghum leaf stage), mid season (10-12 sorghum leaf stage) and at harvest. Four permanent quadrants measuring 1.0 m x 1.0 m were established in each plot. Emerged *Striga* plants were counted within these quadrants, and means for each plot determined. Sorghum plant heights were measured at flowering. Ten plants were randomly measured and mean height derived. At harvest each plot was randomly sampled three times, each measuring 4.0 m x 2.0 m giving a total harvest area of 24 m2. Grain yield was determined from this harvest area.

The results of this experiment indicated that the use of a tolerant sorghum variety, Seredo, in combination with soil fertility enhancement and two hand weedings or interplanting with Celosia argentea and two hand weedings all had favorable increases in yield and suppression of *Striga* emergence. A combination of nitrogen fertilizer and interplanting with C. argentea appeared to have greater impact on *Striga* emergence than when each was applied singly. Application of fertilizer plus interplanting with *Celosia argentea* and two hand weedings increased sorghum grain yield compared to either Sekedo or farmers variety at his management ($P<0.05$). Interplanting Seredo with *Celosia argentea* resulted in a yield not different with fertilizer application. This was eventually reflected in net income that was superior to fertilizer application. The grain yield benefit from integrated *Striga* management strategy appears to be due to a number of factors; the reduction of competition from weeds other than *Striga*, the suppression of *Striga* emergence and the increased soil fertility. All these combined to give a robust plant, as indicated by the greater plant height, that withstands better the pathological effect of *Striga*.

Kenya

Evaluation of *Striga* Resistant Sorghums from INTSORMIL/ Purdue

In Kenya, about 70% of the sorghum crop is produced in areas surrounding Lake Victoria where witch-weed (*Striga* Spp.) is a major production constraint. In the East Africa region losses due this parasitic weed are estimated to range between 65% and 100%. Of late *Striga* has been reported to extend to non-traditional areas. The current control methods involve fertility management, crop rotation and use of trap crops. Of all the varieties being grown in the area, none is resistant to this menace. Purdue university scientists in the USA have made a break through in a rapid laboratory screening method for sorghum resistance to *Striga*. The immediate objectives of the International *Striga* nurseries are:

- Conduct field screening for *Striga* resistant sorghum lines developed at Purdue for adaptation to growing conditions in Kenya
- To assess impact of integrated use of *Striga* resistant sorghum varieties in combination with nitrogen fertilization and water conservation measures.
- Initiate breeding efforts on transfer of *Striga* resistance from various sources into Kenya Sorghum varieties.
- Train Kenyan scientists on laboratory methods for screening for resistance to *Striga* in sorghum.

Administrative

In Kenya, there are two crop seasons in a year as a result of the bimodal rainfall pattern. The efficiency of our INTSORMIL/Kenya collaborative research can be enhanced if sorghum germplasm for adaptive screening can be sent out twice a year. The most appropriate times for sending test material to Kenya is in February for the main crop season (long rains), and in September for the short rainy season. Two or more sets of each test material should be sent to Kenya as that increases the chances for establishing a good crop in at least one location.

The purchase of a computer for the Kenya program will increase their efficiency in data management and retrieval. Valuable time is wasted in waiting for computer time that must be borrowed from other research programs.

Eritrea

Evaluation of Introduced Sorghum Varieties for *Striga* Resistance

The trial was carried out both in 1997 and 1998 in the western lowland (Shambuko), but the 1997 trial failed because of the drought. The trial intended to be carried out in 1997 in the highland (Mendefera) was not carried out because of technical reasons. The result given below was carried out during 1998 in the western lowland (Shambuko) and in the highland (Mendefera).

The objectives of this experiment were as follows:

- To evaluate high-land sorghum cultivars with enhanced level of resistance against *Striga* under Eritrean conditions.
- To evaluate low-land sorghum cultivars with enhanced level of resistance against *Striga* under Eritrean conditions.

A total of 26 varieties of which 24 were received from INTSORMIL/Purdue University (International *Striga* Resistant Sorghum Nursery) with two local varieties.

The trial was carried out at five farmers' plot around Shambuko. Each farmer's plot was considered as a replication. The experimental design was RCBD with four replications. Three rows of 5 m long were used for each treatment (variety) in each replication. Plant height, panicle size, sorghum stand count, *Striga* count and yields of the treatments were recorded.

Eight Sorghum varieties, received from INTSORMIL/ Purdue University (International *Striga* Resistant Nursery), which were selected based on their resistance against *Striga* with one local check used for this trial. The experimental design was RCBD with four replication. Three rows of 5m long were used for each treatment. The experiment was carried out at Shambuko Research Center. Plant height, sorghum stand count, and *Striga* count per plot of 11.25 m^2 were recorded.

From this trial, *Striga* count during the early growth stage of sorghum was very few in number. Greater number of *Striga* was observed during late season when the crop has already been well established to cause reduction of sorghum grain yield. There were significant differences in the number of *Striga* count made in all the treatments. The varieties that produced low amounts of germination stimulants suffered to a lesser degree from this parasitic weed.

Varieties with entry numbers 8579 and 8568 were not infected with *Striga* at all and varieties with entry numbers 8557 and 8580 showed very few numbers of *Striga*. Variety with entry number, 8552, 8556, 8566, 8577 and 8555 sustained fewer *Striga* and as the same time gave good yield with 39.19, 33.24, 29.85, 29.68 and 29.43 q/ha respectively.

Generally yields from these varieties were low as compared with other cultivars. The advantage of these cultivars is that they can give yields under heavy infestation and/or poor seasons as an insurance crop. Under improved management, the resistance of this crop to *Striga* can be enhanced. The *Striga* infestation problem is complicated by environment and/or host parasitic weed relationship. Although the varieties were supposed to show some degree of resistance because of their genetic potential, all the varieties were seriously infested with this weed. Despite the yield of all treatments could not be obtained, being damaged by animals, only one variety with entry number of 8552 was relatively resistant against *Striga*.

Institution Building

Equipment Purchased (1996-2000)

Table-top hand sealer, Sharp copier, slide projector, Mettler precision balance, Altimeter, Hygrothermograph, air conditioner, HP Laserjet printer, power converters, Compaq computer, HP Scan jet, Micron Computer, slide projector, overhead projector, DM LS microscope, power converters, and a Cannon EOS Elan II camera. In addition, books and subscriptions to scientific journals as well as expendable research and lab supplies were purchased and shipped to Ethiopia.

Travel (1996-2000)

U.S. Collaborators Travel

In 1996, John Sanders traveled to Ethiopia to work with IAR economists to evaluate potential for future collaboration.

In 1997, Gebisa Ejeta and John Yohe traveled to Kenya, Uganda, Ethiopia, and Eritrea to establish MOAs with the NARS, conduct discussions ASARECA and REDSO/E

In 1998, Gebisa Ejeta, Bruce Hamaker, John Leslie, Henry Pitre and Tom Crawford to Ethiopia with the first raveling HOA workshop.

In 1999, Gebisa Ejeta to Ethiopia to work with the USAID Mission on the Amhara project; John Sanders to Ethiopia for discussions with EARO and Sasakawa 2000 on impact assessment of *Striga* resistant sorghum varieties

Host Country Scientists Travel

In 1996, Abdel Gabbar Babiker, Abdelmoneim Ahmadi and Abdelatif Nour from Sudan to participate in the INTSORMIL Principal Investigators Conference; Aberra Debelo, Girma Tegegne and Senait Yetneberk from Ethiopia to attend the INTSORMIL Principal Investigators' Conference; Peter Esele from Uganda to attend the INTSORMIL Principal Investigators' Conference.

In May of 2000, Aberra Debelo from Ethiopia, Member of the INTSORMIL Board of Directors attended the Board Meeting in Kansas City.

Training (1996 -2000)

The following students have been trained from the Horn of Africa Region in this grant period.

Regassa, Teshome, Ethiopia, Ph.D.
Nduulu, Lexington, Kenya, Ph.D.
Ibrahim, Yahia, Sudan, Ph.D.
Mohammed, Abdallah, Sudan, Ph.D.
Bugusu, Betty, Kenya, M.S.
Awika, Joseph M , Kenya, M.S.
Admasu, Melakebrhan, Ethiopia, Ph.D.
Mulatu, Tadesse, Ethiopia, M.S.(Deceased)
Mohamed, Ahmed, Sudan, Ph.D.
Murithi, Linus, Kenya, Ph.D.
Nega, Wubeneh, Ethiopia, M.S.

Networking

Our regional initiative in the Horn of Africa has provided us opportunity to forge effective networking with a number of governmental and non-governmental agencies. In addition to bilateral agreements we have developed with each of five NARS in the region, we have also been able to develop linkages with a number of agencies, namely the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA), REDSO and USAID missions, Sasakawa Global 2000, and the Intergovernmental Authority on Development (IGAD).

A summary of collaborative activities with each of these agencies follows:

ASARECA

A memorandum of agreement was signed with ASARECA to engage in joint efforts of developing and promoting improved technologies for sorghum production and utilization in the region. In cooperation with ICRISAT, we assisted ASARECA to hold a workshop in the region and pooled scientists in the region to prepare a document towards resurrecting a network for sorghum and millet improvement in the region. As part of the agenda developed for the 1995 workshop, NARS scientists in the ASARECA region formulated a draft proposal to solicit funding for revitalization and operation of a sorghum and millet research network in the ASARECA region. Both INTSORMIL and ICRISAT expect to be key participants in such a network in the Greater Horn of Africa. Proceedings of the workshop, including the proposal drafted by the NARS scientists in the region, have been published at Purdue University. A network in the region will greatly enhance interaction and dissemination of research results among NARS. It will also facilitate INTSORMIL's efforts in the Horn of Africa.

Plans are for this network, ECARSAM, to start functioning in the region as soon as sponsors are located. We believe that the resurrection of this network will facilitate our collaborative interaction and coordination of efforts with ICRISAT, the NARS and NGOs in the Horn of Africa region. In 1997 we signed MOUs with Ethiopia, Kenya, Uganda and Eritrea following discussions initiated during the workshop. This gave INTSORMIL an excellent nucleus in which to operate an effective regional research network in the Greater Horn of Africa. The USAID Missions in Ethiopia and Eritrea have identified crop research and production as targets for development initiatives. Leaders of the Eritrean program are particularly excited about the opportunity for working with CRSPs because as a new nation, they have identified human capital development as a priority and they see U.S. universities providing graduate education opportunities. Support for INTSORMIL activities in the region has been outstanding.

Sasakawa Global 2000

This agency has been instrumental in testing, demonstration, and dissemination of improved agronomic practices for increasing crop yields in cooperation with NARS in the region. We collaborated with Global 2000 in promoting the adoption of *Striga* resistant sorghum varieties in Ethiopia. Global 2000 sponsored the multiplication of large quantities of seed of the improved sorghum varieties supplied by INTSORMIL. The agency also organized the planning and implementation of several hundred ½ hectare demonstration plots in the Tigre, Amhara, and Oromo regions known to have serious *Striga* infection annually. Successful implementation of these demonstration experiments generated valuable data that was presented to the Ethiopian National Variety Release Committee which recommended the official release of two INTSORMIL bred varieties for commercial cultivation in *Striga* endemic areas of the country.

IGAD

The IGAD Secretariat, in partnership with its Member States and Partners in Development recently identified a new initiative on the development and promotion of drought tolerant high yielding crop varieties for immediate formulation and implementation. INTSORMIL was requested by IGAD to undertake a survey project on "Promoting Sustainable Production of Drought Tolerant High Yielding Crop Varieties through Research and Extension." This comprehensive project required INTSORMIL to engage several scientists from each of the countries in the region as well as from the United States in analyzing the availability and utility of modern technologies resulting from research in the region that may have potential in alleviating the critical food deficit that is a constant in each of the countries in the region. . Inhabitants of the IGAD region continue to experience famine due to repeated food shortages triggered primarily by drought but also by a fragile and degraded environment caused by severe population pressure. In much of the region, farmers attempt to increase food production via horizontal expansion into marginal lands using traditional cultivars and farming practices. More than one-half of the IGAD region is classified as arid or semi-arid lands (ASAL) characterized by management practices, and a severe soil erosion problem. As a result, farmers in the region are often destitute and easily affected by vagaries of low rainfall and food shortages associated with drought. Added to the overall poverty and limited income opportunities for people in rural communities, the majority of the people in the arid regions of Eastern Africa are chronically food insecure. Hence, there is great need for urgent intervention towards more efficient and sustainable practices for food production and natural resource management. There have been great strides made in agricultural research, both in crops and livestock, in the IGAD region. A number of national research programs in cooperation with international and regional organizations have developed technologies that can significantly increase food production in the region. However, much of this technology has not been fully exploited. In some countries greater emphasis has been placed in the more optimal ecologies targeting intensive farming programs. In other countries, research may have generated drought tolerant crop varieties and soil-water conservation practices for marginal lands, but transfer and use of these technologies have been hampered due to various factors including ineffective input delivery systems as well as poor extension infrastructure and services. An organized effort is needed to identify and assess the bottlenecks to increased agricultural productivity in each of these countries. There is a need to examine the existence of capacity for food-self sufficiency in each country. There is also a need to examine the institutional barriers and limitations for technology generation and extension. Where promising technologies have been developed but have not been extended due to lack of proper linkages or absence of an effective delivery system, attention will be drawn to creation of such a mechanism. In countries where drought tolerant, adapted crop varieties or efficient soil-water conservation technologies have not been developed, efforts need be directed towards testing the feasibility of possible transfer of such technologies from neighboring countries. There would also be a need for devising new collaborative research in the region for development of new technologies for addressing some of the more intractable agricultural problems that need long-term joint collaborative efforts. An analysis of on-going public, private, non-governmental (NGOs), as well as regional and international research and development efforts in the region is needed. It is essential to conduct a through survey in each IGAD State to identify available technologies as well as to assess probable constraints and bottlenecks to the development and wide adoption of drought tolerant crop varieties in the IGAD region. The objective of this project, therefore, is to undertake such a survey followed by a regional workshop held where key stakeholders in the IGAD region would provide input into the formulation of a comprehensive document for eventual implementation of a project on the development and promotion of drought tolerant crop varieties.

Amhara Project

At the request of the USAID mission in Ethiopia, INTSORMIL was involved in the discussion and evaluation of an integrated food security program for the Amhara region of Ethiopia. This initiative was based on the premise that the region is one of the most vulnerable areas for food production and current development efforts in the region can not adequately address the food security related problems in most of the drought affected areas of the region. Hence the need for a targeted solution to alleviated food security problems was considered important. A rural development effort with greater emphasis on the agricultural sector was considered. Growth in this sector, however, requires broader support from the research-extension system. The agricultural research component of the food security initiative is designed to address problems related to the alleviation of food security in drought affected areas that are characterized by combinations of moisture deficit, unfavorable climatic conditions, pest infection, degraded and poor natural resource base, and lack of appropriate technology packages. INTSORMIL and other CRSPs were invited to consider development of research projects that would generate sets of technologies that would help increase productivity and thereby support in the alleviation of food security problems. Discussions are underway towards initiating an InterCRSP project in the Amahara region of Ethiopia towards this goal.

Research Accomplishments

Although the Horn of Africa regional project is a new initiative, INTSORMIL has had a strong collaborative program in the region with Sudan as a prime site. Much of the collaborative effort has been in working with the Agricultural Research Corporation (ARC) of the Sudan. The collaborative research relationship between the Agricultural Research Corporation (ARC), Sudan and INTSORMIL that started in 1980 was developed into a strong, mutually beneficial partnership that produced several excellent results. Tangible results ranging from training to development of useful technologies and elite germplasm have been generated.

Even before the advent of INTSORMIL, ARC/Sudan had a "critical mass" of well-trained manpower in place. Sudan is unique in Africa in this regards. Over decades it had invested its own scant resources into developing a sufficient cadre of agricultural manpower. However INTSORMIL has also trained several Sudanese scientists who have returned and filled in key positions particularly in sorghum/millet research related areas. Sudanese graduates of INTSORMIL institutions currently provide service in sorghum breeding (2), plant pathology (1), entomology (1), agronomy (1), food science (1), and agricultural economics (1). A few Sudanese trained and sponsored by INTSORMIL currently also serve IARCs and national programs elsewhere. Of significance has been the contribution made by INTSORMIL in mentoring of young graduates as they returned to ARC. Furthermore, several ARC scientists have spent valuable time in the laboratories of their counterparts in the U.S. Some have done this more than once. In some of these cases, significant research findings have come out of these experiences and the results have been published as joint contributions of ARC and INTSORMIL.

On numerous occasions, and at times on a regular basis annually, INTSORMIL and ARC scientists have held round table discussions on assessing and reevaluating production and utilization constraints in sorghum and millets in Sudan, assessing of research findings and utility technologies jointly developed, and more significantly in setting priorities. The ARC has used these deliberations to assess priorities and progress and to sharpen the focus in the sorghum/millet research in Sudan. ARC has often involved INTSORMIL PIs in setting the national agenda around sorghum/millet research as well as in finding better ways of extending technologies derived from research.

Tangible technologies that resulted from ARC/INTSORMIL partnership include:

- Development, release, and distribution of Hageen Dura-1, as the first commercial sorghum hybrid.

- Identification, wide-testing and release of SRN39 and IS-9830 as the first *Striga* resistant sorghum releases

- The development of an infant seed industry that began with the pilot project around HD-1 seed production. Today over one million acres of sorghum fields are targeted for HD-1 production.

- The testing and recommendation of use of composite-flour for bread making and the better quality mix obtained with use of HD-1 grain.

- The economic evaluation on the impact of HD-1 (the social returns to research investments).

- The development of a technology to produce "instant nasha" as a weaning food.

- Establishing fermentation, a traditional process as an effective method to alleviate problems of protein digestibility associated with sorghum grain..

Benefits accrued to INTSORMIL scientists and U.S. agriculture from ARC/INTSORMIL collaboration include the following:

Contribution of germplasm tested in Sudan in enhancing drought tolerance of material developed for the U.S. seed industry. Recently 10 drought tolerant lines were derived from crosses between U.S. and Sudan sections and were released to the seed industry in the USA

Raw germplasm from Sudan for potential use in the U.S. Recently over 3000 Sudanese land races were contributed by ARC to the USDA.

The development and refinement of new technologies with potential use in the U.S. For instance Long Smut is not a disease of economic importance in the U.S. However, should it become one, screening technology INTSORMIL scientists helped develop in Sudan, will come in handy.

The finding that traditional process of fermentation as a means to alleviate the protein digestibility problem in sorghum laid the foundation for the scientific understanding of factors that influence protein digestibility in grain sorghum.

The excellent field demonstration program by Global 2000 and the persistent efforts of ARC/INTSORMIL in assisting the seed production programs have established Hageen Dura-1 as an ARC generated technology with significant impact to sorghum agriculture in Sudan. Added to other research technologies which have been generated by ARC, including those listed above, ARC has been recognized by the GOS and other agencies operating in Sudan. For instance, the USAID mission, with prodding from INTSORMIL PIs, granted a substantial amount of PL-480 funds to ARC in support of sorghum/millet research. In return, that encouraged the Ministry of Planning to continue to provided unprecedented level of support specifically for sorghum/millet research in Sudan. Individually, particularly ARC scientists in the area of *Striga*, pathology, and cereal quality, have produced significant results that have given them due recognition in the sorghum/millet research community. The collaborative partnership between INTSORMIL and ARC has clearly demonstrated that sustained support and focused research efforts would produce tangible and useful results. It also showed that an effective utilization of research generated technologies would in return eventually bring due recognition to scientists and research programs, and generated increased and sustained support for agricultural research, even in a national program of a developing country with numerous, seemingly insurmountable problems.

Promising results have emerged from the new collaborative research projects between INTSORMIL and the Institute of Agricultural Research in Ethiopia.

- New *Striga* resistant sorghum cultivars introduced from Purdue/INTSORMIL and tested in *Striga* endemic areas with excellent results. Three outstanding lines (P9401, P9403, and P9404) were selected. Seed of these varieties was multiplied during the off-season in a joint effort with Global 2000. About 1 ½ ton of seed was produced to be distributed to several hundred farmers in three regions. Testing and demonstration conducted over the last three years led to the official release of these varieties for commercial cultivation in Ethiopia.

- An integrated *Striga* control study including the three *Striga* resistant selections, nitrogen fertilization, and tied-ridges has been conducted since the 1998 crop season.

- Formulation of a local plant product and an animal by-product traditionally used by Ethiopian sorghum farmers for the control of covered smut was tested and confirmed.

- A comprehensive integrated pest management study for control of stalk borers was initiated and the necessary baseline data generated.

- A Traveling Workshop in Ethiopia and Eritrea for our regional collaborators was held. The workshop allowed for exchange of ideas and establish understanding for undertaking regional sorghum and millet research collaboratively.

Mali

Sustainable Systems for Production, Utilization, and Marketing of Sorghum and Millet in Mali

Coordinators

Dr. Aboubacar Toure, Host Country Coordinator, IER, B.P. 438, Sotuba, Bamako, Mali
Dr. Darrell T. Rosenow, U.S. Country Coordinator, Texas A&M University, Texas Agricultural Experiment Station, Route 3, Box 219, Lubbock, TX

Collaborative Program

Program Structure

The INTSORMIL collaborative program in Mali is a multidisciplinary research program. The vital collaboration continues to provide efficient use of resources. The program has centered around Malian scientists and each Malian scientist develops research plans cooperatively with a US counterpart which provides for effective research planning, communication, and coordination. Each year during the cropping season, INTSORMIL collaborators travel to Mali to observe field trials, consult, review progress and plan future activities with Malian scientists. Occasionally, IER scientists also travel to the US for research review, planning, consolidation and coordination. The planned project activities then become part of the annual Amendment to the MOA between INTSORMIL and IER.

The program includes all aspects of sorghum/millet improvement with major emphasis on germplasm enhancement, utilization and quality, physiology of drought adaptation, nitrogen efficiency, soil management, insect pests, diseases control strategies and striga control.

Financial Input

The USAID Mission has provided significant financial support to IER research program through the SPARC Project which ended in June 1997. In addition to the Malian Government, Novartis and World Bank support the IER research program in a complementary way depending on needs.

Research Disciplines and Collaborators

Genetic Enhancement - (Breeding) - Sorghum and Millet

Sorghum - TAM-222 - D.T. Rosenow, and IER, Aboubacar Touré.

TAM-223 - G.C. Peterson, IER - Abocar Oumar Touré ; Sidi Bekaye Coulibaly; Abdoulaye G. Diallo; and Aly BocarTouré.

Millet - UNL-218 -D.J. Andrews; IER - Moussa Daouda Sanogo and Mody Diagouraga.

Sustainable Crop Protection Systems

Insects -TAM-225 - G.L. Teetes; IER - Yacouba Doumbia and Mme Diarisso Niamoye Yaro.

Diseases - TAM-224 - R.A. Frederiksen; IER - Mamourou Diourté; Mme Diakite Mariam Diarra; and Ousmane Cissé.

Striga - PRF-207 - G. Ejeta; IER - Bouréma Dembélé; Mountaga Kagnatao; and Cheickna Diarra.

Sustainable Crop Production Systems

Agronomy/Drought/Nutrient Use (Sorghum) - UNL-214 - J.W. Maranville; IER - Abdoul W. Touré; and Sidi Bekaye Coulibaly.

Agronomy, Crop Residues (Millet) - UNL-213 - Steve Mason; IER - Samba Traoré; Adama Coulibaly; Minamba Bagayoko.

Soil Management InterCRSP - TAM-223 - G.C. Peterson; and IER - Mamadou Doumbia.

Grain Utilization and Quality - TAM-226 - L.W. Rooney; IER - Mme Aïssata Bengaly Berthé; and Mme Coulibaly Salimata Sidibé.

On-Farm and InterCRSP - IER - Aboubacar Touré; Oumar Coulibaly; and World Vision - Philippe Dembele.

Economics and Marketing - PRF-205 - J.H. Sanders; Icofil IER - Bakary Coulibaly; and Purdue University - Jeffrey Vitale.

Collaborating Institutions

Institute of Rural Economy (IER), Bamako, Mali
Texas A&M University
University of Nebraska

Purdue University
Kansas State Univerity
USAID/Bamako
Novartis/Ciba-Geigy
ICRISAT/WASIP/Mali
WCASRN/ROCARS (Regional Sorghum Network)
ROCAFREMI (Regional Millet Network)
World Vision International and InterCRSP (WVI)
Soil Management CRSP

Sorghum/Millet Constraints Researched

Plant Production Constraints

The yield level and stability in sorghum and millet production is of major importance in the country. Diseases, insect infestations and *Striga* significantly affect sorghum and millet production in Mali. Head bugs and associated grain molds adversely affect sorghum yield and grain quality. Anthracnose is a very severe sorghum disease in Mali and long smut is severe in the drier regions of the country. Striga is a major constraint for both sorghum and millet.

Land Production Constraints

Low soil fertility combined with the low yield and unstable yields of Malian cultivars affect sorghum and millet production in Mali. Major soil related constraints to production in Mali are phosphorus and nitrogen deficiency, and water stress.

