1999

INTSORMIL 1999 Annual Report

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INTSORMIL

Sorghum/Millet Collaborative Research Support Program (CRSP)

INTSORMIL
Sorghum/Millet International Research

Fighting Hunger with Research ... a team effort

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Cover Photographs

Front Cover - Farmer's Field of Sorghum Hybrid NAD-1 in Niger

Back Cover - Variability of Pearl Millet Head Size

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

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Mississippi State University
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Introduction and Program Overview

Presently, worldwide, more than 800 million people do not get enough to eat or have access to a balanced diet to be healthy. At the World Food Summit in 1996, the United States of America (USA) and 185 other countries pledged to reduce the number of malnourished people by one half by 2015. It is shocking that about 33% of preschool children in developing countries will be stunted due to malnutrition by the year 2000. The number of stunted children in Africa alone has increased significantly from 35 million in 1980 to 45 million in 1995 and is predicted to reach 49 million in 2005. 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. In 1999, 65.8 million tons of sorghum were produced worldwide, of which 19.7 million tons were produced in Africa, mainly for direct consumption by humans, and 14.7 million tons were produced in the USA, mainly for livestock feed to produce meat for human consumption. In the crop year 1997-1998, the USA exported 5.3 million tons 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 USA. 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 its utilization as food and feed are vitally important to developing countries and to the USA.

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. Pearl millet, like sorghum, is a staple for 500 million people worldwide. Most of these people are in countries where malnourishment is a persistent problem. In 1999, 37.2 million ha (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 USA. In 1999, the amount of millets harvested worldwide was 29 million tons, of which 12.9 million tons were harvested in Africa and 180 thousand tons were harvested in the USA. 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. The USA and all other participants in the World Food Conference have a stake in promoting the production and utilization of pearl millet to help end hunger, particularly in Africa.

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

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 USA plans to contribute to the global effort to reduce hunger is by the USA's 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 to mobilize 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, developing country National Agricultural Research Systems (NARS), developing country colleges and universities, International Agricultural Research Centers (IARCs), private agencies, industry, and private voluntary organizations (PVOs). The Sorghum and Millet Collaborative Research Support Program is one of eight CRSPs currently in operation.

The Sorghum and Millet Collaborative Research Support Program (INTSORMIL CRSP) conducts collaborative research using partnerships between U.S. university scientists and scientists of the NARS, IARCs, PVOs and other CRSPs. INTSORMIL is programmatically organized for efficient and effective operation and captures most of the public research expertise on sorghum and pearl millet in the USA. ***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 United States of America 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 USA.

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 currently active in the INTSORMIL CRSP are the University of Illinois, Kansas State University, Mississippi State University, University of Nebraska, Purdue University, and Texas A&M University. 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 USA and those countries as a result of all that has been accomplished during the first twenty 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 the 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. 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 U.S. 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 USA, 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 USA 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 INTSORMIL research teams composed of American 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 conservation of millet and sorghum germplasm, natural control of arthropod pests and diseases of sorghum and millet, resource-efficient cropping systems, integrated pest management programs, and cultivars with improved nutrient and water use efficiencies. INTSORMIL also evaluates 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 USA 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 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 semiarid 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 year occurred in the USA and collaborating countries.

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

- Dr. Richard R. Hahn was appointed to the EEP as the utilization/marketing member.

- 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, Dr. John Axtell, Dr. Gebisa Ejeta, Dr. Bruce Hamaker, Purdue University; Dr. Stephen Mason, University of Nebraska; Dr. Henry Pitre, Mississippi State University; Dr. Medson Chisi, Department of Agricultural Research, Zambia; and, Dr. Aboubacar Touré, Institut de Economie Rurale, Mali.

- INTSORMIL, INRAN, ICRISAT and other sponsors held a Regional Hybrid Sorghum and Pearl Millet Seed Workshop in Niger, September 28 - October 2, 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, 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, in-depth review of INTSORMIL activities in West and Southern Africa and in the Horn of Africa.

- 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 proposed 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 year included:

  * 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: 1999 INTSORMIL Directory

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.

During 1998-99, there were 51 students from 23 different countries enrolled in an INTSORMIL advanced degree program and advised by an INTSORMIL principal investigator. This was a decrease of four students from the previous year. Approximately 75% 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 25% of all INTSORMIL graduate students were women.

The number of students receiving 100% funding by INTSORMIL in 1998-99 totaled 20. An additional 12 students received partial funding from INTSORMIL. The remaining 19 students were funded from other sources but are working 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, then 21 in 1995-96 and now 20 in 1998-99. 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.

In addition to graduate degree programs, 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 1998-99.

Networking

The Sorghum/Millet CRSP Global Plan for Collaborative Research includes workshops and other networking activities such as research 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 (WCAMRN/ROCAFREMI WCASRN/ROCARS, ASARECA, SADC and others), private industry and government extension programs to coordinate research and technology transfer efforts.

- Supports 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, East Africa, Mali, Niger, and Zimbabwe; ASARECA, SAFGRAD, WCASRN/ ROCARS, WCAMRN/ROCAFREMI, 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/ROCARS and WCAMRN/ROCAFREMI 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 WCAMRN/ROCAFREMI in West Africa is allowing INTSORMIL utilization scientists to collaborate regionally. WCAMRN/ ROCAFREMI is a good mechanism for promoting millet processing at a higher level than has been seen before in West Africa. During the last two years, INTSORMIL, the Bean/Cowpea CRSP and World Vision International have been working with NARS researchers and farmers in five countries, 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

Regional Activities and Benefits

The four regions of INTSORMIL collaboration include five prime sites where INTSORMIL resources were focused over the past year. These prime sites are Mali and Niger in West Africa, Ethiopia in the Horn of Africa, Botswana in Southern Africa, and Honduras in Central America.

West Africa

In Mali in Year 20, INTSORMIL completed its 15th year of collaboration with IER. The sorghum breeding program in Mali is large and diverse. It includes extensive crossing and intercrossing among elite introductions, improved non-guinea and guinea derived breeding lines, and elite local cultivars. It utilizes genetically diverse germplasm from around the world resulting in much genetic diversity in the breeding program. Extensive use is made of lines developed by ICRISAT and elite lines from the USA. INTSORMIL's collaborative breeding program in Mali focuses on developing lines of sorghum which are highly resistant to head bug and grain mold and which are tan plant types having high-quality grain for human consumption. INTSORMIL's collaborative pearl millet breeding in Mali aims at developing hybrid lines of pearl millet using a breeding technique which utilizes the difference in timing between stigma exsertion and receptivity and pollen production on the same panicle to achieve crossing. Local plant pesticides (biological pesticides derived from local plants) were found to be effective in controlling covered smut and will soon be released to farmers for seed dressing products.

In Niger, a long-term effort to improve nutrition and incomes of Nigerien citizens through the use of hybrid sorghum is coming to fruition. In the mid-1980s a Nigerien graduate student being trained in plant breeding by the INTSORMIL program began to experiment with hybrid sorghum in Niger. During the course of his M.S. and Ph.D. studies, he worked with his professors to develop parents of a sorghum hybrid which was designated NAD-1. This hybrid, which has grain quality acceptable for local food preparations, is well-adapted to drought and has consistently high yields, compared to local varieties. Yield results of NAD-1 in on-farm demonstrations have ranged from 3000 to 4500 kg ha^{-1} with adequate moisture to 1200 to 1500 kg ha^{-1} on dryland, where the national average is around 270 kg ha^{-1}. In October, 1998, INTSORMIL co-sponsored a regional conference with INRAN and ICRISAT in Niger, entitled "Regional Hybrid Sorghum and Pearl Millet Seed Workshop." The workshop was attended by scientists, government officials and business people from countries throughout West Africa, as well as the USA, Europe and India. At the workshop, which included oral presentations as well as trips to the field, the benefits of hybrid crops were discussed, experiences in starting hybrid sorghum seed industries in developing, as well as developed, countries were shared, and philosophy, strategy and tactics for developing a hybrid sorghum industry in Niger were discussed. As a result, commercial production of hybrid sorghum seed is now under way in Niger. This production of hybrid sorghum seed and the resulting increases in sorghum production will help Niger provide food security and is already resulting in higher incomes for those associated with the production and sale of the hybrid sorghum, NAD-1. INTSORMIL scientists both in the USA and in Niger continue to develop new, improved parents for hybrid sorghum seed production in Niger and continue to work with the private sector and government to assure that each plays its crucial role in developing the hybrid sorghum industry. The success of the nascent hybrid sorghum seed industry in Niger is, in large part, due to commitment of INTSORMIL to train Nigerien scientists and conduct collaborative research in Niger over the long term.

Horn of Africa

The Horn of Africa Regional Program follows a productive collaborative research program with the Agricultural Research Corporation in Sudan. From that collaboration, extensive raw and improved sorghum germplasm were identified, assembled, and catalogued for the benefit of agriculture in Sudan and the USA. Sudanese scientists were trained at INTSORMIL institutions in the USA, and U.S. scientists traveled to Sudan to work with their counterparts. The present, regional program has only recently been undertaken, and has as its prime site, Ethiopia. Eritrea, Kenya, Uganda and Sudan also participate in INTSORMIL's Horn of Africa regional program, although participation of Eritrea and Sudan is limited by political issues and current conflict in the region. Major regional constraints to production of sorghum and millet were identified during the past year. According to sorghum and millet scientists in the region, "the major sorghum and millet production and utilization constraints are generally common to all countries." These constraints include lack of improved germplasm, drought, *Striga*, insects and diseases (anthracnose, leaf blight, grain molds, smuts, ergot, blast, and downy mildew). Lack of moisture and soil nutrients and poor husbandry are primary constraints of sorghum and millet production in the Horn of Africa. Research conducted by participating scientists of NARS in the Horn of Africa is primarily applied research.

Southern Africa

In Southern Africa, INTSORMIL activities last year occurred in Botswana (the prime site), Namibia, Zambia, and Zimbabwe. The Southern Africa program is organized in six collaborative research projects in the following areas: development of pearl millet hybrids, using Namibian and Zambian varieties; sorghum disease management by identification and use of resistance; sorghum food quality research; integrated pest management research in Botswana and South Africa, with emphasis on sugarcane aphid; identification of factors limiting commercial production and marketing of sorghum in Botswana; and control of sorghum ergot. An area of collaborative research of major benefit to both the USA and South Africa deals with control of sorghum ergot, a disease which has plagued South Africa for many years and which entered the USA in 1997. INTSORMIL scientists from Southern Africa and the USA are working together to develop a multi-variate model which will incorporate as many of the relevant variables affecting ergot severity in hybrid sorghum seed production systems. The study is being conducted over a range of areas representative of climatic zones including four areas in South Africa and production areas in Zimbabwe and Zambia.

Central America

During the past year, the Central American program has been evolving from a program focused mainly in Honduras to one which is more inclusive of scientists from other countries in the region. The program has extensive ties with the private industry in Central America. A Memorandum of Understanding signed by INTSORMIL and the Nicaraguan Institute of Agricultural and Livestock Technology in May, 1998, made possible collaboration in sorghum breeding by sorghum breeders at INTA and Texas A&M University. During the past year, discussions were held with representatives of two Nicaraguan Universities (the National Agrarian University and the National Autonomous University of Nicaragua) and the Center for Agricultural, Livestock and Forestry Technology in El Salvador. Memoranda of Understanding are being prepared to provide the institutional framework to support collaborative research on sorghum by scientists of these three institutions with scientists of INTA, EAP and universities participating in INTSORMIL in the USA. Collaborative research on breeding sorghum varieties resistant to sorghum midge in Nicaragua was initiated this past year. Long-term research on the "langosta" complex of lepidopterous pests of sorghum and maize resulted in publication of a guide on how to manage these crops to minimize damage from the insects. In 1998, eighteen commercial sorghum hybrids were evaluated by INTSORMIL scientists working with scientists at national agricultural research systems throughout Central America and the Dominican Republic. This annual activity of INTSORMIL provides useful information to seed companies, growers, and breeders throughout the region. Collaborative grain quality research conducted by Honduran and American scientists produced useful information on sorghum tortilla quality traits such as appearance (color), taste, aroma, texture (mouthfeel)) and rollability by a taste panel. This information is being used by sorghum breeders to improve traits of food sorghums.

Regional Benefits by Technical Thrust

Germplasm Enhancement and Conservation

Germplasm exchange, movement of seeds in both directions between the USA and collaborating countries, involves populations, cultivars, and breeding lines carrying resistance to insects, diseases, *Striga*, drought, and soil acidity. 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)

INTSORMIL has been working since the mid-1980s to help Niger develop a hybrid seed industry. Beginning with initial experiments with hybrid sorghum in the 1980s, INTSORMIL scientists of Niger and the USA have collaboratively developed a line of hybrid sorghum, NAD-1, which is well adapted to conditions in Niger, yields higher than most local varieties and has acceptable qualities for consumers. A Hybrid Seed Workshop for W. Africa, was held in Niamey, Niger on 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 W. Africa and to assist the development of a private sector seed industry which brings many benefits to farmers in W. Africa. The Workshop consisted of approximately 150 participants from 15 countries including: United States of America, Niger, Ghana, Mali, Cote d'Ivoire, India, Burkina Faso, Kenya, Chad, Egypt, Senegal, France, Nigeria, Zimbabwe, and Zambia. Following the workshop, our private-sector partners, with the cooperation and support of the public sector, in Niger have made significant progress in the production of NAD-1 hybrid sorghum 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 is 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.

Building on the results of INTSORMIL research in the USA, the potential of brown midrib sorghum sudangrass in W. Africa is being explored through collaboration with an INTSORMIL scientist 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.

The mutable pericarp color gene designated as "candystripe" was first identified in Sudan. Collaborative research 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 us 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 team 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.

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. Sorghum germplasm was identified for advanced testing with resistance to several stresses and will contribute to production of more 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.

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 in 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

An INTSORMIL study focusing 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.

In West Africa, INTSORMIL's main collaborative, agronomic research activities have been focused in Mali and Niger. INTSORMIL participates in the West and Central African Sorghum and Millet Research Networks. This year, INTSORMIL signed a Memorandum of Understanding with the national agricultural research system of Burkina Faso, IN.ERA, and collaborative research was begun. In research conducted during the past year, 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 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.

Research in Mali by WCAMRN/ROCAFREMI 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 USA were finalized. The results of the research are now being prepared for publication by INTSORMIL scientists 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, a visiting INTSORMIL scientist has conducted greenhouse studies at UNL to strengthen the field results from Niger. A former INTSORMIL graduate student 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 him with a new computer and chlorophyll meter, and will also provide operating funds in 1999.

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 9%.

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*.

INTSORMIL researchers from the USA and Africa are accelerating the progress in developing biological defenses to the attack on sorghum by the parasitic weed, *Striga*. Advanced techniques have been developed to rapidly screen lines of sorghum by testing the sorghum seed in order to determine whether these lines have any of several specific modes of resistance to *Striga*. The extended agar assay involves artificially germinating sorghum seeds in the presence of *Striga* seeds to determine which lines of sorghum produce little or no germination stimulant. The paper roll assay is used to determine which sorghum lines inhibit the penetration of *Striga*. Using these techniques, INTSORMIL researchers not only select sorghum lines with specific resistances to *Striga*, but also are learning more about the complex interactions between sorghum and the parasite. The use of these laboratory techniques is rapidly accelerating the selection and breeding of *Striga*-resistant lines of sorghum which can be used to improve the resistance of varieties and hybrids of sorghum in Africa where *Striga* is a major factor in causing famine throughout the continent. 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 USA (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 USA. 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 USA, 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 *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 Caribbean 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 *C. africana* was observed to persist in an active phase predominantly on feral grain sorghum in Mexico and as far north as Corpus Christi, TX 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.

Each growing season, sorghum and maize are attacked by soil inhabiting insects, stem borers and panicle feeding insects that contribute to reduced yields of both crops on subsistence farms in Honduras, as well as other countries in Central America. However, the major insect pest constraint to production of these grain crops in Honduras is foliage feeding insects, whereas, the sorghum midge is the principal insect pest constraint to sorghum production on large commercial fields on the coastal plains of Nicaragua. A complex of defoliators annually damages or destroys the sorghum and maize crops in Honduras resulting in yield losses or replanting. Subsistence farmers may not have the resources to replant. The pest complex has been identified by INTSORMIL scientists to consist principally of three armyworm species and a grass looper.

Soil inhabiting insect pests contributing to sorghum seed and seedling losses in Honduras have been identified and insecticide control methods determined. Although slash-and-burn agricultural practices are used by subsistence farmers to assist in insect control, this cultural practice had limited influence on fall armyworm and neotropical cornstalk borer infestations. The pests were attracted to luxuriant plant growth in burned fields. Seed treatment with insecticide limited damage to seed and seedlings by soil inhabiting insects. Neotropical cornstalk borer attacked sorghum in monoculture at greater infestation levels than sorghum intercropped with maize. Planting sorghum with hybrid maize reduced stalk borer infestations and damage to sorghum compared with sorghum planted with a native maize.

Aspects of the biology, ecology, behavior and population dynamics of the armyworm species in the defoliator complex in Honduras and the sorghum midge in Nicaragua have been investigated. This information has contributed to the successful conduct of entomological research designed to evaluate ecological relationships of the pest insects with crop and noncrop 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, as well as in integrated systems on subsistence farms in southern Honduras. Recommendations for planting dates, weed control and insecticide applications to manage soil inhabiting insect pests and the lepidopterous defoliators have been developed and disseminated.

The information obtained in these INTSORMIL studies on sorghum and maize will assist subsistence farmers in Honduras and commercial farmers in Nicaragua and surrounding areas with similar insect pest constraints in their production of grain crops to increase yield at minimum cost for pest control with reduced risk to human health and the environment. The extension of INTSORMIL entomological research into Nicaragua has expanded the scope of entomological activities in this ecogeographic zone.

Sorghum diseases are, and remain, important factors reducing the potential yield 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.

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 landrace 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 drought year) or 1998.

In Mali, INTSORMIL scientists from the USA and Mali are developing IPM strategies for insect pests, especially panicle-feeding bugs and sorghum midge, that attack traditional and improved insect-resistant and susceptible sorghums.

In Southern Africa, collaborative research relationships were re-established between INTSORMIL scientists in the USA, Botswana and 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.

Progress was made 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 continued writing his dissertation from field studies begun in year 17 on MHM immature stage mortality, adult MHM biology and fecundity, and MHM biology on alternate host plants. His work will form the basis for reporting in 2000. Another graduate student completed and defended his thesis, and returned to Niger in August, 1999. Results from these 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. 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 cereals 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.

This past year, INTSORMIL cereal chemists have developed rapid screening techniques for breeders to use which assesses the new high digestibility trait recently discovered in germplasm of sorghum. A new rapid screening technique, which measures disappearance of alpha kafirin in sorghum grain has been developed by INTSORMIL scientists from the USA and Niger. The test is rapid and readily distinguishes between normal sorghum and the highly digestible sorghum cultivars. A Kenyan scientist 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.

With the hire of a food technologist, in Niger using INTSORMIL regional funds, the couscous project has advanced substantially. The process has been optimized and is waiting for our planned purchase of a decorticator and hammer mill to improve flour quality. This is a critical step in achieving a consistent, high quality final couscous product. There is a good deal of interest both within Niger and in neighboring countries about the potential of commercializing couscous made from sorghum and millet.. The WCAMRN-ROCAFREMI processing project has also focused on this opportunity. In Burkina Faso, where INRAN carried the couscous unit for demonstration, there was a very good response. American and Cameroonian INTSORMIL collaborating scientists will address economic considerations regarding commercial couscous processing. The couscous processing unit designed by CIRAD may not be the most economical, however, there is indication that it probably produces the most consistent, high quality product available from a small-scale process. Consumer acceptability tests showed that the couscous made from the INRAN unit was highly acceptable. Market testing has yet to be done, but is still planned for the upcoming year.

Stronger collaboration should result with the INTSORMIL food scientist in Ethiopia due to INTSORMIL's upcoming purchase of a decorticator and hammer mill for their cereal technology laboratory. With this equipment, there are plans to develop high quality flours that can be used in local Ethiopian industries.

The WCAMRN/ROCEFREMI participation has much potential in allowing INTSORMIL utilization scientists to collaborate regionally. So far ROCEFREMI-WCAMRN 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 research on processing of sorghum has yielded significant results over the past 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.

White food sorghum flour can be substituted for 50% of the wheat flour in Mexican cookie formulae. The effect of particle size and sandiness of sorghum flour were reduced by using 5% pregelatinized corn starch with 95% sorghum flour in cookies. The texture was equivalent to wheat flour cookies. Pregelatinized sorghum could be used as well.

Noodles from 100% sorghum flour were similar to rice noodles but the dry matter losses during cooking were higher. A noodle making procedure that could be used to make nonwheat noodles for special gluten free diets was devised. Factors affecting noodle quality of sorghum were determined. Heterowaxy sorghum grain has advantages for use in tortillas and baked snacks to improve the texture. Waxy grain has excellent functional properties but grain yields are low. Anti-fungal 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.

Two Ph.D., two B.S. and one short-term trainee completed work on sorghum and joined the food industry in Mexico, USA and Nicaragua. Three new graduate students joined the INTSORMIL research team at Texas A&M. Research in Honduras demonstrated that food sorghums produced acceptable tortillas. This work was conducted by a Honduran scientist using the commissary tortilleria at EAP and is used as part of increased educational activities in food technology.