Technological and Socioeconomic Constraints

There is a lack of farm credit policy which would encourage adoption of improved sorghum and millet new cultivars. In addition, the prices of these two cereals are low and unstable. New, shelf-stable foods and industrial sorghum and millet based products which would encourage production, are lacking in the country.

Sorghum and millet research in Mali has attempted to address all three categories of constraints through genetic enhancement of the species, and crop and land management strategies development of novel post-harvest technologies.

Institution Building

IER sorghum and millet programs received, through INTSORMIL collaboration, a vehicle and various field and laboratory research equipment including computers, printers, pollinating bags, and breeding supplies.

Many Malian scientists trained at INTSORMIL institutions are senior staff making important contributions in sorghum and millet research within the IER including:

Dr. Aboubacar Touré (Texas A&M) - Currently Sorghum Breeder, Mali National Coordinator for sorghum, Mali INTSORMIL Coordinator, and on INTSORMIL Technical Committee.

Dr. Mamourou Diourté (Texas A&M and Kansas State) - Currently Head Sorghum Pathologist.

Dr. Samba Traore (Nebraska) - Currently Agronomist and Mali National Coordinator for Millet.

Dr. Mme Diarisso Niamoye Yaro (Texas A&M) - Currently Sorghum Entomologist, and Head of a Vegetable Station in IER.

Dr. Momadou Doumbia (Texas A&M) - Currently Director of Soil Laboratory and Soil Scientist with IER.

Mr. Abdoul W. Touré (Nebraska) - Currently Sorghum Agronomist.

Mr. Adama Coulibaly (Kansas State) - Currently Sorghum Agronomist

Mr. Sidi Bekaye Coulibaly (Nebraska) - Previously Sorghum Physiology/Agronomy and Sorghum Breeding and INTSORMIL Coordinator. Currently working on Ph.D. at Texas A&M/Texas Tech.

Mr. Bakary Coulibaly (Purdue) - Currently Economist with Icofil, IER.

Dr. Bourema Dembelé (Purdue - Short-Training) - Currently Deputy Research Director, IER. Previously Weed Scientist (*Striga*) and National Coordinator for sorghum.

Mme Aissata Bengaly Berthé (Texas A&M - Short-Training) - Currently Sorghum Utilization and Quality P.I.

New students in training include Niaba Témé who has successfully complete his B.S. and is currently an M.S. student at Texas Tech University. Sidi Bekaye Coulibaly, who has served as INTSORMIL Host Country Coordinator, is now a Ph.D. student at Texas Tech/Texas A&M University.

Bocar Sidibé and Sibène Déna received short term training in the USA provided by INTSORMIL in breeding and plant pathology.

U.S. scientists traveling to Mali included: Drs. D.T. Rosenow and G.C. Peterson, Sorghum Breeders; L.W. Rooney, Food Scientist; G.L. Teetes, Entomologist; R.A Fredericken, Plant Pathologist; all from Texas A&M University; Drs J.D. Maranville and S.C. Mason, Agronomists and Prof. D.J. Andrews, Millet Breeder, from the University of Nebraska; Dr. J.H. Sanders, Economist, from Purdue. Dr. Tom Crawford, INTSORMIL Associate Director, and Dr. Jeff Dahlberg, Sorghum Curator, USDA-ARS, Puerto Rico also traveled to Mali.

IER scientists Sidi Bekaye Coulibaly, Yacouba Doumbia, Bouréma Dembélé, Abdoul W. Touré, Mme Berthé Aissata Bengaly and Adama Coulibaly, attended the International Sorghum and Millet Conference at Lubbuck in 1996. Mr. Sidi Bekaye Coulibaly traveled to the US for an INTSORMIL Technical Committee meeting and attended the INTSORMIL PI Conference and Impact Assessment Workshop in June 1998 at Corpus Christi, TX.

All key Malian scientists traveled to Niger, September 25 to October 2, 1998 to participate in the West African Hybrid Sorghum and Pearl Millet workshop, and to discuss collaborative research efforts with Nigerien and other West African scientists. Mde. A.B. Berthé, Aboubacar Touré, and Darrell Rosenow participated in the ROCARS Workshop - Sustainable Production, Utilization, and Marketing in West and Central Africa, April 19-22, 1999 at Lome, Togo. John Sanders and Jupiter Ndjuenga also attended the ROCARS Workshop representing INTSORMIL.

Mme Berthé Aissata Bengaly, Food Scientist, is a member of the Streering Committee of the West and Central Africa Sorghum Research Network, WCASRN (ROCARS).

Two INTSORMIL scientists were presented the CIWARA Award in the fall of 1999 by the IER Director General. The CIWARA Award is presented through the Bambara association of farmers to persons or organizations making significant contributions to agriculture in Mali. Receiving the award were Dr. Richard Frederiksen, on behalf of his contribution to the formation and development of INTSORMIL and in recognition of the contribution of INTSORMIL to Malian agriculture, and Dr. Darrell Rosenow, for his contribution to Mali farming and agriculture through his leadership in collaborative IER research and as Mali Country Coordinator.

Networking

An efficient sorghum and millet research and technology transfer network exists though WCASRN and ROCAFREMI. The INTSORMIL/IER collaborative program is integrated on a regional basis. Technologies developed in Mali are transferable to most countries in West Africa specially in the areas of head bugs, drought and grain mold which are common across West Africa and are world-wide problems. Exchange of elite germplasm with useful traits is ongoing among breeders in the region. The emerging interaction with NGO's, the University of Mali (IPR de Katibougou), farm organizations, and extension in conducting on-farm research and tests is a positive one that efficiently utilizes scarce resources and personnel. The program is using this approach to evaluate new improved breeding cultivars and other technologies in the West Africa Region. Efforts are underway to reinforce coordination of research programs and activities with Niger and Burkina Faso. Some seed money has been made available from INTSORMIL through the Mali Country Budget to develop some collaborative programs in Ghana and Senegal in 2000-2001.

The program has also interacted with ICRISAT, TROPSOILS, NOVARTIS, etc. There has been a long history of collaboration with ICRISAT in Mali especially in breeding, entomology, and weed science. The program has assembled, planted, increased and characterized the Mali Sorghum Collection in collaboration with USDA-ARS, ICRISAT, ORSTOM, CIRAD, and has distributed seed to US, ICRISAT, and ORSTOM. The development of a working group for active use is ongoing. Approximately 450 (the late maturing group) items from the Mali Sorghum Collection were grown in quarantine on St. Croix, U.S.Virgin .Islands in early 2000 with seed increased and characterization completed. Plans are to grow out the other two thirds of the Collection in St. Croix by the winter of 2000-2001.

A workshop on Sorghum Germplasm and Characterization was held at Cinzana, Mali in November 1997 with over 40 sorghum scientists, mostly from West Africa, attending. The workshop was held in cooperation with the working, harvest, etc. of the Mali Sorghum Collection grown at Cinzana and was co-sponsored by INTSORMIL, IER, ICRISAT, USDA-ARS, WCASRN, ORSTOM, and CIRAD.

Another collaborative activity was the search for molecular markers for head bug resistance. This collaboration has involved IER, The Rockefeller Foundation, Texas A&M University, Texas Tech University, INTSORMIL, and CIRAD.

Research Results - 1999

Performance data from the 1999 Sorghum Drought Test grown at the dry, northern Mali Station at Bema is presented in Table 1. Although the 1999 rainfall was rather good, some interesting results were obtained. Some previously drought tolerant non-guinea cultivars from other countries performed well including Tx7000, Ajabsido, El Mota, SC414-12E, CE151, Macia, and 93SU629. As a rule, the drought tolerant Feteritas from Sudan (93SU numbers) performed well and had a desirable early flowering. Also, the durra cultivars from northern Niger, Nigeria, and Mali (Bagoba, Babadia Fara, OH/84-3/5, Gadiaba, and Lakahiri) produced high yields. The guinea cultivars had only average performance, while the converted Malian Guineas (CSM numbers followed by C) were very early and low yielding. The three introduced hybrids showed no superiority over the best adapted cultivars.

The Mali Ministry of Agriculture and IER held a Press Conference in the spring of 2000 to make a public announcement of the commercialization of a cookie made by GAM, a large private bakery in Bamako, called Dali-ken. This cookie uses 20% locally produced flour (combined with wheat) from the grain of the white-seeded, tan-plant IER/INTSORMIL developed sorghum cultivar,

Table 1. Performance data from 51 selected entries from a 75 entry drought trial at Bema, Northern Mali, 1999.

Variety/Cultivar	Days to 50% flower	Plant height (m)	Grain yield kg ha-1
Tx7078	68	.88	800
B35	76	.99	1133
Tx7000	58	.98	1800
1790E	63	.79	627
Ajabsido (Sudan)	59	1.7	1400
ElMota (Niger)	53	1.4	1707
Segaolane (Botswana)	61	.98	400
P954035	67	.97	1867
P898012	61	1.5	1280
SC414-12E (Sudan)	64	.89	1627
CE151 (Senegal)	63	1.2	1893
P37-3	69	1.1	1493
SS130 (Somalia)	81	2.5	1133
SC1211-11E (Honduras)	59	.96	1200
Macia (Mozambique)	73	1.2	2667
Kuyuma (Zambia	73	1.3	1867
MP-531 (SADC)	72	1.6	2267
Malisor 84-7	76	1.0	1533
Malisor 84-5	72	1.6	1600
S-34	65	1.6	1267
ICSV 400	73	1.6	1933
Malisor 92-1	68	1.5	1800
Sureno	74	1.5	2480
93SU629 (Sudan)	55	1.3	1867
93SU1671 (Sudan)	61	1.8	1933
93SU1672 (Sudan)	64	1.1	1307
903SU96 (Sudan)	59	.96	1427
93SU70 (Sudan)	60	1.8	1333
93SU439 (Sudan)	59	2.1	1867
93SU577 (Sudan)	63	1.9	1600
Gadam el Hamon C (Sudan)	61	.68	1467
CSM419C	48	.98	1200
CSM414C	53	1.3	800
CSM388C	55	1.4	893
CSM90C	52	1.03	1426
CSM417C	60	1.3	560
CSM87C	51	1.0	600
CSM207C	51	1.2	693
CSM63	50	1.8	1067
CSM228	66	1.9	1093
CSM219	63	1.9	1400
Seguetana Cinzana - E	74	2.9	1093
CE90	70	1.3	933
Bagoba (Niger)	62	1.9	1600
OH/84-3/5 (Nigeria)	63	2.3	2067
Babadia Fara (Niger)	63	1.9	2173
Gadiaba Cinzana (Mali)	76	2.1	2133
Lakahiri (Mali)	76	2.2	2267
Hageen Dura 1 (Hybrid)	67	1.3	2000
A1*P37-3 (Hybrid)	64	1.2	2000
A35*P37-3 (Hybrid)	74	1.3	2133
Mean of 75 entries	64	134	1330
Significance	**	**	**
C.V. (%)	11.9	18.7	44.8

N'Tenimissa, which was contract grown. This demonstrates that the grain of the newly developed tan-plant Guinea cultivars is superior in quality to the local Guinea cultivars, and that it can enhance the commercial value and utilization of value-added, high quality sorghum grain.

Several new tan-plant-Guinea breeding lines in the multilocation yield trials showed real promise in 1998 and 1999 (Tables 2 and 3). Many are derived from the cross N'Tenimissa*Tiemarfing, and have very good guinea-type grain, being superior to N'Tenimissa grain in resistance to the head bug/grain mold problem. Several appear to be equivalent to N'Tenimissa in yield, but with less stem lodging and breakage than N'Tenimissa. Also, several new F_3, F_4, and F_5 breeding progenies looked outstanding, some being significantly shorter with good lodging resistance. They are primarily guinea or guinea derivative lines involving such lines or cultivars or N'Tenimissa, Tiemarfing, Bimbiri Soumale, CSM219, CSM388, S-34, Malisor 84-7, Naga White, 92-SB-F4-14, 92-SB-F4-97, Seguetana Cinzana, ICSV 1079, ICSV1089, IS22380, and Sureño. Thirty-five of these new breeding lines were introduced into the U.S.

Seed from 10 improved cultivars was increased by farmers, and farmers trained in seed increase in 1999. Table 4 shows the cultivars, farmers involved, and the quantity of seed produced.

Ten local and improved sorghum cultivars were evaluated for malt and dolo (local beer) making.. There was no relation between good malt producers and good beer making. The order for malt from best to worst was: Malisor 92-1; MEIDsor 88-10-02; CSM 388; MIKsor 86-30-41; Foulatiéba; MIDsor 88-10-06; Sorgho rouge; N'Tenimissa; MIPsor 90-30-43; and MIDsor 88-10-01. Foulatiéba made the best beer with excellent color and taste, while Malisor 92-1 made the worst beer.

Breeding crosses have been initiated in Texas and Mali to develop appropriate parental lines (both A-B and restorer) to use in developing a sorghum hybrid breeding program in Mali. Initial research is aimed at identifying restorer or non-restorer reaction among guinea cultivars.

Research Accomplishments - Summary

The most significant impact of INTSORMIL has been the strengthening of the IER both through staff training and research capacity building. Interdisciplinary and cooperative research in sorghum and millet which are in place at the IER are mainly due to INTSORMIL/IER collaborations. The multidisciplinary approach to solving technical problems have been promoted by INTSORMIL, and is fuctioning well in Mali.

Breeding

- Eight local photosensitive sorghum cultivars have been improved through mass selection and are grown by farmers on a significant area in Mali (CSM 388,

Table 2. Summary of data from the early yield trials at Cinzana and Béma during 1998 and 1999.

Varieties	Yield (kg ha^{-1})			50% Flowering (days)			Plant Height (m)		
	1998	1999	Mean	1998	1999	Mean	1998	1999	Mean
96-CZ-F4P-12	2088	3112	2600	76	69	73	2.03	2.10	2.07
97-CZ-F5P-3	1173	3151	2162	81	75	78	1.73	1.80	1.77
97-CZ-F5P-4	1091	2922	2007	86	82	84	1.65	1.84	1.75
97-SB-F5DT-63	1497	2006	1752	79	75	77	3.82	3.70	3.76
97-SB-F5DT-64	1869	2009	1939	79	77	78	3.89	3.54	3.72
97-SB-F5DT-65	1480	1982	1731	82	76	79	3.97	3.52	3.75
CSM-63	1350	2453	1902		66	66	3.06	2.93	3.00
LOCAL	1330	2500	1915		75	75	3.31	3.67	3.49

Table 3. Summary of data from the medium maturity yield trails collected during 1997, 1998 and 1999.

Varieties	50% Flowering (days)	Plant Height (m)	Yield (kg ha^{-1})			
	Mean	Mean	1997	1998	1999	Mean
96-S-CS-FB6-4	76	1.99	2313	1748	1664	1908
96-SB-CS-F6-6	77	2.21	2236	1637	1147	1673
96-SB-CS-F6-8-1	78	2.69	2614	2186	1447	2082
96-SB-CS-F6-F6-8-2	82	3.83	-	-	1156	1156
96-SB-CS-F6-15	80	2.24	2702	2014	1710	2142
97-SB-F5DT-15	89	1.73	-	1966	2106	2036
97-SB-F5DT-74-1	83	4.07	-	1278	1406	1342
97-SB-F5DT-74-2	83	4.02	-	1407	1572	1489
97-SB-F5DT-154	92	1.63	-	1912	1413	1663
97-SB-F5DT-150	89	1.70	-	1828	1925	1877
98-SB-F5DT-78	88	1.75		2004	2375	2375
98-SB-F5DT-82	89	2.26		2171	1844	1844
CSM-388	85	4.13			2126	2065
LOCAL	85	4.06			2133	2152

Table 4. Seed quantities of improved cultivars produced in 1999.

Varieties	Localities	Farmers trained	Area	Quantity (Kg ha^{-1})
CSM-63 E	Cinzana	1	1 ha	1000
CSM-417	Cinzana	1	1 ha	600
CSM-219	Cinzana	1	1 ha	600
CSM-388	Kolombada, Samanko	2	1/4, 1 ha	1270
CMDT-45	Soukoula	-	1/4	415
Seguetana	Soukoula	-	1/4	415
Sariaso 1	Sikasso	1	1/4	500
N'Tenimissa	Tamala	2	1 ha	1000
Seguifa	Cinzana, Sotuba	1	1 ha	1000
CSM-388	Tamala	7	5 ha	3238

CSM 219E, CSM 63E, Foulatiéba, Séguétana CZ, CMDT 45 , CMDT 39).

- The white-seeded, tan-plant Guinea type breeding cultivar, N'Tenimissa, was released. Its yield is equal to or slightly superior to local checks. It has good farmer acceptance regarding yield and food use. Flour from N'tenimissa is currently being marketed commercially (20% N'tenimissa and 80% wheat flour) in a cookie called Dali-ken by the private company, GAM, in Bamako.

- Six new white, tan plant true Guinea breeding lines were identified: 96-CZ-F4-98, 96-CZ-F4-99 (late maturity); 97-SB-F5-74-1, 97-SB-F5-74-2 (medium maturity); and 97-SB-F5-63, 97-SB-F5-64 (early maturity), all from the cross (N'ténimissa*Tiémarifing). They were evaluated on-farm in 1998 and 1999 with promising results. They have somewhat superior grain quality and show less stem breakage than N'tenimissa.

- Several mutant-derived Guinea type breeding lines developed by Dr. Alhousseini Bretaudeau, a geneticist at the Agriculture School at Katiabougou, showed promise for nitrogen use-efficiency and grain yield.

- Varieties of millet selected for the tallest expression of the D2 dwarfing complex (1.7 to 1.9 m) have given good performance in millet/legume intercropping studies.

- Dwarf (D2) inbred millet lines selected at Cinzana from progenies of crosses between Mali and UNL-218 lines appear promising as germplasm sources to develop dwarf varieties for intercropping.

- Testing in Texas and Mali has demonstrated that the drought response in Mali is similar to the drought response in West Texas increasing probability of success in breeding for enhanced drought tolerance.

- Germplasm from U.S. breeders and the Sorghum Conversion Program has been incorporated into the Malian breeding programs.

- Nine improved sorghum lines from Malian program were released (Malisor 84-1 to 84-7 and Malisor 92-1 and 92-2) with some promising results.

- The Mali Sorghum Collection of indigenous cultivars from Mali was successfully grown in 1997, was characterized and seed increased and distributed. A small working collection has been identified. There was greater diversity in the collection than anticipated. Approximately on-third of the Collection was grown in St. Croix in spring '00 with seed increased and characterization completed. The remaining two-thirds is planned for quarantine growout in winter, 2000-2001.

Entomology

- The adverse effect of head bugs on the grain food quality of introduced sorghum across West Africa was first recognized and documented in Mali.

- The INTSORMIL collaborative sorghum entomology research program in Mali has discovered the best source of genetic resistance to head bug (*Eurystylus marginatus*), a major constraint to the quality of grain sorghum in Mali, in an IER Malian developed cultivar, Malisor 84-7.

- An easy, efficient technique for screening for head bug resistance using bagged vs. non-bagged heads has been developed and is used cooperatively by the breeders and the entomologists.

- Malisor 84-7, developed in the IER/ICRISAT, USAID sponsored bilateral program in Mali, was identified to possess excellent genetic resistance to head bugs. Resistance can be genetically transferred to its progeny, but its inheritance is quantitative and primarily recessive.

- New sources of resistance to head bugs were identified: 93-EPRS-F6-GII-5, 94-EPRS-F6-GII-1077, 90-CZ-CS-T-2, 90-CZ-CS-T-12, and PR 2562.

- Observations indicate that head bug infestations in on-farm trials is much lower than in Station Nurseries. This means that sorghum with somewhat lower levels of head bug resistance may well work at the farm level, even though they may show significant damage under certain Station infestations.

Pathology

INTSORMIL collaborative research has shown:

- Grain yield increase of 20% can be obtained by treating millet seed with Apron Plus.

- Protection from head bugs will be a requirement for evaluation of grain mold resistance.

- Long smut (*Tolyposporium ehrenbergii*) is severe in the drier regions of Mali.

- Anthracnose (*Collectostrichum graminicola*) is a very serious sorghum disease in Mali.

- Leaf spot is not as serious in southern Mali as other diseases

- Studies were conducted on covered kernel smut (*Sphacelotheca sorghi*) by using traditional fungicides and the results showed that "Gon" (*Canavalia ensiloformis*) used in seed treatment had the same effects as Apron Plus 50DS and Oftanol.

Agronomy

- INTSORMIL/IER research has demonstrated that millet or sorghum planted after peanut or cowpea results in 36-63% yield increases.

- INTSORMIL collaborative research has shown an increase in pearl millet grain yield and biomass production due to previous cowpea crops and equivalent to the application of 30 to 40 kg ha^{-1} N.

- The study of sorghum response to nitrogen suggests a relationship between response to N and genotype as well as environment.

- The joint INTSORMIL/TROPSOILS collaborative program has addressed soil chemical properties associated with nutrient deficiencies toxicities in sandy soils of the Cinzana Station. Some Durra varieties from Niger and northern Mali show tolerance to soil toxicity (Bagoba, Babadia Fara, and Gadiaba)

- Genotypes of sorghum which accumulated high amounts of proline had significantly greater heat and desiccation tolerance. Landraces obtained from Mali had high heat and desiccation tolerance.

- A method of screening large numbers of sorghum and millet lines for early generation and selection for seedling stage drought resistance using a charcoal pit has been adapted and is used.

- Nitrogen use efficiency (NUE) of improved sorghum cultivars has been better than that of local cultivars at higher N rates, while local cultivars had better NUE at zero and very low N rates.

- Application of N fertilizer and P fertilizer increases pearl millet (and sorghum) grain yields.

- Without fertilizer application all tested cropping systems (including legume rotations) mine the soil of nutrients.

- Crop rotation with cowpea and leaving crop residues in the field (either incorporated or on the surface) increases the sustainability and productivity of pearl millet cropping systems.

Weed Science

- Several *Striga* resistant lines from Purdue evaluated in Mali showed good *Striga* resistance, but had inferior grain quality compared to local cultivars.

- *Striga* resistance using lab screening to *Striga asiatica* in the USA works under field conditions to *S. hermonthica* in Mali.

- New sources of resistance to *Striga* were identified: Séguétana CZ, CMDT 45, CMDT 30, CMDT 39.

Grain Quality and Utilization

- Sorghum and millet postharvest technology systems in Mali were documented in 1979 and strategies for evaluating the quality of cereals, especially sorghum, for tô were devised.

- Mini tests for evaluating milling and tô properties were developed and currently are used in the laboratory.

- Sorghum with hard endosperm and thick pericarps was definitely required for efficient traditional hand pounding.

- The size and shape of the pearl millet kernels affects dehulling properties significantly.

- The souna millet types have reduced yields of decorticated grain.

- Tô quality of millet cultivars does not vary as much as it does among sorghum.

- Head bugs damage reduced sorghum milling yields and produced tô with unacceptable texture and keeping properties.

- Parboiling can convert sorghum and millet into acceptable products. It improves dehulling yieds, especially for soft grains. The cooked milled products can be eaten like rice.

- The combination of cowpea and millet flour (1:3) significantly improved the nutritional status of young children. This technology has been transferred to many villages especially in the Cinzana area.

- Mileg, a weaning food using primarily millet flour has been developed by private entrerprise and marketed in stores in the Bamako area. The product was developed using technology developed in the IER Cereal Technology laboratory.

- New white-seeded, tan-plant, tan-glume guinea-type breeding cultivars, have good potential for use in developing new high quality, value added food products. They posses excellent guinea traits and yield potential.

- Dali-ken, a cookie using 20% N'Ténimissa flour and 80% wheat flour has been developed by private entrerprise GAM and marketed in stores in Mali.

Economics/Marketing

- The domestic cereal economy has been helped by devaluation with the increased relative price of sorghum and millet to rice. A future devaluation is expected to result in much more substitution of traditional cereals now that there is only a minimal rice tariff.

- In spite of substantial introduction of new sorghum and millet cultivars, there has been minimum aggregate impact on yields. Only where inorganic fertilizers and improved water retention or irrigation were combined with new cultivars, have there been large yield increases. Given the low soil fertility and irregular rainfall in semi-arid regions, both increased water availability and higher levels of principal nutrients will be necessary for substantial yield increases. Improved cultivars alone are unlikely to have a significant effect upon yield.

- The lack of a consistent supply of high quality sorghum and millet grain is the major constraint limiting value-added grain processing.

- Lack of farm credit for millet and sorghum, compared to cotton and maize, discourages adoption by farmers of improved millet and sorghum technology, especially in the Sudano-Guinean (higher rainfall) zone.

Niger

John Axtell and Issoufou Kapran
Purdue University and INRAN/Niger

Coordinators

Issoufou Kapran, INRAN/INTSORMIL Coordinator, B.P. 429, Niamey, Niger
John Axtell, Professor and West Africa/Niger Country Coordinator, Agronomy Department, Lilly Hall, Purdue University, W. Lafayette, IN 47906

Description of Collaborative program

In 1999, INTSORMIL/INRAN hired an administrative assistant to assist Dr. Kapran with the day-to-day management of the project. She is Mrs. Katy Ibrahim's counterpart and they work closely in managing and implementing activities related to the program.

The INTSORMIL Niger program continues to be interdisciplinary and multi-institutional involving INRAN, ICRISAT and U.S./INTSORMIL institutions (University of Nebraska, Texas A&M University, and Purdue University). Activities include development of the new sorghum hybrid, NAD-1, *Striga* research using INTSORMIL/INRAN tested varieties, millet breeding and cropping systems, farm level studies on the effect of tied-ridging and fertilization, pearl millet/cowpea cropping systems, production of sorghum and millet couscous, pathology, entomology, and analyzing interactions between input-output market development and adoption of new millet and sorghum technologies in Niger.

In 1998, the Niger program was successful in procuring additional funds from The McKnight and Rockefeller Foundations in support of the Regional Hybrid Seed Workshop. World Bank/Niamey also partially funded Dr. Lee House, INTSORMIL consultant, to assist INRAN in developing a seed multiplication unit.

ICRISAT is an active collaborator on the seed production of a new INRAN sorghum hybrid designated NAD-1. Participants include Drs. Anand Kumar, S.C. Gupta, and D.S. Murty. In addition, Dr. Ousmane Youm supervised an INRAN graduate student in conducting field biology and laboratory studies on millet head miner.

Approximately 150 participants from 14 different countries attended the Regional Hybrid Seed Workshop which was held September 28 through October 2, 1998 in Niamey. Countries included: the United States, Niger, Ghana, Mali, Cote d'Ivoire, India, Burkina Faso, Kenya, Chad, Egypt, Senegal, France, Nigeria, Zimbabwe, and Zambia. The following organization also participated:

Winrock International (Senegal/Mali)
PROCELOS-CILSS (Burkina Faso)
World Bank ONAHA (Niamey)
USAID/Washington
ITRA (Chad)
INTSORMIL
ARC/FCRI (Egypt)
INRAN
CIRAD-CA (France)
IER/Mali
ISRA (Senegal)
WCASNR/ROCARS (Mali)
DDEIA/CUN (Niamey)
IDESSA (Côte d'Ivoire)
Premier Seed Nigeria Ltd. (Nigeria)
Mahyco Seed Ltd. (India)
ICRISAT Sahelian Center/Niger
C.TRA.P.A. (Burkina Faso)
ICRISAT/WCA (Nigeria)
ROCAFREMI (Niger)
Ministry of Food & Agric. (Ghana)
Mahindra Hybrid Seed Co. (India)
PASP (Niamey)
ANNOYER (Burkina Faso)
Ministry of Agriculture (Namibia)
Care Intl. (Niamey)
SADC/ICRISAT/SMIP (Bulawayo)
World Vision Int. (Ghana, Mali)
AGRIMEX (Niamey)
Rockefeller Foundation (Kenya)
USAID/REDSO/ESA (Nairobi)

Partial funding support was also provided by the West African Regional Sorghum (ROCARS), Millet (ROCAFREMI) Networks and ICRISAT.

A second workshop activity during the spring of 1999 was a training program conducted at the ICRISAT Sahelian by Lee House and Issoufou Kapran. Training was on elements of hybrid seed production for INRAN and World Bank technicians in Niger. This activity was very useful and productive during the growing season and was repeated in the Spring of 2000. A practical training manual on hybrid seed production in Niger was prepared in English and French.

There are several interdisciplinary activities involved in this program. These include sorghum and millet breeding, agronomy, pathology, physiology, food quality, and economics. U.S. INTSORMIL Principal Investigators and their INRAN collaborators develop research plans on an annual basis. The host country collaborators then submit a preliminary budget which is then incorporated within the total country program in consultation with the INRAN country coordinator. The request is then reconciled with the INTSORMIL allocation.

Sorghum/Millet Constraints Researched

Production and Utilization Constraint

Drought, insect pests, long smut and *Striga* are the major constraints in Niger. Extremely high soil temperatures lead to difficult problems in crop establishment. Sand blasting of young seedlings is also a complicating factor. Plant breeding for tolerance to these major constraints is one of the most feasible solutions. New cultivars must be acceptable for couscous and tô preparation.

Research Methods

Research methods appropriate for each of these disciplines are used for this research program. Regional scientists in these disciplines are involved in collaboration as appropriate, (i.e., Steve Mason and Wayne Hanna in Burkina Faso) and Nigeria with National Program Staff in these countries and with Dr. Gupta at ICRISAT in Kano, Nigeria.

Examples of Research Progress

Cereals Quality and Utilization

Principal Investigators - Mr. Moustapha Moussa, Food Chemist, INRAN, Niger; Drs. B. Hamaker and Adam Aboubacar, Department of Food Science, Purdue University; Dr. Moussa Oumarou, Chemist, Mr. Kaka Saley, Food Technologist, Dr. Issoufou Kapran, Sorghum Breeder, Mrs. Ramatou Seydou, Food Technologist, Dr. Jupiter Ndjeunga, ICRISAT, Niger

Research Approach

Couscous, a very popular food in Sahelian West Africa is prepared from sorghum or millet flour that has been agglomerated, steamed and dried. Couscous is usually consumed with milk for breakfast or with sauce or stew for the evening meal. In Niger although couscous is consumed by the majority of the population, no commercial sorghum or millet couscous are available. In urban areas, imported wheat-based couscous is commonly bought.

The non-availability of appropriate processing technology of sorghum/millet, the recent devaluation of the CFA, the progressive urbanization, the newly approved free trade agreement in West Africa, and the possibility of processing quality sorghum/millet flours are reasons that should motivate the creation and production of adequate sorghum/millet processing technology.

With INTSORMIL's financial assistance a small processing unit has been initiated at the INRAN cereal lab for research, demonstration and testing. The unit consists of an agglomerator/siever designed by CIRAD (France), a couscoussier (Nigeral-Niger), food mixer (Kenwood electronics), a decorticator/mill (URPATA, Senegal), a solar dryer (ONERSOL, Niger) and sealer for packaging.

The overall objective of this project is the production and commercialization of value-added millet and sorghum products with particular emphasis on utilization of locally and/or regionally fabricated food processing equipment. The specific objectives are to 1)optimize the couscous agglomerator. The rationale is to increase couscous yield and improve couscous particule size; 2) improve the quality of the flour by using modern decortication and milling techniques; 3) Increase the capacity of drying the couscous; 4) Initiate a marketing test for the couscous; and 5) transfer of the technology to beneficiaries.

Research Output (1996-2000)

The first survey conducted by the cereal lab of INRAN on traditional processing of millet/sorghum couscous revealed that color and texture are the most important attributes that determine consumer acceptability of couscous.

Since 1997 there were two studies on sorghum and millet couscous using the existing processing equipment at the cereal lab. Flours from two sorghum cultivars (NAD-1 and Sepon 82) and two millet cultivars (HKP and Souna III) were used. Two studies were conducted; the first, on the influence of flour-to water ratio on couscous granule size distribution, and the second on the effect of grains fermentation on couscous color.

Decortication and milling were carried out manually. Decorticated grains were fermented for 48 hours at ambient temperature with water. Mixing of flour/water was done with a food mixer and granulation was carried out with the agglomerator/siever adjusted at 36 rpm. A cooking stove using butane as fuel with a couscoussier were used to steam the couscous for 30 min., and a solar dryer was used to dry the couscous for 48 hours.

The study revealed that the optimum amount of water used to hydrate flour whose particule size range between 0.2 to 0.5 mm varied from 60 to 72% for sorghum cultivars and 45 to 55% for millet cultivars. The result indicated that the particle size of the couscous is strongly influenced by the amount of water used for agglomeration and by cultivar type. By controlling the hydration of flour agglomeration, couscous of desired particle size (1 and 2 mm) can be produced and marketed separately. The fermentation test carried out was found to considerably improve the color of couscous from millet cultivars and Sepon 82, whereas it has little effect on the color of NAD-1 couscous. This study also revealed the possibility of processing sorghum/millet couscous. Efforts will have to be made to optimize the efficiency of the processing equipment and complete the product development. This year the couscous unit is now complete with the addition of a commercial-scale abrasion type electrical decorticator with a treatment capacity of 250 kg of grains/hour and electrical hammer mill with capacity of grinding 300 kg of decorticated grains/hour. A large scale-size solar dryer (50 kg/day) was constructed at the cereal lab. The agglomerator conditions and settings have been optimized to increase output to approximately 40 kg/hour.

Sorghum hybrid NAD-1 grown at two different periods at the breeding station of Tillabery under recommended cultural conditions have been studied for their couscous making ability. In this study the effect of flour extraction and hydration on couscous yield and color were monitored. Dry decortication has been carried out at various flour extraction level (60, 65, 70, and 75%) according to time using an abrasion-type decorticator having eight abrasive discs rotating at 1420 rpm. A hammer mill machine having six hammers rotating at 3000 rpm has been used to grind the unwashed and washed decorticated grains to flour of desired particle size (0.2-0.5mm).

After mixing flour with water, agglomeration, steaming and solar drying with the processing equipment, various samples of couscous were obtained. We observed that optimum fine couscous yield particle size = 1mm was obtained from 60 to 70% flour extraction at an approximate hydration of 61to 66%. Acceptable medium couscous yield particle for both sowing dates. These values obtained, confirmed the findings of 19 97-98. We also observed an improvement of couscous color from washed grains of both sowing dates. This may be due to the complete removal of bran after washing. This observation agreed with the recent study made on sorghum flours where suggested optimum ash content to obtain good quality flour was about 1%. From our study this value was obtained from washed grains of both sowing date between 60-70% flour extraction.

Moisture content of the dried couscous varied from 6-9%, value that may confirm the efficiency of the new solar dryer constructed by the couscous research team.

Current Research (2000)

This year good quality NAD-1 seed was used to produce 700 kg of very nice and consistent quality sorghum couscous that may compete with maize and wheat-based couscous. A marketing study will be initiated, to learn about the consumer acceptability and the potential market for processed sorghum couscous. The plan is to administer the couscous and a questionnaire to selected households to learn about the acceptability of the couscous and also to develop a proper stratification of the products into market segments that are substantially different from one to another with the collaboration of agro-economists, food processors, distributors and NGOs.

Expected Impact

By the end of the year we expect to complete the marketing study, the optimization of the processing equipment and to obtain a quality sorghum/millet couscous which could produce impact by 1) creating additional market for grain; 2) act as driving force for adoption of sorghum and millet hybrids; 3) generate income through entrepreneurial activities.; and 4) reduce import of wheat-based couscous and maize.

Other Collaborative Research Work

In collaboration with Dr. Jupiter Ndjeunga, Agronomist at ICRISAT, consumer preference was evaluated for different millet couscous/Tô characteristics using co-joint analysis methodology. Results support that product taste, color, and textural attributes are important. Increased demand for processed products requires investment by food processors in physico-chemical characterization of varieties to determine their suitability to specific processed products or develop products that would include traits preferred by consumer.

Sorghum Breeding/Hybrid Seed Activities (1996-2000)

Principal Investigators -Dr. Issoufou Kapran, Habou Kano, Siraji Moumouni, Sabiou Mahaman, Dr. Issaka Mahaman, Illa Bawa, Moussa Oumarou, Dr. Lee House, Dr. D.T. Rosenow, Professor D.Andrews, Dr. B. Hamaker, Dr. John D. Axtell and Dr. Gebisa Ejeta.

Background

Sorghum is a staple food crop in Niger. Together with pearl millet it contributes 75% of the total caloric intake of the population. On average 85% of total production is consumed directly and the remaining is sold on local markets. Sorghum acreage has increased steadily from less than half a million hectares in 1961 to more than two million hectares of essentially dryland in 1999. Grain yield declined from 0.6 t ha^{-1} to 0.2 t ha^{-1} during the same period. Sorghum production in Niger is severely limited by biotic and abiotic stresses including drought, poor soils, insect pests (especially midge and headbugs), diseases including long smut, and *Striga*. The Institut National de Recherches Agronomiques du Niger (INRAN) has overall responsibility of agricultural research in Niger. A long term strategic plan for research in Niger was prepared and published by INRAN in 1998. For rainfed crops the objective is to increase and stabilize production to cope with demand from a fast growing population. This is sought mainly through significant yield increases. For sorghum and millet, emphasis is placed on technology transfer, development of varieties with better yield stability, and plant protection. For most of the 1996-2000 period, a World Bank project was the major source of funding for the sorghum improvement activities at INRAN. INTSORMIL support to sorghum improvement was significant in terms of human resource enhancement and vision for technologies that can be transferred and adopted by farmers and other end-users. This was especially the case for NAD-1 hybrid seed production. Activities conducted during the 1996-2000 period are described under the four categories that follow.

Ph.D. Training

With support from INRAN, INTSORMIL, the McKnight Foundation and the Rockefeller Foundation, Issoufou Kapran was trained at Purdue University (1993-1998). For his thesis research, Kapran worked on the genetics of maturity, a critical trait for sorghum adaptation. He used the tools of DNA marker technology to identify genetic loci for plant maturity, height, and grain yield in two sorghum populations. The summary of his thesis follows:

Maturity is a critical trait for better adaptation and productivity of sorghum (*Sorghum bicolor L. Moench*) in stress environments where this crop is usually grown. Despite accrued knowledge of how genotypes with different maturity respond to environments, breeding efficiency is still limited by poor characterization of individual quantitative trait loci (QTL) affecting this trait. The objective of this research was to identify factors of sorghum maturity through DNA marker association, and to determine their relationships with other important agronomic traits. The 10% earliest and 10% latest maturing sorghum lines were identified in FGxM90812 (Cross 1) and MmxSepon72 (Cross 2). Parents and progeny were evaluated at one temperate location in the USA and six semi-arid tropical locations in Niger. For each cross maturity (days to anthesis), plant height, and grain yield data were statistically analyzed considering six alternative groupings of locations. Genetic variability for maturity and plant height was high. For grain yield however there was significant genetic variability only in Cross 2 under rainfed conditions of Niger. Seventy-three random amplified polymorphic DNA (RAPD) and six simple sequence repeat (SSR) markers in Cross 1, and 62 RAPD markers in Cross 2, were used in single marker analyses. In Cross 1, 17 of the 79 markers (22%) detected maturity loci with stable expression across environments. Most of these markers also identified plant height factors in all environments, but grain yield and maturity were related only when the temperate location was included. In Cross 2 four markers out of 62 (6%) detected maturity factors in all environmental settings. In this cross, maturity influenced plant height and grain yield especially under rainfed conditions in Niger. A set of 121 recombinant inbred lines (RIL) independently developed from Cross 1 was used to confirm association of six of the above DNA markers with maturity factors. Four RAPD and two SSR collectively explained 47% of the phenotypic variation for maturity in the RIL. They mapped to one genomic segment defining the position of a putative QTL for maturity in sorghum.

The program was organized in such a way to allow Kapran to make two trips a year in Niger to supervise the breeding program and other on-farm activities, which are described below.

On-farm Variety Trials (Hybrids, New Striga Lines)

Although NAD-1 and other improved varieties were demonstrated to farmers across sorghum growing areas, on-farm yield data were not systematically collected. To create a more substantial database a trial was designed to check the extent of NAD-1 superiority over locals under as diverse conditions as possible with farmer management, and assess its area of best performance. A second hybrid with better grain quality, NAD-3 (ABON34xMR732), was included after it showed good yield potential on-station. Independently of farmer choice of variety check (different in each location), the local variety Mota Maradi (MM) was always used as an overall check because of its wide adaptation in Niger. After harvest farmers organized their production in relatively identical bundles tied with ropes. Yield estimates were obtained by threshing and weighing a single bundle and multiplying by the number of bundles. Mean yields for 1995, 1997, 1998, and 1999 are presented in Table 1. NAD-1 yield superiority over local checks varied between 24% and 96%. It is particularly interesting to note that on-farm yields where no fertilizer inputs were provided to farmers were in two years out of four, close to the long-term average of 3 t ha^{-1} obtained for NAD-1 on station. Data range for each cultivar showed that extremely poor conditions as well as extremely good conditions could exist on-farm. Indeed the trial was often conducted outside the boundaries of agricultural land (northern Niger) so that the extent of cultivar adaptation could be identified. Although NAD-1 maturity did not fit those areas the hybrid usually produced at least as well as the local. On the other hand, excellent yields were obtained in areas of better farming (southern Niger). Farmer ranking of varieties usually put NAD-1 on top because of visible yield potential, adaptation to light or heavy soils, and in some cases reported tolerance of midge or *Striga*. The performance of NAD-3 was not as good as that of NAD-1 and sometimes less than the local checks. This hybrid was selected because tan plants in both parents (to surmount the loss of quality observed in NAD-1 grain under heavy rains and insect infestation), and also because its seeds were easier to produce (better nicking of parents). Unfortunately it seems to have stand problems especially on poorly-managed farms, which results in reduced yield. Its maturity is also slightly on the late side of NAD-1 which is a disadvantage in Niger. These results led us to reconsider the option of replacing NAD-1 with NAD-3 and pursue the evaluation of experimental hybrids for better material.

Striga is a serious constraint to sorghum production especially in the Maggia zone (Konni to Madaoua) where sorghum is intensively grown as sole crop. Previously, variety SRN39 was successfully identified as *Striga* resistant through this program. However, its yield potential was not

Table 1 On-farm mean yields of grain sorghum hybrids in Niger.

Year	Cultivar	Grain yield (kg ha^{-1}) Range	Mean	% check mean
1995	MM	85-6600	1030	100
	NAD-1	38-7000	1562	152
1997	CHECK	5-8333	1411	100
	MM	20-10333	1252	89
	NAD-1	20-16000	2721	193
	NAD-3	12-5333	1447	103
1998	CHECK	125-3933	1201	100
	MM	183-6333	2485	207
	NAD-1	128-6500	2355	196
	NAD-3	100-5067	1401	117
1999	CHECK	567-2000	1215	100
	MM	767-2400	1399	115
	NAD-1	793-2800	1503	124
	NAD-3	533-2133	1053	87

good and it has a high susceptibility to grain weathering in Niger. The opportunity to test new *Striga* resistant and higher yielding varieties was offered with the development and release of eight new lines by the program at Purdue University. The eight lines (P9401-P9408) were tested for two years at the Moulela irrigated perimeter near Galmi, where striga is endemic in farmer fields. Field observations and plant counts showed clearly that the new lines were highly resistant compared to local Mota Galmi (MG) and the positive effect of nitrogen fertilizer on reduced *Striga* effect was confirmed. Unfortunately it was not possible to show a significant impact on grain yield. Still farmers themselves selected two of the eight lines (P9401, P9407) which are currently being tested in other *Striga*-endemic zones and using in hybrid combinations with elite female parents.

Hybrid Seed Research and Initiation of Private Production in Niger

Starting in 1995, a major step was taken in the production of hybrid seed (NAD-1), in that INTSORMIL agreed to help promote a stable seed production in the private sector. Dr. L. R. House was contracted by the Niger/INTSORMIL country program to help evaluate the progress of the hybrid breeding program and propose strategies for the supply of good quality seed to farmers in Niger. Based on the premises of enough land being devoted to sorghum, the existence of a high yielding hybrid that is recognized by farmers, feasibility of seed production for the hybrid, the challenge was to identify highly motivated private individuals or farmer groups that can produce and market hybrid seed. NAD-1 seed production has gone through a positive evolution since, and many aspects are still evolving: Table 2 illustrates progress in NAD-1 seed production.

Table 2. NAD-1 seed production in Niger

Year	Producer	Type of seed	Total seed produced (kg)
1995	INRAN	dhybri	700
1996	INRAN	hybrid+parents	1,400
	Private	hybrid	minimal
1997	INRAN	hybrid+parents	2,813
	Private	hybrid	4,288
1998	INRAN	hybrid+parents	4,000
	Private	hybrid	7,000
1999	INRAN	hybrid+parents	4,500
	Private	hybrid	7,500

Qualitative Changes Have Occurred

- there is more hybrid seed available in Niger than ever before, although quantity is still small compared to actual needs and requests;
- hybrid seed is now sold instead of being given away for free, which serves to establish an economic basis for seed production;
- more seed is produced by private individuals or farmer cooperatives while INRAN is reducing its production;
- areas of better seed production have been identified: Tillabery is ranked first on the basis of availability of good soils and irrigation water, semi-arid climate for better seed quality, relative easiness to access, virtual absence of any of the major sorghum pests (midge) and weeds (*Striga*), and existence of a nearby plant for seed cleaning and storage (Lossa seed farm);
- INRAN is able to produce large quantity of parental seed for emerging private seed producers to acquire;

- some crucial equipment was purchased including small tractable seed cleaners, light irrigation pumps, bird nets for off-season seed increase;

- training in techniques of seed production received high priority and a manual has been written to that effect;

- INRAN has created a seed unit to help with foundation seed production and management, and help private seed producers become better professionals;

- a regional workshop on sorghum and millet hybrid seed was successfully organized in 1998;

- a seed trade association was started in 1999 by a group of mostly NAD-1 seed producers.

Current plans focus on increasing the availability of NAD-1 seed through contracting with farmers at selected sites (Tiaguirire near Kollo, Galmi and Moulela near Konni, Jirataoua near Maradi, and Diffa). Private seed producers benefit from INRAN's technical support for their own activities. Problems, however, remain to be solved.

The takeover from INRAN to private seed producers is slow. Some constraints include lack of startup funds which limits producers' capacity to use good farm machinery and/or chemicals. Land and water management appear to be a serious issue with most producers, ultimately leading to low seed yields and little profit. Support in this area will be needed. The other critical issue is that of seed quality, starting with harvest, drying, packaging and storing under good conditions. Small farmers with interest in seed production are the most handicapped by these problems; however, in many cases they would be useful as contract producers for bigger producers such as the ones organized in the seed trade association.

Germplasm Introduction and Evaluation for Cultivar Development and Release

Activities initially were organized around germplasm conservation and observation nurseries. In this period, one of the breeding lines introduced from Purdue was released as open pollinated variety 90SN7 (P967083xSEPON72). 90SN7 was ranked overall No.1 in the West and Central Africa Sorghum Network trial in 1997. The major threat was however the need to identify new hybrids to replace NAD-1 whose value was seen as mostly educative of the expression of heterosis in a Sahelian environment. NAD-1 has limitations because of weathering susceptible under high rainfall and not early maturing for some of the dryland area. Added to this, its seed production requires staggered planting in most cases because the two parents have different maturities; this is not easy to work out especially for beginning seed producers. Our major objective was to select new hybrids based on quality, feasibility for seed production, and performance. The hybrid described as NAD-3 (ABON34 × MR732) was our first choice: it is produced by crossing two tan plants, has a higher yield than local checks on station (NAD-3=3.0 t ha^{-1}; MM=2.7 t ha^{-1}; MG=2.2 t ha^{-1}); but NAD-3 is not as good as NAD-1 (3.6 t ha^{-1}) and was even later maturing. Its performance under farmer conditions was also less convincing as noted above. We concluded that NAD-3 has a high potential mostly under good farming conditions.

In a more systematic fashion, large sets of F1 hybrids as well as potential R lines and seed parents were produced at INRAN stations (Tillabery, Lossa, Kollo, Maradi), or introduced from Purdue University, Texas A&M University, and University of Nebraska-Lincoln starting in 1997. A limited set of 58 A lines and 65 potential R lines was prepared and tested for adaptation across several locations. In addition at Lossa an early planting were used to detect weathering susceptibility in the material. This approach allowed us to put different lines in different maturity groups for making all possible crosses. This resulted in identification of some excellent potential parents that we are currently using in developing various experimental crosses (Table 3).

Table 3. Elite lines identified as testers

Identification	Maturity group (days to flowering)	Source
	A Linces	
P9511A	61-65	Purdue
AHF8	66-70	TAMU
P9526A	71-75	Purdue
223A	76-80	Nebraska
	R Lines	
97M10522	61-65	Nebraska
Macia	66-70	TAMU
SEPON82	71-75	INRAN/Purdue
MR732	76-80	INRAN/Purdue

Nurseries were open for visits by seed producers to expose them to available genetic variability and get their observations on most advanced materials. A few crosses have so far been selected for wide testing in hope of rapid replacement of NAD-1 hybrid.

Mutuality of Research Benefits

Use of drought tolerant materials from West African countries, including Niger, have been used extensively by the private and public sectors in the US. The principal benefit to Niger will be an efficient and productive research program at INRAN through training and collaborative research activities of INRAN staff. Extensive research accomplishments by INRAN scientists are presented in the Research Accomplishments of this report.

Institution Building

The Cereals Laboratory at INRAN has now been fully equipped to optimize the quality of the flour to ultimately improve the quality of the couscous. In addition, a laptop computer, overhead projector and other research materials were purchased in support of the program.

When INTSORMIL first began collaborative research relationships with INRAN there were relatively few highly trained Ph.D. level scientist in their organization. Over the past 16 years this situation has changed dramatically within INRAN. INTSORMIL has played some part through training and through collaborative research efforts in the institutional development of INRAN. INTSORMIL scientists have also grown during this period in terms of their collaborative research capabilities in sorghum and millet research and technology. The collaborative research relationship now is an effective system for delivering excellent research and for the application of this research for the benefit of farmers in Niger and in the USA. INRAN now has excellent leadership, excellent scientific direction and excellent scientists, either fully trained or in the final stages of their M.S. or Ph.D training programs. They now have a critical mass of excellence in research capability for the agricultural sciences. When one looks at progress in institutional developments over a longer time frame, it is easy to be optimistic about the future of INRAN/INTSORMIL collaborative research.