A Sorghum Quality Assessment Workshop organized by the University of Pretoria, CSIR, and Texas A&M University, took place in Pretoria, South Africa. More than 36 participants from the food industry, university and research institutes in Southern Africa interacted during the 3.5 day workshop . It included tours to a Sorghum Brewery and the ARC Summer Grains Institute in Potchefstroom. Students participated who are enrolled in the Southern African Regional M.S. degree program at the University of Pretoria.

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.

Benefits to the USA

Germplasm Enhancement and Conservation

Several seed companies in the USA are now producing seed of brown midrib sorghum sudangrass commercially. 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 5 million acres of sorghum sudangrass in the USA at the present time, compared with 9 million acres of hybrid sorghum for grain production. Estimating that eventually 50% of the sorghum sudangrass acreage in the USA will be planted to brown midrib cultivars, $42.84/acre value added per acre times 2.5 million acres is equal to $107.1 million additional value to the farmer each year.

The sorghum and pearl millet breeders in Nebraska have taken lines from world wide sources in crosses with U.S. stocks to produce new hybrid parents for the USA, and elite germplasm for selection in developing country programs. Breeding techniques, researched in the project are enhancing the millet breeding programs in Namibia, Zambia and Mali, and the sorghum program in Botswana.

Plant biotechnology has become a powerful tool to complement the traditional methods of plant breeders in plant improvement. During the past year, INTSORMIL researchers have developed a protocol for sorghum transformation using a bacterium, *Agrobacterium tumefaciens*. It demonstrates that Agrobacterium-mediated transformation is a feasible technique for the genetic transformation to improve sorghum. 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 to improve the characteristics of sorghum once the protocol is further refined and improved.

Both applied and basic research were conducted in both crops. In pearl millet INTSORMIL bred and tested new hybrid parents, many in two cytoplasms, A_1 and A_4, and some with white grain, that gave higher yielding hybrids (trial mean yield at Mead, University of Nebraska Research Center, was 4.3 t ha^{-1}) with better lodging resistance. Detailed research, in conjunction with an ICRISAT visiting scientist at the University of Nebraska-Lincoln compared isonuclear hybrids in A_1 A_4 and normal (non sterile) cytoplasm. Evidence of cytoplasmic nuclear interaction was found, which means certain hybrids are best in one cytoplasm, others in another, and may be better in sterile cytoplasm than normal. The implication for other crops like maize for instance, is that a hybrid may be better if made by CMS than by detasseling. A_4 hybrids had better seed set at low temperatures, fertility restoration is better, and inheritance is simple and clear. Three further male sterile cytoplasms, A_5 A_{egp} and A_{av} are being incorporated into the isonuclear parent set to permit further studies. A visiting scientist from Namibia for six months working on hybrid breeding also studied direct effects of pollination on hybrid seed. In inbreds, male parent pollen directly increased seed size in pollinated heads relative to selfed pollinated seed. This means that in hybrid seed production fields some male parents can significantly increase yield, through increased seed size, on seed parents. Similarly, pollination of one hybrid with another slightly increased seed size, but not significantly.

INTSORMIL scientists found large differences between pearl millet genotypes for ability to germinate in cool soils - which would be useful in the Midwest. It is, therefore, possible to breed for this ability. INTSORMIL scientists tested food quality sorghum hybrids from a new generation of parental lines synthesized from earlier project germplasm; yields of the best hybrids were up to 18% better than commercial checks. Tests in 1999 with more extensive combinations produced in the winter nursery should lead to five or six new seed parents and two early male parents. Releases in the germplasm category (advanced lines) are also planned for 1999.

Sustainable Production Systems

During the past year INTSORMIL research has shown that pearl millet has potential as an alternate grain crop in dry, short growing season regions of the Great Plains of the USA. Planting date studies indicate a recommended date of June 1, but there is a wide window of planting dates from May 15 through July 15 for which there is minimal yield loss. This wide window of planting dates in the Great Plains is a characteristic which makes pearl millet feasible as an emergency crop or as a double crop.

Damage to young millet plants occurs for a variety of reasons. When 10 cm was mowed off of 25-day- old plants to simulate damage, increased tillering resulted. In early plantings later maturing varieties compensated well in terms of yield, while in later plantings, when yields from undamaged plants is lower, later varieties actually gave higher yields after mowing, demonstrating pearl millets' remarkable ability to rapidly switch resources to new tillers.

This years results of a multi-year study to determine recommended planting date and row spacing for dwarf pearl millet hybrids was continued on a sandy soil site in Ogallala, NE and a silty clay loam site in Mead, NE, and expanded to include a loam soil site in Sidney, NE, which has low rainfall and a short growing season. At the Sidney site, efforts are being made to intensify wheat -fallow production systems by incorporating a summer annual crop. Averaged over eight environments, narrowing row spacing increased yield of both pearl millet and grain sorghum by 12 to 15%. Pearl millet produced the higher yield when planted on June 1, but yield declines were small when planting as early as May 15 and as late as July 15, while grain sorghum had a narrower window for planting. Averaged over environments, grain sorghum produced approximately 0.4 Mg ha^{-1} more grain than pearl millet, but at planting dates after July 1, 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 in the Great Plains is merited.

Research of INTSORMIL scientists on weed interference in grain sorghum production showed that velvetleaf (*Abutilon theophrasti* Medic.) is less successful in competing with sorghum hybrids of tall height, compared to the hybrids of medium height. The use of tall grain sorghum hybrids with high vertical leaf area distribution would be a useful component of an integrated weed management program.

Sustainable Plant Protection Systems

INTSORMIL research on *Striga*, the parasitic weed of sorghum which is widespread in Africa and which invaded a small, now quarantined, area in the USA is providing valuable fundamental information about the chemical signals exchanged between crop plants and parasitic weeds. The components of biological resistance of sorghum to *Striga* which are being discovered by INTSORMIL research in the USA and collaborating countries are allowing the USA to build defenses against *Striga* while helping collaborating countries deal with the widespread yield losses of sorghum in Africa.

Ergot, *Claviceps africana*, which attacks sorghum was first observed in the USA in 1997. This fungus decreases sorghum yields by preventing pollination of the female flower of the sorghum plant and can make harvesting difficult by preventing machinery from operating normally due to sticky "honeydew" secreted by the fungus. Non-tariff barriers to importation of U.S. grain sorghum to Mexico and other countries could have become a significant problem once ergot had been identified in U.S. sorghum fields, so INTSORMIL researchers responded to the need for scientific information on which to base international agreements for importation of U.S. sorghum. During this past year, a visiting scientist from Zimbabwe conducted research on several epidemiological and biological aspects of *C. africana* in Mexico and the USA Sclerotia of *C. africana* developed from within sphacelia, so sclerotia always have some sphacelial tissue present. Sphacelia and sclerotia of *C. africana* should be thought of as different tissues of the same structure rather than entirely independent structures. Captan fungicide greatly reduced conidial germination associated with fresh sphacelia but did not penetrate far into the sphacelia. Temperature and relative humidity clearly interact to affect survival of conidia of *C. africana*. Several cumulative factors reduce presence and survival of *C. africana* in seed making seedborne ergot a negligible source of initial inoculum for infection in the field, especially in regions where ergot is already a recurrent pathogen. A four page pamphlet was prepared which outlined the prominent features of sphacelia and sclerotia. A well-illustrated manual "A laboratory guide to the identification of *Claviceps purpurea* and *Claviceps africana* in grass and sorghum seed samples" was also prepared in collaboration with Oregon scientists and utilized as part of a training workshop for Mexican seed inspectors at Sanidad Vegetal in Mexico City. Both publications are available in English and Spanish. The biological knowledge determined during the course of this project and the associated publications and training workshops are promoting the establishment of more scientifically-based import/export regulations for the international seed trade in sorghum.

Collaboration of INTSORMIL entomologists was successful with INTSORMIL sorghum breeders and molecular biologists to develop, evaluate, and deploy insect-resistant sorghums and add to the information database to increase resistance durability and identify the role of insect-resistant sorghums in integrated pest management (IPM) systems for the USA. New insect-resistant parental lines and hybrids were evaluated from selections and crosses made the previous year. Data collected will result in release of sorghum midge-resistant lines. Data were collected and good progress was made in advancing greenbug biotype I- and K-resistant parental lines for anticipated release. Insect resistance technology will contribute to better and more environmentally sound sorghum IPM.

INTSORMIL research is the basis for IPM of sorghum insect pests in the USA, especially in Texas. The information from INTSORMIL entomological research in Texas is used extensively by extension personnel, private agricultural consultants and farmers. A "Questionnaire on the 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, and 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, a method of pest control which is central to INTSORMIL research and INTSORMIL's outreach partnerships in the USA and developing countries. 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%). 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 new IPM practices. Most farmers (74%) 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.

During the past year, INTSORMIL plant pathologists have worked closely with INTSORMIL sorghum breeders to select lines of sorghum resistant to sorghum head smut, an important soil-borne fungal disease which appears at the seedling stage and results in complete inability of the plant to produce grain. In Mississippi, INTSORMIL entomologists evaluated the efficacy of insecticides applied to sorghum for control of fall armyworm and sorghum midge. This information is useful in providing recommendations to farmers for control of fall armyworm and sorghum midge on sorghum in the USA.

Crop Utilization and Marketing

The digestibility of sorghum is a trait which can be improved by plant breeding. INTSORMIL cereal chemists were this year developing an improved rapid screening assay based on a turbidity measurement for the high protein digestibility trait. This was done with a buy-in to the INTSORMIL project from the Texas Grain Sorghum Board. INTSORMIL food scientists at Purdue are still working on further improving the assay by way of using microtiter plates to decrease sample size and increase sample throughput per day. This rapid assay will enable sorghum breeders to more rapidly screen and select lines of sorghum with high digestibility, so that highly digestible sorghum can be commercially produced sooner to benefit both the livestock industry and producers of food for humans.

Sorghum food products are becoming more available in the USA, because some commercial hybrid seed companies have expanded their efforts to produce white, tan plant, food-type sorghum. Food-type sorghums are being segregated in storage to preserve their food-quality characteristics. INTSORMIL food scientists analyzed commercial food sorghums grown in 1997 and 1998, and they found that the protein and fat content of food type sorghums averaged 10.7 and 3.4%, respectively. The advantages of food type sorghums over red grain include color more acceptable to consumers and higher yield of decorticated grain. During this last year, INTSORMIL food scientists have worked closely with INTSORMIL sorghum breeders 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 cultivars produce well in dry climates, but these sorghums need more resistance to molds and weathering to be grown in hot humid areas, for example, in the Coastal Bend of Texas.

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 USA. Advances in sorghum and millet research over INTSORMIL's first 20 years, INTSORMIL scientists in the USA, Africa and Central America are now able to jointly plan and execute collaborative research which will have increased benefits to developing countries and the USA. 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 information 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 KSU-210A
John F. Leslie
Kansas State University

Collaborating Scientists

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Summary

The mating type locus in most fungi governs the ability of the organism to reproduce sexually. In ascomycete fungi, such as many plant pathogens, the trait is controlled by a single locus with two idiomorphic alleles. The alleles share no homology with each other, but some regions have been generally conserved across wide evolutionary distances and can be amplified using degenerate primers and the polymerase chain reaction. We used such primers to identify the conserved regions of the mating type alleles from *Fusarium* species commonly recovered from sorghum and millet. After subcloning and sequencing the amplified fragment, we constructed primer pairs that were specific for these *Fusarium* species. These primer pairs reduce the amount of time required to test for mating type from 4-8 weeks to 4-6 hours, and greatly speeds the analysis of populations, in which the scoring of mating type is an essential component of the analysis of the population's reproductive history. This PCR amplification also can be used to determine mating type in strains that are sterile, either because they are genetically blocked or because a suitable partner of the opposite mating type has not been identified. The ability to identify mating type without doing complete intercrosses of populations of field strains reduces the number of crosses required to identify new mating populations to less than half of the number now used. When combined with AFLP technology for identifying strains in the same apparent species, strain identification times can be markedly reduced and accuracy increased. The similarities between mating type in *Fusarium* species and mating type in better studied systems, e.g. *Neurospora crassa* and *Podospora anserina*, suggests that the basic biological functions and genomic organization are the same in the plant pathogens as it is in the better-studied model systems. Such similarities should allow the immediate application of findings from these model systems to these economically important plant pathogens. Physiological blocks of mating function could potentially be used to prevent sexual recombination under field conditions and limit these organisms to a strictly asexual form of reproduction. Blocking sexual reproduction would retard the ability of strains within the species to exchange genetic information and should slow the pathogen's ability to evolve in response to changes in its environment.

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 *Fusarium* associated diseases 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 put, 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. We used 128 progeny from a mapping population used to construct a genetic map for *G. fujikuroi* mating population A (see 1995 Annual Report), and 62 additional strains representing *Gibberella zeae*, *Fusarium oxysporum*, and all of the described mating populations of *Gibberella fujikuroi*. Strains were cultured on a synthetic minimal medium, if they had no auxotrophic requirements, or on a semi-synthetic complete medium, if nutritional supplements were needed. All incubations were performed at 25°C under a 12 h light/dark diurnal cycle. Strains were preserved for long term storage as spore suspensions in a 15:85 glycerol:water mixture that was frozen at −70°C.

Sexual crossing protocol. Crosses with the *G. fujikuroi* strains were made on carrot agar using standard tester strains as the female parents. Fertile crosses produced perithecia that exuded a cirrhus of ascospores 4-8 weeks after fertilization.

DNA manipulation. DNA was isolated with a cetyltrimethyl ammonium bromide (CTAB) procedure. In brief, frozen samples (app. 1.5-2 g wet weight) were ground to a fine powder under liquid nitrogen with a mortar and pestle. Then we added 8 ml of hot (65°C) 2% CTAB buffer (2% CTAB, 100 mM Tris-HCl pH 8.0, 20 mM EDTA, 1.4 M NaCl). We incubated the samples at 65°C for 30 minutes, extracted once with an equal volume of chloroform:iso-amyl alcohol (24:1), removed the aqueous layer and precipitated the crude nucleic acids with an equal volume of 2-propanol. We dissolved the pellet in 1 ml TE (10 mM Tris-HCl, 1 mM EDTA, pH 7.4) and extracted sequentially with equal volumes of phenol:chloroform:iso-amyl alcohol (25:24:1), and chloroform:iso-amyl alcohol (24:1). The last extract (app. 600 μl) was treated with 1.5 μl of RNase (2 mg/ml), and the remaining nucleic acids precipitated with either 2.5 volumes of 95% ethanol or 1 volume of 2-propanol. The resulting pellets were washed twice with 70% ethanol, dried briefly, and then resuspended in 50-100 μl of TE buffer. We estimated final DNA concentrations against *Hind*III-digested bacteriophage λ DNA with an Applied Biosystems IS-1000 digital imaging system (Alpha Inotech Corp., San Leandro, CA) by running samples and sample dilutions in 1% agarose gels.

Plasmid isolation, restriction digestion, ligation, and bacterial transformation and Southern hybridizations were performed using standard procedures. Agarose gels containing the amplification products were capillary blotted onto Hybond N+ membrane (Amersham International, Amersham, UK) and probed with DNA fragments labeled with [α-^{32}P]dCTP. Stringent conditions were used for Southern hybridization, i.e., membranes were first washed in 2 × SSC, 0.1% SDS at 25°C for 20 min, then two times in 0.1 × SSC, 0.1% SDS at 65°C for 20 min.

PCR products amplified from *G. fujikuroi* strain A-00999 were extracted from an agarose gel with QIAEX II (Qiagen Inc., Chatsworth, CA) following the manufacturer's instructions. Purified DNA fragments were blunt-end ligated into the *Eco*RV site of the plasmid pBluescript KS II+ (Stratagene, La Jolla, CA).

Amplification conditions. We used degenerate oligonucleotide primers NcHMG1 (5'-CCYCGYCCYCC YAAYGCNTAYAT-3') and NcHMG2 (5'-CGNGGRTTR TARCGRTARTN RGG-3') to amplify the putative HMG box from the 14 STANDARD *G. fujikuroi* mating type tester strains. The PCR reaction mixtures (50 μl) contained 1 × PCR buffer (Promega, Madison, WI), 20 ng fungal DNA, 2.5 mM $MgCl_2$, 0.25 mM of each dNTP (Promega), 2 μM of each degenerate primer, and 1 unit of *Taq* DNA polymerase (Promega). Amplification used the following program: initial denaturation at 95°C for 3 min, then 30 cycles of 1 min at 94°C, 30 sec at 55°C, and 1 min at 72°C, with a final elongation incubation at 72°C for 10 min. PCR-amplification products were separated by electrophoresis in 1.5% (w/v) agarose gels, stained with ethidium-bromide, and visualized with ultraviolet light.

We designed two *Gibberella*-specific primers GfHMG1 (5'-ACCGTAAGGAGCGTCACCA TT-3') and GfHMG2 (5'-GGGGTACTGTCGGCG ATGTT-3') based on the sequence of the 262 bp putative HMG-box amplification product from *G. fujikuroi* strain A-00999 (EMBL accession number AJ 131527). These specific primers were used to confirm the results obtained from amplifications with the degenerate primers, to identify the mating type of previously untested field isolates, and to confirm mating type assignments made by classical analysis of progeny of laboratory crosses. When the specific primers replaced the degenerate primers, we altered the amplification protocol by increasing the annealing temperature from 55°C to 60°C and by reducing the primer concentration from 2 μm to 0.1 μm.

Sequencing protocol. DNA was sequenced with the Sequenase kit (Version 2.0, USB, Cleveland, OH). Nucleotide sequence comparisons were made with the GCG software package.

Research Findings

Identification of a *MAT-2* HMG-box fragment. When NcHMG1 and NcHMG2 were used to amplify the *mat-2* HMG box from the tester pairs of mating populations A-G of the *G. fujikuroi* species complex, all of the strains had a bright band of unincorporated primers, and the two *G. fujikuroi* mating population D strains each had an additional amplification product of approximately 800 bp. As the 800 bp amplification product was found in strains of both mating types, this amplification product is not specifically associated with either mating-type idiomorph. Another PCR product, approximately 260 bp in size, was clearly amplified from one member of each of the tester pairs for mating populations A, C, E, F, and G but not from their counterparts. A similar amplification product was obtained from the representatives of the B and the D mating populations, but the resulting band was less intense that seen for the other five mating populations.

We cloned and sequenced the 262 bp fragment amplified from *G. fujikuroi* strain A-00999. The nucleotide sequence of this fragment, including the intron, was 58% and 62% similar to the HMG boxes in the *Neurospora crassa mt a* and *Podospora anserina FPR1* sequences, respectively. The *G. fujikuroi* mating population A sequence also contains a putative intron (12) at a conserved site between bp 92 and bp 138.

We used the nucleotide sequence of the putative *MAT-2* HMG box from strain A-00999 to design two primers to be used to amplify the homologous fragment from any MAT-2 strain of the *G. fujikuroi* species complex. Primer GfHMG1 corresponds to bases 29-49 at the 5` end, and primer GfHMG2 corresponds to bases 223-252 at the 3` end of the HMG box. When we used this pair of primers to amplify PCR products from genomic DNAs of the seven pairs of mating type testers, a single PCR product, 213 bp in size, was generated from one, and only one, of the mating type tester strains for each mating population. We identified PCR amplification products from GfHMG1 and GfHMG2, corresponding to the *MAT-2* allele in strains representing *matA*$^{+}$, *matB*$^{+}$, *matC*$^{-}$, *matD*$^{+}$, *matE*$^{+}$, *matF*$^{-}$, and *matG*$^{-}$. We probed Southern blots of these PCR amplifications with the 262 bp HMG fragment cloned from A-00999, and observed strong hybridization signals under high stringency conditions. No hybridization was observed when the PCR-product amplified from *N. crassa* was probed using the same conditions.

Based on the observed amplification patterns, we assigned MAT-1 and MAT-2 allele designations to the known mating types (Table 1) that correspond to those assigned in

Table 1. Correspondence between previous and revised mating type terminology in the *Gibberella fujikuroi* species complex.

Species[1]	G. fujikuroi Mating population	Mating type designation Present	Revised
Fusarium moniliforme	A	matA^{+}	MATA-2
(Fusarium verticillioides)		matA^{-}	MATA-1
(Gibberella moniliformis)			
Fusarium subglutinans	B	matB^{+}	MATB-2
(Fusarium sacchari)		matB^{-}	MATB-1
Fusarium fujikuroi	C	matC^{+}	MATC-1
		matC^{-}	MATC-2
Fusarium proliferatum	D	matD^{+}	MATD-2
		matD^{-}	MATD-1
Fusarium subglutinans	E	matE^{+}	MATE-2
(Gibberella subglutinans)		matE^{-}	MATE-1
Fusarium thapsinum	F	matF^{+}	MATF-1
Gibberella thapsina		matF^{-}	MATF-2
Fusarium nygsamai	G	matG^{+}	MATG-1
Giberella nygamai		matG^{-}	MATG-2

[1]Anamorph (Fusarium) name followed by teleomorph (Gibberella) name if other than a mating population of Gibberella fujikuroi. Other synonymous names follow in parentheses. See 1998 Annual Report for a more detailed discussion of these species

other ascomycetes, e.g. *Cochliobolus heterostrophus*, *Cryphonectria parasitica*, *Neurospora crassa*, and *Podospora anserina*. The form for the new terminology includes the mating population with which the allele is associated, because of the multiple biological species in the *G. fujikuroi* species complex and the potential for significant differences in the sequences associated with different biological species. Such differences might be exploited to design primers that are specific for both mating population and mating type. If a single species is identified by name, *e.g. G. moniliformis* instead of *G. fujikuroi* mating population A, then the letter in the gene symbol for the mating population is not needed and may be deleted.