In 1996-2000, 25 U.S. PIs and INRAN trainees traveled to Niger.

Currently, there are two Nigerien students being trained in U.S. institutions. They are Abdoulaye Tahirou, Ph.D agricultural economics, at Purdue University and Mamame Nouri, Ph.D agronomy, University of Nebraska.

Networking

The major constraint for adoption of new technologies in West Africa is the lack of a viable seed industry to deliver elite genetic materials to the farmers in a timely fashion and at a reasonable cost. A major contribution of INTSORMIL was a West African Seed Production workshop held in Niamey September 27 to October 2, 1998. This highlighted the important contribution that can be made by a seed industry and offered opportunities for West African countries to share experiences. One of the major foci of the meeting was hybrid seed production for sorghum and millet as well as other crops. Extensive collaboration with ROCARS, ROCAFREMI, ICRISAT, and World Vision, and included many organizations participating in the workshop. Since then, a Farmer Seed Producer Association has been set up for hybrid seed production.

Research Accomplishments

Entomology

Principal Investigators - Mr. Hamé Abdou Kadi Kadi, Drs. Ousmane Youm, Frank E. Gilstrap, George L. Teetes, and Bonnie B. Pendleton

Description of the Collaborative Program

The research program is a collaborative effort between Texas A&M University entomologists through INRAN, INTSORMIL, and ICRISAT-Niger. The research activity on Laboratory Life-Fertility Table Assessment and Field Biology of Millet Head Miner (Lepidoptera: Noctuidae) in Niger was part of the requirements for the Master of Science Degree at Texas A&M University. The principal objective of this research was to use life table analysis of data collected in the laboratory to assess the effects of temperature and diets on millet head miner abundance and capacity for increase. Field studies of millet head miner biology were conducted to support results obtained from laboratory experiments.

During year 18 and 19, Dr. Gilstrap, Texas A&M University, provided leadership for this research. Financial support from Texas A&M/Entomology (TAM 125-B/225-B project) was used to conduct laboratory and field experiments on millet head miner. Dr. Youm, ICRISAT entomologist, and Dr. Owusu E. Ebnezer, Post-doctoral Research Scientist provided support, advice, and allocated the research facilities (field, laboratory equipment, and supplies) and other local support needed.

During 1999-2000, activities were concentrated on finalizing the academic studies to fulfill the requirements for a Master of Science degree at Texas A&M University. A thesis was written and defended on July 15, 1999. Since his return, Kadi Kadi was assigned as Entomologist at the CERRA at Maradi.

Millet Constraints Researched

Introduction

Pearl millet, *Pennisetum glaucum* (L.) R. Br., is planted each year on 12 million hectares in western Africa and annually produces 9.6 million tons. Millet production accounts for >30% of the total agricultural production in most of the Sahelian countries. Millet production comprises ≤53% of agricultural production and <75% of all cereal food produced and consumed in Niger (FAO and ICRISAT 1996). Millet head miner, *Heliocheilus albipunctella* de Joannis, has been the major pearl millet insect pest since 1972-1974. Young larvae cut and feed on flowers and perforate glumes of pearl millet. Late-instar larvae bore and create tunnels under the kernels on pearl millet spikes.

Different management tactics were tested, including cultural and chemical controls, to reduce damage by millet head miner in West Africa. However, most management tactics are impractical or expensive. Therefore, finding alternative strategies are important for managing millet head miner in the Sahel.

To reduce damage in Niger and other Sahelian countries, more research is needed on millet head miner biology and assessment of natural enemy impact on millet head miner abundance. One way to understand millet head miner biology better is to assess life table parameters (fecundity, survivorship, birth and death rates, etc.) calculated by using standard life table construction and analysis techniques. This understanding could help in devising management strategies and enable scientists to evaluate the feasibility of cultural management methods (e.g., removal of eggs from millet spikes, hand picking of larvae, etc.) and their effects on abundance of this insect pest.

Results and Discussions

Laboratory studies: Cool and warm temperatures tended to increase and decrease, respectively, survival and fecundity of millet head miner cohorts. An apparent difference was noted for number of days required for eggs to hatch at cooler (fewer days) and warmer temperatures (fewer or more days). More individuals of millet head miner cohorts survived when fed Bio-Serv® than any of the millet-based diets. Developmental times from eggs to adults were longest (51.1-55.4 d) when millet head miner cohorts were fed Bio-Serv® diet and shortest (40.2-50.2 d) when fed soft-dough millet diet. Percentages of survival from eggs to adults were greatest when millet head miner cohorts were fed Bio-Serv® diet, 2.4-5.4%. Survival to the adult stage was lower, 1.3-2.6, 1.1-2.9, and 0.0-2.3%, when millet head miner cohorts were fed soft-dough, middle-flowered, and early exerted millet diets, respectively.

Temperature influenced population increase of millet head miners fed Bio-Serv® diet. The best temperature to rear millet head miners fed Bio-Serv® diet could be 28 or 30°C because percentages of survival from eggs to adults were 3.5 and 5.4, respectively

Suitability of food and environmental conditions affected fecundity and development of millet head miner in the laboratory and field. Fecundity of millet head miner was 2-4 time greater when abiotic conditions were controlled in the laboratory than when abiotic and biotic factors influenced fecundity in the field. Millet head miner in the laboratory survived best when fed Bio-Serv® diet at 30°C (5.4%), but 51.1 days were required for development to the adult stage. Eleven fewer days were required for millet head miner to develop from eggs to adults when fed soft-dough millet diet at 24°C in the laboratory, but survival was only 2.6%. More prepupae and pupae developed but more days were required for development on spikes of pearl millet planted in June than later. Manipulation of planting date could be a recommended management tactic to reduce survival and damage by millet head miner in the Sahel.

Economics

Principal Investigators - Tahirou Abdoulaye and John Sanders

The principal activities continue to be the economic analysis of new technologies in the Sahelian countries, especially Mali, Senegal, and Niger. The program interacts with IER, INSAH, INRAN and ISRA in this process so that the results will be more accessible to researchers and policymakers. Also through this collaboration, the program can give better direction to priority research activity.

Presently, there is concern with the input and output markets. Hence, in Mali, Senegal, and Niger, a principal focus of our research is on the utilization of inorganic fertilizers on the cereals. The impact intended is for these countries to recognize the necessity for inorganic fertilizers and to improve their policy support for improved fertilizer markets. This will clearly make a big difference on cereal yields and the introduction of new cereal cultivars.

Similarly, the program has become involved in some marketing and price-stability issues since they have been identified as critical factors in new technology diffusion from both modeling and fieldwork. Specifically, a major factor in historic consumption shifts between cereals in the Sahelian countries is government policy distortions; some of these are now being removed.

Another research focus has been on the changes in consumption patterns of the principal cereals. This is an important concern for sorghum and millet because some have argued that these are inferior food commodities which will be displaced by wheat and rice as incomes increase. However, there is evidence that as the distortions from previous policies toward food imports are taken off, that there is some recovery in the consumption of the traditional cereals. Calling the attention of policymakers to the continuing importance of traditional cereals is an important aspect of our work

During the past year Sanders has become involved in a study for IGAD/INTSORMIL analyzing the introduction of new technologies into the semi arid zones of six Horn of Africa countries. One fundamental message of the IGAD/INTSORMIL study is the neglect in these countries of the network connections with other scientists working in the drylands so that the rate of new cultivar introduction seriously lags and is not responding to the emerging biotic constraints.

Senegal has income levels per capita about three times those of other Sahelian countries and so serves as a model for what will happen as the other Sahelian countries develop, in various forms. Also, the intensive poultry industry is rapidly becoming more important but still with the base of imported maize. Cooperatives of millet producers could exploit this potential demand if they could guarantee quantity and quality. So a focus on new and expanding markets is clearly the emphasis in Senegal presently for the traditional cereal, millet. The economics program continues to evaluate developments in these new marketing channels to obtain better understanding of the directions of other countries as well as Senegal.

Lately this project has been involved with ASA and with IFDC. This has been very useful for learning more agronomy, and will have some impact on the economic analysis.

Tahirou Abdoulaye and Sanders spent two weeks in 1998 reviewing the seed production program for a new hybrid sorghum being promoted there. They visited several regions in Niger and talked to farmers and scientists. Tahirou did a report on the economics of seed production. He is presently working with ICRISAT scientists Andre Bationo and Jupiter Ndjeunga on his Ph.D. dissertation on the economics of fertilizing millet in Niger.

Tahirou presented a paper entitled "Farm Level Profitability and Input-output market Evolution: Economic Perspective: at the Regional Hybrid Sorghum and Pearl Millet Seed workshop,Niamey, Niger, organized by INTSORMIL, INRAN and ICRISAT from 09/28/98 to 10/02/98.

The paper examined the effects of the economic environment (prices of inputs and outputs) and the ability of the farmer to finance input purchases on the adoption decision of the new hybrid. It was suggested that:

Hybrid sorghum technology is profitable and expected to be adopted by farmers on rainfed and irrigated areas. Improvements in economic conditions will increase diffusion of hybrid sorghum technology. Strategies to offset seasonal price collapses after harvest and to moderate the price declines resulting from good weather or improvement in input markets (seed and fertilizers) are critical. Also improvements in the infrastructure can have similar effects. Better access to markets, farmer management practices (storage) or increased demand for sorghum through research on new uses (processing, industry) can give farmers better prices for their outputs. Storage opportunity costs may be high for most farmers if they are pressed to repay loans or to make urgent purchases immediately after the harvest. For diffusion of hybrid technology to be sustained, input markets (seed and fertilizers) need to be well developed. Farmers often complain about the availability of necessary inputs. Farmers need access to fertilizers and seed for production of NAD-1. The private marketing sector needs to make seed and fertilizers available at the village level.

Decision-makers often fear increases in basic food prices including cereals because of the burden this imposes on urban consumers. Because of the power of urban consumers, decision-makers often adopt policy measures, which reduce the prices of cereals. This type of action hinders the introduction of technological change in agriculture. Policy makers need to recognize the importance of a favorable economic environment for agriculture to hasten farm level investment and technological change.

Tahirou attended the Global Agriculture and the America Midwest: A win-win Exchange, conference organized by USAID and ISU from 03/18/99 to 03/19/99. The main objective of the meeting was to increase awareness about how foreign aid benefits the US also. He made a presentation, which identifies two types of benefits of the INTSORMIL program to host countries including research results and national research programs enhancement.

Tahirou's thesis research will focus on interaction between input-output market development and adoption of new millet and sorghum technologies in Niger. The research will focus on seed industry and new uses for millet and sorghum.

Agronomy-Millet

Principal Investigators: Mr. Nouri Maman, Drs. Botorou Ouendeba, Salvador Fernandez-Rivera, Mr. Moustapha Moussa, and Dr. Stephen Mason

In the semi-arid regions of sub-Saharan Africa with 800 mm and more annual rainfall, farmers use two types of pearl millet [*Pennisetum glaucum* (L.) R. Br.]: early maturing (Guero) and late maturing (Maiwa) in intercrop and sole crop. Contrary to Guero pearl millet, few studies on Maiwa pearl millet have been reported in Niger (Botorou, 1992, 1993, 1994; and Reddy et al., 1992). There is no specific recommendation from INRAN for farmers. New varieties of Maiwa actually tested with farmers. However, for better productivity, there is need for specific crop production practices including plant population, thinning and fertilizer application. Maiwa pearl millet produces more tillers than Guero pearl millet; that is why the recommended plant population for pearl millet in Niger is not appropriate for Maiwa since some of these tillers do not produce panicle. Farmers feed their animals with the stem of pearl millet as there is an increasing integration of crop production and animal husbandry. Pre-harvest of some tillers before plant maturity will provide more nutritive feed to animals and probably will improve the grain yield and quality. A two-year study will be conducted at Bengou INRAN station in 1998 and 1999 before going to the on-farm study.

Objective

The main objective of the study is to develop specific crop production practices for Maiwa pearl millet which takes into account the increasing integration of crop production and animal husbandry. To do so the intermediate objectives are 1) evaluate the effect of plant population on grain yield and quality; 2) determine the effect of pre-harvest of tillers on grain yield and quality; and, 3) determine the nutritive value of pre-harvest tillers as animal feed.

Pearl millet is generally grown on nutrient-poor soils and low rainfall conditions in Niger. Nitrogen and P accumulation and utilization are very important factors in pearl millet growth, and are affected by environment and management.

An understanding of seasonal N and P accumulation is necessary to improve pearl millet production. A two-year field study was conducted in 1995 and 1996 at Kollo with the objective to determine N and P concentration and accumulation by pearl millet as affected by variety and management level. Treatments were factorial combinations of three pearl millet varieties: 'Heini Kirei', a tall land race variety; 'Zatib', an improved tall variety; and '3/4HK', a short improved variety, with low management (10,000 hills ha^{-1} with no fertilizer) and high management (20,000 hills ha^{-1} with manure and N and P fertilizer application). Management level had no influence on N and P concentration even though N and P fertilizer and manure were applied. Variety influence was small and inconsistent. More N and P were translocated from the stem and leaves to the panicle in the higher rainfall year when grain yield was greater. The shorter variety 3/4HK had less N and P accumulation than the tall varieties which was likely due to less dry matter production. The average maximum total plant N accumulation for low management was 1.42 g N m^{-2} in 1995 and 0.62 g N m^{-2} in 1996, while for high management in either year, while grain nitrogen use efficiency was 17 g grain g^{-1} N higher with high with low management than with high management. The short, early maturing variety '3/4HK' tended to have lower N use efficiencies than the other varieties. Nitrogen and P accumulation, and grain N use efficiency was influenced more by management that N variety.

Agronomy – Sorghum

Principal Investigators - Seyni Sirfi and Jerry Maranville

The main objectives were (1) on-farm testing on the effect of tied-ridging and fertilization on sorghum growth and productivity in comparison with the traditional cultural practices, (2) determining the effect of ridging in combination with organic and chemical fertilizer on soil structure and texture, and (3) water and nutrients use efficiency of sorghum under these cropping conditions.

On-farm studies on nutrient use and ridges were conducted in Niger during the cropping seasons. Sites of the studies were located in three different agro-ecological zones (dry, intermediary and humid). The dry location, Tillakaina, has an average annual rainfall of 300 mm, while Konni, in the intermediate rainfall zone, received annually on average 400 mm of rain. Bengou located in the humid zone has usually an average rainfall of more than 600 mm. Two improved genotypes (NAD-1 and 90SN7) were compared to land race cultivars under improved and traditional sorghum cultivation. The improved cultivation consisted of ridges and tied ridges combined with 5 t ha^{-1} manure and 50 kg ha^{-1} urea. Manure was applied before planting at soil preparation, while urea was used at early growth stage. A randomized complete bloc was used where each producer was considered as a replicate and five replicates were planned to be installed in each location. Plots size was 4m x 8m and planting density was 41,675 hills (0.80 m x 0.30 m) with 0.80mm between rows and 0.30 n between hills. Three plants were left per hill after thinning. During the 1998/99 season the rainfall was at Tillakaina, the dry location, 456.7 mm in 31 days, while in Konni it was 398.5 mm in 29 days. Rainfall in the dry location was higher than the one received in the intermediate region in this cropping season. Trials were weeded twice and any major problem was observed during the growing period. Harvest was ended in October at Konni and in November at Tillakaina. Production of grain and stover of each plot was weighed to estimate the yield of these variables.

Analysis of variance (ANOVA) was performed only on the results of trials from Tillakaina, in the dry region and Konni, in the intermediate zone. Trials conducted at Bengou, in the humid climate, failed due to bad germination and development. Their results were not analyzed, therefore, they are not included in the report. In the dry location (Tillakaina), results of five trials were analyzed while in the medium site (Konni), results of four trials were used in the analysis, the fifth trial failed to produce. Grain yields for all the treatments and genotypes were much higher in the dry zone that in the medium rainfall one. But there was no significant difference in the dry zone or in the medium rainfall zone. No significant difference was observed in stover yields in both locations. The contrasting situation observed in grain yield could be explained by the fact that in the 1998 season, rainfall in the dry location was greater than the one obtained in the medium rainfall zone. Moreover, drought occurrence and severity appeared to be enormous in the medium zone than in the dry region of Tillakaina. Rainy season also was shorter in the medium location than in the dry location. The genotype NAD-1 produced the highest grain yield (2240 kg ha^{-1}) with tied ridges at Tillakaina. But at Konni its yield was only 432 kg ha^{-1} for the same treatment (tied ridges). Grain yields of the same genotype (NAD-1) at Tillakaina were not different between ridges (non-tied) and traditional cultivation treatments. They were estimated at 1401 and 1614 kg ha^{-1} for ridges and traditional cultural practices, respectively. At Konni, nonetheless, grain yields of NAD-1 were not only low but also decreased from the improved to the non-improved treatments. They were 432, 602 and 625 kg ha^{-1} for tied ridges, ridges and traditional culture. Grain yields for the local germplasm in the dry location looked stable and high in all the treatments. They were 1752 kg ha^{-1} for tied ridges, 2473 kg ha^{-1} for ridges and 2236 kg ha^{-1} for traditional culture.

Average stover yield for all the treatments in all locations were around 4500 kg ha^{-1} for most of the genotypes. Significant differences were not observed between treatments for this variable either in the dry or medium rainfall zone.

Results of the 1998 season were variable compared to those of 1997 in terms of grain and stover yield. In 1997, all locations, tied ridges performed better than traditional cultivation and genotype NAD-1 gave the highest yield. In 1998, however, the performances of genotypes were diverse and in some cases the traditional and the local varieties tended to be more productive than the improved. Due to that contrasting situation, it is difficult to make any conclusion about the results of the 1998 study.

Pathology

Principal Investigators - Issoufou Kollo Abdourhamane and Richard Frederiksen

Acremonium wilt (caused by Acremonium strictum) has become a serious disease of sorghum in the sorghum growing areas of Niger, particularly near Konni. Before the 1990s, the disease was a minor problem. However, with the introduction of improved cultivars and hybrids the disease has become a serious threat to sorghum production in that area. Although the disease is generally more serious on the improved cultivars there are cases where even the land races are severely attacked. This indicates that there are other factors besides A. strictum involved in the development of acremonium wilt.

The objective of the present study is to investigate the role played by plant pathogenic nematodes, especially Pratylenchus spp. Therefore, a nematicide trial was conducted in Niger in the area of Konni on a farmer's field where the disease is particularly severe. Two nematicides Furadan, and Counter were used. The nematicides were band applied at the time of planting and incorporated in the soil. Rates for Counter were 1.1, 2.2 and 3.3-kg a.i./ha. Rates for furadan were 2.0, 4.0 and 6.0 kg a.i./ha. The control plot did not receive a nematicide. One sorghum land race Mota and the hybrid NAD-1 were used. The experimental design was a factorial with 14 treatments in a randomized complete block replicated 6 times.

In order to estimate the preplant nematode population level, at least eight soil samples were randomly taken from each plot. The sample was thoroughly mixed to make a composite sample. From this composite, 250 cm3 of soil was taken for nematode extraction. Near harvest, the nematode population was estimated from soil samples and the number of Pratylenchus zea per gram of root was estimated. Disease incidence was estimated near physiological maturity. Yield and yield components were taken.

For the susceptible hybrid, NAD-1 the presence of nematode is not necessary for disease development. The high susceptibility of this hybrid to acremonium wilt is evident. With the land race Mota, the level of infection increases as the nematode number increases (R2=0.42). In the presence of nematodes, Mota becomes susceptible to A strictum. This experiment is being actually repeated in the greenhouse in Niger during the off-season.

The nematicide treatments did not significantly affect the incidence of acremonium wilt in either 1997 (which is a drought year) or in 1998. For Mota, stand establishment, the number of plants harvested and grain yield were significantly improved by the nematicide treatments. These treatments did not have any significant effect on the susceptible hybrid NAD-1.

In Niger, soils have generally low pH (4-5.5) and are very poor in nitrogen and other essential nutrients. Both soil pH and nitrogen are know to influence soil borne diseases. An experiment to study the effect of nitrogen form and lime on the development of acremonium wilt on sorghum was conducted at the Konni research station during the 1997 and 1998 cropping seasons. The hybrid NAD-1 was used. Two levels of limestone was used, 0 and 1 t ha^{-1}. Limestone was obtained form the Malbaza cement plant (40 km from Konni). The lime was powdered and sieved with a 60-mesh screen. Before planting, the powder was broadcast and thoroughly mixed in the soil. Two sources of mineral nitrogen, urea and calcium ammonium nitrate (CAN), and farmyard manure were used. CAN was used because KNO3 was not available in Niger. Mineral-N was applied at the rate of 69 kg ha^{-1} as urea or CAN. Manure was applied at the rate of 20 t ha^{-1} before planting and mixed in the soil. Both urea and CAN were also applied at the time of planting. The control plot did not receive any nitrogen. The factorial treatments were arranged in a randomized complete blocks with replications. Disease incidence was monitored and yield components were measured.

Stand was significantly improved by lime and nitrogen. The interaction between the nitrogen and lime was not significant. The control treatments had the lowest number of plants; the best stand was obtained with CAN. Although the wilt incidence was highest in the control plots differences were not significant at the 5% level (p=0.08 for the main effect of lime, and p= 0.11 for nitrogen). For the number of plants harvested, the interaction between lime and nitrogen was not significant at the 5% level. However, the effect of lime was significant and the effect of nitrogen form was highly significant. The control plots had the lowest number of plants harvested. Therefore, the ability of the plant to survive was increased by the addition of lime or nitrogen. CAN was better than urea or manure. For stover and grain yield, there was a significant interaction between lime and source of nitrogen. In the absence of lime, mineral nitrogen tends to decrease the straw weight. Whereas the straw yield was increased in the presence of lime. Manure in presence of lime reduced the stover yield. In absence of lime, urea tends to reduce the grain yield. Whereas liming without any nitrogen significantly reduced grain yield by about one third.

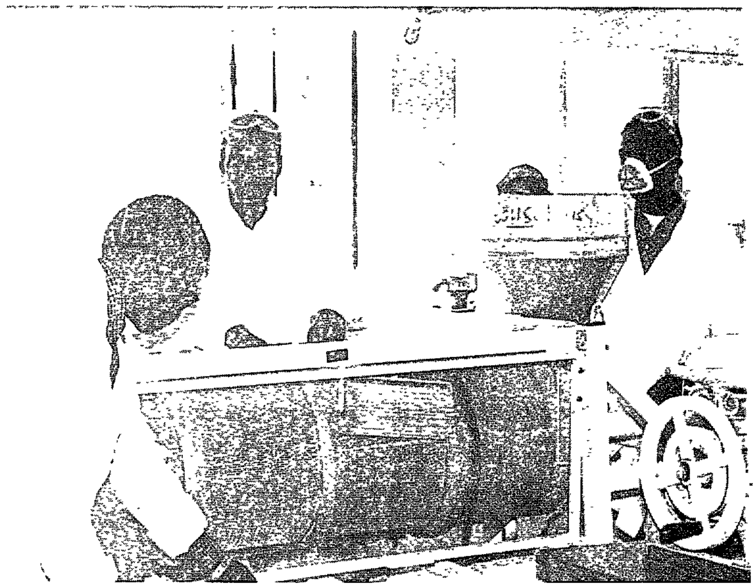
The data, indicated that urea might not be the most *suitable* form of nitrogen for sorghum. Liming may be important in managing soil borne diseases and to increase yield of cereals such as sorghum. This is important because Niger has huge deposits of lime and the agricultural use of lime is not known by many extension agricultural agents. The management of the cement plant in Malbaza is very much interested in knowing the potential of using lime for agricultural purposes.