Independent blind tests of the diagnostic ability of GfHMG1 and GfHMG2 were conducted in Godollo, Pretoria and Manhattan using 128 progeny (49 matA+ and 79 matA-) from the mapping population, the 14 standard testers representing the seven G. fujikuroi mating populations, and 48 field strains representing five of the seven mating populations, Fusarium oxysporum, and Gibberella zeae. For these tests, these strains were coded such that we knew the mating population to which a strain belonged, but did not know its mating type. The results of the PCR amplifications were identical to the results from sexual crosses with standard strains. Thus, the PCR results were predictive of the crossing results and the crossing results were predictive of the PCR results.

To summarize, there are three lines of evidence to support the hypothesis that the 262 bp fragment is part of one of the MAT alleles of G. fujikuroi. First, the fragment shares significant sequence similarity with N. crassa mt a-1 and P. anserina FPR1. Second, of the 52 field strains from the seven different mating populations examined, the fragment is consistently associated with only one mating type within a mating population. Finally, the presence of the amplified fragment co-segregated with the matA+ mating type and the absence of the fragment co-segregated with the matA- mating type for 128 progeny of the mapping population previously used to construct a G. fujikuroi genetic map (48, 49). On the basis of these classical genetic mapping data, the amplified fragment maps with 95% certainty to a 2.3 map-unit region that includes MAT, and is unlikely to map more than 1 map unit from MAT if it is not coincident with it.

Analysis of homothallic strains and species. We scored *MAT-1* as the absence of the *MAT-2* amplification product. The accuracy of scoring will increase when we finish the design and testing of primers to amplify a specific fragment from the conserved α box of *MAT-1*1, since, at the moment, anything that results in no amplification automatically leads to a diagnosis of *MAT-1*. Development of a system in which positive results are used to identify both *MAT* alleles is probably essential for studying the molecular basis of homothallism in *G. zeae* and *G. fujikuroi* mating population B.

We observed no PCR amplification products when GfHMG1 and GfHMG2 were used to prime PCR containing DNA from two *G. zeae* strains. This lack of amplification may have several causes. First, the HMG-box-containing *MAT-2* allele may be absent, as is known for some homothallic *Neurospora* species. Alternatively, the sequence may be present, but divergent enough from that of strains in the *G. fujikuroi* species complex so that amplification does not occur. Thirdly, it is possible that some *G. zeae* strains have *MAT-1* and some have *MAT-2*, and that the two strains we examined had only *MAT-1*. Finally, there are preliminary reports that some *G. zeae* strains have coding sequences from both *MAT-1* and *MAT-2*. Presumably the region corresponding to either GfHMG1 or GfHMG2 was altered in this fusion process resulting in no amplification in a PCR reaction using this primer pair.

We also examined strains, e.g. B-03852 and B-03853, that have been identified as occasionally homothallic. One of these strains (B-03852) clearly yields a *MAT-2* PCR amplification product, while the other strain does not. Thus, the basis for homothallism in these strains cannot be due to mating-type switching, as has been observed in some yeasts and filamentous fungi, but must be due to a novel and as yet undescribed mechanism.

Analysis of strains and species with no known sexual stage. With the *F. oxysporum* strains, four of the eight strains examined had a PCR amplification product indicative of the *MAT-2* allele. The availability of molecular diagnostics for mating type also may enable the analysis of purportedly asexual fungi, *e. g., Fusarium oxysporum*, and 12 of the 13 new *Fusarium* taxa recently described by Nirenberg *et al.*. These latter taxa have no known sexual stage, but should have *Gibberella* teleomorphs. There is circumstantial evidence in *F. oxysporum* for sexual reproduction in the form of high levels of diversity with respect to the multi-locus vegetative compatibility trait, especially in populations of putatively nonpathogenic strains. As described in my 1996 Annual Report, sexual reproduction need not be frequent to still play an important role in the maintenance and generation of genotypic diversity within field populations of these fungi. The availability of mating-type data should make it easier to identify potentially cross-fertile strains that can be used to test some of these hypotheses.

Implications for screening field populations and the identification of new biological species (mating populations). Molecular scoring of mating type will reduce the amount of effort required to screen field populations for sexual fertility and should increase the efficiency of the process through which new mating populations are identified. For example, in the analysis of field populations of *G. fujikuroi*, all field isolates commonly are crossed with both mating type testers representing all seven mating populations (a total of 14 crosses). These crosses are usually repeated twice, if there is a positive result, and 3-4 times if no perithecia producing ascospores are observed. If strains were tested molecularly for mating type before starting the crossing process, then the number of crosses needed to identify a strain to mating population is reduced by one half.

Crosses can be limited to the pair of testers from a single mating population if an alternative technique, e.g., isozymes (see my 1998 Annual Report), has been used to identify the mating population to which a strain belongs. Molecular diagnosis of mating type can reduce the number of crosses needed in two ways. First, only crosses with the tester of the opposite mating type need to be made, thereby reducing the number of crosses by one half. Second, if the initial crosses are successful, then the crosses need not be repeated to confirm fertility since the molecular diagnosis provides this confirmation, thereby reducing the number of crosses needed to one quarter of the original number.

The identification of a new mating population has always been a laborious exercise. Each putative member of the new mating population must be used as both a male and a female parent in crosses with all of the other putative members of that mating population to identify female-fertile strains that can potentially be used as tester strains for the new mating population. If a set of 60 strains is used, then 3600 crosses (60^2), repeated three times are needed to test the 60 strains for the presence of female fertility at the 5% frequency level with 95% confidence. If mating type is scored molecularly, then the number of crosses that need to be made is significantly reduced. For example, if a 40:20 split at mating type is detected following PCR amplification, then only 1660 crosses (still repeated thrice) would be needed.

Networking Activities

Editorial and committee service (1998):

* 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 (1998):

* Denmark – January 12-19
* The Netherlands – April 30 – May 5
* Egypt – May 3-12
* United Kingdom – August 16-23
* Israel – August 23-30
* Greece – October 26 – November 1
* Czech Republic - November 1-3
* Austria – November 3-5
* Hungary – November 5-7
* South Africa – November 8-25
* Egypt – December 7-18
* The Netherlands – December 18-20

Seminar, Workshop and Invited Meeting Presentations (1998)

* Danish Society of Plant Pathology, Copenhagen, Denmark - 1/98.
* Plant Pathology Research Institute, Agricultural Research Center, Giza, Egypt - 5/98.
* Novartis Biotechnology Center, Research Triangle Park, North Carolina - 5/98.
* Department of Plant Pathology, North Carolina State University, Raleigh, North Carolina - 5/98.
* Ivy Laboratories, Inc., Overland Park, Kansas - 6/98.
* 8th International *Fusarium* Workshop, Egham, United Kingdom - 8/98.
* 6th International Mycology Congress, Jerusalem, Israel - 8/98.
* Keynote Address, 1st European COST Symposium on Genetics of Mycotoxigenic Fungi, Athens, Greece – 10/98.
* Institute of Biochemical Technology, Technical University of Vienna, Vienna, Austria – 11/98.
* Agricultural Genetic Engineering Institute, Budapest, Hungary – 11/98.
* Forest & Agricultural Biotechnology Institute, University of Pretoria, Pretoria, South Africa – 11/98.
* PROMEC, Medical Research Council, Tygerberg, South Africa – 11/98.
* Summer Grains Research Center, Agricultural Research Council, Potchefstroom, South Africa – 11/98.
* Egyptian National Agricultural Library, Dokki, Egypt – 12/98.

During 1998 Standard Fusarium Cultures were Provided to:

* Dr. T. Aust, Chemwerth, Inc., Woodbridge, Connecticut.
* Dr. Charles Bacon, USDA Russell Research Center, Athens, Georgia.
* Drs. R. L. Bowden, L. E. Claflin & D. J. Jardine, Department of Plant Pathology, Kansas State University, Manhattan, Kansas.
* Dr. L. W. Burgess, University of Sydney, Sydney, New South Wales, Australia.
* Dr. Fun S. Chu, Institute for Food Safety, University of Wisconsin, Madison, Wisconsin.
* Dr. S. Chulze, Universidad Nacional de Rio Cuarto, Rio Cuarto, Argentina.
* Dr. M. Diourte, IER, Bamako, Mali.
* Fungal Genetics Stock Center, University of Kansas Medical Center, Kansas City, Kansas.
* Dr.W.Gams, Centraalbureau voor Schimmelcultures, Baarn, The Netherlands.
* Dr. L. Hornok, Agricultural Biotechnology Center, Institute for Plant Sciences, Godollo, Hungary.
* Dr. S. C. Jong, American Type Culture Collection, Manasas, Virginia.

* Dr. D. C. Kenison, Ivy Laboratories, Inc., Overland Park, Kansas.
* 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.
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Agroecology and Biotechnology of Fungal Pathogens of Sorghum and Millet from the Greater Horn of Africa

KSU-210B
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Summary

Sorghum accessions susceptible to *Claviceps africana* included *S. drummondii, S. virgatum, S. arundinaceum, S. halepense,* and *S. bicolor* (broomcorn, Tx6232, P954063). Ergot symptoms were not observed on *S. verticilliflorum* (IS 142257) and *S. drummondii* (IS14131). Finger millet, pearl millet, proso millet, foxtail millet, big bluestem, little bluestem, Osage indiangrass, switchgrass, maize, and Canada wild rye were immune to ergot.

Macroconidia of *C. africana* were recovered from various surface materials between sorghum cropping seasons in Kansas. Recovery was over 95% from surface materials infested with honeydew over the six-month sampling period. In a diluted honeydew suspension, less than one percent were recovered. Viability of the macroconidia rapidly declined over the six-month period.

Objectives, Production and Utilization Constraints

Objectives

- USA/Mexico/Guatemala/Honduras: Determine the survivability of macro- and microconidia of *Claviceps africana*, causal agent of ergot disease of sorghum on various surfaces. USA: Determine the overseasoning viability of macro- and microconidia of *C. africana* in infected sorghum panicles.

- USA/Kenya/Egypt: Continue to screen for genetic variability of sorghum germplasm to covered kernel smut and ergot diseases.

- USA/Mexico/Guatemala/Honduras: 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.

- USA/Kenya/Mali: Develop an effective screening protocol to ascertain genetic variability of various sorghum accessions to *Ramulispora sorghi*, causal agent of sooty stripe disease.

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, 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 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 drcuth 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 (D. T. Rosenow, personal communication).

Research Approach and Project Output

Ergot:. An extremely high incidence of ergot was reported in grain sorghum over a several week period in February (1997) on numerous islands within the Caribbean. This is likely attributable to an airborne spore-shower. This may occur under climatic conditions of moderate temperatures and favorable levels of relative humidity, coupled with a tropical disturbance or a prevailing wind to disseminate the spores over wide geographical areas. Ergot was detected in ratoon sorghum from Vera Cruz, Mexico to Dallas, Texas and also in Florida in mid-December, 1998. It is believed that hurricane "Mitch" was the primary source of dissemination.

Durability of ergot conidia will be determined by evaluating longevity of spores under natural field conditions. The survival rate will also be 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 temp. 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 X 10^7 cells/ml of microconidia and 1.1 X 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 45-60 min. Plates were removed and 250 μl from each well was added to a hemacytometer. 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 hemacytometer.

Volunteer plants: Various species of *Panicum, Cenchrus, Sorghum, and Andropogon* have been reported as susceptible to *C. africana*. Seeds of these plants will be obtained from the plant introduction centers and planted. In addition, various *Sorghum* sp. such as *aethiopicum, almum, japonicum, miliaceum, plumosum, saccharatum, sudanense, versicolor, verticilliflorum, and virgatum* will be evaluated under greenhouse conditions as some are potentially serious weeds if escapes occur. Koch's postulates will be used as to identify those susceptible.

Modeling System: Kramer-Collins spore traps were placed in Crosbyton and Corpus Christi, TX; Lahoma, OK; Garden City, Hays, Hesston, and Manhattan, KS; and Clay Center, NE during the 1999 growing season in an attempt to detect movement of ergot macroconidia. This information will be utilized 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 will be purchased which will determine the optimum epidemiological parameters for optimum disease severity under growth chamber conditions.

Research Findings

Ergot

Recovery of *C. africana* macroconidia was over 95% from surface materials infested with honeydew over the 6-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 6-month sampling period (Table 2).

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

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

NPD - No panicle development

Networking Activities

Research Investigator Exchanges

The PI on KSU-210B spent a portion of Year 20 on a sabbatical leave from Kansas State University on a joint research project involving ergot disease of sorghum in Mexico and the USA

Research Information Exchange

Assistance Given

Fourteen sorghum accessions from the Plant Genetic Resources Unit, Griffin, GA were bioassayed for the presence of *Pseudomonas andropogonis* as part of the quarantine regulations for shipment to Mexico.

Thirteen bacterial cultures were identified for the Plant Pathology Research Institute, Giza, Egypt.

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Table 2. Viability (%) [a] of *Claviceps sorghi* macroconidia over a 2-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

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

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 (*Spodoptera frugiperda, S. latifascia* and *Metaponpneumata rogenhoferi*) 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 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 insect 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 (1998, 1st year) concentrated on the principal insect pest constraint to sorghum production on large, commercial farms on the coastal plains. Sorghum midge, *Stenodiplosis sorghicola*, distribution, occurrence, host plants, aspects of population dynamics, and response to planting date, insecticides, and variety-insecticide interactions were studied. These observations and studies will be repeated in 1999 to 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

- Investigate insect occurrence, infestation levels, and aspects of populations dynamics of the sorghum midge on sorghum on the coastal plains in Nicaragua.

- Determine insecticide efficacy, and effects of variety-insecticide relationships and planting date on populations of and damage to sorghum by the sorghum midge in Nicaragua.

- Determine the influence of improved sorghums, developed in the Honduran breeding program, on insect pest infestations and specific insect pest population dynamics in selected cropping systems in Honduras.

- Evaluate chemical and biological insecticide use patterns and economic returns for control of whorl, stem, and panicle feeding insects on sorghum in Mississippi.

- Continue interest in developing collaborative entomological research programs on sorghum in Ethiopia and the Greater Horn of Africa.

- Publish collaborative research in scientific journals, as well as popular papers and extension articles, for distribution throughout the sorghum and maize production areas in Honduras and Nicaragua.

- Direct graduate students, attend scientific meetings and travel to host countries to plan research and collaboration in entomological investigations.

Constraints

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.

The lepidopterous pest complex, 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 *S. frugiperda* (fall armyworm), *S. latifascia* (black armyworm), and *M. rogenhoferi*, in determining the role of each species in causing damage to the intercropped sorghum and maize in southern 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 crop damage.

During the past ten years, research emphasis was principally on *S. frugiperda* and *S. latifascia*, with limited research on *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 given 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).

Research in MSU-205 has identified insect pest management tactics that are practical for use by low income subsistence farmers. A package 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 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 will be distributed within farm communities.

The extension of MSU-205 into Nicaragua is expanding INTSORMIL's presence and collaborative participation in Central America. Sorghum production in Nicaragua is predominantly in commercial systems on large farms on the coastal plains. The principal insect pest constraint to production is the sorghum midge. Studies have been initiated on 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 indicated limited host range for this insect pest, with only sorghum, johnsongrass and broom sorghum identified as hosts. Infestations on each of these hosts throughout the year is under investigation, as is aspects of midge seasonal survival (diapause) during the dry period. The influence of planting date, and variety-insecticide interactions on midge infestations was investigated in 1998 and these studies will be repeated in 1999. A trifold 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 into farm communities in Nicaragua.

MSU-205 activity in the Greater Horn of Africa in recent years has been limited to site visits in Ethiopia and Sudan and communications with collaborator scientists in the region in reviews of host country work plans for entomological studies. The principal insect pest constraints to sorghum production are stem and stalk borers. This communication and participation will continue as time allows.

Research Approach and Project Output

Research Methods and Research Findings

MSU-205 activities in Honduras

Weed Management: Influence on insect pest and natural enemy populations. The influence of weed management systems on pest and natural enemy (parasitoid) populations in 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. 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 and 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*. With research completed on aspects of the biology of *M. rogenhoferi*, the second most abundant species on sorghum and maize throughout the growing season in most years in southern Honduras, the literature that was searched revealed that the taxonomic characteristics of this species was lacking in comparison with other closely related species. This is an important consideration when identification of the particular pest species in a complex of species is critical in defining control recommendations. Therefore, a taxonomic study of the morphology of *M. rogenhoferi* was completed and a manuscript prepared and accepted for publication in a scientific journal. The life stages of this important insect pest were described using illustrations and scanning electron microscope pictures of the egg, larva, pupa, and adult (E and G genetalia) stages. Comparative notes on host plants and geographical distribution of related species in the tribe Eustrotiin: (Noctuidae) are presented in the publication.

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 in agricultural research in Honduras. This publication will be distributed within farm communities and will describe insect pest management tactics for the lepidopterous constraints to intercropped sorghum and maize production in southern Honduras.

MSU-205 activities in Nicaragua

The PI traveled to Nicaragua in mid-1997 to establish collaborative research relationships with INTA and other agricultural organizations involved in sorghum production in that Country. This trip was successful in identifying the interest of INTA, as well as academic/research institutions in collaborating with INTSORMIL. A collaborative agreement between INTA and INTSORMIL was signed in May 1998. As the sorghum midge has been identified as the principal insect pest on sorghum in commercial production fields on the coastal plain, the MSU-205 project initiated collaborative research on this pest constraint to production in 1999. Research is coordinated with Ing. Laureano Pineda, sorghum breeder and others in INTA. Collaboration with agricultural universities at Leon and Managus is planned.

Farm Survey (1998). Results of this survey revealed that 72% of the farmers on the coastal plain planted sorghum after the canicula (day season) and reestablishment of the rainy season. The most prevalent variety planted was DK-65 (DeKalb Seed Company); Esmeraldo (Asgro Seed Company) is planted on 25% of the farms. One to three chemical insecticide applications are used for control of fall armyworm. Granulated insecticides are used by 90% of the farmers at planting to control early season insect pests. Biological insecticides are seldom used in insect management programs for lepidopterous pests. Chemical insecticide sprays are used for sorghum midge control without adequate information on the need for the pesticide during the blooming period of the crop.

Planting Date. Sorghum was planted on three dates (August 18 and September 7 and 15 in a replicated test to measure sorghum midge infestations. Infestation levels ranged from 40 adults per panicle in the early planted sorghum to 110 adults per panicle in the late planting, with the later plantings having significantly greater seed loss than the early planting.

Variety-Insecticide Effects. Three sorghum varieties were planted and one-half of each plot (in replicated design) was sprayed with Lorsban insecticide (3 applications on 3 day schedule) at a recommended rate. Levels of varietal resistance to sorghum midge were observed, and the Lorsban insecticide treatment had lower levels of midge per panicle and reduced *Aprostocetus sp.* (parasitic wasp) parasitization of midges compared with the untreated (no insecticide).

Midge Population Occurrence and Host Plants. Sorghum, broom sorghum and johnsongrass were observed to serve as hosts for the sorghum midge. A population curve was developed for the sorghum midge based on infestations on these hosts during the sampling period (August 1998 - February 1999).

MSU-205 activities in Ethiopia

MSU-205 PI participated in the EARO-INTSORMIL Traveling Workshop in Ethiopia (and Eritria) in October of 1997. The PI had previously corresponded with the INTSORMIL/Horn of Africa Coordinator (Dr. Gebisa Ejeta, Purdue University) and EARO collaborator in Ethiopia (Mr. Tsedeke Abate) in reviewing proposed entomological research programs for conduct in Ethiopia. These programs involve: 1) Development of pest management strategies for sorghum stalk borers and panicle feeding insects emphasizing integration of cultural, chemical, and biological control tactics, and 2) Economic impact of insect pests on sorghum production to be determined and value of management tactics to be assessed.

The principal insect pest constraints on sorghum include stalk borers and panicle feeding head bugs. The principal entomological research activities are visualized to include studies on insect pest biology, ecology, behavior, dynamics and pest control using selective insecticides and/or cultural control tactics. Participation in this project during the next few years would extent MSU-205 research activities into East Africa (Greater Horn of Africa).

MSU-205 activities in the United States

The efficacy of insecticides applied to sorghum was again evaluated for insect pest control. A select group of insecticides was evaluated for control of fall armyworm and sorghum midge on sorghum in northeastern 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 in the 1999-2000 issue of "Insecticide and Acaricide Tests", published by the Entomological Society of America.

Direction of graduate students in 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, and traveled to Honduras and Nicaragua to work with collaborators and graduate students.

Networking Activities

Germplasm and Research Information Exchanges. Supplies and equipment required by graduate students in performance of research activities in the laboratory and field in Honduras were supplied (as in previous years) by MSU-205. Some financial support is provided annually to the students for research expenses while in Honduras. This support will continue with further INTSORMIL participation in Honduras and Nicaragua. 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 will be distributed into farm communities.

Publications and Presentations

Journal Articles

Castro, M. T., H. N. Pitre and D. H. Meckenstock, and F. Gomez. 1998. Influence of slash and burn and slash and mulch practices on insect pests in intercropped sorghum and maize in southern Honduras. Ceiba. 39: 1-4.

Portillo, H. E., H. N. Pitre, D. H. Meckenstock, and K. L. Andrews. 1998. Performance of a lepidopterous pest complex (the langosta) on sorghum, maize, and noncrop vegetation in Honduras. Environ. Entomol. 27: 70-79.

Books, Book Chapters and Proceedings

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.

Dissertations and Theses

Calderon, Pedro. 1998. Occurrence, host plant relationships, and diapause of *Metaponpneumata rogenhoferi* (Moschler) (Lepidoptera: Noctuidae) in southern Honduras. MS Thesis. Miss. St. Univ. 63 pp.

Vergara, Oscar. 1998. Economic evaluation of integrated pest management systems for lepidopterous pests in intercropped sorghum and maize in southern Honduras. MS Thesis. Miss. St. Univ. 98 pp.

Miscellaneous Publications (presentations)

Pitre, H. N., G. L. Teets, and G. C. Peterson. 1998. INTSORMIL: Two decades of entomological research for improved crop production. Display presentation. American Soc. Agron. Ann. Meeting. Baltimore, MD.

Pitre, H. N. 1998. Insect pests of grain sorghum. 1998 Conference of Mississippi Agricultural pest Management Associations. Ann. Meeting. Greenville, MS (2-24-98).

Striga Biotechnology Development and Technology Transfer

Project PRF-213
Gebisa Ejeta
Purdue University

Principal Investigator

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Collaborating Scientists

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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 Year 20, we report on progress of our effort to characterize novel mechanisms of resistance to *Striga* in sorghum. *Striga* causes much of its damage hidden under ground where only the negative effects of its attack are observed on the host plant. Our effort is geared towards simulating these early stages of parasitic infection in the laboratory so that we can develop appropriate assays for identifying genetic variants that can not have complete parasitic association with host plants. We recently developed a new procedure, a paper roll assay, for identifying early post-infection mechanisms of resistance to *Striga*. Using this assay, we observed two phenomena which may represent host defense mechanisms to *Striga* establishment. First, a hypersensitive response where an infected root shows reddening around haustorial attachment sites followed by reduced attached and penetration. We refer to the second phenomenon we observed, an incompatibility response, which is similar to hypersensitivity in discouraging development of *Striga* beyond attachment, except in incompatibility, there is no apparent necrosis in host tissue around attachment sites. An attached *Striga* rarely develops on this cultivar in the paper roll assay. We need to verify the power of these *Striga* resistant mechanisms in field tests in Africa.

Objectives, Production and Utilization Constraints

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. is 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, 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 objectives 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. Future emphasis, therefore, will be placed 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 development of assays for some of the above stages of parasitic development.

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 will also serve as an effective way to network our *Striga* research with NARS that are not 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 focussing 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

Characterization of Novel Mechanisms of Resistance to Striga in Sorghum

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* seed 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. Currently we are exploring a similar process to develop a laboratory culture 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 defense system that discourages penetration or further growth of the parasite. Our objective is to identify sorghum variants with unique and specific mechanisms of resistance to *Striga*. Agar culture allows easy visualization of developing *Striga* but attachment frequency to sorghum is low in agar.

Mr. Abdalla Mohamed, a Ph.D. student from Sudan, has developed a new laboratory assay that allows observations of the early stages of *Striga* infection of sorghum. The assay is still under refinement to optimize attachment of *Striga asiatica* to its sorghum host. We call it the paper roll assay. Briefly, it involves growing sorghum seedlings with their roots between rolled layers of germination paper. When seedlings are a week old, papers are opened and filter paper strips containing artificially germinated *Striga* seed are placed on sorghum roots. Papers are then rerolled and placed in an enclosed glass container which allows light to reach growing sorghum shoots. After an interval of 2-3 weeks, papers are unrolled to reveal parasite progress on its host.

By this method we typically see several attachment events. The paper roll assay works best if *Striga* seed is pregerminated with ethylene. This treatment overcomes differences in host genotypes for germination stimulant production. Moisture is also critical for encouraging infection. Saturated or dry papers reduce attachment events in the assay. We are still working out optimal light, temperature, aeration and nutritional factors that contribute to reproducibility.

We are confident that the paper roll assay can be an effective tool for identifying early post-infection resistance mechanisms. We are currently using the assay, in combination with the agar assay for germination stimulant production, to screen a collection of sorghum cultivars with reported field resistance to *Striga*. Among these we have observed two phenomena which may represent host defense mechanisms to *Striga* establishment.

By the first, 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 on the host. We call this a hypersensitive response, though it remains largely uncharacterized. 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, but not all, haustorial attachment sites. Some sites on the host root which appeared necrotic upon attachment fade and *Striga* grow 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.

We have observed another response in one cultivar that we call incompatibility. Incompatibility is similar to the hypersensitive response in that it discourages development of *Striga* beyond attachment. However, there is no apparent necrosis in host root tissue surrounding the attachment site. Incompatibility is more consistently expressed in a given individual than the hypersensitive response, at least among the cultivars we've screened. An attached *Striga* will rarely develop on this cultivar in the paper roll assay.

We plan to further refine the paper roll assay, working out those details that improve reproducibility. We will continue screening our collection of sorghum cultivars of tested field resistance to *Striga* since they have already yielded some promising results. Our collection includes both high and low *Striga* germination stimulant producers. We will continue to characterize the hypersensitive response and incompatibility among the cultivars and make crosses to determine their inheritance.

We are currently developing populations from crosses made between lines contrasting for the hypersensitive response and incompatibility. Progeny of these crosses await screening by the paper roll assay. After this, pot and field studies under *Striga* pressure will help us determine the predictive power of the paper roll assay. We expect to have sorghum ready for these studies by the 2000 growing season. By then we also hope to identify molecular markers as selection aids for the hypersensitive reaction and incompatibility.

Refinement of the paper roll assay seem to be painstakingly slow, however, once refined this assay should facilitate characterization of mechanisms of *Striga* resistance as well as pyramiding multiple sources of resistance into selected sorghum germplasm. This will be a powerful and inexpensive technology for breeding *Striga* resistance sorghums which research programs in developing countries can readily and 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 of Striga Resistant Sorghum Selections

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*. In order to allow selection of experimental varieties in a field environment having *Striga* pressure, we rely on collaborators throughout Africa to establish an INTSORMIL International *Striga* Resistance Sorghum Nursery. In 1997, we sent 25 entries to scientists in 12 African countries for field testing in *Striga*-sick plots. Some data on yield and *Striga* count are presented from this trial in the table below. Several experimental entries look promising, having both broad environmental adaptation and good resistance to *Striga*. A second trial for the 1998 season has been conducted in 13 African locations, but the results from several stations have not been received. We hope to receive these reports and summarize them for in due time. 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.

Networking Activities

Workshop and Program Reviews

Participate in African Dissertation Internship Awards Selection, Rockefeller Foundation, 18 May 1998, New York.

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

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

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

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

Participate in Regional Collaborative Research in Ethiopia and provide technical guidance to sorghum research in Ethiopia, 19-26 September, 1998.

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

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

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

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

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

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 project year:

Dr. Aberra Debelo, Ethiopian Agricultural Research Organization (EARO, Addis Ababa, Ethiopia.

Dr. Paula Bramel-Cox, ICRISAT, India

Dr. Yilma Kebede, Pioneer, Manhattan, KS, USA

Dr. Brian Hare, Advanta, Pacific Seeds Pty Ltd, 268 Anzac Avenue, P.O. Box 337, Toowoomba, Qld 4350, Australia.

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 over 10 countries in 1998.

Publications

Refereed Papers

Menkir, A., P. Goldsbrough, and G. Ejeta. 1998. RAPD Based Assessment of Genetic Diversity in Cultivated Races of Sorghum. Crop Science 37:564-569.

Tuinstra, M., G. Ejeta, and P. Goldsbrough. 1998. Evaluation of Near-Isogenic Sorghum Lines Contrasting for QTL Markers Associated with Drought Tolerance. Crop Science 38:835-842.

Mohammed, A.H., G. Ejeta, L. G. Butler, and T. L. Housley. 1998. Moisture Content and Dormancy in *Striga* asiatica seeds. Weed Research 38:257-265.

Conference Proceedings

Axtell, J.D., I. Kapran, Y. Ibrahim, G. Ejeta, and D. Andrews. 1998. Heterosis in Sorghum and Pearl Millet. In Coors (ed) The Genetics and Exploitation of Heterosis in Crops. CIMMYT Press, Mexico City, Mexico

Kapran, I., J.D. Axtell, G. Ejeta, and T. Tyler. 1998. Expression of Heterosis and Prospects for Marketing of Sorghum Hybrids in Niger. In Coors (ed) The Genetics and Exploitation of Heterosis in Crops. CIMMYT Press, Mexico City, Mexico.

Published Abstracts

Ejeta, G. 1998. Interdisciplinary Collaborative Research Towards The Control of *Striga*, p.46. Agronomy Abstracts. ASA, Madison, WI.

Mohamed, A., P.J. Rich, A. Melakeberhan, T. Housley, and G. Ejeta. 1998. An *in vitro* system for evaluating sorghum germplasm for post-infection *Striga* resistance mechanisms. p.76. Agronomy Abstracts. ASA, Madison, WI.

Ibrahim, Y., G. Ejeta, and W. E. Nyquist. 1998. G x E Interaction Analysis in Sorghum Using AMMI, p.79. Agronomy Abstracts. ASA, Madison, WI.

Ibrahim, Y., A. Melakeberhan, Y. Weerasuriya, N. Cisse, J. Bennetzen, G. Ejeta. 1998. Construction of a Sorghum Linkage Map and Identification of Loci Involved in *Striga* Resistance, p.156. Agronomy Abstracts. ASA, Madison, WI.

Invited Research Lectures

Ejeta, G. 1998. How Purdue Researchers Outwitted *Striga*. Presented at Workshop for Wabash Area Lifetime Learning Association, Morton Community Center, West Lafayette, April 1, 1998.

Ejeta, G., J.D. Axtell, B. Hamaker, and K. Ibrahim. 1998. INTSORMIL: A Win- Win Program for US and Developing Country Agriculture. Presented at the Dean of Agriculture Team Award Ceremony, Purdue University, 12 May, 1998.

Ejeta, G. 1998. Strategies in Collaborative International Development Efforts in Plant Breeding. Presented at the Summer Institute for African Agricultural Research. 17 June, 1998, University of Wisconsin, Madison

Ejeta, G. 1998. Interdisciplinary Collaborative Research Towards the Control of *Striga*. Presented at the Symposium on CRSP: A Unique USAID Partnership with Higher Education. American Society of Agronomy, Baltimore, MD, 19 October 1998.

Disease Control Strategies for Sustainable Agricultural Systems

Project TAM-224

R.A. Frederiksen
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Summary

This has been a year of transition and downsizing. R. Frederiksen has elected to retire from Texas A&M University on or about August 31, 2000. R. Frederiksen visited the collaborative research program in Niger and attended the Conference on Sorghum Hybrids for Niger. Acremonium wilt is a serious disease of NAD-1, the putative hybrid for Niger. Mr. Kollo's dissertation is on the etiology of this disease and the apparent interaction of *Acremonium strictum*, the fungal pathogen, with soil borne nematodes. Three trips were made to Mexico, first to review the research done by collaborator, J. Narro at Celaya on predicting ergot and on the evaluation of hybrids and varieties to the diseases. Ing. Narro was able to predict the disease with accuracy based on the models developed by South African co-worker Neal McLaren. Two other trips were made in selecting hotel sites and support for the Global Conference on Sorghum and Millet Diseases for September 2000. A study in collaboration with Sylvie Pazoutova, and Ranajit Bandyopadhyay on the origin of the sorghum ergot inoculum found in the Americas, was submitted for publication. 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 the *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 between studies on toxicology between Australian and American isolates. The aggressiveness of the *C. africana,* probably in part because of its secondary sporulation, may account for its rapid dissemination in Asia and the Americas. Continuing progress on grain mold, anthracnose, head smut, and ergot are reported in the text.

Objectives, Production and Utilization Constraints

Objectives

India/ICRISAT

- Continue collaboration with ICRISAT on growing, distributing, and evaluating the International Sorghum Anthracnose Virulence Nursery.
- Continue collaboration on ergot.
- Begin a collaborative initiative on application of biotechnology for control of grain mold.
- Develop technical program for the Global Conference on Sorghum and Millet Diseases in Mexico.

Mali

- Continue efforts to establish a 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 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. These involve the identification of sorghums with excellent resistance(s) to specific pathogens, and collaborate on the incorporation of the resistance(s) into useful cultivars. Essentially all of this work is done cooperatively with plant breeders, biotechnologists, geneticists, and entomologists in the Texas programs, but also occasionally with breeders in other states, nations (NARS), or with an International Crop Research Centers, specifically ICRISAT and CIMMYT. This includes the application of such technologies to manage ergot.

Collaborative Research in Niger

During 1997 three trials were conducted in the sorghum growing areas of Konni in Niger on Acremonium wilt (*Acremonium strictum*) of sorghum.

Acremonium wilt (*Acremonium strictum*) of sorghum in Niger: Association with nematodes and effect of nitrogen and liming (Prepared by A. Issoufou Kollo Abdourhamane)

Association of Acremonium strictum with Pratylenchus zea

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 the Konni area. Although the disease is generally more serious on the improved cultivars, there are cases where even the landraces 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 was 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 landrace 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 thouroughly 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 (Figure1). The high susceptibility of this hybrid to acremonium wilt is evident. With the landrace Mota, the level of infection increases as the nematode number increases (R^2=0.42). In presence of nematodes, Mota becomes susceptible to *A strictum.* This experiment is being actually repeated in the green house in Niger during the off-season.

The nematicide treatments did not significantly affect the incidence of acremonium wilt in either 1997(which is a droughty year) or in 1998 (Table 1). 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.

Effect of Liming and Nitrogen Forms on the Development of Acremonium Wilt of Sorghum.

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 known to influence soil born diseases. The objective of this experiment was to study the effect of nitrogen form and lime on the development of acremonium wilt on sorghum.

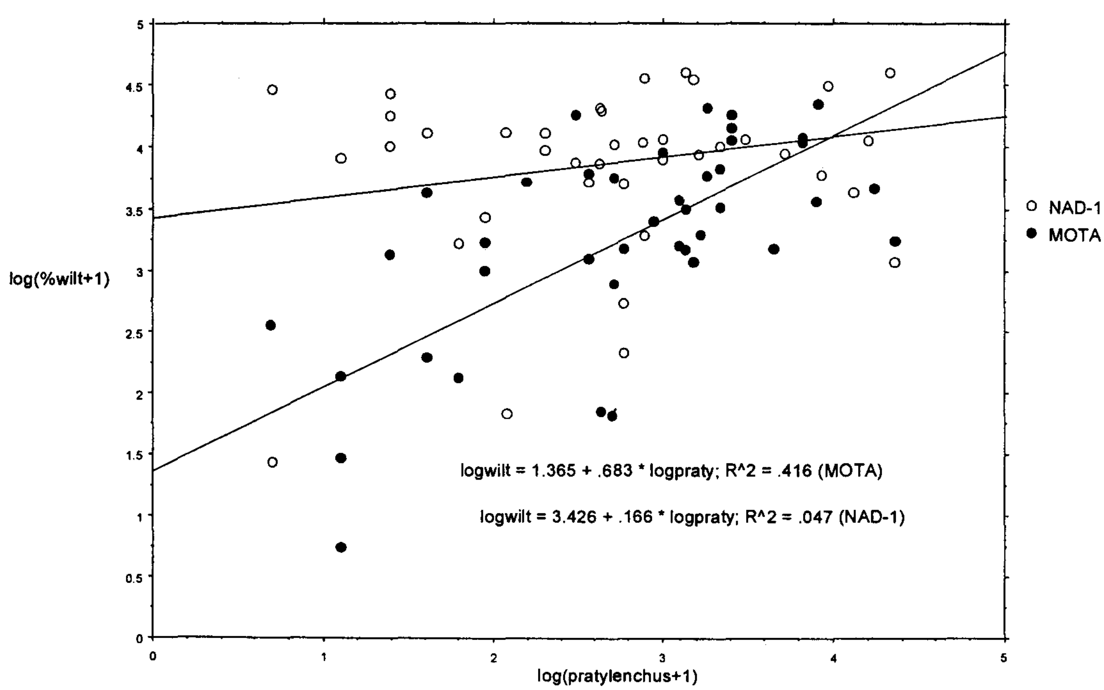

Figure 1. Relationship between *Pratylenchus zea* and acremonium wilt on sorghum in Niger. 1997 cropping season.

Table 1. Effect of nematicide application on acremonium wilt incidence in sorghum and yields of sorghum in a farmer's field in Niger, cropping 1998.

Nematicide	Plants/plot		Percent wilt		Plants harvested		Grain yield (kg/plot)	
(Kg a.i/ha)	NAD-1	MOTA*	NAD-1	MOTA	NAD-1	MOTA*	NAD-1	MOTA*
Counter								
1.1	56	82	65.22	28.24	29	37	0.55	0.62
2.2	55	84	61.65	16.73	27	45	0.42	1.52
3.3	58	96	39.23	20.21	28	54	0.54	1.73
Furadan								
2.0	2.0	56	74	76.37	35	37	0.63	1.01
4.0	4.0	38	83	84.89	28	44	0.29	1.66
6.0	6.0	45	98	80.56	28	53	0.31	1.63
Control		47	71	78.64	28	29	0.40	0.86

*Differences are significant at the 5% probability level.

The experiment was conducted at the Konni research station during the 1997 and 1998 cropping seasons (Data for 1997 are shown here, Tables 2, 3 and 4). The hybrid NAD-1 was used. Two levels of limestone was used, 0 and 1 t/ha. Limestone was obtained from 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 KNO_3 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 six replications. Disease incidence was monitored and yield components were measured.

Stand was significantly improved by lime and nitrogen (Table 2). 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 (Table 3). Although the wilt incidence was highest in the control plots (Table 3), the differences were not significant at the 5% level (p=0.08 for the main effect of lime, and

Table 2. Analysis of variance for the effects of liming and nitrogen source on the development of acremonium wilt and yield of sorghum. Konni Reseach Station 1997.

		Mean Square				
Source	df	Plant/plot[a]	%Wilt[b]	Plants harvested[c]	Straw yield (kg/plot)[d]	Grain yield (kg/plot[e])
Block	5	0.088	0.007	186.183	0.0.756***	0.020
Lime	1	0.531***	0.022*	588.00**	0.178	0.050**
Nitrogen source	3	0.126**	0.014	409.861***	0.135	0.017
Lime × nitrogen source	3	0.056	0.005	201.556*	0.444*	0.036**
Error	35	0.043	0.007	85.793	0.144	0.011
		a) cv=5.12%	b)cv=27.19%	c)cv=22.30%	d)cv=14.24%	e)cv=11.85%

*** significant at 0.01 probability level
** significant at the level of 5% probability
* significant at the level of 10% probability.

Table 3. Means for stand establishment as affected by liming and the different forms of nitrogen, Konni, Niger 1997

Lime stone (t/ha)	Plants/plot	%Wilt	Plants harvested
0.0	52 B	33 A	38 B
1.0	64 A	24 A	45 A
Nitrogen form			
69 kgN/ha (urea	59 AB	20 A	40 B
69 kgN/ha (CAN	64 A	29 A	48 A
Manure 20 t/ha	60 AB	33 A	44 AB
Control	50 BC	33 A	35 BC

Mean followed by the same letter are not significantly different at the 5% level.

Table 4. Means of sorghum grain and stover yields as affected interaction between liming and form of nitrogen

Limestone (t/ha)	Nitrogen form	Stover weight (kg/plot)	Grain weight (kg/plot)
	69 kgN/ha (urea)	5.875 AB	0.619B
0.0	69 Nitrogen kg/N/ha (CAN)	6.083 AB	0.700 BA
	Manure (20 t/ha)	7.417 A	0.799 BA
	Control	7.500 A	0.754 BA
0.1	69 kgN/ha (CAN	7.750 A	0.910 A
	69 kgN/ha (CAN)	8.042 A	0.883 A
	Manure (20 t/ha)	4.792 B	0.913 A
	Control	7.125 A	0.613 B

Means followed by the same letter are not significantly different at the 5% level of probaility.

p=0.11 for nitrogen). For the number of plants harvested, the interaction between lime and nitrogen was not significative at 5% level. However, the effect of lime was significant and the effect of nitrogen form was highly significant (Table 2). The control plots had the lowest number of plants harvested. Therefore, the ability of plants 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 (Table 4). 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.

These data were obtained during the 1997cropping season. The 1998 data is being analyzed and compared with those of 1997. This comparison is important because 1998 had excellent rainfall. 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.

Collaborative Research in Mali

Dr. M. Diourte and I reviewed his program last year at Niamey, Niger. I have no report of his work, but he has written regarding his needs. With Dr. Rosenow, we have arranged for him to have an incubator and I have made *Colletotrichum sclerotia* storage units for a study on the survival of these bodies in Mali. The idea is that this is how the pathogen survives in west Africa. Dr. Diourte and I discussed the opportunities of networking specific nurseries in west Africa, and this is one reason for my visiting his program and those of Dr. Zachee Ngoko in Cameroon this fall.