Transformation Equipment
Local Cereals (Sorghum and Millet)

Decorticator

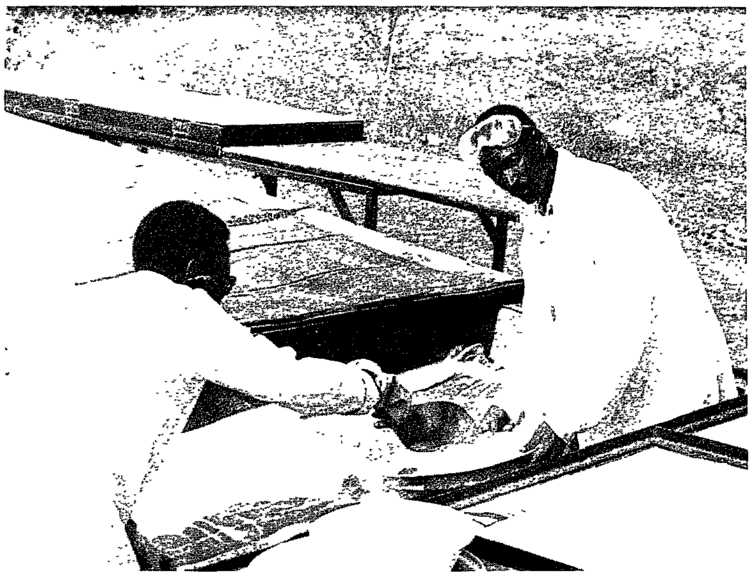
Mill

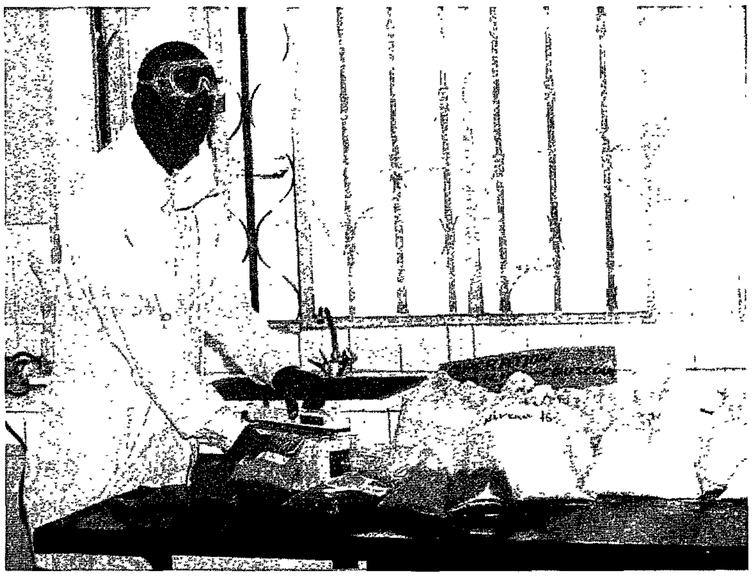
Mixer



Roller Agglomerator

Couscoussier





Dryer

Packaging

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

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Collaborative Program

Organization

During the last four years, INTSORMIL's collaborative research in the Southern Africa region has increased from 3 projects (breeding, pathology, sorghum food quality) to 6 (with the addition of entomology, market development and sorghum ergot studies), and through a Memorandum of Agreement with SADC/ICRISAT/SMIP the project has become fully integrated with regionally planned sorghum and pearl millet research. The MOU allowed INTSORMIL grant funds to be disbursed to collaborating NARS scientists, of which there are now 14 in 5 countries. Discipline scientists and the SMINET regional coordinator at the ICRISAT SMIP Center at Matopos, Zimbabwe are also involved. Due to INTSORMIL's previous management of a major post graduate training program for the Southern Africa region (25 Ph.D. and 50 M.S. students from nine countries completed their degrees), many of the collaborating scientists in Southern Africa are INTSORMIL trained and had INTSORMIL PIs as their major advisors. Activities in each project are planned annually in conjunction with NARS collaborators. Where SADC/ICRISAT/SMIP (called SMIP hereafter) has scientists in the research discipline, these are also involved. The plans are then reviewed at the SMIP annual Steering Committee Meeting to ensure they continue to fit in the profile of work needed on the development of sorghum and pearl millet production in the region.

Six research projects were being conducted in the Southern Africa region in 1999-2000. They were:

99-1 *Breeding:* Development of pearl millet R_4 top cross hybrids, using popular Namibian and Zambian varieties

99-2 *Pathology:* Disease management research, identification and use of resistance to sorghum diseases

99-3 *Food quality:* Sorghum food quality research

99-4 *Pests:* Genetic resistance to sugarcane aphid and integrated pest management in Botswana and South Africa

99-5 *Production and Marketing:* Identification of factors limiting commercial production and marketing of sorghum in Botswana

99-6 *Ergot:* Control of sorghum ergot

Financial Inputs

Following the finalization of the MOU in October 1998 with SMIP/ICRISAT, Matopos, regional funds were transferred and disbursement against planned expenditures commenced.

Collaboration with Other Organizations

Research on pearl millet and sorghum breeding is organized with NARS scientists in collaboration with the SMIP Technology Transfer program (now a regional organization - SMINET) at Matopos, Zimbabwe, which ensures complementarity to existing SMIP and NARS sorghum and pearl millet programs.

Grain quality research is collaborative with the University of Zimbabwe, University of Pretoria, CSIR (South Africa), Agriculture Research Corporation, South Africa, and SMIP. The CSIR has strong interactions with the private sectors in the region which will assist in transfer of information to help private entrepreneurs. Sorghum and pearl production constraints are being investigated with the Botswana College of Agriculture. Ergot research is collaborative with the ARC Summer Grain Crops Institute, Potchefstroom, RSA. Other projects operate directly with NARS governmental research departments.

The Planning Process

Research projects in breeding, pathology, entomology, and food quality were based on on-going linkages. Production and marketing, and ergot research projects were based on availability of regional expertise. The future program will be shaped by priorities decided by SADC/NARS (SADC = Southern Africa Development Community) and the availability of matching INTSORMIL scientists and funds. The INTSORMIL collaborative research in SADC will thus be developed as part of the SMIP Regional Research and Technology Transfer program (SMINET) to ensure full integration with other sorghum and pearl millet research and development projects in the region.

As of October 1999, donor funding for Phase IV of the SMIP program to ICRISAT at Matopos focused entirely on technology transfer, with no further crop improvement research. Since ICRISAT has no core funded plant breeders resident in the SADC area, INTSORMIL's continued participation in regional collaborative crop improvement research is now regarded as essential by SMINET.

Sorghum and Pearl Millet Constraints Researched

Production and Utilization Constraints

Sorghum and pearl millet are major food crops in the SADC region. Sorghum is also used to make opaque beer. Sorghum is the major cereal in Botswana and parts of Zambia, Mozambique, Malawi, and Tanzania, and pearl millet is the major cereal in Namibia and parts of Tanzania, Mozambique, Zambia, and Zimbabwe. Most of the usual constraints associated with low resource agriculture are present. These include low yield potential, infertile soils, variable moisture availability, numerous pests and diseases, and poor market facilities. Genetic improvement can economically address some of these constraints by increasing yield levels and matching grain qualities to meet end-use requirements. However, market channels still need improvement since there are sorghum varieties with the required quality to meet commercial consumer requirements, but production has been inconsistent. The availability of a consistent supply of improved quality sorghum and millet for processing into value added urban products is a major problem limiting utilization. Food companies can use but cannot consistently acquire sufficient quantities of high quality sorghums for processing. A strong need exists for developing a system of identity preserved production, marketing, and processing.

New varieties and hybrids with increased yield potential, drought tolerance, or other desirable traits are being developed by national programs, and other sorghums are continuously being introduced into various SADC regions. It is imperative that all improved cultivars have the required levels of resistance to major endemic disease pathogens and pests along with adaptation to environments present in given regions where they are intended for production.

Identification of regionally-adapted sorghum with stable, multiple disease resistance will help the NARS sorghum improvement teams in their development of lines, varieties, and hybrids for the diverse environments and sorghum production systems in each country and throughout similar environments in the SADC region.

Sorghum ergot is prevalent through the region and may be severe in hybrid seed production fields. Research on control involves the use of genetic resistance, location, time of planting and possibly chemicals.

Constraints Addressed by Project Objectives

Breeding: Raise grain yields by developing A_4 CMS pearl millet hybrids with local adapted varieties as male parents in Namibia and Zambia.

Pathology: Reduce yield losses by identifying adapted, agronomically desirable sources of resistance to drought stress and charcoal rot to include sources with resistance to sugarcane aphid (Botswana, Zimbabwe, Zambia). Identify adapted, agronomically desirable sources of resistance to the major foliar pathogens: leaf blight, anthracnose, and sooty stripe (Zimbabwe, Zambia).

Food Quality: Improve sorghum food quality by evaluating qualities of Zimbabwean sorghums. Examine methods of using high polyphenol sorghums in foods through dry milling, malting and brewing.

Pests: Reduce yield losses by identifying, evaluating, and incorporating sugarcane aphid resistance into sorghum varieties and hybrids adapted to Southern African agricultural systems. Develop integrated pest management strategies for sorghum insect pests in Southern Africa.

Production and Marketing: Through structural village surveys and country-wide equilibrium analysis, identify alternative feasible sources of supply for sustainable sorghum processing in Botswana and their distributional economic welfare impacts. These analyses can then be extended throughout the region.

Ergot: Reduce the risk of ergot through analyses of weather data, and develop control strategies involving host plant resistance, management to improve pollination, and chemical control.

Mutuality of Benefits

The productivity and utilization of both sorghum and pearl millet will ultimately be improved both in SADC countries and the USA through joint research. Germplasm flow is useful in both directions. Basic research from the USA can often be adapted for use in developing countries where yield potential, along with adaptation, need to be increased. U. S. pathologists and entomologists can become familiar with diseases and insects not yet present in the USA, or find new resistance to existing pests. Sorghum ergot disease, which recently entered the USA from South America, is a case in point. Prior research in South Africa on sources of ergot resistance, understanding environmental conditions conducive to disease spread, and methods of research are now of vital interest to U.S. scientists. Nutritional components of food quality researched in collaborative projects have relevance to grain values for livestock feed.

Examples of findings

Breeding

The breeding project initially collaborated on sorghum breeding in Botswana with the sorghum breeder, Peter Setimela, at DAR, Sebele, and on pearl millet breeding in Namibia with S. A. Ipinge and W. R. Lechner. In both cases, the work was planned to fit in with the ongoing NARS research and that supported by the SMIP program managed for sorghum by Tunde Obilana and pearl millet by Emmanuel Monyo. Both participated in the INTSORMIL initiatives by growing additional breeding materials and providing off-season nursery space. As a result, 36 A/B sorghum seed parent lines were developed for Botswana and released as SDSA/B 1 through SDSA/B 36. The relative combining ability of these lines was determined by a series of yield trials conducted by ICRISAT SMIP.

The pearl millet research planned for Namibia was to take parents of the hybrids, shown experimentally by ICRISAT SMIP to be at least 20% higher yielding than existing varieties, and convert them to the A_4 CMS system (shown to be superior to the A_1 system - see UNL-218 report) - a feature essential for commercial seed production and reliability of hybrid performance. INTSORMIL supplied the A_4 CMS needed to make two seed parents male sterile (88006, an ICRISAT SMIP proven A_1 seed parent, and an IBMV 8401 selection made by UNL218 from a long headed Senegalese population). Both seed parent conversions have been completed and supplied to Namibia, along with some test hybrids. INTSORMIL UNL-218 also supplied the R_4 genes required to make the Namibian varieties, Okashana and MKC, into solid R_4 restorer male parent populations. Two backcrosses with each were made and sent for completion to Namibia. A test hybrid IBMV 8401 A_4 x MKC (made from partially backcrossed parents), was exceptionally productive. MKC also was converted into an R_5 restorer in consonance with research on this new (A_5/R_5) CMS system at ICRISAT Center, India, so that when A_5 seed parents become available from ICRISAT there will be at least one African based R_5 variety with which to produce hybrids.

Following the departure of Peter Setimela (the only sorghum breeder) from Botswana to UNL-218 for his Ph.D., collaborative sorghum research in Botswana was put on hold and recommenced in 1999-2000. Pearl millet A_4 hybrid development for Zambia was begun in 1998 using the same methods as for Namibia, with Mr. F. P. Muuka at Kaoma Research Station, Western Zambia. At Kaoma a number of good varieties suitable as male parents for top cross hybrids had been developed. Donor material for both seed parent development and male parent development were supplied. Mr. Muuka is proceeding with the backcross program. He has been supported by the supply of selfing bags and a single head thresher.

In summary, this breeding project for Southern Africa has followed through with the concept that adapted hybrids developed, preferably with the use of the best (i.e. well adapted) local varieties, is the most cost effective way of increasing yields at all levels of productivity. Hybrids facilitate the use of other inputs that raise production (better management and fertilizer). Also, they attract private enterprise into producing quality seeds for farmers. Namibia has a successful pearl millet certified seed production program (now an autonomous cooperative of skilled farmer-seed producers) based on variety production. Hybrid production is the next logical progression for them, and this will be an example for others to follow.

Pathology

Several sorghum disease nurseries were planted yearly (1997-2000) at one or more locations in Zambia, Zimbabwe, Botswana, and South Africa (1999- 2000). Strategic nursery locations for foliar disease evaluation were the Mansa (anthracnose) and Golden Valley (sooty stripe) stations in Zambia and the Panmure (sooty stripe) and Henderson (leaf blight) stations in Zimbabwe. Most standard entries in the nursery continued to have their previously identified resistance or susceptibility response to the major pathogens present. Most of newly introduced materials in these nurseries had a high susceptibility to either or both sooty stripe and anthracnose under moderate to heavy disease pressure at these locations; however, some of these new sorghums may still be of value in other SADC regions where foliar pathogens are not a production constraint. As in previous years, SC326-6 derived material like 86EON 361 and 86 EON362 were consistently resistant to foliar pathogens (low to moderate response) and demonstrated good regional adaptation and favorable agronomic characteristics.

Several drought resistant materials were tested yearly at the Sebele station and occasionally the Pandamatenga station in Botswana. Yearly response to drought stress and agronomic appearance was utilized to identify those cultivars for continued and expanded evaluation and to target potential new cultivars for inclusion in drought resistance nurseries. Beginning in 1998, cultivars previously tested in Botswana or closely related cultivars were selected for expanded evaluation at the Matopos station in Zimbabwe and the Golden Valley station in Zambia. Unfortunately, several entries were extremely susceptible to sooty stripe (EO366 derivatives) at Golden Valley and did not appear to have good adaptation to that location. In a previous season some EO366 x WSV387 (Kuyuma) derivatives had shown good drought tolerance and agronomic characteristics at Sebele. However, other entries did have both acceptable adaptation and at least moderate or good resistance (as in SRN39 derivatives) to sooty stripe. Derivatives of several crosses with Macia had both resistant and susceptible representatives, but those of Macia x Dorado and ICSV1089 x Macia commonly had both excellent sooty stripe response and good agronomic characteristics at Golden Valley. These derivatives also had good to excellent drought tolerance at the Sebele station in Botswana over more than one season.

Sugarcane aphid resistant sorghums were concurrently evaluated with drought tolerant sorghums at the Sebele station. From these and related materials a sugarcane aphid resistance nursery (50 entries, 2 reps) was initiated in collaboration with TAM-223, TAM-225, and TAM-222 and other NARS scientists and planted at several SADC locations including Matopos, Zimbabwe and Golden Valley, Zambia. Most had a susceptibility to sooty stripe at Golden Valley but may be useful elsewhere in the SADC region where sooty stripe is not a production problem.

Virus reactions in the International Sorghum Virus Nursery (ISVN) at the Sebele and Pandamatenga Research Stations in Botswana were typical of previous years but do not appear to adequately fit host differential response patterns for SCMV-B. Live virus specimens collected two years ago in Botswana and Zambia were identified as being similar to SCMV-B by S. Jensen, USDA, Lincoln, NE. Mahube, an early maturing released variety in Botswana, was identified as being vulnerable to the virus at both the Sebele and Pandamatenga locations where it sometimes showed extensive Red Leaf Necrosis (RLN) when virus-infected plants were exposed to cool night temperatures.

In the 1999-2000 season, a multilocational nursery initially dubbed the Southern Africa Sorghum Breeding Nursery was developed from the disease, drought, and sugarcane aphid nurseries to identify cultivars that had both broad adaptation to the SADC region and resistance to major disease and insect pests. Cultivars showing good foliar disease resistance at three nursery locations in 1999-2000 are shown in Table 1. This initial nursery was made up of two replicates of 100 entries with the eventual goal of a more space efficient 50 entry nursery for widespread deployment in the SADC region. The smaller nursery would be re-named as the SADC Regional All Disease and Insect Nursery. In addition to regional adaptation, the nursery is intended to identify cultivars adapted to individual locations, determine relative importance of specific pest constraints by site and region, determine needed types of pest resistance, and identify potential cultivars with adequate individual and multiple pest resistance for direct farmer use or as proven parents in breeding programs.

Food quality

Dry Milling of Sorghum

Roller milling and abrasive decortication reduced the polypohenol content of brown sorghums by nearly 50% but the endosperm products were still dark in color. Pretreatment of the grains with dilute NaOH and HCl at 12, 16 and 20% moisture prior to milling did not affect the yield of endosperm products. The yield of roller milled flour was 90.7, 88.5 and 90.2 respectively for optimum tempered grain (16% moisture) of white food type and two brown sorghums

Table 1. Cultivars in the 1999 Southern Africa Sorghum Breeding Nursery with good foliar disease resistance at nursery locations in Golden Valley Station, Zambia, Matopos Station, Zimbabwe, and Cedara Station, South Africa[1]

Designation	Sooty stripe	Anthracnose	Leaf Blight
(SRN39*90EO328)-HF4. .CA2	0.5	0.5	0.6
(SRN39*90EO328)-HF4. .CA1	0.5	0.4	0.6
Sima./WSV187	0.5	0.0	0.9
Segaolane	0.6	0.0	0.8
(B1*Segaolane)HL?-HL2	0.6	0.0	1.5
(B1*Segaolane)HF31	0.6	0.1	1.0
SRN39	0.7	0.0	1.6
(Macia*Sureño)-HF19-GWO193	0.7	0.0	0.4
(Dorado*SRN39)-??. . . .	0.8	0.0	1.5
(Sureño*SRN39)-HD5	0.8	0.0	0.6
(B1*Town)-HL?-HL2	0.8	0.0	1.4
(86EO361*Macia)-HD15	0.8	0.0	0.3
(B1*Segaolane)HF1-BE3-C101	0.4	0.9	0.9
(B1*B9501)-HF88	0.5	0.0	1.9
(Macia*Dorado)-HD2	0.5	2.0	0.9
B1 (BTx625*B35)	0.6	0.8	1.0

[1] All disease ratings from 0 to 5 were done by N. McLaren in April 2000 where 0 is resistant and 5 is susceptible. Numbers in each column are mean values of disease ratings from two sites for sooty stripe (Golden Valley and Matopos), anthracnose (Golden Valley and Matopos) and leaf blight (Matopos and Cedera). Causal fungal pathogens are *Ramulispora sorghi* for sooty stripe, *Colletrichum graminicola* for anthracnose, and *Exserohilum turcicum* for leaf blight.

respectively. Tempering did not affect the yields of decorticated grain obtained by abrasive milling. The NaOH treatments gave slightly lower phenol content for roller milled endosperm products but did not affect the phenol content of abrasively decorticated products. The color of the brown sorghum flour was very dark with high levels of phenols. Roller milling of grain treated with NaOH at 16% moisture produced flour with significantly reduced levels of phenols. Light color, bland flavor and quite acceptable flours were prepared from the white sorghum while the brown varieties had dark colored flours with a strong flavor.

Malting of Sorghum

Tannin sorghums are malted for use in opaque beer brewing. The condensed tannins adversely affect the ability of the malt enzymes to accomplish their task. Treatment of the sorghum with formaldehyde inactivates the tannins and improves the quality of malt significantly. An alternative to formaldehyde, NaOH, was found effective by South African scientists recently. Dr. Beta evaluated several treatments to confirm that NaOH is effective in eliminating the effects of tannin. She confirmed that NaOH was as effective in elimination of condensed tannins as formaldehyde; in addition, water uptake during steeping was significantly increased by the NaOH treatment. Thus, Dr. Beta's confirmation of the effectiveness of NaOH as a pretreatment of tannin sorghum prior to malting should lead to improved malting efficiency. Elimination of formaldehyde from malting will alleviate questions about the safety of formaldehyde in opaque beer. The increased rate of water uptake during steeping of sorghum could enhance malt production from non-tannin sorghum as well.

Sorghum Starch Properties

Starch was isolated from ten Zimbabwean sorghum varieties using alkali steeping and wet milling procedures. A tannin-free variety with white pericarp and tan plant color, SV2, gave a very white starch. Varieties with red or white pericarp gave pink starches. Hunter L, a and b values of starches were not correlated with grain phenol content or grain appearance. This was probably because all of these sorghums had purple or red plant color and intense red or purple glumes. The anthocyanins from the glumes and the pericarp of slightly weathered grain penetrated into the starch during wet milling giving highly colored starch. These starches would not be useful in applications where color is important. The starch of the white SV2 would be acceptable in food products of light color.

Sorghum starches had higher peak viscosities than commercial maize starch. Since commercial corn starch is isolated by acid steeping, some of the differences are related to the milling procedures. The amylose content of the sorghum starches varied from 21 to 29 % of the starch. The viscosity changes during cooking were related to amylose content. Amylose and starch gel hardness was positively correlated. The setback properties were highest for starches with increased levels of amylose. Peak gelatinization temperature (Tp) occurred over a narrow range of 66 to 69°C. The reduced amylose content of the commonly grown high tannin hybrid DC-75, if it can be confirmed in additional experiments, might be related to its generally acceptable malting quality.

Chemical treatments in wet milling could improve the physio-chemical properties of starch isolated from high-tannin sorghums. Sorghum varieties, Chirimaugute (medium-tannin), DC-75 (high-tannin) and SV2 (tannin-free) were steeped in water, dilute HCl (0.9%, v/v), formaldehyde (0.05%, v/v) and NaOH (0.3%, w/v) solutions prior to wet milling and starch separation. Chemical treatments during steeping of sorghum greatly affected starch properties. Steeping in NaOH produced starches with higher peak viscosity (PV), cool paste viscosity (CPV), and setback than when water, HCl and formaldehyde were used. The time to peak viscosity and temperature of peak viscosity were markedly reduced by treatment with NaOH. The texture of DC-75 starch gels was slightly firmer in NaOH treated grains. Starch from NaOH treated grain generally had slightly higher gelatinization temperatures than when water, HCl or formaldehyde was used. Dilute alkali steeping during wet milling could be used to modify properties of starch isolated from tannin-containing sorghums. However, the color of the starches will probably limit their applications.

Ms. L. Hugo found that increased quantities of sorghum flour can be added to composite bread when the flour comes from malted sorghum. It improves the texture of the flour eliminating harsh, sandy particles and significantly improving the crumb properties of the baked bread. This research continues with completion in 2000.

Pest Management

A trip was made in April, 2000, to South Africa, Botswana, Mozambique, and Zambia by Dr. Peterson to continue the collaborative research program for Southern Africa directed at development, evaluation, and deployment of sorghum genotypes resistant to the sugarcane aphid, *Melanaphis sacchari*. The primary collaborators in initiating the project are Dr. van den Berg and Dr. Manthe. However, Dr. Manthe has taken a position with the Botswana College of Agriculture, and his continued participation in this research is questionable. Dr. van den Berg is currently conducting many research projects on several insect pests of sorghum, and research on sugarcane aphid represents an expansion of his research program.

A 50-entry test for sugarcane aphid resistance was sent to Southern Africa in collaboration with TAM-228, TAM-225, and TAM-222. The test was distributed for greenhouse screening in Botswana and South Africa and field evaluation in Zambia. For sugarcane aphid resistance, 11 experimental entries sustained no more damage than the most resistant checks (WM#322, Ent. 62/SADC, FGYQ353, and TAM424)(Table2). Sugarcane aphid resistant breeding materials are in development for the collaborative program. Resistance sources including TAM428, CE151, WM#177, Sima (IS23250), SDSL89426, and FGYQ336 have been intercrossed or crossed to locally adapted cultivars to develop a range of populations. Exotic cultivars used include Segaolane, Marupantse, Macia, Town, SV1, and A964. The lines were crossed to elite TAM-223 germplasm in order to introduce additional favorable traits including foliar disease resistance, and backcrosses of selected F_1's to adapted cultivars were made. The germplasm is planted in sub-tropical South Texas (Corpus Christi or Beeville) and temperate Lubbock to select for wide adaptation. Selections from Texas will be provided to collaborators in Southern Africa for evaluation in the local environment. The lines should contain wide adaptation, sugarcane aphid resistance, and disease resistance (primarily sooty stripe and anthracnose). Plant traits selected to enhance potential use include tan plant, white pericarp, and appropriate height and maturity.

Research on host plant resistance for Southern Africa will be increased for 2000-2001. INTSORMIL, through the Texas A&M University breeding/entomology program, will provide to regional scientists a replicated 100-entry test for evaluation for resistance to sugarcane aphid and local adaptation at sites to be determined. The replicated Midge Line Test will be provided to South Africa to evaluate the population density of sorghum midge (*Stenodiplosis sorghicola*) at anthesis and the level of resistance and adaptation present in the TAMU sorghum midge resistance breeding program. INTSORMIL also will develop new sorghum germplasm lines with novel gene combinations and provide the germplasm to local collaborators for evaluation for resistance to sugarcane aphid. INTSORMIL will lead in developing a regional sorghum disease/insect adaptation test for planting at numerous locations. Material in the test will represent a range of diversity to stress resistance, plant type, and yield. The material will be available to regional scientists for use in their research programs.

Production and Marketing/Research

A pre-survey of farm households in Baralong, Botswana revealed that government agricultural programs and off-farm income create disincentives for the consistent annual production of sorghum, raising questions about the ability of domestic sorghum supply to meet the demand of domestic processors. These initial, informal findings will be quantified through a rural household survey that will be conducted in Baralong. During this year the comprehensive survey instrument was developed, pre-tested, and revised. The administration of the survey will be under the direction of Dr. Tebago Seleka of the Botswana College of Agriculture. One other researcher, to be identified by Dr. Seleka, will direct the field operations of the survey.