Collaborative Research in Honduras

Basically, our only relation with Honduras and Central America at this time is through the graduate research done by Jorge Moran on determining the reaction of sorghum pollen and ergot. These studies will be part of his M.S. thesis with Dr. Bill Rooney, plant breeder at Texas A&M University.

Domestic Research

Fine Mapping of Non-Meristematic Head Smut (Sporisorium reilianum) Resistant Gene in Sorghum (Prepared by Dr. Ramasamy Perumal)

Sorghum head smut is an important soil borne fungus disease, which appears at seedling stage and results in complete inability of the plant to produce grain. Host plant resistance is the only most effective way to control this disease. The line RT × 635 possesses both meristematic (race specific, vertical resistance, and resistance factors are expressed in the apical meristem) and non-meristematic (non-race specific, horizontal resistance, and resistance factors are expressed in the exterior plant tissues surrounding the apical meristem). Hence, a total of 1600 F_3 recombinant inbred lines from the cross B1 × RTx635 were screened both under natural, and artificial conditions for the present study. Approximately 3000 individual F_3 plants were artificially inoculated under greenhouse condition using hypodermic syringe technique to differentiate meristematic and non-meristematic resistance reaction, since artificial inoculation bypasses non-meristematic resistance. Finally, 209 F_3 mapping populations were selected for identifying closely linked markers through RAPD and AFLP techniques. The RAPD marker OPH 4 having 5.1-cm distance has been validated for its co-segregation pattern in the present population. To identify the marker for non-meristematic resistance, and to differentiate it from meristematic resistance marker, a high resolution automated Licor technique is being used for AFLP marker. Two AFLP markers viz., aflp 1 and aflp 2 having 2.6 and 2.9 cm distances identified in RTx635 for head smut meristematic mechanism (Osorio, 1996) were used in the present population and these two markers resolved high polymorphism in the parents. Further, all the F_3 progenies will be tested with the same markers for fine mapping of non-meristematic mechanisms.

Grain Mold (Prepared by Chris Little)

Work as of late has focused in characterizing the level of virulence and aggressiveness of isolates of *F. moniliforme* and *C. lunata* to grain mold resistant (R), moderately resistant (MR), and susceptible (S) lines of sorghum. These lines are being evaluated for levels of several disease incidence parameters, including presence/absence of kernel, fungal colonization of intact kernels, kernel filling, germinability, and vigor. Similar approaches are being taken with R × S hybrids in field trials at the Brazos Bottoms Field Laboratory (TAES).

RNA blots are currently being produced which correspond to control, *F. moniliforme*, and *C. lunata* treatments of R, MR, and S spikelet tissues over a broad range of timepoints. At this time, two phenylpropanoid pathway enzymes are the focus of our attention as being candidates for functional defense response genes, these are phenylalanine ammonia-lyase (PAL) and chalcone synthase (CHS). Expression patterns of these genes appear to differ between inoculated and control over several time points. There may be a tendency for expression of the genes to be higher overall in inoculated plants than in control. This needs to be confirmed by use of an internal loading control, to ensure that differences that have been observed are due to real changes in expression levels and not to quantification errors. An actin probe is being generated for *Sorghum bicolor* using primers produced from a *S. vulgare* sequence (SVOAc1). Actin levels should remain constant from treatment to treatment and line to line. Comparisons between R, MR, and S lines, between fungi, and different genes will be ongoing.

Anthracnose

The research on the inheritance of resistance and mapping of resistance began by Mr. Curtis Wiltse is continuing by Mr. P. J. Mehta for his dissertation. Additional progeny evaluations have confirmed the three or four loci with resistance genes and these sources are now being advanced in recombinant lines for genetic mapping. Mr. Mehta will continue this research over the next two years under the direction of Dr. William Rooney.

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.

Elite sorghums are also distributed and evaluated for multiple resistances in international nurseries, which also provide a means of distributing elite germplasm from different breeding programs in INTSORMIL. The most widely grown is the International Disease and Insect Nursery (IDIN), a 30-entry test, followed by the All Disease and Insect Nursery (ADIN), a 70-entry test, which is composed in part of unreleased experimental materials that are evaluated in many different disease environments. Both of these collections represent one of the best means of comparing germplasm from region to region.

Networking Activities

Conferences attended or organized

R. Frederiksen attended the International Congress on Plant Pathology in August, 1998 where he received the Jokob Ericksson Prize presented by the Royal Swedish Academy of Sciences and the International Society of Plant Pathology. Following these meetings, R. Frederiksen traveled to Egypt to review the status of the collaborative work on sorghum downy mildew. He observed that most of the downy mildew was caused by pathotype 1 of *Peronosclerospora sorghi* with some evidence of pathotype 2. Most of the work done by the Egyptians was on evaluation of host material for disease reaction in the field, on biological control, and to a limited extent on disease management. In October, Dr. Frederiksen traveled with Mr. Kollo in Niger and visited the research nurseries at Maradi, Konni, Lossa, and Tillabery and later attended the hybrid sorghum workshop. In October, March, and June, Dr. Frederiksen traveled to Celaya, Mexico to review the work on ergot and make preparations for the Global Conference on Sorghum/Millet diseases.

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

Other Cooperating Scientists

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Insect Pest Management Strategies For Sustainable Sorghum Production

Project TAM-225
George L. Teetes
Texas A&M University

Principal Investigator

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Summary

The PI traveled to Mali during this reporting period to participate in the review by the External Evaluation Panel of the IER/INTSORMIL collaborative research program and to determine the progress of sorghum entomology research by Drs. Niamoye Diarisso and Yacouba Doumbia, both IER entomologists. Dr. Diarisso is a recent Texas A&M University graduate whose Ph.D. program was directed by the PI Emphasis was on the need to increase the amount of research to assess insect pest severity on newly developed and deployed sorghum varieties in farmers' fields and as a venue for technology transfer. There is need to determine sorghum entomology research responsibilities between Drs. Diarisso and Doumbia and this could be done best by developing work plans for each scientist with funding from the Mali country budget. The PI also traveled to South Africa and Botswana during this reporting period. The trip was to establish (reestablish) an INTSORMIL research program directed at managing sugarcane aphid, *Melanaphis sacchari*, and developing integrated pest management (IPM) approaches for sorghum insect pests in southern Africa. The entomology/breeding program in conjunction with Dr. Christopher S. Manthe, Department of Agriculture Research (DAR) entomologist, Gaborone, Botswana, previously conducted research on sugarcane aphid in Botswana and Zimbabwe. The rejuvenated collaborative research program involves Drs. Manthe and 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 further evaluate were made among segregating lines. Lines and hybrids for resistance to greenbug biotypes E and I were evaluated for TAM-223 and a commercial seed company. 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*. Progress was made on cloning sorghum QTLs resistant to greenbug and differential expression of genes in response to greenbug infestation. Several techniques are being used to accomplish these objectives, but data are too pre-

liminary to report here. Graduate education programs of six students were directed during this reporting period. Two Ph.D. students graduated. Efforts were continued to use sequences from the mitochondrial genome to assess genetic diversity among populations of greenbug. The program of a new Ph.D. student was started. This student will determine fitness and virulence of 11 greenbug biotypes to sorghum genotype differentials. Education programs of two African graduate students, one Malian and one Nigerian who conducted research in Niger, were co-directed with Dr. Frank Gilstrap. One student will graduate this fall. The PI 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 survey 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. Agricultural consultants obtain most new IPM information from workshops and conferences.

Objectives, Production and Utilization Constraints

Objectives

Mali

Long-term objectives are to (1 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, 2) increase entomological research efforts in farmers' sorghum fields, and 3) direct graduate education programs, provide technological assistance, and promote technology transfer and networking. The objectives for this reporting period were to 1) substantiate, for use by sorghum breeders, the most reliable and efficient method to protect sorghum panicles from bugs so resistance can be assessed by comparing protected with naturally infested panicles, 2) determine the role of insects and pathogens in kernel deterioration by applying different combinations of insecticides and fungicides, and 3) 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 is 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 (1) identify, evaluate, and incorporate resistance to sugarcane aphid into sorghum varieties and hybrids adapted to southern Africa agricultural systems; (2) develop IPM strategies for sorghum insect pests in southern Africa; (3) identify opportunities for graduate education of southern Africans; and (4) elucidate needs for technical assistance, technology transfer, and networking.

USA

Long-term objectives are to provide the research base for IPM of sorghum insect pests. Emphasis is 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 are being applied to increase resistance durability by understanding the genetic relationship of insects and resistant plants. Ancillary research includes 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 are delivered to sorghum growers. Reporting period objectives were to 1) conduct field and greenhouse experiments to evaluate sorghums resistant to greenbug, sorghum midge, and yellow sugarcane aphid; and 2) supervise graduate student research. Graduate students supervised are a U.S. Ph.D. student using RFLP technology to assess genetics of greenbug resistance in sorghum,a U.S. Ph.D. student using RFLP/RAPD technology to assess genetic variability of greenbug and its biotypes, a U.S. Ph.D. student assessing fitness and virulence of greenbug biotypes to sorghum genotype differentials, a 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.

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 the grain 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 readily available 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 are the 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 uses 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 emphasizes the development and use of insect-resistant sorghums. Insect pests given most attention are greenbug, sorghum midge, yellow sugarcane aphid, and panicle-infesting bugs and caterpillars.

Research Approach and Project Output

Four approaches are 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 are divided into these approaches.

Collaboration/Partnership with Developing Country Scientists

Collaborative Sorghum Panicle-feeding Bug Research in Mali.

The PI traveled to Mali during October of this reporting period. The purpose of the travel was to participate in the review, by the External Evaluation Panel, of the IER/INTSORMIL collaborative research program and to determine the progress of sorghum entomology research by Drs. Niamoye Diarisso and Yacouba Doumbia, both IER entomologists. Dr. Diarisso is a recent graduate whose Ph.D. program at Texas A&M University was directed by the PI

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.

It is the opinion of this PI that the External Evaluation Panel that reviewed the collaborative program rated the Mali program as excellent in all aspects of research and technology development and deployment. The Malian scientists planned and executed an outstandingly effective and efficient program review. The schedule provided opportunity for research activities to be reviewed in a timely way, but thoroughly enough that progress was apparent in all research disciplines. The IER sorghum and millet research team presented an excellent overview of production in Mali, production constraints, and research to address the constraints. Most important was the effort of the IER scientists to show benefits of research through development of technology with direct application to Malian agriculture. The IER scientists showed success from team research and real accomplishments in technology development and improvement being adopted by Malian farmers with expectation of important economic and social impacts. INTSORMIL's collaboration with IER is at the point of pay-off. The graduate education and research partnering resulted in sustained progress that will continue to benefit Malian agriculture.

The success of the IER program occurred because of dedicated scientists, despite many obstacles. A disappointing situation has existed with a former student of Dr. George Teetes, Dr. Niamoye Diarisso. When she returned to Mali following completion of her Ph.D. Degree at Texas A&M University, IER failed to assign her a postion. This failure has been costly in time, research opportunity, enthusiasm, and professional status. She was eventually assigned to the sorghum research program but there was no clear delineation of responsibility with regard to another IER sorghum entomologist, Dr. Yacouba Doumbia. This led to confusion as to the division of responsibility in sorghum insect research. Recent information however, indicates that areas of responsibility have been clarified. Dr. Diarisso is now the leader of a new World Bank Entomology Project on sorghum insects and she serves as the Head of the Entomology Research Unit on Fruits and Vegetables. She is also responsible for aphid and midge insect research on sorghum and Dr. Douumbia is responsible for head bug research on sorghum.

One very important change needed in the Mali program is to provide direct funding to IER scientists from the Mali

Country budget. This issue was discussed with Drs. Rosenow and Toure who agree such action would benefit the Mali program. Budgets to individual IER scientists would be based on Plans of Work. Continued funding would be based on research productivity. Another action agreed on was that the PI would develop a research protocol that provides options for divided, yet complementary, responsibility and explores new opportunities for technology development and transfer. Much sorghum entomology research conducted during past years has been directed toward a complex of panicle-feeding bugs. Much research still is needed. Some research needs to be conducted on the Research Station at Sotuba, while other research needs to be in farmers' fields. Also, as new varieties are introduced, other insects may increase in importance and this potential problem needs to be evaluated.

Having two IER scientists in a discipline is a luxury that needs to be exploited. Critical research responsibilities for each person should be identified and justified. Budgeting individual researchers from the country budget based on work plans will be a workable approach to resolving the confusion of research responsibility.

Collaborative Sorghum IPM Research in Southern Africa.

During April of this reporting period the PIs for TAM-223 and TAM-225 traveled to South Africa and Botswana. The trip was to establish (reestablish) an INTSORMIL research program in southern Africa directed at managing the sugarcane aphid and developing IPM approaches for sorghum insect pests. The entomology/breeding program in conjunction with Dr. Manthe previously conducted research on sugarcane aphid in Botswana and Zimbabwe. The rejuvenated collaborative research program involves Dr. Christopher S. 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 also proposed a survey be conducted of insect pests of sorghum and millet on small farms. He thought the 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 also has been establishing ties with extension specialists working with producers on small farms.

Dr. Manthe (Ph.D. in Entomology from Texas A&M University) conducts some entomological research in addition to numerous administrative duties. Dr. Manthe also 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 anticipates returning to more entomological research in the future. The DAR breeder should return to Botswana in Fall 1999. Multi-disciplinary collaboration then can be established for the DAR breeding/entomology program. The team of Drs. van den Berg and Manthe will provide excellent on-site expertise for developing the sugarcane aphid resistance and IPM program.

Research on developing resistance to sugarcane aphid will be increased for 1999-2000. INTSORMIL, through the Texas A&M University breeding/entomology program, will provide 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 their research programs.

In Botswana, plots of sorghum were evaluated at Goodhope and Sebele. Production was difficult because of dry conditions. Only 168 mm of rain fell at Sebele during the growing season. The South African commercial hybrid test was evaluated at Goodhope. Evaluated were mostly hybrids from private industry in South Africa. Because of the environment, genotypic differences in lodging, leaf/plant death, and grain yield were apparent. Most sorghums were purple plants with red kernels. Few food-type (tan plant, white kernel) hybrids were evaluated. The DAR food-type hybrid BSH1 expressed excellent grain yield potential and agronomic traits. The sorghums also were grown at Sebele where BSH1 had excellent grain yield potential and agronomic traits. INTSORMIL, through Texas A&M University, provided many sorghums to the DAR. The sorghums should be provided again to DAR. Errors in packaging seed or planting resulted in plots not matching listed nursery pedigrees. A subsequent experiment would be planted more carefully.

Because it was so dry during the growing season in both South Africa and Botswana, infestation by sorghum insect pests was low. Dr. van den Berg currently maintains a large research program on stem borers. The INTSORMIL entomology/sorghum breeding program has little to contribute to this research. Its greatest contribution to a collaborative research partnership in South Africa and Botswana is on sugarcane aphid because of past experience with and breeding for resistance to this insect. Also, Texas germplasm is well adapted to southern Africa. Collaboration also will contribute to general encouragement of use of IPM in the region. From this visit it is apparent there is excellent opportunity for collaborative research of mutual benefit. The sugarcane aphid is a potential invader of sorghum in the USA

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

During this reporting period, in collaboration with TAM-223, standard, annual evaluations of sorghum midge-resistant lines and hybrids were conducted at Corpus Christi and College Station. Resistance to sorghum midge of 57 hybrids (including resistant x resistant experimental hybrids, resistant x resistant checks, a resistant x susceptible check, and susceptible checks), 77 lines (including resistant and susceptible checks), 58 and 744 converted sorghum lines, 200 segregating lines, and several thousand breeding lines was evaluated. Susceptible sorghum planted 3 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 = 81-100% 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.

Drought conditions hindered plant growth at Corpus Christi and sorghum midge abundance at College Station where the sorghum was irrigated. For the most part, experimental hybrids and resistant × resistant checks, were significantly less damaged by sorghum midge and produced significantly more grain within and over 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 will be advanced for future evaluation and some 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.

With regard to greenbug, 1077 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 possessed moderate resistance to biotype I. Six hundred forty sorghum lines from Cargill Seed Company were evaluated for resistance to biotype E. Results indicate 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. A summary of procedures and results are presented here. Results have been published.

A labeled pyrethroid (Baythroid) and organophosphate (Lorsban) insecticide were evaluated for control of fall armyworm in the whorls of sorghum plants. Seed of hybrid sorghum (ATx399 × RTx430) was planted 15 June 1998 on rows spaced 30 inches apart. Insecticide treatments were compared in plots, 4 rows x 35 ft long, arranged in a randomized complete block design with four replications. Insecticides were applied on 8 July at 1030 hours to all four rows of each plot by using a hand-held backpack sprayer with four TX3 hollow cone nozzles at 35 psi, producing a finished spray volume of 5.5 gpa. Insecticides were applied when the plants were 12-18 inches tall. Data on abundance of larvae in the whorl of five randomly selected plants in each plot were collected on 13 and 14 July (5 and 6 days after treatment) and combined. Each plant whorl was dissected in the field. Whorls from treated sorghum contained significantly fewer fall armyworm larvae than did nontreated sorghum. Sorghum plants treated with Baythroid had significantly fewer larvae than did plants treated with Lorsban. Plants treated with Baythroid were significantly taller than nontreated sorghum at the flagleaf stage.

Efficacy of 10 insecticides and garlic and hot pepper extracts were evaluated for control of sorghum midge. Procedures used were similar to those described for evaluation of insecticides against fall armyworm. However, sorghum was planted 21 May 1998 and plots were eight rows with only the center two rows treated. Insecticides were applied on 16 (when 40-80% of the panicles were flowering) and 20 July (when 90-100% of panicles were flowering). Before each application, 20 randomly selected panicles were inspected visually and numbers of adult sorghum midges recorded. Data on grain yield were collected from the two treated rows of each plot. Panicles were hand harvested from two, 8.75-ft sections of treated row per plot and mechanically threshed. Sorghum midge abundance was near the economic threshold level, about one adult per panicle, before both insecticide applications. All treated sorghum except that treated with azadirachtin or hot pepper extract yielded more than nontreated sorghum. Highest yields resulted from sorghum treated with the highest rate of TD-2344-03. No significant yield differences were found among plots of sorghum treated with labeled pyrethroid insecticides (Baythroid, Asana XL, or Karate).

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 were previously 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) were 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. At the three-leaf stage, 10 apterous greenbugs per plant were placed on the second true leaf of each plant when plants were 6-8 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 RNA isolation. For each pot containing infested plants, a pot of noninfested plants served as a control. 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 sorghum leaf tissue of PI550607 and Tx2783 in lambda ZAP vector, 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. These experiments are in progress.

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 last year's annual report. However, based on her research, she formulated a new concept in IPM to be considered for deployment of resistance genes. 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 pests is complicated by the ability of some pest populations to rapidly propagate virulent biotypes. In only 30 years, greenbug gave rise to eight new biotypes that overcame plant resistance or organophosphate insecticides. *Sorghum bicolor*, *Triticum aestivum*, and *Hordeum vulgare*, 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 greenbug resistance genes 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. "Gene rotation" strategies using positional and functional information about resistance genes in different crops to challenge pests with a series of diverse resistance mechanisms may add a new dimension to IPM, more effectively preserving the efficacy of existing resistance genes. Discovery of a large epistatic component of resistance to greenbug, together with resistance genes located in one genomic region intentionally subjected to a genetic bottleneck by humans, warrant accelerated efforts to introgress novel resistance genes from exotic genotypes into cultivated varieties.

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 will be used to determine the degree of divergence among greenbug biotypes and whether greenbug 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 A, B, C, E, F, G, H, I, K, 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) will be PCR amplified and sequenced during July and August. The tentative completion date for this phylogeny is September 1999.

Microsatellite probes will be 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 will continue to be developed while screening of field collections will begin in August 1999.

Hame Abdou Kadi Kadi. This Nigerian M.S. student conducted laboratory and field research on fecundity, longevity, and oviposition of millet mead miner in Niger. His education program is near completion and he soon will return to Niger. Results of this student's research are in the report of TAM-225B.

Soualika Boire. This Malian Ph.D. student conducted research on the impact of natural enemies on abundance of millet head miner in Niger. The student completed his research but not his courses, preliminary exam, or dissertation defense. Results of his research are in the report of project TAM-225B.

Roberto Gorena. This Ph.D. student is new to the INTSORMIL project. His research objectives are to determine fitness and virulence of 11 greenbug biotypes to sorghum genotype differentials. Preliminary data from two experiments using choice procedures are provided in the following table.

Technology Transfer

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%),

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	8.0a	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
PI550607	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
PI550607	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
PI550607	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.

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 is 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 regard 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 provide services for insect pests (100%), weeds (88%), and diseases (72%) in 41 counties. Consultants had consulted for averages of 16 years on 18,719 acres. Farmers had farmed for averages of 25 years on 2,621 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 USA, 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. The criteria used to determine an IPM user were very stringent and based on quantitative assessment. Other impact assessments have shown that research, primarily from this project, resulted in a 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. Using this methodology, several new, improved, bug-resistant sorghum varieties have been developed and are being tested in on-farm experiments.

Networking Activities

Workshops

George Teetes, Tom Fuchs and Bonnie Pendleton. Questionnaire on importance of IPM. Entomology Science Conference. 27-29 October 1998, College Station, Texas.

George Teetes, Bonnie Pendleton and Roger Anderson. Review of sorghum entomology research. Entomology Science Conference. 27-29 October 1998, College Station, Texas.

George Teetes. Farmer and ag consultant perceptions of use and contributions of IPM. Texas Pest Management Association Annual Meeting. 18 February 1999, Galveston, Texas.

George L. Teetes, Bonnie B. Pendleton and Roy D. Parker. Texas sorghum growers are extensive users of IPM.

1999 Sorghum Conference. 21-23 February 1999, Tucson, Arizona.

Bonnie B. Pendleton, George L. Teetes and Thomas W. Fuchs. Farmers and private ag. consultants' assessment of successful IPM use. Forty-seventh Annual Meeting of the Southwestern Branch of the Entomological Society of America. 23-26 February 1999, Las Cruces, New Mexico.

George Teetes. Farmer and ag consultant perceptions of use and contributions of IPM. IPM Technical Advisory Committee Meeting. 5 March 1999, College Station, Texas.

Research Information Exchange

The PI provided much information in different forms to scientists from several developing countries. Journal reprints were sent to 39 scientists. The newly revised insect management guide for sorghum is extremely popular, and 15 copies were sent to scientists in developing countries. The most rapidly increasing way to request information on sorghum entomology is by electronic means. The PI receives many requests for sorghum entomology information via e-mail. Also, he authored an Internet site chapter 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 electronically provide information 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 discount rate. Other calculations indicated the value of sorghum midge-resistant hybrids to be $9.3 million annually. Following are the citations from which the information was obtained.

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.

Eddleman, B. R., C. C. Chang and B. A. McCarl. 1991. Economic benefits from INTSORMIL grain sorghum variety improvements in the United States. TAMRF No. 9045. Report to University of Nebraska-Lincoln USAID/INTSORMIL.

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

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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 addresses biological control of the millet head miner (MHM). An important part of the program in the USA is to provide training for graduate students and evolve theory and concepts for implementing biological controls in West Africa, evolve concepts and definitions for functional agroecosystems, develop methods for measuring impacts of natural enemies, and validate results of biological controls when implemented.

In INTSORMIL Year 17 (January 1996), I accepted two scientists from West Africa to begin research programs in Niger, and they are working at the International Crops Research Institute for the Semi-Arid Tropics- Sahelian Center (ISC) in collaboration with Dr. Ousmane Youm. One student is a Ph.D. candidate (S. Boire, Mali) and the other an M.S. candidate (H. Kadi Kadi, Niger). Their research objectives and results build on findings for MHM biological control reported by this project in INTSORMIL Years 15 and 16.

In Year 20, Boire began writing his dissertation on field studies he began in Year 17 on MHM immature stage mortality, adult MHM biology and fecundity, and MHM biology on alternate host plants. All of his work is conducted in the field with some experiments at ISC, and others in nearby farmers' fields. His is assessing sources and importance of natural mortality of MHM. In Year 20, Kadi Kadi completed his thesis work initiated in Year 17 on MHM immature stage development and adult biology using four temperatures and four artificial diets. Boire will defend his dissertation in INTSORMIL Year 21.

Results from these students' research are being used to construct stage-specific life tables, providing an understanding of factors that regulate the abundance of MHM. These results will be used for improved plans to manage MHM on pearl millet in West Africa. Using the database available on 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 MHM before it damages pearl millet.

Objectives, Production and Utilization Constraints

Objectives

Collaborative Research Objectives

The collaborative research objectives of TAM-225B are to (1) assess natural enemies for biological control of stalk borers and the MHM; (2) implement effective biological controls; and (3) provide graduate level training on processes and strategies for biological controls in sorghum and millet, and (4) assess biological control for on farm pest management of sorghum and millet pests in local crop protection practices. We pursue the listed objectives in the United States and in the Republic of Niger on millet.

Graduate Student Research Objectives

TAM-225B is training two scientists from West Africa. Their objectives are to (1) improve methodologies for sampling and manipulating populations of MHM, (2) assess the spatial distribution and mortality of all life stages of MHM, (3) conduct experiments to show age-specific mortality in populations of MHM, (4) identify and assess the role of alternate host plants occupied by MHM, (5) determine the optimal survival of MHM in a laboratory environment, and (6) conduct field cage experiments to assess MHM fecundity. Both students conducted research in Niger in collaboration with Dr. Ousmane Youm, ICRISAT-Sahelian Center. Other graduate students associated with TAM-225B in Year 18 finished their degrees, or have finished their research and are writing their dissertations.

Constraints

Insect pests of sorghum/millet addressed by this project are key pests and constraints to production in the U.S. and West Africa. Detailed ecological understanding of pests and their natural enemies is essential for 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 addresses biological control of MHM. USA research seeks to provide training for graduate students that evolves theory and concepts for implementing biological controls in West Africa, evolves concepts and definitions for functional agroecosystems, develops methods for measuring impacts of natural enemies, and validates 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, and early in network activities, crop protection participants identified key pests of Sahelian millet as the millet head miner (*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, we are assessing extant natural enemies, a particularly important step for low input and fragile Sahelian farming systems. We began this process in 1993 with a research project on MHM survival, seeking to understand the contributions of MHM natural enemies to total mortality. Specific objectives of our research are 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 Methods

Methodology for Boire and Kadi Kadi was reported in Year 18.

Research Findings

Boire. Mr. Boire is currently preparing his dissertation, and this will be the basis for reporting for INTSORMIL Year 21.

Kadi Kadi. On pearl millet spikes, young millet head miner larvae cut and feed on millet flowers and perforate glumes. Late-instar larvae bore and create mines or tunnels under the kernels on spikes. In the mined kernels, millet head miner larvae destroy flower pedicels, prevent kernel formation, and cause kernels to abscise before maturity. Different management tactics have been tested including cultural techniques (e.g., fire, tillage, ploughing, and planting date) to reduce damage by millet head miner in West Africa.

The longevity of millet head miner adults was longer and more affected by temperature than was that of males. Millet head miner females reared in the laboratory at 24°C, the coolest temperature tested, lived a mean of 4.0 d, 0.8 d longer than the male longevity of 3.2 d. The longevity of females declined by .0.2 d for each 2°C increase in temperature. At warmer temperatures of 26-30°C, millet head miner longevity was 3.5-3.8 and 3.2-3.5 d for adult females and males, respectively. Millet head miner females and males survived in exclusion cages in the field for 3.1-4.0 and 3.2-3.8 d.

The oviposition period of millet head miner was significantly longer at 28°C, 3.2 d, than at 24°C, 2.3 d, or 30°C, 2.7 d. Mean numbers of days of oviposition in the laboratory were similar to those in the field, 2.4 and 3.1 d in 1996 and 1997, respectively. Females in the laboratory tend to lay more eggs at higher than lower temperatures, but not significantly more. For example, each female laid a total of 144.8 and 125.0 eggs at 28 and 30°C, respectively, compared with 106.0 and 99.8 eggs at 24 and 26°C, respectively. In the field, each female laid means of 29.6 and 44.9 eggs in 1996 and 1997, but the number of eggs laid differed by the time of year. Each female laid only 7-10 eggs on pearl millet planted on 23 June 1997, but 13-106 eggs on pearl millet planted 4 July 1997. Temperature differences influenced, but not significantly, the hatching of millet head miner eggs. Mean percentages of eggs that hatched in the laboratory were 66.1% of 106.0 and 77.9% of 99.8 eggs laid at 24 and 26°C, respectively. Lesser percentages hatched, only 55.5% of 144.8 eggs and 61.6% of 125.0 eggs laid, at 28 and 30°C. During both years, many eggs were laid and hatched at 28EC in the laboratory.

When millet head miner cohorts were fed Bio-Serv® diet, mean developmental times in days from eggs to adults were less at 28 and 30°C. Survival to the adult stage was greatest (5.4%) at 30°C. When fed early exerted millet diet, mean developmental time from eggs to adults was least and percentage survival was greatest, 2.3, at 26°C than at the three other temperatures. Developmental times were shortest and survival greatest when millet head miner cohorts fed middle-flowered millet diet were reared at 28 and 30°C. Millet head miner cohorts fed soft-dough millet diet developed faster and survived best to the adult stage when reared at 24°C.

Temperature affected millet head miner development rate, reproduction, and cohort survival. Low and high temperatures tend to increase and decrease, respectively, these parameters. 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 was lower, 1.3-2.6, 1.1-2.9, and 0.0-2.3%, when millet head miner cohorts were fed soft-dough millet, middle-flowered millet, and early exerted millet diets, respectively.

Results indicated that temperature influenced population increase of millet head miner fed Bio-Serv® diet. The best temperature to rear millet head miner 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. The next best diet to rear millet head miner, could be soft-dough millet diet at 24°C because only 40.2 d were required for cohorts to develop and become reproductive adults and 2.6% of the individuals of the cohort survived to become adults.

Assessment of millet head miner reproductive statistics revealed that the highest net reproductive rates (R_0) of 5.84 and 4.33 females per female were estimated when millet head miner was fed Bio-Serv® diet at 30°C and early exerted millet diet at 24°C, respectively. Cohort generation time (T_c) was shortest when millet head miner cohorts were fed middle-flowered millet diet at 28°C (16.98 d) or soft-dough millet diet at 24°C (18.37 d).

Survivorship curves for all millet head miner reared on four different diets at four different temperatures revealed that most of the population died as larvae. Based on the different survivorship curves observed, millet head miner cohorts could best be reared on soft-dough millet diet because cohort survival was similar to that illustrated by the cumulative curve.

In 1996, mean percentages of different millet head miner life stages were greater on early than late-planted pearl millet in the field. Mean developmental times for millet head miner life stages on pearl millet spikes enclosed in field exclusion cages showed that time when pearl millet was available influenced survival. Developmental time from eggs to neonates required only 5.0 d on pearl millet planted on 6 June or late, 7 July. But, a significantly higher developmental time of 6.9 d was required for millet head miner on pearl millet planted on 21 June.

Most eggs developed into medium-sized larvae (18.8%), prepupae (5.6%), and pupae (1.8%) on pearl millet planted on 6 and 21 June 1996, but only 9.9, 2.0, and 0.5% of the eggs developed into medium-sized larvae, prepupae and pupae, respectively, on pearl millet planted late, on 7 July. Developmental times from eggs were longest on pearl millet planted 6 June - 13.7 d to medium-sized larvae, 22.2 d to prepupae, and 27.8 d to pupae.

In 1997, the percentage of neonates that developed was inversely proportional to the amount of eggs placed on a pearl millet spike. Percentages of eggs that developed into neonates were greater, 89.0 and 92.5 and 96.0 and 91.5, when 5 and 10 eggs were placed on spikes of pearl millet planted on 23 June and late, on 16 July, respectively. When 15 or 20 eggs were placed on spikes, 70.5-77.0% survived to become neonates on pearl millet planted on the three dates. Developmental times from eggs to neonate stages were 5.0-6.7 d on pearl millet planted on the three dates.

Percentages of eggs that developed into medium-sized larvae, 47.0-73.0, prepupae, 26.3-54.5, and pupae, 6.5-21.3, were greater on pearl millet planted 23 June than on pearl millet planted later. When 10 eggs were placed on each spike of pearl millet, significantly more, 73.0%, developed into medium-sized larvae but significantly fewer, only 6.5%, developed into pupae.

Overall, time when pearl millet was available in the field influenced millet head miner cohort survival and developmental times. During both years, more prepupae and pupae developed on spikes of pearl millet planted in June than later. More days were required for millet head miner to develop from eggs to pupae on early planted pearl millet than on pearl millet planted late. Manipulation of planting dates could be a recommendable management tactics that can reduce survival and damage by millet head miner in the Sahel.

Because a cohesive management strategy is not available for millet insect pests, efforts should be devoted to searching for solutions to efficiently control this insect pest of pearl millet. Determination of the contribution of parasites and predators to millet head miner natural mortality (Soualika Boiré, unpublished data) could lead to a major breakthrough in managing this insect pest by using biological control. A biological control plan could be designed to use natural enemies to control millet head miner larvae because most mortality of millet head miner occurs during the vulnerable larval stages. Because many indigenous parasites and predators of millet head miner were identified in Sahelian countries, efforts should be made to conserve these natural enemies by manipulating the ecosystem so that we can enhance their activity against millet head miner.

It is possible to develop improved management strategies and a simulation model by using the database on agro-climatic conditions in the Sahel and information gained from millet head miner life tables. Over several years, we need to quantify major millet head miner mortality factors required to develop an agro-ecological model as a basis for designing integrated pest management strategies. Such a model may be used to devise a "Millet Head Miner Warning System" to forecast the probability of millet head miner attack in a given area so appropriate measures can be taken to control the pest before it damages pearl millet. This may require interdisciplinary team research during a long period and should cover the area where millet head miner is a threat to pearl millet.

Networking Activities

Networking activities consisted of Hame Kadi Kadi sharing his research results with his colleagues at INRAN. Also, preparations were made for Dr. Julio Bernal to represent TAM-225B by participating in the Scientific Conference of the African Association of Insect Scientists in Ouagadogou, Burkina Faso, July 19-23, 1999.

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

TAM-228
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Summary

Several sorghum nurseries were established in Botswana, Zimbabwe, and Zambia by TAM -228 in collaboration with other INTSORMIL projects and NARS scientists for evaluation against foliar diseases, charcoal stalk rot and drought, and sugarcane aphids. The response of some cultivars indicated it was possible to use multilocational testing to identify sorghum that had both broad adaptation to the SADC region and resistance to major disease and insect pests. Sorghum ergot was almost non-observable in commercial sorghum fields in Northern Mexico and Texas in 1998 during the normal growing season. Rains and flooding beginning in September, 1998, across much of Texas promoted sorghum growth and conditions for ergot. By mid-December 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*. *Claviceps africana* 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. TAM-228 participated in publication of a manual, training workshop, and pamphlet that will assist in training personnel involved in identifying and detecting sorghum ergot in seed. Workshops and well-illustrated reference material will increase accuracy of ergot detection and reduce misidentification to produce seed import and export regulations based on readily

available scientific data. Several fungicides were evaluated for efficacy in sorghum ergot control but triazoles, especially triadimefon, continue to provide the best control which was also demonstrated in aerial application. Actigard, an SAR (systemic acquired resistance) chemical that stimulates host plant defense mechanisms, provided good control of sorghum ergot but it reduced or prevented seed set.

Objectives, Production and Utilization Constraints

Objectives

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

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

- 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)

- 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, United States)

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

Research Approach and Project Output

Foliar Diseases (Anthracnose, Leaf Blight, Sooty Stripe)

In 1998-99, 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. 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). Twenty entries were new to the ARGN 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 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. In Zimbabwe, late-planting and low levels of disease allowed only the identification of disease susceptible cultivars which was evident in the standard checks. The adaptation of SC326-6 derived material like 86EON 361 and 86 EON362 continued to be impressive across Zimbabwe and Zambia; however, even these materials had higher levels of sooty stripe at Golden Valley, Zambia under the heavy sooty stripe pressure observed this year.

The inaugural sugarcane aphid resistance nursery (50 entries, 2 reps) was put together in concert with TAM-223, TAM-225, and TAM-222. This nursery was planted at several SADC locations including Matopos, Zimbabwe and Golden Valley, Zambia. The latter location occasionally has heavy sugarcane aphid activity but the primary screening factor in 1999 was provided by sooty stripe. Several entries were susceptible to sooty stripe and did not appear to have good adaptation to the Golden Valley region but the others did have both acceptable adaptation and at least moderate resistance to sooty stripe. This indicated it was possible to use multilocational testing to identify cultivars that had both broad adaptation to the SADC region and resistance to major disease and insect pests.

Cultivar Evaluations for Drought Tolerance and Disease in Botswana, Zimbabwe and Zambia

Several drought resistant materials either new or previously tested in Botswana were selected for additional evaluation in Botswana and two different subsets were to be evaluated in Matopos, Zimbabwe and Golden Valley, Zambia. Due to drought the materials were not planted in Sebele, Botswana and the planting at Matopos was a month later than most materials which reduced some stand establishment due to shoot fly and other factors. Of 103 cultivars established at this location, 56 had "days to physiological maturity" that were equal to or less than a parental standard, Macia. At Golden Valley, Zambia sooty stripe was the most prominent disease and ratings showed which crosses had high and low susceptibilities to sooty stripe and other foliar pathogens that were present at lower levels (Table 1). EO366 crosses were generally susceptible to sooty stripe while those of SRN39 were generally resistant. Several crosses with Macia had both resistant and susceptible representatives but several Macia derivatives had both excellent sooty stripe response and good agronomic characteristics at the Golden Valley location. Macia x Dorado and ICSV1089 × Macia selections were particularly outstanding.

Virus Identification

Virus reactions in the International Sorghum Virus Nursery (ISVN) at the Pandamatenga Research Station 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

Table 1. Sooty stripe ratings of advanced generation cultivars at Golden Valley, Zambia in April1999. Most entries had previously shown good drought response in Botswana.

Pedigree	Sooty Stripe Rating (1-5)[1]	Pedigree	Sooty Stripe Rating (1-5)[1]
(CE151*BDM499)-LD14	2.5	(M84-7*87EO366)-LF40	3.0
(Sureno*87EO366)-CW3	3.0	(86EO361*TX2783)-HL2	3.5
(CE151*BDM499)-LD17-BE1	3.0	(M84-7*WSV387)-HD7. . CA1	3.5
(CE151*BDM499)-LD17-BE2	3.0	(M84-7*WSV387)-HD7. . CA4	3.0
(CE151*BDM499)-LD17	4.0	(TAM428*SV1)-HD10	3.5
(Sureno*CE151)BE-25-BE3	3.0	(TAM428*SV1)-HD40	5.0
(SRN39*90EO328)-HF12	2.5	(Macia*TAM428)-HD1	4.0
(SRN39*90EO328)-HF5	2.5	(Macia*TAM428)-HD2	3.0
(SRN39*90EO328)-HF1	2.5	(Macia*TAM428)-HD12	5.0
(SRN39*90EO328)-HF4	2.5	(Macia*Dorado)-HD4	2.5
(Sureño*SRN39)-BE15	3.0	(Macia*Dorado)-HD12	2.5
(Sureño*SRN39)-BE15-CWBK??	3.0	(Macia*Dorado)-HD2	2.5
(Sureño*SRN39)-BE1-CW5-BE5-BE1	2.5	(86EO362*TX2783)-F5-BE2	5.0
(Sureño*SRN39)-BE1-CW5-BE5-BE2	2.5	(Macia*TAM428)-LL2	5.0
(Sureño*SRN39)-HD5	2.5	(Macia*TAM428)-LL9	2.5
(Sureño*SRN39)-LD2	5.0	(Macia*TAM428)-LL1	2.0
(Sureño*SRN39)-BE6	4.5	(Macia*Dorado)-LL1-CA1	2.0
(Dorado*SRN39)-??	2.5	(Macia*Dorado)-LL1-CA3	2.0
(SRN39*87EO366)-LD23	2.5	(Macia*Dorado)-LL2	2.0
(SRN39*87EO366)-LD39-BE1	3.5	(Macia*Dorado)-LL6-CA1	2.0
(SRN39*87EO366)-LD39-BE2	3.5	(Macia*Dorado)-LL6-CA3	2.0
(86EO366*WSV387)-HD19	4.0	(ICSV1089BF*Macia)-HF2	3.0
(86EO366*WSV387)-HD27. . CA1	5.0	(ICSV1089BF*Macia)-HF6	3.0
(86EO366*WSV387)-HD27. . BE5	5.0	(ICSV1089BF*Macia)-HF8	4.0
(86EO366*WSV387)-HD25	5.0	(ICSV1089BF*Macia)-HF9	2.0
(86EO366*WSV387)-HF2	4.5	(ICSV1089BF*Macia)-HF11	2.5
(86EO366*WSV387)-HF3	5.0	(ICSV1089BF*Macia)-HF28	2.0
(86EO366*WSV387)-HF14	3.5	(ICSV1089BF*Macia)-HF35	3.5
(86EO366*WSV387)-HD25/6BRO222	5.0	(Macia*Sureno)-HF11	3.5
(86EO361*Macia)-HD4	5.0	(Macia*Sureno)-HF19	3.0
(86EO361*Macia)-HD14	2.0	(Macia*Sureno)-HF36	3.0
(86EO361*Macia)-HD17	4.5	(86EO361*Macia)-HF41	3.5
(87EO366*TAM428)-HF31	5.0	(86EO361*Macia)-HF46	5.0
(87EO366*TAM428)-HF2	5.0	(86EO361*Macia)-HF52	2.5
(87EO366*TAM428)-HF4	5.0	(86EO361*Macia)-HL25	2.5
(87EO366*TAM428)-HF13	5.0	86EO361	2.5
(87EO366*TAM428)-HF60	5.0	87EO366	—
(87EO366*TAM428)-HF63	5.0	Dorado	4.0
(87EO366*TAM428)-HF15	5.0	Macia	2.5
(87EO366*TAM428)-HF22	4.5	ICSV1089BF	3.0
(R2241*(R5646*SC326-6)-HD25)	2.0	TAM428	5.0
(R2241*(R5646*SC326-6)-HD25)	5.0	Sureño	2.5

1 Sooty stripe rating, 1 to 5, 1= no disease and 5= plants killed by sooty stripe, — no rating possible because plants killed by anthracnose

SCMV-B by S. Jensen. He is also evaluating additional live virus specimens recently collected in South Africa in April 1999.