Drs. Seleka and Carl Nelson began work on a model of general equilibrium in the Botswana economy, incorporating sorghum supply from South Africa (which is currently the main source). This model will be constructed to analyze the differential economic welfare impacts of alternative sorghum supply channels for the Botswana sorghum processing industry. Such information is needed to make judgments about the value of promoting and/or subsidizing domestic supply.

Tshepo Makape, a student from the Botswana College of Agriculture, is currently taking prerequisite course at the University of the Orange Free State in South Africa. He will

Table 2. Rating of sorghum lines for resistance to sugarcane aphid based on aphid damage and aphid abundance to Potchefstroom, South Africa.

Pedigree	Aphid damage[1]	Aphid abundance[2]
WM#322	1	1
Ent. 62/SADC	1	1.5
FGYQ353	1	1
PRGC/E#222879	1	1.5
PRGC/E#69414	1	1.5
TAM428	1	1
(Macia*TAM428)-LL2	1	1.5
(Macia*TAM428)-LL7	1	1
(CE151*BDM499)-LD17-BE2	1	1
(Macia*TAM428)-LL9	1	1
GR128-92M12/(GR105*(R5646*SC326-6))	1	1
(Tx2783*VG15/M50009)-LG9-	1	2
(Tx436*GR108-90M24)-LG8	1	1
(Tx2883*(Tx2864*(Tx436*(Tx2864*PI550607))))-PC1-	1	1
(Tx2883*(Tx2880*(GR108-90M24*(Tx2862*(Tx430*(Tx2862*PI550607))))))-PR3-	1	1
(Tx430*Sima/IS23250)-LG5-	1	2
(6OB128/(Tx2862*6EO361)*CE151)-LG19-	1	1
FGYQ336	1.5	1
PRGC/E#222878	1.5	1.5
SDSL89426	1.5	2
(Macia*TAM428)-HD1	1.5	1.5
(87EO366*TAM428)-HF2 (F6)	1.5	1
6OB124/(GR104*((Tx432*CS3541)*SC326-6))	1.5	1.5
GR127-90M39/(GR105*((Tx432*CS3541)*SC326-6))	1.5	1.5
MB108B	1.5	1.5
(Tx2883*(Tx2864*(Tx436*(Tx2864*PI550607))))-PC2-	1.5	2.5
(Tx2883*(Tx2880*(GR108-90M24*(Tx2862*(Tx430*(Tx2862*PI550607))))))-PR2-	1.5	2.5
(SDSL89426*6OB124/GR134B-LG56)-LG5-	1.5	1
(6OBS124/GR134-LG56-*WM#177)-LG2-	1.5	1.5
CE151	2	1
WM#177	2	1
Macia	2	3
(CE151*BDM499)-LD17-BE1	2	1.5
(TAM428*SV1)-HD10	2	2
(87EO361*Macia)-HL25	2	2
(Tx2783*(Tx2737*(Tx436*(Tx2783*PI550607))))-PC4	2	2.5
(Sima/IS23250*5BRON131/(80C2241*GR108-30)-LG1-	2	2
(SV1*Sima/IS23250)-LG6-	2	2.5
(87EO366*TAM428)-HF4 (F6)	2.5	2
(91BE7414/(R8505*(R5646*SC326-6))	2.5	2
(87EO366*GR134A-90M50)-LG6-	2.5	1
(EPSON2-40/E#15/SADC*A964)-LG6-	2.5	2
Segaolane	3	2
Sima (IS23250)	3	1
Kuyuma	3	2.5
(Tx2882*SRN39)-CM3-	3	2
(5BRON154/(87BH8606-14*GR107-90M46)*EPSON2-40/E#15/SADC)	3	2
(Macia*Dorado)-HD4	3.5	3
(PM12713*Tx2880)-CM3-	3.5	2.5
(Sima/IS23250*6OBS129/(Tx2862*6EO361)-LG1-	4	3
Test Mean	1.8	1.6
LSD .05	1.5	1.2

[1] Rated on a scale of 1 = no damage up to 4 = plant death.
[2] Rated on a scale of 1 = few aphids up to 3 = high infestation.

begin work in the agricultural economics M.S. program at the University of Illinois in January, 2001.

Pre-survey results provided qualitative information about how government agricultural programs and off-farm income create disincentives for regular, annual production of sorghum in Botswana. These effects will be quantified with data from a formal rural household survey.

Ergot

Incidence of ergot, caused by *Claviceps africana* Frederickson, Mantle & deMilliano, is dependent on the rate of pollination and fertilization, and on weather conditions during early post-anthesis. Rate of pollination and fertilization is affected by pre-flowering minimum temperatures that reduce pollen vigor. Once fertilization has taken place, susceptibility declines rapidly, and effective pollination and fertilization facilitate escape from infection.

The objective current research is to develop a multi-variate risk analysis model which incorporates as many of the relevant variables as possible that affect ergot severity in commercial hybrid seed production systems. The study is being conducted in areas representative of a range of climatic zones, including three areas in South Africa and Mt. Makulu in Zambia. The current report is based on data from Cedara and Makulu (Pietermaritzburg, South Africa) pending receipt of data from the other trials sites.

Trials consisted of blocks of 27 rows, 25 m in length, spaced 0.9 m apart. The outer rows of each block were A-lines planted three weeks before the remaining rows, and inoculated prior to flowering with a *C. africana* spore suspension (*ca* 10^6 spores per ml) to serve as ergot spreaders. The next two rows were pollinator (fertile) rows and the inner 23 rows were male-sterile A-lines. At each locality blocks were replicated at three planting dates from late November to early January to create a range of ergot potentials during flowering. On each planting date six blocks of A-lines were planted. Pollinator row splits of 0, 7 and 14 days after A-lines were used. Three blocks each were planted to PAN8564 and NK283 as pollinators.

Flowering of pollinator rows was monitored and the percentage heads shedding pollen determined on a weekly basis. Pollen was randomly collected from each row for assessment of pollen viability and mean pollen viability was determined for each flowering date. Heads of A-lines with approximately 10% stigma emergence were marked with the date of flowering in each alternate row. This was repeated weekly in each block until flowering was complete. Approximately four weeks after flowering, heads were visually assessed for percentage seed set and ergot severity.

NK283 was more cold sensitive than PAN8564, showing an approximately linear increase in non-viable pollen with decreasing temperature (Figure 1). PAN8564 showed little decrease in pollen viability, even as minimum temperatures declined to the lowest temperature of 13.6°C.

Flowering of pollinators relative to A-lines and pollen viability was used as a measure of pollen available to A-lines on specific assessment dates, i.e., percentage of pollinator heads shedding pollen × proportion viable pollen. The relationship between "available pollen" and ergot severity was determined by regression analyses in each A-line row. Ergot development in A-line rows 1 (adjacent to pollinators) and 11 (middle row) relative to "available pollen" is given in Figure 2. Based on the reaction of row 1 (adjacent to pollinators), the rate of ergot increase per percentage decline in "available pollen" is 0.73 and 0.88 with PAN8564

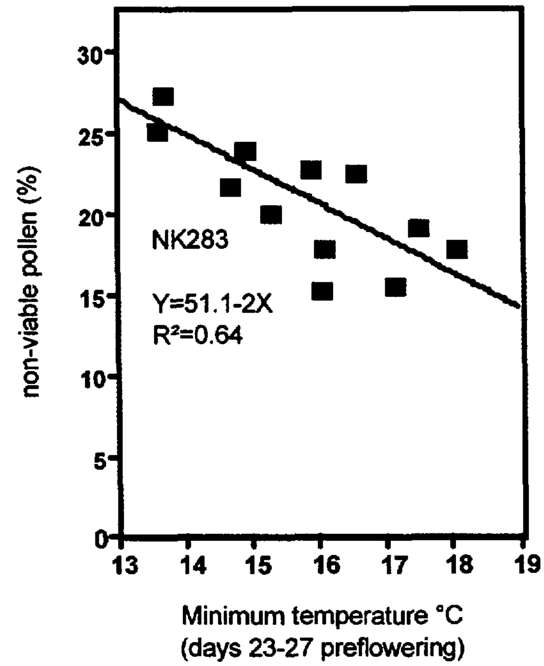

Figure 1. Relationship between pre-flowering minimum temperature (days 23-27 preflowering) and pollen viability in NK283.

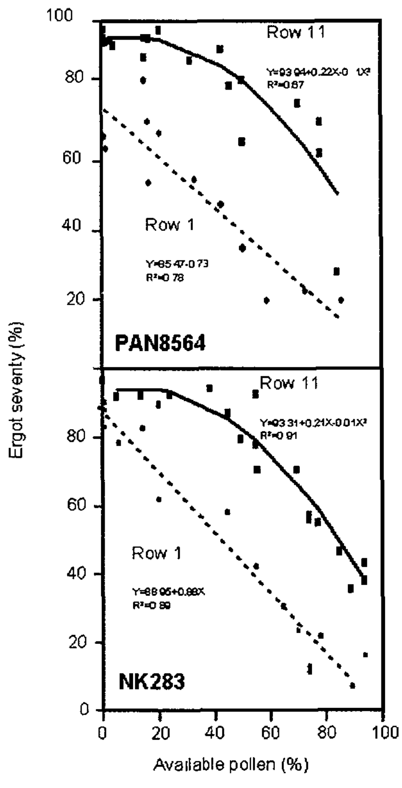

Figure 2. Relationship between available pollen at flowering of sorghum A-lines and ergot severity.

and NK283, respectively. This rate increases with distance from the pollinator row.

As indicated in Figure 3, a gradient in ergot severity was evident with distance from the pollinator rows. Distance from the pollinator row resulted in an increase in ergot severity at a rate of 2.76 and 1.89 % (PAN8564 and NK283, respectively) for each meter distance from the pollinator row. Results indicate that PAN 8564 was a more efficient pollinator than NK283, and seed set was the direct inverse of ergot severity.

The ergot × pollen interaction with weather during the critical phases of crop development is still to be quantified and modeled pending data from remaining sites. At Cedara, maximum temperature during flowering ranged from 17.8 to 28.6 °C with RH for the greater part, higher than 90 %. Thus, conditions were highly conducive for ergot development, particularly under relatively low pollen pressures.

Results to date suggest that under disease favorable conditions, relatively small variations in available pollen as well as distance from the pollinator can result in large differences in disease severity. Observations based on Figure 4 indicated that under the conditions of this study with PAN8564 a significant increase in ergot can be expected where the pollinator to A-line ratio is greater than 1:5. With a poorer pollinator such as NK283, ergot increases significantly with a ratio greater than 1:3. It is important that seed producers take into account pollen viability and associated factors to minimize the impact of ergot on seed production.

Institution Building

Funding Support and Equipment

The MOU with the SMIP program was signed in October, 1998. INTSORMIL collaborative research projects became fully integrated in the SMINET research and development program for the Southern African region and were again reviewed at the SMIP Steering Committee meeting in October, 1999.

A head and small plot belt thresher was provided to the Namibian pearl millet breeding program at Okashana Research Station and a head thresher to the Zambian pearl millet breeding program at Kaoma, Zambia. Twenty thousand pearl millet pollinating bags were also supplied to each of these programs and to Botswana.

Four computers and two printers were purchased for collaborators in Zambia and Botswana.

Training of Host Country Researchers

Ms. Trust Beta, Zimbabwe, completed her Ph.D. program in food quality research in the University of Pretoria, Harare, Zimbabwe under Dr. Taylor, co-advised by Dr. Lloyd Rooney. Research equipment and partial subsistence costs were provided by INTSORMIL.

Mr. Peter Setimela, sorghum breeder, Department of Agricultural Research, Sebele Research Station, Botswana,

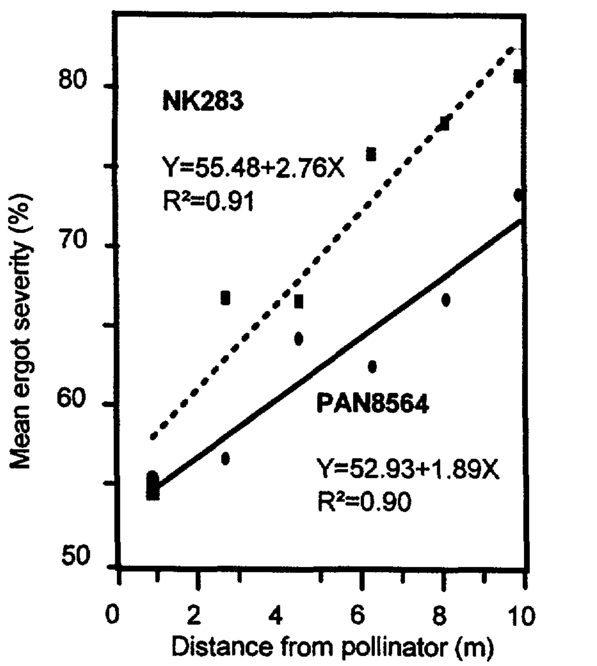

Figure 3. Relationship between distance of A-line from pollinators and ergot severity.

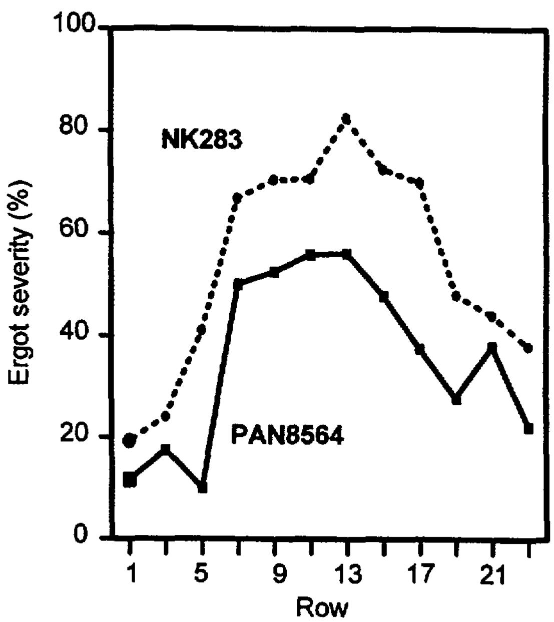

Figure 4. Ergot severities in A-line rows on the flowering date most favorable for pollination (28 February 2000)

completed his Ph.D. program in November 1999 on the genetics of seedling heat tolerance in sorghum at the University of Nebraska with David Andrews under project UNL-218.

Mr. S. A. Ipinge, pearl millet breeder in Northern Namibia, completed a six month visiting scientist program with David Andrews at the University of Nebraska in October, 1998 working on selection methods and breeding techniques.

Mr. M. Mogorosi, sorghum/pearl millet scientist, Botswana, commenced a five month training program at the University of Nebraska in June 2000 on breeding and seed production.

Host Country and U.S. Scientist Visits

Two members of the INTSORMIL External Evaluation panel, Drs. Fran Bidinger (ICRISAT) and Walter DeMilliano, accompanied by Dr. John Yohe, INTSORMIL Director; John Swanson, USAID-Washington; Dr. Darrell Nelson, INTSORMIL Board from UNL; and, David Andrews, Southern Africa Regional Coordinator, visited Namibia, Zimbabwe, and Botswana March 1 - March 13, 1999.

Carl Nelson attended a SADC/ICRISAT planning and review meeting in Harare, Zimbabwe and visited Botswana in July 1998. Dr. Nelson returned to Botswana in March, 1999 to initiate collaborative research.

Lloyd Rooney traveled to the University of Pretoria in March 1999 as co-organizer of Sorghum End Use Quality Assessment Workshop, and visited ARC/GCI Potchefstroom.

Gary Peterson and George Teetes visited South Africa and Botswana for pest research in April 1999.

Gary Odvody traveled to Southern Africa for approximately three weeks each year in March-April 1997-00 to evaluate nurseries and determine future collaborative research activities in the region. Locations visited include SMIP scientists and the Zimbabwe national sorghum breeder in Bulawayo (Matopos), Zimbabwe, PPRI/RSS in Harare, Zimbabwe, sorghum program scientists in Mt. Makulu, Golden Valley, Mansa, Lusitu, Zambia, DAR in Sebele and Pandamatenga, Botswana, and the sorghum pathologist and sorghum entomologist at Grain Crops Institute in Potchefstroom, South Africa.

Gary Peterson traveled to South Africa, Botswana, Zambia, and Mozambique in April 2000 to evaluate sugarcane aphid research and plan future regional collaborative research activities.

TAM-228 sponsored the travel of N. McLaren within the region in 1999 and 2000 to promote his collaborative research activities in sorghum ergot and to establish research linkages between all scientists in the region.

Human Resource Strategy

In the past, through a regional USAID program INTSORMIL has trained a large number of sorghum and millet scientists from the SADC region. Human resource development continued with support for Ms. Trust Beta's Ph.D. program in sorghum grain quality research at the University of Pretoria and Mr. Peter Setimela's Ph.D. program in plant breeding at the University of Nebraska. Mr. S. A. Ipinge completed a six month visiting researcher program with the UNL-218 pearl millet breeding program at the University of Nebraska. Mr. M. Mogorosi started in June 2000 a five month training program in breeding and seed production with UNL-218.

Networking

An efficient sorghum and millet research and technology transfer network exists in the SADC region conducted by the SMIP program. The memorandum of understanding allows INTSORMIL to be a component of the SADC sorghum and pearl millet research and technology transfer network, so that INTSORMIL's SADC collaborative research program is completely integrated on a regional basis. The emerging interaction of the University of Zimbabwe, University of Pretoria, Council for Science and Industrial Research, South Africa and SMIP in conducting sorghum and millet utilization research efficiently utilizes scarce resources and personnel. A jointly organized workshop on Sorghum Food Quality was held at the University of Pretoria and CSIR in South Africa in April 1999 at which there were 36 participants, including industrial representatives. Graduate students in the Food Science Department at the University of Pretoria are from many other African countries. Many of them are participating in the Regional Master of Science program which consists of joint programs between CSIR and University of Pretoria. The regional program has the goal of providing education for African scientists on African crops that are of importance in the region. Sorghum and millets are a key components of these food systems. Thus, interactions with this program informs many future African food industry leaders on the potential role of sorghum and millets as food and industrial ingredients. INTSORMIL can provide assistance to the region by involvement in these programs where possible.

Several graduate students are conducting research on aspects of sorghum utilization with Professor Taylor at the University of Pretoria. Dr. Trust Beta completed her Ph.D. on processing sorghum with high levels of polyphenols into foods. She has published several manuscripts related to dry milling, malting, and brewing applications of local Zimbabwean sorghum cultivars. Her work has been cooperative with the Matopos (Zimbabwe) grain quality lab. She has worked on starch properties at the University of Hong Kong with Professor Harold Corke and is a faculty member at the University of Zimbabwe in the food science area. Lloyd Rooney served on her committee and was a thesis examiner.

Ms. Leda Hugo, Mozambique, is a PhD student at University of Pretoria working on the effect of malting sorghum on its use in composite breads. She is a professor at University of Eduardo Mondlane University and completed her MS at Texas A&M University. Lloyd Rooney serves on her PhD committee.

Lloyd Rooney served as external examiner for the M.S. program of Mr. Joseph Wambugo from Kenya who completed a thesis on weaning foods from sorghum. Ms. S. Yetneberk from Ethiopia is initiating her Ph.D. program, and Lloyd Rooney will serve on her committee as well. Her project will be related to determination of the factors affecting the quality of injera from sorghum.

Mr. J. Awika from Kenya is a M.S. candidate in the Cereal Quality Lab at Texas A&M University nearing completion of his degree. He will continue on to a Ph.D. in food science and technology.

In the 1998-99 growing season, SMIP sorghum breeder Tunde Obilana grew 1344 materials from national collections of eight SADC countries at the irrigated Aisleby nursery site near Bulawayo, Zimbabwe. N. McLaren and Gary Odvody rated much of the collection for diseases that were present and trained assisting SMIP personnel to evaluate the remaining entries. Disease pressure at this location was only adequate to assess susceptibility and not resistance. If sufficient seed is available multiple location plantings of these materials at disease-intensive nursery locations in Zimbabwe, Zambia, and South Africa would provide more relevant and specific disease response information. Inoculated nurseries at certain locations might also be useful. Insect response (sugarcane aphid) could also be included at another South Africa location.

Germplasm Exchange

Several hundred sorghum lines and cultivars were evaluated yearly for response to various diseases, adaptation, drought response, and sugarcane aphid resistance in the SADC region in 1997-2000 (collaborative with TAM-222, W. Rooney, TAM-223, TAM-224, and TAM-225).

Thirty-five sorghum parents and lines selected from UNL-218 nurseries by Peter Setimela were sent to Botswana, October, 1999.

Twenty pearl millet germplasms selected by Mr. Ipinge were sent to Namibia in October 1998. Backcrosses of two Namibian varieties (to R_4 donors) and two seed parents (to A_4) were sent both to Namibia and ICRISAT SMIP in 1997, 1998, and 1999. A_4 and R_4 donors were sent to Zambia, October 1998.

Research Accomplishments

Breeding

Seed was sent from UNL-218 and planted by Mr. Ipinge in Namibia during 1998 to complete the third cross to develop two A_4 CMS Namibian pearl millet top cross hybrids. A similar process was started by Mr. Muuka in Kaoma, Zambia, using A_4 CMS seed parents from SMIP, an A_4R_4 donor from UNL-218 and eight adapted Zambian varieties as potential male parents. Mr. Ipinge completed his studies at the University of Nebraska - Lincoln in hybrid breeding in October 1998, and Mr. Mogorosi, Sorghum/Millet scientist commenced a five month training course at the University of Nebraska-Lincoln with Project UNL-218 in June 2000.

Single head/small plot threshing machines for research use and 20,000 pearl millet pollinating bags were supplied each to the Namibian and Zambian pearl millet breeding programs. Pollinating bags were also supplied for millet work in northern Botswana.

Pathology

Nurseries have provided good disease, drought and in some cases insect information from 1997-2000. Entries from these nurseries are being used to develop a small 50 entry, two replicate nursery for wide deployment in the SADC region called the SADC Regional All Disease and Insect Nursery. Neal McLaren is in the second year of his ergot research, but was hampered in year one with lateness in the availability of funding so that he concentrated on locations only in South Africa. In year two, 1999-2000 he was able to establish nurseries in South Africa, Zimbabwe, and Zambia. He was able to get ergot information from Zambia and South Africa locations but not Zimbabwe. In year three, he will establish ergot trials in South Africa and Zambia as before but in Zimbabwe he will re-locate his trials to the Matopos station where D. Frederickson will collaborate on this study. D. Frederickson is currently located at the SADC/ICRISAT facility in Matopos through at least June 30, 2001 as a consultant research scientist working collaboratively with TAM-228 on sorghum ergot.

Food Quality

INTSORMIL co-sponsored the Sorghum End Use Quality Workshop at the University of Pretoria in April 1999, and supported Mrs. Beta to the conclusion of her Ph.D. program. Her research on high tannin sorghums indicate treatment with NaOH prior to roller milling is preferable to the use of formaldehyde and can reduce tannin levels to an acceptable level for food use.

Pests

Sources of resistance to the sugarcane aphid were identified, which, except for sooty stripe, were well adapted in Botswana and Zambia. Crosses have been made to incorporate sooty stripe resistance and higher levels of anthracnose resistance.

Production and Marketing Constraints

The principal investigator made a first visit to the region in July 1998 followed by a second visit in March 1999. The primary objectives for the first year were: to establish a collaborative working relationship; to identify specific research projects for collaboration; and to initiate those projects. These objectives have been accomplished. A good working relationship has been established with the Botswana College of Agriculture and Department of Agricultural Research. Surveys have been researched and developed.

Ergot

Results obtained in two years of trials show that several factors can and need to be managed to reduce ergot levels in hybrid seed production fields. These involve genetic ability in male parents to shed good amounts of viable pollen following adverse conditions and being certain that male parents are flowering throughout the duration of female flowering. This may involve multiple planting of male rows, a higher ratio of male to female rows, and reduced width of female strips. Depending on economic factors, time of planting, or even choice of location for seed production fields can be used to avoid the worst probabilities of occurrence of environmental conditions favorable to ergot attack.

Planned Accomplishments

All projects were active and reached their planned goals.

Review of Program

There were several significant achievements in this funding phase:

The Memorandum of Understanding with the SMIP project was signed in October 1998, enabling funds to be disbursed to collaborating NARS scientists for collaborative research.

Projects on production and marketing constraints, ergot, and entomology were started.

The regional collaborative program was favorably reviewed by the INTSORMIL External Evaluation Panel, March 1-13, 1999.

The sorghum and millet research and technology transfer Southern Africa regional network (SMINET) became operational, and Dr. Mary A Mgonja was appointed as Coordinator.

INTSORMIL collaborative project annual work plans were reviewed and accepted by the SMIP Steering Committee in October 1998 and October 1999.

INTSORMIL funded collaborative research has produced results that are important to increasing the production and quality 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 ecogeographic 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 shown to be very important. Using NaOH to reduce tannin effects (where high tannin cultivars have to be grown), instead of the traditional formaldehyde, has several benefits. Larger amounts of sorghum flour can be blended with wheat flour for bread making if sorghum is malted before milling.