Survival and Re-occurrence of Claviceps africana in South Texas and Mexico in 1998

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 during the normal growing season. In Tamaulipas and surrounding states in Mexico sorghum ergot again began to be observed 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 Lower Rio Grande Valley (LRGV) of Texas 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 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. The epidemic occurred outside of the normal growing season so it had minimal or no economic impact but it demonstrated that *C. africana* is a well-established, recurrent pathogen of Mexico and Texas. *Claviceps africana* 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.

In 1999, sorghum ergot was present in winter nurseries on the West Coast of Mexico and common in Puerto Rico. Sorghum ergot developed at low levels on commercial grain sorghum hybrids in the LRGV and Coastal Bend regions of Texas and regions of Northern Mexico but by the end of June it had been observed primarily in regions of South Texas.

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

Only sorghum species have been observed with sorghum ergot across Mexico and Texas. In May and June 1999, environmental conditions at Corpus Christi were extremely favorable for sorghum ergot development but pearl millet remained uninfected despite being grown among sorghum plants of a male-sterile heavily infected with *C. africana*.

Chemical Control of Ergot in the Field

In fall 1998 tests utilizing inoculation and natural secondary spread of *C. africana* the strobilurin fungicides provided limited or no protection against ergot when applied at any time from pre-boot to bloom initiation. The triazoles propiconazole (Tilt), tebuconazole (Folicur), and triadimefon (Bayleton) effectively controlled sorghum ergot when applied to heads at bloom initiation using concentrations from 125 to 250 ppm. In the fall tests, ergot control dropped off rapidly at 62 ppm with propiconazole and tebuconazole and 31 ppm for Bayleton. In 1999 field tests utilizing different blooming male-steriles at Corpus Christi, TX (ATX623) and Rio Bravo (AVar), triadimefon was at least 3 times more effective than propiconazole or folicur in control of *C. africana* when data was analyzed using exponential decay regression models.. Triadimefon was also the most effective triazole when aerial applications were made at rates of 125 g a.i./ha in 47 l/ha (5 gal/ac) of water.

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 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 prior to bloom initiation provided no control of sorghum ergot.

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. S. for susceptibility to sorghum ergot at several locations in Mexico and the U.S. At some of the locations sorghum heads are being inoculated with *C. africana* at bloom initiation to provide a uniform level of inoculum for sorghums with different maturities. Susceptibility to other naturally-occurring diseases is also being evaluated if they occur at sufficient severity at these locations.

Networking Activities

Sorghum Ergot Activities

TAM-228, Noe Montes, J. Narro (INIFAP) and D. Frederickson were the authors of the sorghum ergot section of the manual entitled "A Laboratory Guide to the Identification of *Claviceps purpurea* and *Claviceps africana* in Grass and Sorghum Seed Samples". The guide was sponsored by Mexican, American, Oregon, and Texas seed trade associations for use in a seminar and training workshop for seed inspection personnel in Mexico. The meeting was held April 19-20, 1999 at the Sanidad Vegetale Headquarters in Mexico City. Noe Montes presented the sorghum ergot information at the workshop and provided translation for the other speakers. The Spanish translation for this guide was also done by N. Montes.

A pictorial pamphlet entitled "Sorghum Ergot, Distinguishing Sphacelia and Sclerotia of *Claviceps africana* in Seed" was prepared by TAM-228 and D. Frederickson and published in June 1999 to assist seed inspection personnel and other sorghum workers who work with sorghum ergot in seed. A Spanish version of the pamphlet provided by additional co-author N. Montes will be published in July 1999.

TAM-228 participated in a review of current and projected sorghum ergot research activities at an NC-501, Ergot: A New Disease of U.S. Grain Sorghum, meeting at Manhattan, KS in September, 1998 and a USDA-ARS sponsored review (S. Jensen) at Kansas City, MO in April 1999.

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.

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

Member of graduate committee of J. Moran, Honduras, B. Rooney, Texas A&M University, major professor.

Continuing research collaboration with INIFAP of Mexico through N. Montes, a visiting INIFAP research scientist from the Rio Bravo Experiment Station, Rio Bravo, Mexico.

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

International Travel

TAM-228 PI traveled to Southern Africa April 5-22, 1999 to evaluate nurseries and determine future collaborative research activities in the region. Locations visited include SMIP scientists and Zimbabwe national sorghum breeder in Bulawyao (Matopos), Zimbabwe, and collaborating scientists at PPRI/RSS in Harare, Zimbabwe, Mt. Makulu and Golden Valley Zambia, DAR in Sebele and Pandamatenga, Botswana, and the sorghum pathologist and sorghum entomologist at Grain Crops Institute in Potchefstroom, South Africa.

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 TAM-228 rated much of the collection for diseases that were present and trained assisting SMIP personnel to evaluate the remaining entries.

Publications

Journal Articles

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

Proceedings

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.

Isakeit, 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.

D. E. Frederickson and G. N. Odvody. 1999. Survival of sorghum ergot, *Claviceps africana*. p. 54. In Proceedings of the 21st Biennial Research and Utilization Conference. Tucson, AZ, Feb 21-24, 1999.

Miscellaneous Publications

Alderman, S., D. Frederickson, G. Milbrath, N. Montes, J. Narro-Sanchez, and G. Odvody. 1999. A Laboratory Guide to the Identification of Claviceps purpurea and *Claviceps africana* in Grass and Sorghum Seed Samples. 18 p., April 19, 1999, Oregon Department of Agriculture. Also available at "www.oda.state.or.us"

Frederickson, D. and G. Odvody. 1999. Sorghum Ergot, Distinguishing Sphacelia and Sclerotia of *Claviceps africana* in Seed. L-5315, 6-99 5 p. Texas Agric. Extn Svce.

Sorghum Ergot - Special Project

Debra Frederickson and Gary Odvody
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Summary

Temperature and relative humidity clearly interact to affect survival of conidia of *Claviceps africana* with greatest survival associated with low temperature and low relative humidity. Seed storage environments would not favor high viability of conidia to persist in sphacelia stored (with seed) from the end of one season until the beginning of the next. In late 1998 *C. africana* demonstrated that it is a well-established, recurrent pathogen of Mexico and Texas with the capacity for survival under extended unfavorable dry environments and the ability to quickly reach epidemic proportions over vast regions upon a return to favorable wet, cool environments. 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 10's to 100's of Km. However they are unlikely to survive travel over 100's to 1000's of Km like the pigmented rust spores. Disease spread over a large continent like N. 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 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 bodies 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 was published outlining the prominent features of sphacelia and sclerotia. The external sphacelial surfaces and internal tissue cores of fresh sphacelia treated with captan had a greatly and slightly reduced percentage of sphacelia, respectively, that showed any visible conidial germination compared to controls. The cumulative factors of low survival of conidia in sphacelia and honeydew, the removal of nearly all sphacelia by standard seed cleaning operations, seed (sphacelia) treatment with captan, and the planting of seed below the soil surface indicate that captan-treated seed should not be considered as a potential source of inoculum, especially in regions where the pathogen is already endemic. In these regions inoculum from other sources is more likely to be present in higher numbers at a time when environmental conditions and host maturity are favorable for disease development.

Objectives, Production and Utilization Constraints

- Evaluate epidemiology and survival of *C. africana* in Mexico and across the Great Plains environments of the U.S. (Puerto Rico, Latin America [Mexico], and U.S.)

Research Approach and Project Output

Survival of Claviceps africana

Macroconidia and secondary conidia are responsible for the dissemination of *Claviceps africana*, and the spread of ergot disease, in the sorghum growing season. Macroconidia, spread by rain-splash, carry disease over relatively small distances (Bandyopadhyay et al., 1990). Secondary conidia, which are derived from macroconidia, have the potential for spread over much greater distances because they are windborne (Frederickson et al., 1989; Frederickson et al., 1993). Thus any source of primary conidia must also be considered a potential source of wind-borne secondary conidia. Few studies have been undertaken to consider how key environmental factors affect the longevity of these spores. Yet studies of this nature are key to inferring the role of each spore-type in disease propagation following extended periods away from the host.

The obvious honeydew exuded from parasitic sphacelia is only one source of conidia. Any surface coated with honeydew, e.g., leaves, seeds, soil, may also be a source. Similarly, sphacelia, which may become incorporated into seed at harvest, or are residual in the field after harvest, may be a source of conidia. Sclerotia/sphacelia, normally only considered for the production of the teleomorph, also carry a large population of macroconidia in the sphacelial portion and should be considered more important as a potential source of secondary conidia than of ascospores. A major concern of all those associated with the sorghum seed trade has been the possibility of seedborne transmission of disease through inoculum associated with sclerotia/sphacelia mixed with seed.

Pertinent information required to address this question is firstly the correct recognition of sorghum ergot fungal bodies. Whether or not these sources are productive and are important sources of inoculum will depend on how the macroconidia are affected by environmental variables such as temperature, moisture and ultraviolet radiation. If inoculum does survive, the next question is whether current seed treatment procedures are effective at eliminating inoculum or sufficiently reducing its viability.

Effect of Storage Temperature and Relative Humidity on Survival of Conidia in Sphacelia

Sorghum panicles with *C. africana* sphacelia from recent inoculations were harvested, rinsed and allowed to dry overnight. They were divided to give three replicate samples for incubation at each of the following temperatures: 6°C, 20°C, 32°C and oscillating temperatures of the greenhouse, or were divided for incubation at one of three relative humidities (5.5, 49, 90%) at a temperature of 20°C. At set-up, the viability of conidia, retrieved by crushing sphacelia from each batch, was measured in triplicate by spreading a suspension of 10^6 spores per ml over nutrient agar. Germination (%) was measured after 24 h at 20°C. Germination was re-assessed in this way at regular intervals following storage.

Results

There was a marked effect of temperature on survival of conidia (Figure 1). Storage of sphacelia at high greenhouse temperatures or at 32°C resulted in a rapid loss of viability. No spores survived after only two weeks at 32°C or seven weeks in the greenhouse. However conidia still showed some germination even after 17 weeks at 20°C. Viability did not begin to decline until after 12 weeks at 6°C, and was still 50% at 22 weeks.

Low relative humidity of 5.5%, which caused desiccation of sphacelia, maintained a high viability of conidia. In contrast, viability was reduced to zero after four weeks at both of the other humidities tested (Figure 2).

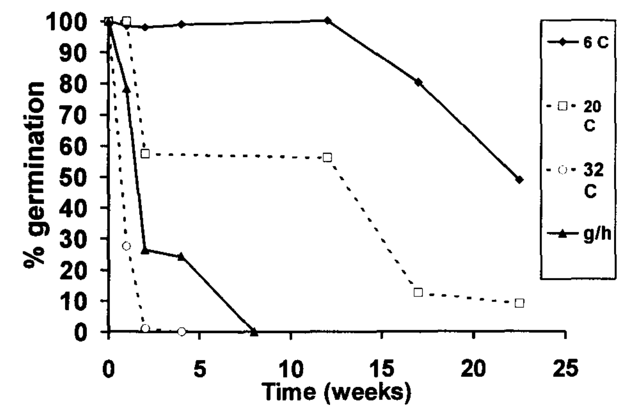

Figure 1. Effect of storage temperature of sphacelia on survival of conidia ***of C. africana.***

Survival of conidia is promoted by low temperature and low relative humidity and, comparing the 20°C curve in Figure 1 with Figure 2, temperature and relative humidity clearly interact to affect survival. Under natural environmental conditions there are wide diurnal and seasonal fluctuations in temperature and relative humidity, which are factors that do not promote survival. Viability of conidia from stored sphacelia was not found to exceed five months in Kansas and the sharpest decline was coincident with a rise in warm temperatures in March/April (Claflin, 1998). We would therefore not expect a high viability of conidia to persist in sphacelia stored (with seed) at the end of one season until the beginning of the next. This verifies what has already been found by several workers in Africa. Futrell & Webster (1966), Mower et al. (1973) and Frederickson et al.

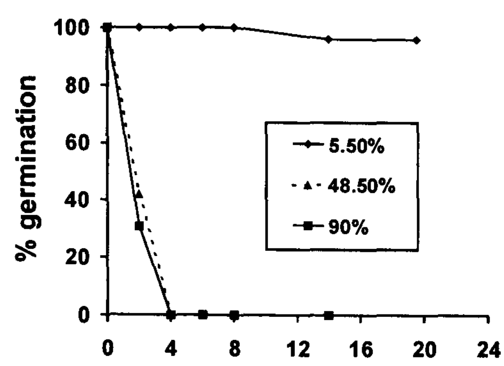

Figure 2. Effect of storage relative humidity of sphacelia on survival of conidia of ***C. africana.***

(1991; 1993) all used conidia from low-temperature- or dry-stored sphacelia to inoculate sorghums the following year but only a very low severity (<1%) of ergot resulted.

However, as long as there are flowering johnsongrass panicles or panicles from sorghum regrowth, there is the potential for infection of an alternate host before inoculum viability declines altogether, maintaining inoculum in an active state.

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 in early January 1998 at the INIFAP San Fernando Experimental Station but drought prevented further ergot development and observation in this and surrounding states until September 1998. Cool wet weather in the Pacific coast states favored ergot from February through May 1998 and cool weather during September promoted ergot on sorghum in several states in the Bajio and High Plains regions of Mexico. Despite active *C. africana* through February 1998, season long drought and heat stress prevented observation of any naturally-occurring sorghum ergot across South Texas during the normal growing season. 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. By mid-December 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*. This demonstrated that *C. africana* is a well-established, recurrent pathogen of Mexico and Texas that has the capacity for survival under extended unfavorable dry environments and the ability to quickly reach epidemic proportions over vast regions upon a return to favorable wet, cool environments.

Effect of UVB Dose on Longevity of Macroconidia and Secondary Conidia: Probable Consequences for Long-Distance Dispersal

A macroconidal suspension (10^6 conidia per ml) made from fresh sphacelial infections was plated at least in triplicate onto fresh Kirchoff's agar of thin depth. Plates were maintained on ice in the dark until irradiation of spores with UVB (290-320 nm λ) of measured energy (radiometer) for increasing doses. Irradiated spores were incubated at 20 C and total darkness, or under the fluorescent lights of the incubator, for approx. 18 h and then germination was assessed. Germination of irradiated spores was expressed as a percent of non-irradiated spores (controls). Germination of conidia in controls was 70-80%. Experiments with secondary conidia were essentially the same except for one additional, early step to produce the secondary spores from the macroconidia. The plated macroconidia were incubated at 20°C for 18-20 h and then the secondary spores were detached and spread over the plate surface using a glass rod.

Results

The effect of UVB was far more pronounced when conidia were incubated in the dark following irradiation than in the light (Figure 3). The lethal dose was 9-15 KJ/M^2 after dark incubation compared to 40-50 KJ/M^2 following light incubation. The rate of decline was also far more rapid for dark incubated spores, with the LD50 being approximately 5 KJ/M^2 compared to 20 KJ/M^2 for light incubated. A photo-activated, DNA repair mechanism involving DNA photolyase, similar to that found in other fungi and bacteria (Kim & Sancar, 1993; Sundin & Murillo, 1999), would explain these differences.

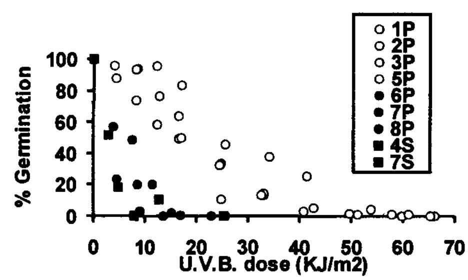

Figure 3. Effect of UVB dose on survival of conidia of *C. africana*. (Open circles indicate germination was in light; solid shapes, dark; P, primary conidia; S, secondary conidia).

It is apparent from the literature that most UV irradiation experiments are conducted in complete darkness to eliminate the complication of DNA repair. Our data show that the susceptibilities of UVB-exposed macroconidia and secondary conidia are the same. Comparing the data to data of other fungus spores, conidia of *C. africana* would be grouped with *Venturia inequalis* (Aylor & Sanogo, 1997), far behind such pigmented spore-types as *Puccinia species* (Maddison & Manners, 1973). In lab. experiments (Aylor &Sanogo, 1997), 95% of *V. inequalis* conidia were killed by a dose of 8-11 KJ/m^2 and it is estimated that the conidia can survive as long as12 hrs in nature. If *C. africana* conidia have a survival comparative to *V. inequalis in vivo*, as *in vitro*, this would suggest that the windborne secondary conidia may remain viable over distances of 10's to 100's of Km. However they are unlikely to survive to travel 100's to 1000's of Km like the pigmented rust spores. Disease spread over a large continent like N. America would therefore be due to inoculum dispersal in a series of moderate "leaps" rather than one longer distance dispersal event. This mirrors exactly what was witnessed once ergot reached Brazil. It also rules-out the possibility of the initial origin being due to windborne spread from Africa to Brazil. We hope to confirm these *in vitro* data from *in situ* experiments in Southern Africa, assessing the combined effects of temperature, relative humidity, UV and other variables.

Recognizing Sclerotia/Sphacelia in Seed

The field symptoms of ergot are familiar to just about everyone involved in the sorghum production industry, but recognizing the pathogen in seed is more difficult. This is because there is a poor understanding of the structure and function of sphacelia and sclerotia. Additionally, cracked and moldy seed and other foreign objects are often mistaken for ergot fungal bodies in seed. If seed is viewed as a potential source of introduction of ergot inoculum, correct recognition of sphacelia and sclerotia is critical both to remove ergot bodies in the seed-processing plant and to minimize wrong rejection by the importing country. We responded to the difficulty of identification with the production of a 4 page paper outlining the prominent features of sphacelia and sclerotia (Frederickson et al., 1999). The salient points are as follows:

* Sphacelia/ sclerotia can only be accurately differentiated from other objects using a magnification of at least 10X. To aid diagnosis it is strongly recommended that suspect bodies are soaked in water for a few hours before examination. If used, the saline float test should ALWAYS be followed by a close visual examination of products at magnification because it is a highly inaccurate method if used alone.

* C. africana sclerotia develop from within, and to the base of, sphacelia. The ergot fungal bodies may thus range from being entirely sphacelial, through having some, to 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.

* Sphacelial tissues are cream to white in color, comprised of loosely woven "threads" of fungal hyphae, forming a furrowed and convoluted surface. Sphacelial tissue forms the conical to pointed portion at the top of the structure if sclerotial tissue is present as well. During soaking, the loosely-packed tissues absorb water, swell, become soft and spongy to the touch; conidia diffuse into the water.

* Sclerotial tissues, found at the base of the structure, consist of a thin, orange-brown surface (rind) enclosing a white interior. The tissues are sub-globose in shape when mature and are comprised of tightly compacted fungal "cells" unlike the "threads" or filaments of sphacelia. The tissues remain firm after soaking due to their compact structure and lack of water absorbance and swelling.

Effect of Captan Seed-Treatment on Germination of Conidia from Sclerotia/Sphacelia mixed with Seed

Sorghum seed is routinely treated with captan, which has been shown to prevent the germination of *C. africana* conidia on the seed surface. However the efficacy of captan applied to sphacelia/sclerotia has been questioned since the fungicide may only have low penetrative ability and it's activity against innermost conidia would be limited to the time of diffusion of conidia following contact with moisture.

Fresh sphacelia/sclerotia were dissected from panicles, washed, spread to dry overnight, and added to sorghum seed. Captan 400 at the commercial rate of 3.0 fl oz/100 wt, was added to each 8 oz seed/ergot batch with a red dye (Pro-ized red-colorant) to assist in even application. Controls were dye only. Sphacelia/sclerotia were then manually retrieved from the seed.

Intact sphacelia/sclerotia from treatments or controls, or the interior tissues (cores) were tested. The experiment was performed twice, on completely different batches of sphacelia/sclerotia each time. Tests consisted of plating 10 bodies (4-5 plates of 10 per rep; 3-6 reps) on Kirchoff's agar, adding a drop of water to promote honeydew leaching, and incubating at 20 C overnight. The surface of each individual sphacelium or core and the zone of conidial diffusion on the agar was examined at X100 magnification for spore germination. Germination was assessed on a 0-3 scale where 0=no germination; 1=germination barely detectable; 2=abundant germination, often in clusters; 3=profuse germination covering a large, unbroken area. Incidence was recorded as the number of the total with any germination at all.

Results

There were clear differences between treatments (Tables 1 and 2). The percent of captan-treated sphacelia/sclerotia with any germination was significantly reduced (P, 0.0001). There was a slight reduction in percent of captan-treated cores with germination, indicating that captan has some penetration. Data for the mean germination of conidia from control sphacelia, control cores and cores of treated sphacelia were not significantly different ($P<0.001$). However the mean germination of conidia in treated sphacelia was significantly less, with the value of 0.9 being just below the threshold of detection of germination.

Conclusions

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

Table 1. Percent of sphacelia with any germination of conidia following captan treatment. Data followed by the same letter are not significantly different at P< 0.0001.

Treatments	Percent of Sphacelia with germination
Untreated Sphacelia	100 a
Untreated Sphacelial Cores	95 a
Captan-treated Sphacelia	38.7 c
Captan-treated Sphacelial Cores	85.3 b

Table 2. Germination of conidia from sphacelia following captan treatment. Data followed by the same letter are not significantly different at P, 0.001.