Initial results in production and marketing of sorghum in Botswana show government agricultural support initiatives and alternative employment opportunities adversely affect sorghum production. A survey instrument has been prepared to provide more detail.

The INTSORMIL Southern Africa collaborative research project is now well structured to address many of the regional constraints to sorghum(S) and pearl millet(M) production and utilization, and is now fully integral with other regional S&M activities, from the planning stage to co-funding agreed research projects.

Publications

Beta, Trust 1999. Processing of polyphenol-rich sorghum for food. PhD. Diss. University of Pretoria, Pretoria, South Africa. 187 pp

Training

Year 21 TRAINING

INTSORMIL gives high priority to training host country scientists who will have major responsibilities for sorghum and millet research in their home countries. Training is also provided for young U.S. scientists who plan for careers in international development work.

The most frequently used mode of training is graduate study for advanced degrees, with the students' research forming an integral part of an INTSORMIL project. During the year covered by this report, 51 students from 22 different countries were enrolled in an INTSORMIL advanced degree program. Approximately 73% of these students come from countries other than the USA which shows the emphasis placed on host country institutional development (Figure 1).

INTSORMIL also places a high priority on training women which is reflected in Figure 2. In 1999-00, 31% of all INTSORMIL graduate participants were female. Eighteen of the total 51 students received full INTSORMIL scholarships. An additional 14 students received partial INTSORMIL funding and the remaining 19 students were funded from other sources as shown in Figure 3.

All 51 students worked directly with INTSORMIL principal investigators on INTSORMIL projects. These students are enrolled in graduate programs in six disciplinary areas, agronomy, breeding, pathology, entomology, food quality, and economics (Figure 4).

The number of INTSORMIL funded students has decreased gradually over the years. This is related to decreases in program budget and the loss of U. S. Principal Investigators. In 1993-1994 there were 25 U.S. PIs with the program and in 1999-2000 there are 19.

Graduate degree programs and short-term training programs have been designed and implemented on a case by case basis to suit the needs of host country scientists. Five post doctoral scientists and nine visiting host country scientists were provided the opportunity to upgrade their skills in this fashion during 1999-2000.

The following table is a compilation of all INTSORMIL training activities for the period July 1, 1999 through June 30, 2000.

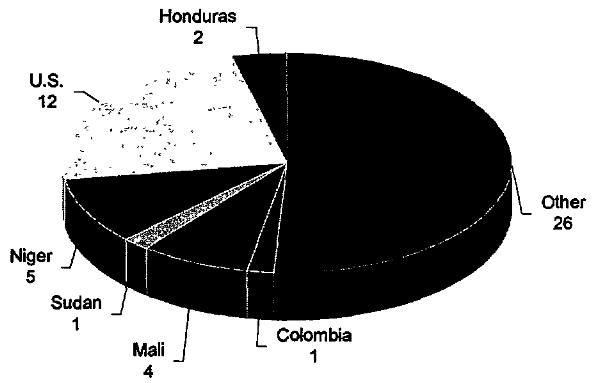

Figure 1. Participants by Country

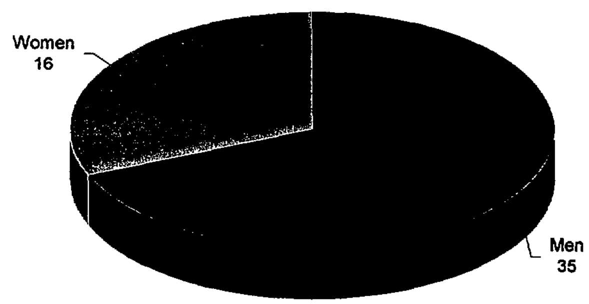

Figure 2. Participants by gender

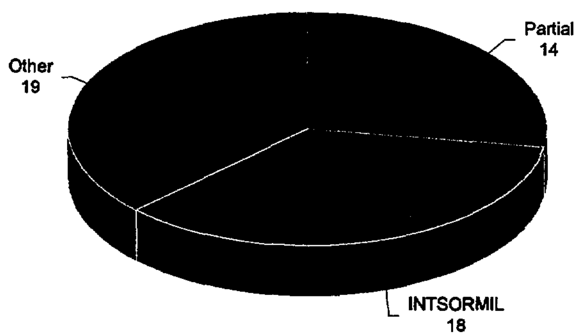

Figure 3. Source of Funding

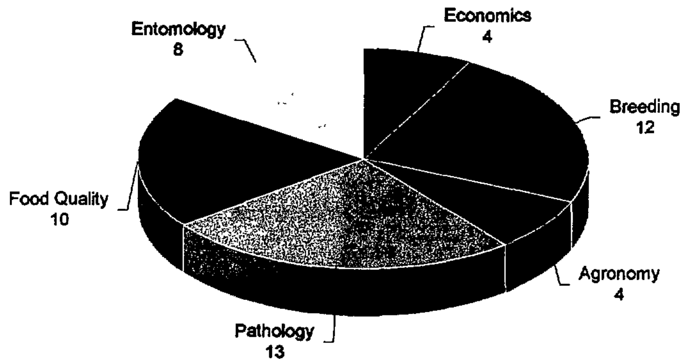

Figure 4. Discipline Breakdown

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Year 21 INTSORMIL Training Participants

Name	Country	Univ.	Discipline	Advisor	Degree	Gender	Funding*
Regassa, Teshome	Ethiopia	UNL	Agron/Physiol	Maranville	PHD	M	O
Cimino, Suzanne	U.S.	UNL	Agronomy	Mason	MSC	F	P
Maman, Nouri	Niger	UNL	Agron/Physiol	Mason	PHD	M	P
Seibou, Pale	Burkina Faso	UNL	Agronomy	Mason	MSC	M	I
Carvalho, Carlos H.S.	Brazil	PRF	Genetics/BioTech	Axtell	PHD	M	P
Nduulu, Lexingtons	Kenya	PRF	Breeding	Axtell	PHD	M	I
Grenier Cecile	France	PRF	*Striga* Physiology	Ejeta	PD[2]	F	O
Gunaratna, Nilupa	U.S.	PRF	Breeding	Ejeta	MSC	F	I
Mohammed, Abdalla	Sudan	PRF	Breeding	Ejeta	PHD	M	P
Phillips, Felicia	U.S.	PRF	Breeding	Ejeta	MSC	F	O
Rich, Patrick	U.S.	PRF	*Striga* Biology	Ejeta	PD[2]	M	I
Coulibaly, Sidi Bekaye	Mali	TTU	Breeding	Rosenow/Peterson	PHD	M	P
Sibene, Dena	Mali	TAM	Breeding	Rosenow	VS[1]	M	I
Teme, Niaba	Mali	TTU	Breeding	Rosenow	MSC	M	I
Mogorosi, Michael	Botswana	UNL	Breeding	Andrews	VS[1]	M	I
Setimela, Peter	Botswana	UNL	Breeding	Andrews	PHD	M	O
Kazianga, Harounan	Burkina Faso	PRF	Economics	Sanders	PHD	M	O
Tahirou, Abdoulaye	Niger	PRF	Economics	Sanders	PHD	M	O
Vitale, Jeff	U.S.	PRF	Economics	Sanders	PHD	M	I
Wubeneh, Nega G.	Ethiopia	PRF	Eonomics	Sanders	MSC	M	I
Gorena, Roberto Luis	U.S.	TAM	Entomology	Peterson/Teetes	PHD	M	I
Boire, Soualika	Mali	TAM	Entomology	Gilstrap/Teetes	PHD	M	I
Kadi Kadi, Hame	Niger	TAM	Entomology	Gilstrap/Teetes	MSC	M	I
Lingren, Scott	U.S.	TAM	Entomology	Teetes	PHD	M	O
Jensen, Andrea	U.S.	TAM	Entomology	Teetes	PHD	F	I
Carrillo, Mario	Argentina	MSU	Entomology	Pitre	MSC	M	I
Cordero, Roberto	Nicaragua	MSU	Entomology	Pitre	MSC	M	I
Johnson, Zeledon	Nicaragua	MSU	Entomology	Pitre	MSC	M	I
Aboubacar, Adam	Niger	PRF	Food Quality/Util	Hamaker	PD[1]	M	O
Bugusu, Betty	Kenya	PRF	Food Quality/Util	Hamaker	PHD	F	I
Maladen, Michelle	India	PRF	Food Quality/Util	Hamaker	MSC	F	P
Mix, Nadege	France	PRF	Food Quality/Util	Hamaker	MSC	F	I
Awika, Joseph Mobutu	Kenya	TAM	Food Quality/Util	Rooney/Waniska	MSC	M	P
Bueso, Francisco (Javier)	Honduras	TAM	Food Quality/Util	Rooney/Waniska	PHD	M	P
Gordon, Leigh Ann	U.S.	TAM	Food Quality/Util	Rooney	MSC	F	P
Leon-Chapa, Martha	Mexico	TAM	Food Quality/Util	Rooney/Waniska	MSC	F	P
Maurer, Giselle	U.S.	TAM	Food Quality/Util	Rooney	BSC	F	O
Mitre-Dieste, Marcelo	Mexico	TAM	Food Quality/Util	Rooney	MSC	M	P
Zelaya, Nolvia	Honduras	TAM	Food Quality/Util	Rooney/Waniska	MSC	F	P
dos Santos, Claudia	Brazil	KSU	Pathology	Claflin	VS[1]	F	P
Narvaez, Dario	Colombia	KSU	Pathology	Claflin	PHD	M	O
Chulze, Sofia	Argentina	KSU	Pathol/Mycology	Leslie	VS[1]	F	O
Jurgenson, Jim	U.S.	KSU	Pathol/Genetics	Leslie	VS[1]	M	O
Hanson, Amy	U.S.	KSU	Pathol/Genetics	Leslie	MSC	F	O
Kereny, Zoltan	Hungary	KSU	Pathol/Genetics	Leslie	PD[2]	M	P
Lee, Yin-Won	South Korea	KSU	Pathology	Leslie	VS[1]	M	O
Neumann, Melody	Canada	KSU	Pathol/Mycology	Leslie	VS[1]	F	O
Rheeder, John	South Africa	KSU	Pathology	Leslie	VS[1]	M	O
Salah, Amgad	Egypt	KSU	Pathology	Leslie	PHD	M	O
Silva, Gabriella	Uruguay	KSU	Pathol/Genetics	Leslie	VS[1]	F	O
Zeller, Kurt P.	U.S.	KSU	Pathology	Leslie	PD[2]	M	O
Kollo, Issoufou	Niger	TAM	Pathology	Frederiksen	PHD	M	O

* I = Completely funded by INTSORMIL
P = Partially funded by INTSORMIL
O = Other source
[1]VS = Visiting Scientist
[2]PD = Post Doctoral

KSU = Kansas State University
MSU = Mississippi State University
PRF = Purdue University
TAM = Texas A&M University
TTU = Texas Tech University
UNL = University of Nebraska - Lincoln

Years 18-19-20 and 21 Training

INTSORMIL gives high priority to training host country scientists who will have major responsibilities for sorghum and millet research in their home countries. Training is also provided for young U.S. scientists who plan for careers in international development work.

The most frequently used mode of training is graduate study for advanced degrees, with the students' research forming an integral part of an INTSORMIL project. During the years covered by this report, 213 students from 33 different countries were enrolled in an INTSORMIL advanced degree program. Approximately 77% of these students come from countries other than the USA which shows the emphasis placed on host country institutional development (Figure 1).

INTSORMIL also places a high priority on training women which is reflected in Figure 2. During the period of 1997-2000, 22% of all INTSORMIL graduate participants were female. Seventy nine of the total 213 students received full INTSORMIL scholarships. An additional 62 students received partial INTSORMIL funding and the remaining 72 students were funded from other sources as shown in Figure 3.

All 213 students work directly with INTSORMIL principal investigators on INTSORMIL projects. These students are enrolled in graduate programs in six disciplinary areas, agronomy, breeding, pathology, entomology, food quality, and economics (Figure 4).

The number of INTSORMIL funded students has decreased gradually over the years. This is related to decreases in program budget and the loss of U.S. Principal Investigators. In 1993-1994 there were 25 U.S. PIs with the program and only 19 in 1999-2000.

Graduate degree programs and short-term training programs have been designed and implemented on a case by case basis to suit the needs of host country scientists. Eighteen post doctoral scientists and 22 visiting host country scientists were provided the opportunity to upgrade their skills in this fashion during this four year period.

The following tables are a compilation of all INTSORMIL training activities for the period of July 1, 1996 through June 30, 2000.

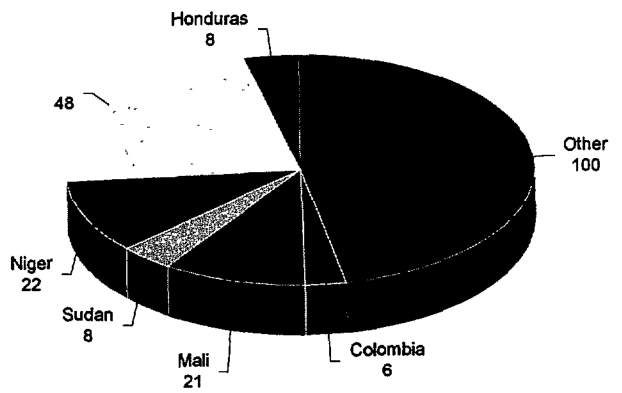

Figure 1. Participants by Country

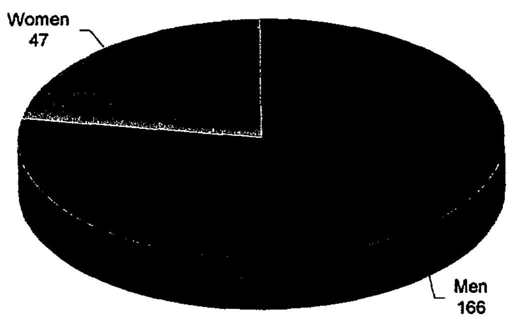

Figure 2. Participants by gender

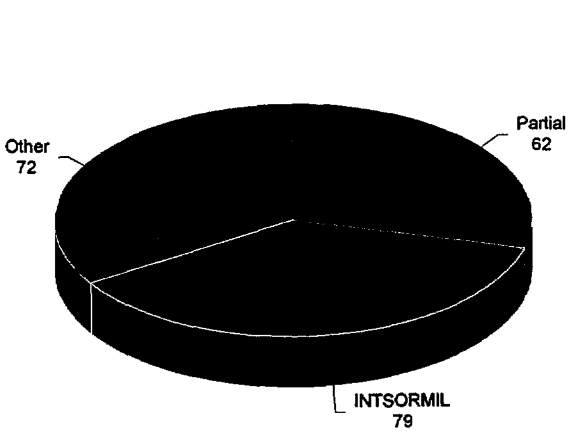

Figure 3. Source of Funding

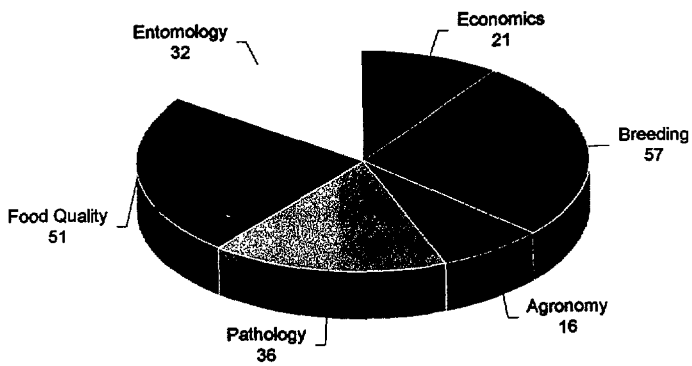

Figure 4. Discipline Breakdown

Year 20 INTSORMIL Training Participants

Name	Country	Univ.	Discipline	Advisor	Degree	Gender	Funding*
Regassa, Teshome	Ethiopia	M	Agron/Physiol	Maranville	PHD	M	O
Traore, Samba	Mali	UNL	Agronomy	Mason	PHD	M	P
Carvalho, Carlos H.S.	Brazil	PRF	Genetics/BioTech	Axtell	PHD	M	P
Kapran, Issoufou	Niger	PRF	Breeding	Axtell	PHD	M	I
Ndulu, Lexingtons	Kenya	PRF	Breeding	Axtell	PHD	M	I
Gunaratna, Nilupa	U.S.	PRF	Breeding	Ejeta	MSC	F	I
Ibrahim, Yahia	Sudan	PRF	Breeding	Ejeta	PHD	M	I
Mohammed, Abdalla	Sudan	PRF	Breeding	Ejeta	PHD	M	P
Phillips, Felicia	U.S.	PRF	Breeding	Ejeta	MSC	F	O
Rich, Patrick	U.S.	PRF	*Striga* Biology	Ejeta	PD[2]	M	I
Coulibaly, Sidi Bekaye	Mali	TTU	Breeding	Rosenow/Peterson	PHD	M	P
Teme, Niaba	Mali	TTU	Breeding	Rosenow	MSC	M	I
Ipinge, S.A.	Namibia	UNL	Breeding	Andrews	VS[1]	M	I
Rai, K.N.	India	UNL	Breeding	Andrews	VS[1]	M	P
Setimela, Peter	Botswana	UNL	Breeding	Andrews	PHD	M	O
Tiryaki, Iskender	Turkey	UNL	Breeding	Andrews	MSC	M	O
Ndjeunga, Jupiter	Cameroon	UIUC	Economics	Nelson	PD[2]	M	P
Coulibaly, Bakary	Mali	PRF	Economics	Sanders	MSC	M	O
Kazianga, Harounan	Burkina Faso	PRF	Economics	Sanders	PHD	M	O
Sidibe, Mamadou	Senegal	PRF	Economics	Sanders	PHD	M	O
Tahirou, Abdoulaye	Niger	PRF	Economics	Sanders	PHD	M	I
Vitale, Jeff	U.S.	PRF	Economics	Sanders	PHD	M	I
Gorena, Roberto Luis	U.S.	TAM	Entomology	Peterson/Teetes	PHD	M	P
Boire, Soualika	Mali	TAM	Entomology	Gilstrap/Teetes	PHD	M	I
Kadi Kadi, Hame	Niger	TAM	Entomology	Gilstrap/Teetes	MSC	M	I
Carrillo, Mario	Argentina	MSU	Entomology	Pitre	MSC	M	I
Johnson, Zeledon	Nicaragua	MSU	Entomology	Pitre	MSC	M	I
Jensen, Andrea	U.S.	TAM	Entomology	Teetes	PHD	F	I
Katsar, Catherine Susan	U.S.	TAM	Entomology	Peterson/Teetes	PHD	F	P
Lingren, Scott	U.S.	TAM	Entomology	Teetes	PHD	M	O
Aboubacar, Adam	Niger	PRF	Food Quality/Util	Hamaker	PD[1]	M	O
Bugusu, Betty	Kenya	PRF	Food Quality/Util	Hamaker	MSC	F	I
Mix, Nadege	France	PRF	Food Quality/Util	Hamaker	MSC	F	I
Zhang, Genyi	China	PRF	Food Quality/Util	Hamaker	PHD	M	P
Awika, Joseph Mobutu	Kenya	TAM	Food Quality/Util	Rooney/Waniska	MSC	M	I
Barron, Marc	U.S.	TAM	Food Quality/Util	Rooney	BSC	M	O
Leach, Michelle	U.S.	TAM	Food Quality/Util	Rooney	BSC	F	O
Leon-Chapa, Martha	Mexico	TAM	Food Quality/Util	Rooney/Waniska	MSC	F	P
Medina, Jorge	Nicaragua	TAM	Food Quality/Util	Rooney/Waniska	VS[1]	M	I
Miranda-Lopez, Rita	Mexico	TAM	Food Quality/Util	Rooney/Waniska	PHD	F	P
Rodriguez-Hererra, Raul	Mexico	TAM	Food Quality/Util	W.Rooney/Waniska	PHD	M	O
Quintero-Fuentes,Ximena	Mexico	TAM	Food Quality/Util	Rooney/Waniska	PHD	F	P
Zelaya, Nolvia	Honduras	F	Food Quality/Util	Rooney/Waniska	MSC	F	I
Narvaez, Dario	Colombia	KSU	Pathology	Claflin	PHD	M	O
Jurgenson, Jim	U.S.	KSU	Pathol/Genetics	Leslie	VS[1]	M	O
Hanson, Amy	U.S.	KSU	Pathol/Genetics	Leslie	MSC	F	O
Salah, Amgad	Egypt	KSU	Pathology	Leslie	PHD	M	O
Silva, Gabriella	Uruguay	KSU	Genetics	Leslie	VS[1]	F	O
Zeller, Kurt P.	U.S.	KSU	Pathology	Leslie	PD[2]	M	O
Kollo, Issoufou	Niger	TAM	Pathology	Frederiksen	PHD	M	I
Torres-Montalvo, Jose H.	Mexico	TAM	Pathology	Frederiksen	PHD	M	O

* I = Completely funded by INTSORMIL
P = Partially funded by INTSORMIL
O = Other source
[1]VS = Visiting Scientist
[2]PD = Post Doctoral

KSU = Kansas State University
MSU= Mississippi State University
PRF = Purdue University
TAM= Texas A&M University
TTU = Texas Tech University
UIUC University of Illinois at Urbana-Champaign
UNL = University of Nebraska - Lincoln

Year 19 INTSORMIL Training Participants

Name	Country	Univ.	Discipline	Advisor	Degree	Gender	Funding*
Traore, Abdoulaye	Mali	UNL	Agronomy	Maranville	PHD	M	I
Kim, S. Young	Korea	UNL	Agron/Physiol.	Maranville	MSC	M	O
Stockton, Roger	U.S.	UNL	Agronomy	Mason	PHD	M	P
Traore, Samba	Mali	UNL	Agronomy	Mason	PHD	M	O
Carvalho, Carlos H.S.	Brazil	PRF	Breeding	Axtell	PHD	M	P
Kapran, Issoufou	Niger	PRF	Breeding	Axtell	PHD	M	I
Ndulu, Lexingtons	Kenya	PRF	Breeding	Axtell	PHD	M	I
Ibrahim, Yahia	Sudan	PRF	Breeding	Ejeta	PHD	M	I
Melakebrhan, Admasu	Ethiopia	PRF	Breeding	Ejeta	PD[2]	M	I
Mohammed, Abdalla	Sudan	PRF	Breeding	Ejeta	PHD	M	P
Mulatu, Tadesse	Ethiopia	PRF	Breeding	Ejeta	MSC	M	P
Rich, Patrick	U.S.	PRF	Breeding	Ejeta	PD[2]	M	I
Tuinstra, Mitchell	U.S.	PRF	Breeding	Ejeta	PD[2]	M	O
Katsar, Catherine Susan	U.S.	TAM	Breeding	Peterson/Teetes	PHD	F	P
Rodriguez-Hererra, Raul	Mexico	TAM	Breeding	Rosenow/Rooney	PHD	M	P
Teme, Niaba	Mali	TTU	Breeding	Rosenow	MSC	M	I
Ipinge, S.A.	Namibia	UNL	Breeding	Andrews	VS[1]	M	I
Rai, K.N.	India	UNL	Breeding	Andrews	VS[1]	M	O
Setimela, Peter	Botswana	UNL	Breeding	Andrews	PHD	M	P
Tiryaki, Iskender	Turkey	UNL	Breeding	Andrews	MSC	M	P
Ahmed, Mohamed M.	Sudan	PRF	Economics	Sanders	PD[2]	M	I
Coulibaly, Bakary	Mali	PRF	Economics	Sanders	MSC	M	O
Kazianga, Harounan	Burkina Faso	PRF	Economics	Sanders	PHD	M	O
Kebbeh, Mohamed M.	Gambia	PRF	Economics	Sanders	VS[1]	M	O
Sidibe, Mamadou	Senegal	PRF	Economics	Sanders	PHD	M	O
Tahirou, Abdoulaye	Niger	PRF	Economics	Sanders	PHD	M	I
Vitale, Jeff	U.S.	PRF	Economics	Sanders	PHD	M	I
Boire, Soualika	Mali	TAM	Entomology	Gilstrap/Teetes	PHD	M	I
Kadi Kadi, Hame	Niger	TAM	Entomology	Gilstrap/Teetes	MSC	M	I
Calderon, Pedro	Honduras	MSU	Entomology	Pitre	MSC	M	O
Cordero, Roberto	Nicaragua	MSU	Entomology	Pitre	MSC	M	I
Johnson, Zeledon	Nicaragua	MSU	Entomology	Pitre	MSC	M	I
Vergara, Oscar	Ecuador	MSU	Entomology	Pitre	MSC	M	O
Jensen, Andrea	U.S.	TAM	Entomology	Teetes	PHD	F	I
Lingren, Scott	U.S.	TAM	Entomology	Teetes	PHD	M	O
Aboubacar, Adam	Niger	PRF	Food Quality/Util	Hamaker/Axtell	PHD	M	I
Bugusu, Betty	Kenya	PRF	Food Quality/Util	Hamaker	MSC	F	I
Zhang, Genyi	China	PRF	Food Quality/Util	Hamaker	MSC	M	I
Acosta, Harold	Colombia	TAM	Food Quality/Util	Rooney	PHD	M	P
Asante, Sam	Ghana	TAM	Food Quality/Util	Rooney	PHD	M	P
Barron, Marc	U.S.	TAM	Food Quality/Util	Rooney	BSC	M	P
Bueso, Francisco Javier	Honduras	TAM	Food Quality/Util	Rooney/Waniska	MSC	M	I
Kunetz, Christine	U.S.	TAM	Food Quality/Util	Rooney/Waniska	MSC	F	P
Lee, Jae K.	Korea	TAM	Food Quality/Util	Rooney/Waniska	VS[1]	M	O
Leon-Chapa, Martha	Mexico	TAM	Food Quality/Util	Rooney/Waniska	MSC	F	I
Mateo, Rafael	Honduras	TAM	Food Qualtiy/Util	Rooney/Waniska	VS[1]	M	I
Miranda-Lopez, Rita	Mexico	TAM	Food Quality/Util	Rooney/Waniska	PHD	F	P
Omueti, Olusola	Nigeria	TAM	Food Quality/Util	Rooney/Waniska	VS[1]	F	O
Quintero-Fuentes,Ximena	Mexico	TAM	Food Quality/Util	Rooney	PHD	F	P
Narvaez, Dario	Colombia	KSU	Pathology	Claflin	MSC	M	P
Jurgenson, Jim	U.S.	KSU	Pathol/Genetics	Leslie	VS[1]	M	O
Hanson, Amy	U.S.	KSU	Pathol/Genetics	Leslie	MSC	F	O
Zeller, Kurt P.	U.S.	KSU	Pathology	Leslie	PD[2]	M	O
Kollo, Issoufou	Niger	TAM	Pathology	Frederiksen	PHD	M	I
Torres-Montalvo, Jose H.	Mexico	TAM	Pathology	Frederiksen	PHD	M	O

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O = Other source
[1]VS = Visiting Scientist
[2]PD = Post Doctoral

KSU = Kansas State University
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PRF = Purdue University
TAM= Texas A&M University
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UNL = University of Nebraska - Lincoln

Year 18 INTSORMIL Training Participants

Name	Country	Univ.	Discipline	Advisor	Degree	Gender	Funding*
Gutierrez, Patricio F.	Ecuador	UNL	Agronomy	Clegg	PHD	M	I
Masi, Cassim	Zambia	UNL	Agronomy	Maranville	PHD	M	O
Traore, Abdoulaye	Mali	UNL	Agronomy	Maranville	PHD	M	I
Maman, Nouri	Niger	UNL	Agronomy	Mason	MSC	M	I
Stockton, Roger	U.S.	UNL	Agronomy	Mason	PHD	M	P
Traore, Samba	Mali	UNL	Agronomy	Mason	PHD	M	O
Carvalho, Carlos H.S.	Brazil	PRF	Breeding	Axtell	PHD	M	P
Kapran, Issoufou	Niger	PRF	Breeding	Axtell	PHD	M	I
Ndulu, Lexingtons	Kenya	PRF	Breeding	Axtell	PHD	M	I
Ibrahim, Yahia	Sudan	PRF	Breeding	Ejeta	PHD	M	I
Melakebrhan, Admasu	Ethiopia	PRF	Breeding	Ejeta	PD[2]	M	I
Mohammed, Abdalla	Sudan	PRF	Breeding	Ejeta	PHD	M	P
Mulatu, Tadesse	Ethiopia	PRF	Breeding	Ejeta	MSC	M	P
Tuinstra, Mitchell	U.S.	PRF	Breeding	Ejeta	PD[2]	M	I
Katsar, Catherine Susan	U.S.	TAM	Breeding	Peterson/Teetes	PHD	F	P
Rodriguez, Raul	Mexico	TAM	Breeding	Rosenow/Rooney	PHD	M	P
Teme, Niaba	Mali	TTU	Breeding	Rosenow	MSC	M	I
Wiltse, Curtis	U.S.	TAM	Breeding	Rosenow/Rooney	MSC	M	P
Jeutong, Fabien	Cameroon	UNL	Breeding	Andrews	PHD	M	O
Setimela, Peter	Botswana	UNL	Breeding	Andrews	PHD	M	O
Tiryaki, Iskender	Turkey	UNL	Breeding	Andrews	MSC	M	O
Coulibaly, Bakary	Mali	PRF	Economics	Sanders	MSC	M	O
Sidibe, Mamadou	Senegal	PRF	Economics	Sanders	PHD	M	O
Tahirou, Abdoulaye	Niger	PRF	Economics	Sanders	PHD	M	I
Vitale, Jeff	U.S.	PRF	Economics	Sanders	PHD	M	I
Boire, Soualika	Mali	TAM	Entomology	Gilstrap/Teetes	PHD	M	I
Kadi Kadi, Hame	Niger	TAM	Entomology	Gilstrap/Teetes	MSC	M	I
Calderon, Pedro	Honduras	MSU	Entomology	Pitre	MSC	M	O
Cordero, Roberto	Nicaragua	MSU	Entomology	Pitre	MSC	M	I
Vergara, Oscar	Ecuador	MSU	Entomology	Pitre	MSC	M	I
Diarisso Yaro, Niamoye	Mali	TAM	Entomology	Teetes/Peterson	PHD	F	P
Jensen, Andrea	U.S.	TAM	Entomology	Teetes	PHD	F	I
Lingren, Scott	U.S.	TAM	Entomology	Teetes	PHD	M	O
Aboubacar, Adam	Niger	PRF	Food Quality/Util	Hamaker/Axtell	PHD	M	I
Buckner, Becky	U.S.	PRF	Food Quality/Util	Hamaker	PHD	F	P
Itapu, Suresh	India	PRF	Food Quality/Util	Hamaker	PD[2]	M	O
Mamadou, Lewamy	Niger	PRF	Food Quality/Util	Hamaker	MSC	M	P
Zhang, Genyi	China	PRF	Food Quality/Util	Hamaker	MSC	M	I
Acosta, Harold	Colombia	TAM	Food Quality/Util	Rooney	PHD	M	P
Asante, Sam	Ghana	TAM	Food Quality/Util	Rooney	PHD	M	P
Bueso, Francisco Javier	Honduras	TAM	Food Quality/Util	Rooney/Waniska	MSC	M	I
Floyd, Cherie	U.S.	TAM	Food Quality/Util	Rooney/Waniska	PHD	F	P
Kunetz, Christine	U.S.	TAM	Food Quality/Util	Rooney/Waniska	MSC	F	P
Quintero-Fuentes, Ximena	Mexico	TAM	Food Quality/Util	Rooney	MSC	F	P
Seetharaman, Koushik	India	TAM	Food Quality/Util	Rooney/Waniska	PHD	M	P
Suhendro, Elly	Indonesia	TAM	Food Quality/Util	Rooney	PHD	F	P
Zhao, Haiyan	China	TAM	Food Quality/Util	Rooney/Waniska	VS[1]	M	O
Diourte, Mamourou	Mali	KSU	Pathology	Claflin	PHD	M	O
Lu, Ming	China	KSU	Pathology	Claflin	PHD	M	P
Muriithi, Linus M.	Kenya	KSU	Pathology	Claflin	PHD	M	O
Narvaez, Dario	Colombia	KSU	Pathology	Claflin	MSC	M	P
Nzioki, Henry S.	Kenya	KSU	Pathology	Claflin	MSC	M	O
Arjula, Vaishali	India	KSU	Pathology	Leslie	MSC	F	O
Zeller, Kurt P.	U.S.	KSU	Pathology	Leslie	PD[2]	M	O
Kollo, Issoufou	Niger	TAM	Pathology	Frederiksen	PHD	M	I
Torres-Montalvo, Jose H.	Mexico	TAM	Pathology	Frederiksen	PHD	M	O

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Appendices

INTSORMIL Sponsored and Co-Sponsored Workshops 1979 - 2000

	Name	Where	When
1.	International Short Course in Host Plant Resistance	College Station, Texas	1979
2.	INTSORMIL PI Conference	Lincoln, Nebraska	1/80
3.	West Africa Farming Systems	West Lafayette, Indiana	5/80
4.	Sorghum Disease Short Course for Latin America	Mexico	3/81
5.	International Symposium on Sorghum Grain Quality	ICRISAT	10/81
6.	International Symposium on Food Quality	Hyderabad, India	10/81
7.	Agrimeteorology of Sorghum and Millet in the Semi-Arid Tropics	ICRISAT	1982
8.	Latin America Sorghum Quality Short Course	El Batan, Mexico	4/82
9.	Sorghum Food Quality Workshop	El Batan, Mexico	4/82
10.	Sorghum Downy Mildew Workshop	Corpus Christi, Texas	6/82
11.	Plant Pathology	CIMMYT	6/82
12.	Striga Workshop	Raleigh, North Carolina	8/82
13.	INTSORMIL PI Conference	Scottsdale, Arizona	1/83
14.	INTSORMIL-ICRISAT Plant Breeding Workshop	CIMMYT	4/83
15.	Hybrid Sorghum Seed Workshop	Wad Medani, Sudan	11/83
16.	Stalk and Root Rots	Bellagio, Italy	11/83
17.	Sorghum in the '80s	ICRISAT	1984
18.	Dominican Republic/Sorghum	Santo Domingo	1984
19.	Sorghum Production Systems in Latin America	CIMMYT	1984
20.	INTSORMIL PI Conference	Scottsdale, Arizona	1/84
21.	Primer Seminario National Sobre Produccion y Utilizacion del Sorgo	Santo Domingo, Dominican Republic	2/84
22.	Evaluating Sorghum for Al Toxicity in Tropical Soils of Latin America	Cali, Colombia	4/84
23.	First Consultative and Review on Sorghum Research in the Philippines	Los Banos, Philippines	6/84
24.	INTSORMIL Graduate Student Workshop and Tour	College Station, Texas	6/84
25.	International Sorghum Entomology Workshop	College Station, Texas	7/84
26.	INTSORMIL PI Conference	Lubbock, Texas	2/85
27.	Niger Prime Site Workshop	Niamey, Niger	10/85
28.	Sorghum Seed Production Workshop	CIMMYT	10/85
29.	International Millet Conference	ICRISAT	4/86
30.	Maicillos Criollos and Other Sorghum in Middle America Workshop	Tegucigalpa, Honduras	12/87
31.	INTSORMIL PI Conference	Kansas City, Missouri	1/87
32.	2nd Global Conference on Sorghum/Millet Diseases	Harare, Zimbabwe	3/88
33.	6th Annual CLAIS Meeting	San Salvador, El Salvador	12/88
34.	International INTSORMIL Research Conference	Scottsdale, Arizona	1/89
35.	INTSORMIL Graduate Student Workshop and Tour	College Station, Texas	7/89
36.	ARC/INTSORMIL Sorghum/Millet Workshop	Wad Medani, Sudan	11/89
37.	Workshop on Sorghum Nutritional Grain Quality	West Lafayette, Indiana	2/90
38.	Improvement and Use of White Grain Sorghums	El Batan Mexico	12/90
39.	Sorghum for the Future Workshop	Cali, Colombia	1/91
40.	INTSORMIL PI Conference	Corpus Christi, Texas	7/91
41.	Social Science Research and the CRSPs	Lexington, KY	6/92
42.	Seminario Internacional Sobre los Cultivos de Sorgo y Maiz sus Principales Plagas y Enfermedades	Colombia	1/93
43.	Workshop on Adaptation of Plants to Soil Stresses	Lincoln, NE	8/93
44.	Latin America Workshop on Sustainable Production Systems for Acid Soils	Villavicencio, Colombia	9/93
45.	Latin America Sorghum Research Scientist Workshop (CLAIS Meeting)	Villavicencio, Colombia	9/93
46.	Disease Analysis through Genetics and Biotechnology: An International Sorghum and Millet Perspective	Bellagio, Italy	11/93
47.	INTSORMIL PI Conference	Lubbock, Texas	9/96
48.	International Conference on Genetic Improvement of Sorghum and Pearl Millet	Lubbock, Texas	9/96
49.	Global Conference on Ergot of Sorghum	Sete Lagoas MG Brazil	6/97
50.	Conference on the Status of Sorghum Ergot in North America	Corpus Christi, Texas	6/98
51.	Principal Investigators Meeting and Impact Assessment Workshop	Corpus Christi, Texas	6/98

	Name	Where	When
52.	Regional Hybrid Sorghum and Pearl Millet Seed Workshop	Niamey, Niger	9/98
53.	INTSORMIL End Use Quality Assessment Workshop	Pretoria, South Africa	12/98
54.	Central America Regional Planning Workshop	Zamorano, Honduras	10/99

Acronyms

AAA/SFAA	American Anthropological Association/Society for Applied Anthropology
ABA	Abscisic Acid
ADC's	Advanced Developing Countries
ADIN	All Disease and Insect Nursery
ADRA	Adventist Development and Relief Agency
A.I.D	Agency for International Development
AID/H	Agency for International Development in Honduras
ALDEP	Arable Lands Development Program
APHIS	Animal and Plant Health Inspection Service, U.S.
ARC	Agricultural Research Corporation, Sudan
ARC	Agriculture Research Council, South Africa
ARGN	Anthracnose Resistant Germplasm Nursery
ARS	Agricultural Research Service
ASA	American Society of Agronomy
ASARECA	Association for Strengthening Agricultural Research in Eastern and Central Africa
ATIP	Agricultural Technology Improvement Project
BAMB	Botswana Agricultural Marketing Board
BIFADEC	Board for International Food and Agricultural Development and Economic Cooperation
BFTC	Botswana Food Technology Centre
CARE	Cooperative for American Remittances to Europe, Inc.
CARO	Chief Agricultural Research Officer
CARS	Central Agricultural Research Station, Kenya
CATIE	Centro Agronómico Tropical de Investigación y Enseñanza, Costa Rica
CEDA	Centro de Enseñanza y Adiestramiento, SRN, Honduras
CEDIA	Agricultural Document and Information Center, Honduras
CENTA	Centro de Technologia de Agricola, El Salvador
CFTRI	Central Food Technological Research Institute - India
CGIAR	Consultative Group on International Agricultural Research
CIAB	Agricultural Research Center of the Lowlands, Mexico
CICP	Consortium for International Crop Protection
CIDA	Canadian International Development Agency
CIAT	International Center for Tropical Agriculture, Colombia
CILSS	Interstate Committee to Combat Drought in the Sahel
CIMAR	Centro de Investigación en Ciencias del Mar y Limnologia, Costa Rica
CIMMYT	International Maize and Wheat Improvement Center
CIRAD	Centre International en Recherche Agronomique pour le Dèveloppement
CITESGRAN	Centro Internacional de Tecnologia de Semillas y Granos - EAP in Honduras

CLAIS	Consejo Latin Americana de Investigadores en Sorgho
CMS	Cytoplasmic Male-Sterility System
CNIA	Centro Nacional de Investigaciones Agricolas, Nicaragua
CNPQ	Conselo Nacional de Desenvolvimento Cientifico e Tecnologico
CNRA	National Center for Agricultural Research, Senegal
CORASUR	Consolidated Agrarian Reform in the South - Belgium
CRSP	Collaborative Research Support Program
CSIR	Council for Scientific and Industrial Research
CSIRO	Commonwealth Scientific and Industrial Research Organization, Australia
DAR	Department of Agricultural Research, Botswana
DARE	Division of Agricultural Research and Extension - Eritrea
DICTA	Direccion de Ciencia y Tecnologia Agricola - Mexico
DR	Dominican Republic
DRA	Division de la Recherche Agronomique, IER Mali
DRI-Yoro	Integrated Rural Development Project, Honduras-Switzerland
EAP	Escuela Agricola Panamericana, Honduras
EARO	Ethiopian Agricultural Research Organization
EARSAM	East Africa Regional Sorghum and Millets
EAVN	Extended Anthracnose Virulence Nursery
ECHO	Educational Concerns for Hunger Organization
EEC	European Economic Community
EEP	External Evaluation Panel
EIME	Ensayo Internacional de los Maicillos Enanos
ELISA	Enzyme-linked Immunosorbent Assay
EMBRAPA	Empresa Brasileira de Pesquisa Agropecuaria, Brazil
EMBRAPA-CNPMS	EMBRAPA-Centro Nacional para Maize e Sorgo
ENA	National School of Agriculture, Honduras
EPIC	Erosion Productivity Impact Calculator
ERS/IEC	Economic Research Service/International Economic Development
EZC	Ecogeographic Zone Council
FAO	Food and Agriculture Organization of the United States
FEDEARROZ	Federación Nacional de Arroceros de Colombia
FENALCE	Federacion Nacional de Cultivadores de Cereales
FHIA	Fundacion Hondurena de Investigacion Agricola, Honduras
FPX	Federation of Agricultural and Agro-Industrial Producers and Exporters
FSR	Farming Systems Research
FSR/E	Farming Systems Research/Extension
GASGA	Group for Assistance on Systems Relating to Grain after Harvest
GMB	Grain Marketing Board
GOB	Government of Botswana

GOH	Government of Honduras
GTZ	German Agency for Technical Cooperation
GWT	Uniform Nursery for Grain Mold
HIAH	Honduran Institute of Anthropology and History
HOA	Horn of Africa
IAN	Institute Agronomia Nacional, Paraguay
IANR	Institute of Agriculture and Natural Resources, University of Nebraska - Lincoln
IAR	Institute of Agricultural Research - Ethiopia
IARC	International Agriculture Research Center
IBSNAT	International Benchmark Soils Network for Agrotechnology Transfer
ICA	Instituto Colombiano Agropecuario/Colombian Agricultural Institute
ICAR	Indian Council of Agricultural Research
ICARDA	International Centre for Agricultural Research in the Dry Areas
ICC	International Association for Cereal Chemistry
ICRISAT	International Crops Research Institute for the Semiarid Tropics
ICTA	Instituto de Ciencias y Technologia Agricolas, Guatemala
IDIAP	Agricultural Research Institute of Panama
IDIN	International Disease and Insect Nursery
IDRC	International Development Research Center
IER	Institute of Rural Economy, Mali
IFAD	International Fund for Agricultural Development, Rome
IFPRI	International Food Policy Research Institute
IFSAT	International Food Sorghum Adaptation Trial
IGAD	Intergovernmental Authority on Development
IHAH	Instituto Hondureno de Antropologia e Historia
IICA	Instituto Interamericano de Cooperación para la Agricultura
IIMYT	International Improved Maicillo Yield Trial
IITA	International Institute of Tropical Agriculture
ILCA	Instituto Interamericano de Cooperación para la Agricultura
ILRI	International Livestock Research Institute - Niger
INCAP	Instituto de Nutricion de Centro America y Panama
IN.E.R.A.	Institut d'Environnement et de Recherche Agricoles
INFOP	National Institute for Professional Development
INIA	Instituto Nacional de Investigacions Agricola, Mexico
INIAP	National Agricultural Research Institute, Ecuador
INIFAP	Instituto Nacional de Investigaciones Forestales Y Agropecuarias - Mexico
INIPA	National Agricultural Research Institute, Peru
INRAN	Institut National de Recherches Agronomiques du Niger
INTA	Instituto Nicaraguense de Technologia Agropecuaria, Nicaragua
INTSORMIL	International Sorghum/Millet, Collaborative Research Support Program (CRSP)

IPA	Instituto de Pesquisas Agronomicas, Brazil
IPIA	International Programs in Agriculture, Purdue University
IPM	Integrated Pest Management
IRAT	Institute of Tropical Agriculture and Food Crop Research
IRRI	International Rice Research Institute, Philippines
ISAVN	International Sorghum Anthracnose Virulence Nursery
ISC	ICRISAT Sahelian Center
ISRA	Institute of Agricultural Research, Senegal
ISVN	International Sorghum Virus Nursery
ITA	Institut de Technologie Alimentaire, Senegal
ITAT	International Tropical Adaptation Trials
ITESM	Monterrey Institute of Technology, Mexico
ITVAN	International Tall Variety Adaptation Nursery
JCARD	Joint Committee on Agricultural Research and Development
KARI	Kenya Agriculture Research Institute
KIRDI	Kenya Industrial Research and Development Institute
KSU	Kansas State University
LASIP	Latin American Sorghum Improvement Project, Mexico
LDC	Less Developed Country
LIDA	Low Input Dryland Agriculture
LIFE	League for International Food Education
LUPE	Land Use and Productivity Enhancement
LWMP	Land and Water Management Project
MAFES	Mississippi Agricultural and Forestry Experiment Station
MC	Maicillo Criollo
ME	Management Entity
MFC	Mechanized Farming Corporation, Sudan
MHM	Millet Head Miner
MIAC	MidAmerica International Agricultural Consortium
MIPH	Honduran Integrated Pest Management Project
MNR	Ministry of Natural Resources, Honduras
MOA	Memorandum of Agreement
MOA	Ministry of Agriculture, Botswana
MOALD	Ministry of Agriculture and Livestock Development, Kenya
MOU	Memorandum of Understanding
MRN	Ministerio de Recursos Naturales, Honduras
MSU	Mississippi State University
NAARP	Niger Applied Agricultural Research Project
NARO	National Agriculturall Research Organization - Uganda
NARP	National Agricultural Research Project

NARS	National Agricultural Research System
NCRP	Niger Cereals Research Project
NGO	Non-Government Organization
NSF	National Science Foundation
NSP	National Sorghum Program
NSSL	National Seed Storage Laboratory, Fort Collins, CO
NU	University of Nebraska
OAS	Organization of American States
OAU	Organization of African Unity
OICD	Office of International Cooperation and Development
ORSTOM	L'Institut français de recherche scientifique pour le développement en coopération - France
PCCMCA	Programa Cooperativo Centroamericano para el Mejoramiento de Cultivos Alimentícios
PI	Principal Investigator
PL480	Public Law No. 480
PNVA	Malien Agricultural Extension Service
PPRI/DRSS	Plant Protection Research Institute/Department of Research and Specialist Services
PRF	Purdue Research Foundation
PRIAG	Regional Program to Strengthen Agronomical Research on Basic Grains in Central America
PROMEC	Program for Research on Mycotoxicology and Experimental Carcinogensis, South African Medical Research Council
PROFIT	Productive Rotations on Farms in Texas
PROMESA	Proyecto de Mejoramiento de Semilla - Nicaragua
PSTC	Program in Science & Technology Cooperation
PVO	Private Volunteer Organization
QTL	Quantitative Trait Loci
RADRSN	Regional Advanced Disease Resistance Screening Nursery
RAPD	Random Amplified Polymorphic DNA
RARSN	Regional Anthracnose Resistance Screening Nursery
RFLP	Restriction Fragment Length Polymorphism
RFP	Request for Proposals
RIIC	Rural Industry Innovation Centre, Botswana
ROCAFREMI	Réseau Ouest et Centre Africain de Recherche sur le Mil, Niger
ROCARS	Réseau Ouest et Centre Africain de Recherche sur le Sorgho - Mali
RPDRSN	Regional Preliminary Disease Resistance Screening Nursery
RVL	Royal Veterinary and Agricultural University, Frederiksberg, Denmark
SACCAR	Southern African Centre for Cooperation in Agricultural Research
SADC	Southern Africa Development Community
SAFGRAD	Semi-Arid Food Grains Research and Development Project
SANREM	Sustainable Agriculture and Natural Resource Management CRSP
SARI	Savannah Agricultural Research Institute - Ghana

SAT	Semi-Arid Tropics
SDM	Sorghum Downy Mildew
SDMVN	Sorghum Downy Mildew Virulent Nursery
SICNA	Sorghum Improvement Conference of North America
SIDA	Swedish International Development Agency
SMIP	Sorghum and Millet Improvement Program
SMINET	Sorghum and Millet Improvement Network
SPARC	Strengthening Research Planning and Research on Commodities Project, Mali
SRCVO	Section of Food Crops Research, Mali
SRN	Secretaria de Recursos Naturales, Honduras
TAES	Texas Agricultural Experiment Station
TAMU	Texas A&M University
TARS	Tropical Agriculture Research Station
TC	Technical Committee
TropSoils	Tropical Soils Collaborative Research Program, CRSP
UANL	Universidad Autonoma de Nuevo Leon, Mexico
UHSN	Uniform Head Smut Nursery
UNA	Universidad Nacional Agraria - Nicaragua
UNAN	Universidad Nacional Autónoma de Nicaragua UNAN-Leon - Nicaragua
UNILLANOS	Universidad Technologica de los Llanos
UNL	University of Nebraska - Lincoln
UPANIC	Union of Agricultural Producers of Nicaragua
USA	United State of America
USAID	United States Agency for International Development
USDA	United States Department of Agriculture
USDA/TARS	United States Department of Agriculture/Tropical Agriculture Research Station
VCG	Vegetative Compatibility Group
WASAT	West African Semi-Arid Tropics
WASIP	West Africa Sorghum Improvement Program
WCAMRN	West and Central African Millet Research Network (ROCAFREMI) - Mali
WCASRN	West and Central Africa Sorghum Research Network (ROCARS) - Mali
WSARP	Western Sudan Agricultural Research Project
WVI	World Vision International