Treatments	Germination of Conidia (0-3 scale)
Untreated Sphacelia	2.5 a
Untreated Sphacelial Cores	2.4 a
Captan-treated Sphacelia	0.9 b
Captan-treated Sphacelial Cores	2.2 a

and at the gravity table. With good clean-up, very few are incorporated into seed. In a final step, the seed is treated with captan using equipment that accurately delivers the fungicide and provides good coating of seed and any contaminating ergot. The percentage germination of conidia from those few remaining sclerotia/sphacelia per Kg seed is negligible compared to fresh sphacelia, and is reduced by the captan to below 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 inoculum potential. To get the perspective even clearer, 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 certainly provided conditions more favorable for disease development. Therefore sclerotia/ sphacelia in captan-treated seed should not be considered a potential source of inoculum.

Networking Activities

June 24,1998. Ergot of Sorghum — a Global View. D. Frederickson, Keynote address. In: Conference on the status of sorghum ergot in North America. Corpus Christi, Texas.

February 2, 1999. Current Research on Sorghum Ergot of Special Relevance to the Sorghum Seed Trade (Including how to recognise sclerotia). D. Frederickson, Invited speaker at the Texas Seed Trade Association Production and Research Conference, Dallas, Texas.

February 23, 1999. Survival of the Sorghum Ergot Pathogen, *Claviceps africana*. (How to recognize sclerotia). D. Frederickson, 21 Biennial Research and Utilization Conference.Tucson, AZ, Feb 21-24, 1999.

February 24, 1999. D. Frederickson (jointly with R. Bandyopadhyay and N. McLaren) received the award for outstanding achievement in the sorghum industry at the 21 Biennial Research and Utilization Conference. Tucson, AZ, Feb 21-24, 1999. The award was in recognition of their contributions to international collaborative sorghum ergot research.

A pictorial pamphlet entitled "Sorghum Ergot, Distinguishing Sphacelia and Sclerotia of *Claviceps africana* in Seed" was prepared by TAM-228 and D. Frederickson and published in June 1999 to assist seed inspection personnel and other sorghum workers who work with sorghum ergot in seed. A Spanish version of the pamphlet provided by additional co-author N. Montes will be published in July 1999.

D. Frederickson, G. Odvody, Noe Montes, and J. Narro (INIFAP) were the authors of the sorghum ergot section of the manual entitled "A Laboratory Guide to the Identification of *Claviceps purpurea* and *Claviceps africana* in Grass and Sorghum Seed Samples". The guide was sponsored by Mexican, American, Oregon, and Texas seed trade associations for use in a seminar and training workshop for seed inspection personnel in Mexico. The meeting was held April 19-20, 1999 at the Sanidad Vegetale Headquarters in Mexico City. Noe Montes presented the sorghum ergot information at the workshop and provided translation for the other speakers. The Spanish translation for this guide was also done by N. Montes.

Publications

Miscellaneous

Alderman, S., D. Frederickson, G. Milbrath, N. Montes, J. Narro-Sanchez, and G. Odvody. 1999. A Laboratory Guide to the Identification of Claviceps purpurea and *Claviceps africana* in Grass and Sorghum Seed Samples. 18 p., April 19, 1999, Oregon Department of Agriculture. Also available at "www.oda.state.or.us

Frederickson, D. and G. Odvody. 1999. Sorghum Ergot, Distinguishing Sphacelia and Sclerotia of *Claviceps africana* in Seed. L-5315, 6-99 5 p, Texas Agric. Ext. Serv.

Frederickson, D.. and G. Odvody. 1999. Survival of sorghum ergot, *Claviceps africana*. p. 54 *In* Proceedings of the 21 Biennial Research and Utilization Conference. Tucson, AZ, Feb 21-24, 1999.

Journal Articles

Frederickson, D.E., Monyo, E.S., King, S.B., Odvody G.N. & Claflin, L.E. (1999). Identification of *Pseudomonas syringae*, the Cause of Foliar Leafspots and Streaks on Pearl Millet in Zimbabwe. Journal of Phytopathology (Phytopathologische Zeitschrift), In press.

Sustainable

Production Systems

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

PRF-205
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Summary

Coulibaly's study of urban consumption patterns in Mali 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. Future devaluations will have a larger substitution effect now that rice tariffs are only 11%. Lawrence's study of the impact of household and agricultural technologies on women showed the importance of household technologies independent of decision-making in the household. As the bargaining position of women improves, there was a substantial combined effect of the two types of technology on the potential income of women. In a third study the importance of increasing productivity of sorghum and millet was stressed, especially with the impending dietary shifts to higher animal-protein consumption. Finally, we reviewed two very different initiatives for increasing productivity in Burkina Faso and Ethiopia.

Objectives, Production and Utilization Constraints

The general objectives of our research are to estimate the potential effects of new technologies, to identify the constraints to their diffusion, and to recommend complementary policies to accelerate the introduction process. (1) We compare urban food consumption in Bamako before and after the 1994 devaluation. The principal emphasis was on the substitutability between the cereals, especially between imported rice and the traditional cereals (millet and sorghum). (2) We consider the impacts on women from several technologies with different systems of household decision-making. (3) Then some research policy implications from a review of the Burkina research/extension investments are made. Our concern here was on moving beyond the first generation low-input, low-risk, low-yield-increase technologies in semiarid regions and on anticipating the shift in demand for animal protein with the consequent rapid increase in feedgrain demand. (4) Both Burkina Faso and Ethiopia have developed national programs to increase food crop productivity. In Burkina the emphasis is on subsidizing the utilization of rock phosphate. In Ethiopia the government has promoted demonstration trials of new cultivars, inorganic fertilizer and other chemicals.

Research Approach and Project Output

Cereal Consumption after Devaluation in Urban Bamako

For two decades Sahelian countries have been promoting the substitution of imported cereals for their traditional cereals, sorghum and millet, with their emphasis on food aid, low urban cereal prices, and an overvalued exchange rate. These policy distortions make it difficult to introduce new technology involving higher input expenditures in the traditional cereal sector. With devaluation changing the prices of imported inputs and cereals, an important research question is the responsiveness of consumers to changes in relative cereal prices.

In the absence of domestic responses of supply and/or demand for rice the 50% reduction of the CFA in 1994 would double the price of imported rice. However, one year after devaluation the government reduced the tariff on imported rice from 100% to 46% and then a year later to 11% (Coulibaly, 1999, p.8). The rice price relative to domestic cereals actually declined after devaluation. Thus the expected price-incentive effect of devaluation, stimulating domestic cereal production was offset by government policy to eliminate rice tariffs.

Sorghum/millet was shown to be a substitute for imported rice but not for domestic rice. Note that Mali imports the low-quality, low-cost, high-broken rices. The overall change in the consumption pattern was modest. The substitution could not be explained using relative price changes since the net effect of devaluation and changes in rice tariffs was to increase the relative price of sorghum and millet to rice. Note that traditional cereals are still cheaper than rice in absolute terms[1] and that devaluation has an income reduction effect even if cereal prices do not increase. Income effects[2] apparently encouraged a small increase in sorghum/millet consumption.

The government was able to protect urban consumers from the cereal price effects of this devaluation by removing most of the import tariff on rice. A future devaluation is expected to result in more substitution of traditional cereals for rice now that there is only a minimal rice tariff. A 9 to 19% increase in monthly sorghum/millet consumption, when the imported rice price increases, is a substantial recovery for traditional cereals (Table 1). Since soil fertility is an increasingly serious problem in the Sahel, the increased profitability of traditional cereals will enable more intensive production practices to overcome the nutrient depletion. Now governments need to resist the impulse to drive down urban cereal prices and thereby discourage investment in their agricultural sectors.

Table 1. Changes in cereal consumption from the 1994 devaluation and future imported rice price changes.

	Before devaluation 1993	With 1994 devaluation[a] (1996)	Imported rice price increased by	
			25%	50%
Imported rice	0.8	0.7	0.6	0.4
Sorghum/millet	9.7	10.3	10.6	11.5

[A] Also included tariff reduction on imported rice from 100 to 11%.
Source: B. Coulibaly, 1999, pp. 22, 53.

The Impact of Technologies on Women in Burkina Faso

Many new agricultural 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 (Lilja and Sanders, 1998; 1997 INTSORMIL Annual Report, pp. 52, 53). However, there are presently institutional changes, in which other family members besides the household head (including women) are struggling to obtain a larger share of the income streams generated by the new technologies.

The concern here was with the combination of technologies and household decision-making that would most affect women's incomes. Farm modeling had already been undertaken in a higher rainfall zone of Burkina Faso, where technological change has been rapidly introduced in the last two decades. The income levels of individual women on the farm were estimated by summing their wage payments on the commonly farmed area with their revenue from their private plots for different actual and potential technology levels.

On-farm wages were determined by the type of family decision making on the farm. The most commonly discussed types of decision making were exploitative, altruistic, and bargaining. In exploitative decision-making the household head can make dictatorial decisions and capture the gains from technological change on the commonly farmed area. In the altruistic model the wife is paid the value of her marginal product.[3] The bargaining model assumes that the household is similar to a firm in which there is cooperation to produce a final product and conflict over the revenue from the product. The share of each party then depends upon their bargaining power. Here the threat points of the household head and the average female household member were calculated based upon what it would cost the household head to use hired labor and for the women their opportunity costs. Then we split the difference in the standard Nash equilibrium method.[4]

With the introduction of new agricultural technologies farm income increased by 26% and the area in private plots decreased by almost half. In the exploitative case women do not benefit from this agricultural technology introduction. The combination of household and agricultural technologies does benefit women and increases farm income by 37% in the exploitative case (Table 2). Household technologies release the time of women and directly benefit them as well as the household.

At lower income levels, there is centralized decision-making by the household-head. As technology introduction proceeds, increasing within-family contention over the new income streams would be expected, with an evolu-

[1] Coulibaly adjusted for processing costs so that both products were in the ready-to-cook stage.
[2] From de-valuation and income increase over time.
[3] A further extension would be for the household head to split the profits with the family members, as in a cooperative, after paying them the valu of their marginal products.
[4] Note that more recent bargaining models are concerned with the bargaining process and make adjustments for the relative power position. There were insufficient data for going any further with these techniques here.

Table 2. Annual farm income of a female worker and a farm family before and after the introduction of new technologies incorporating different household behavior in animal-traction farm households (U.S.$)

Household behavior	Traditional agricultural technologies[a]	New agricultural technologies[b]	New agricultural and household technologies[c]
Exploitative	63	63	86
Bargaining	68	88	114
Altruistic	79	99	129
Total farm income	724	911	1024

[a] Traditional technologies: animal traction, manure, no inorganic fertilizers or other chemical inputs.
[b] Agricultural technologies: moderate inorganic fertilizer, pesticides, and new cultivars of cotton and maize.
[c] Household technologies: include wood-burning stoves, parboiling sorghum, grain processing, wells, and water pumps.

Exchange rate: 541 CFA/US$, January 1997. World Fact Book.

Source: Lawrence et al., 1999, p. 212

tion towards the conflict and cooperation of bargaining household decision-making.

With bargaining, agricultural technologies increase the income of women by 29% and the combined agricultural and household technologies by 68%. With economic growth, the bargaining decision-making is expected to become predominant but at any given time all three decision-making methods would be expected among farm families.

Policy recommendations are to accelerate the introduction of technological change onto the commonly farmed areas while also increasing the bargaining power of women. The evolution in family decision-making toward bargaining will be influenced by the opportunity costs of women, which in turn are determined by increasing off-farm opportunities for women and their achievement of higher educational levels.

Agricultural Development Prospects in the Sahel: The Traditional Cereals

In a recent review of agricultural development performance, some inferences about progress and performance were relevant to the sorghum-millet sector in the Sahelian countries.

The Sahelian countries have generally been very successful in the higher-rainfall regions in increasing the productivity and output of cotton, maize, and rice. Now donors and national governments are also emphasizing niche crops based upon the demand prospects for these activities. Niche crops benefit only a few farmers and consumers but they can be useful by paying for services to the research and extension systems. However, the missing element is raising productivity and farmers' incomes in the low-rainfall regions of these countries.

In these regions, the crops with a comparative advantage are the traditional cereals with their tolerance to inadequate water availability and low soil fertility. Unfortunately, with higher population pressure and government policies maintaining low cereal prices, these crops are being pushed into more marginal soils and there is little nutrient replacement where soil fertility is being exhausted. Hence, area is expanding and yields declining for the traditional cereals. Area expansion of the other cereals, rice, maize, and wheat is constrained by their higher water and nutrient requirements.

New cultivars of sorghum and millet are increasingly available but the low-cost, low-risk methods presently used to increase water availability and soil fertility in the Sahel (contour dikes or bunds, zaï, animal manure, composting) are insufficient to respond to the nitrogen and phosphorus deficiencies and the seasonal water shortages. Technologies are available but the missing factors are public policy support and sufficient market development to reduce the price collapse in good and even normal rainfall years. National governments react to price increases of the cereals with appeals for food aid. Governments need to be concerned with their farmers earning profits and making expenditures for inputs to increase soil fertility and water availability.

As the shift to animal products occurs with economic growth, there will be very rapid increases in the demand for feed grains to support poultry operations and milk production. The Sahelian countries need to begin anticipating these demand shifts and making it more profitable to make the necessary investments in traditional cereal production so that soil fertility is improved and risk of traditional cereal production reduced. In the long run, technological change will reduce costs enabling prices to fall and agriculture to remain profitable. In the short run, farmers need to know there is governmental support to increase the profitability of cereal production.

Finally, large sectors of the population of the Sahelian countries (45% in Burkina Faso) do not earn enough income to purchase a diet to move them out of malnutrition. Improvements in agricultural productivity of the cereals will only help this group in the long run, given their lack of purchasing power. In the short run, ways to increase the ability of the poor to obtain minimum diets need to be found. It is necessary to distinguish between responses to demand shifts and the development of income or entitlement measures to increase the access of the poor to minimum diets.

Developing Fertilizer Strategies in Sub-Saharan Africa

With the accelerating nutrient depletion especially of nitrogen and phosphorus, the principal focus for raising productivity and output is improving soil fertility. Elsewhere we have pointed out the importance of combining soil-fertility improvement with increases in water retention (1997 INTSORMIL Annual Report, pp.54, 55).

Over the last decade there have been searches for low-cost, low-risk methods for increasing soil fertility. Various methods to increase the quantity and quality of animal manure have been successfully extended in the Sahel. Presently, several countries are now promoting rock phosphate to be applied directly to the farm or put into the compost heap for increased solubility. Unfortunately, these various substitutes for inorganic fertilizers also are low-yield solutions because they do not provide sufficient N and P2O5.There is an increasing consensus among soil scientists and economists that combinations of organic and soluble[5] inorganic fertilizers will be necessary.

Burkina Faso's response has been to build a national consensus to attempt to convince donors to subsidize the application of rock phosphate all over the country. The proposed donor costs to extend these input subsidies to 700,000 farmers would be $25 million. So far, no major donors have signed up to support this program.

In Ethiopia a strategy of subsidizing demonstration trials of new cultivars, inorganic fertilizers, and other agricultural chemicals has been pursued on a large scale all over the country. Maize yields on the trials average 5.2 to 5.7 t ha^{-1} compared with 1.7 t ha^{-1} country averages. There have been significant increases in yields and production of maize, teff, and some minor cereals on farmers' fields. Moreover, substantial progress has been made in developing private input and product markets.

It is unlikely that Sub-Saharan Africa will discover new methods to increase crop yields that are different from what is being done in the rest of the world. For how long is it worthwhile to hold up on just adapting what is done in the rest of the world to increase crop yields while searching for new, unique solutions? The magic-solution approach of national programs that believe they are going to make a breakthrough in soil-fertility improvement without their farmers incurring out-of-pocket expenses and without utilizing foreign exchange for inorganic fertilizer imports threatens to further delay the improvement of yields in Sub-Saharan Africa.

In many regions it will be necessary or economical to combine inorganic fertilizers with other fertility measures, such as manure or rock phosphate, but the starting point will need to be getting the input markets functioning for the importation and distribution of inorganic fertilizers. (Also, the input markets need to function better for seeds and credit.) Countries that have been rationing foreign exchange and putting a low priority on fertilizer imports will have to reconsider their priorities. Once the input markets and the product markets for the increased output are functioning better, more effort needs to be made to reduce the costs of fertilization with one or more of the very labor-intensive measures now commonly recommended as alternatives to inorganic fertilizers.

Networking Activities

Workshops

In September, Tahirou Abdoulaye presented a paper at the Regional Hybrid Sorghum and Pearl Millet Seed Workshop organized by INTSORMIL, ICRISAT, and INRAN in Niamey, Niger.

In October, Sanders presented a paper at a workshop on soil fertility jointly organized by the World Bank and the American Society of Agronomy/Soil Scientists in Baltimore, Maryland. The paper compared and contrasted the technology-introduction processes in Burkina Faso and Ethiopia.

In November, with Will Masters and Jeff Vitale, Sanders gave a two-week workshop on estimating the impacts of technological change in agriculture to 18 economists from the various Sahelian countries. The workshop was organized and coordinated by INSAH, the regional economic organization for CILSS, and held in Ouagadougou, Burkina Faso.

In December and April, Sanders participated in workshops of the West African Millet and Sorghum networks in Côte d'Ivoire and Togo, respectively. In Côte d'Ivoire, he participated in their performance review and plans for the future and explained some of the potential collaboration between INTSORMIL and the Millet network. In the Sorghum workshop in Togo, he presented a paper on the introduction of new sorghum and millet cultivars (see Presentations).

In March, Sanders represented INTSORMIL at an IFAD stakeholders meeting to plan the implementation of a technology-introduction project developed by ICRISAT for the five West African countries. With Barry Shapiro he re-

[5] The solubility of the rock phosphate is extremely low unless it is acidulated and this process generally requires importing the acid. In more acid soils and highter rainfall regions, solubility is increased but the rock phosphate still requires the addition of more soluble inorganic fertilizers for a moderate, sustainable yield increase.

viewed some problems of sorghum-technology introduction. The meeting was held in Sadore, Niger.

In April, Tahirou Abdoulaye represented INTSORMIL at the conference on Global Agriculture and the Midwest organized by USAID and Iowa State University. Tahirou gave a talk on the benefits of INTSORMIL to host countries.

Research Investigator Exchanges

In September, Sanders went to Addis Ababa to collaborate with Barry Shapiro of ILRI (now with ICRISAT) on finishing up papers. The principal objective of the trip had been fieldwork on *Striga*-resistant sorghum introduced principally in Tigre. Gebisa Ejeta also came but we were unable to visit the fields because they were in the war zone of the Eritrea/Ethiopia conflict.

In November, Sanders went to Dakar, Senegal, as one of the members of the scientific advisory committee to evaluate the performance of ISRA during the previous year.

From late December through March, Sanders participated in a review of the investments of the World Bank in Burkina Faso during the last decade. Sanders' contribution was to analyze the Agricultural/Natural Resource sector. He also did an audit (Bank review) of the specific programs in agricultural research and extension.

Publications and Presentations

Journal Articles

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Lawrence, Pareena G., John H. Sanders, and Sunder Ramaswamy, 1999. "The Impact of Agricultural and Household Technologies on Women: A Conceptual Analysis in Burkina Faso," Agricultural Economics 20:203-214.

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Presentations

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

Project UNL-213
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Summary

Research completed during the past year indicated that plant breeding efforts to produce high yielding grain sorghum genotypes that are tall or have high vertical leaf area distribution would be more competitive 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.

Pearl millet shows potential as an alternate grain crop in 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 15 until July 15 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 12 to 15% in both eastern and western Nebraska.

Studies on management of late maturing Maiwa pearl millet in southern Niger was initiated. This type of pearl millet tillers profusely, and 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. This provides a unique opportunity to integrate grain and livestock production.

Research in Mali and by the West and Central Africa Pearl Millet Research Network (ROCAFREMI-WCAMRN) indicates 10 to 19% yield increase to crop rotation with cowpea or peanut across the region, while other production practices appeared to be more site specific. 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.

Collaborative research ties with IN.ERA in Burkina Faso were formalized during 1998-1999 with signing a Memorandum of Collaboration, initiating collaborative research, and identifying a student for graduate study. Strong collaborative activities with the ROCAFREMI Agronomy (P4) Project were maintained.

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 Kamboise, Burkina Faso.
- Conduct long-term studies to determine the influence of crop residue removal, incorporation, and leaving on the surface on grain and stover yield of pearl millet, and the long-term effects on soil nutrient levels.
- Actively participate in the West and Central Africa Pearl Millet Research Network (ROCAFREMI) agronomic research in West Africa.
- Develop production practice recommendation for long-season Maiwa pearl millet production for grain yield while utilizing tillers for livestock forage in southern Niger.
- Determine the influence of planting date and row spacing on grain yield of dwarf pearl millet hybrids in eastern and western Nebraska.
- Determine the effect of velvetleaf interference on growth of grain sorghum genotypes.
- Determine the role of ethylene in grain sorghum emergence problems under stress inducing temperatures.
- Convert long-term crop rotation study at Mead, NE from grain sorghum-soybean to pearl millet-soybean with nodulating and non-nodulating isolines.

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, the project conducts most activities either as graduate education programs for scientists from this region, mentoring collaborative activities upon return of former graduate students, or collaborating with pearl millet research network (ROCAFREMI) activities. In the U.S. Great Plains, availability of high yielding, dwarf hybrids, markets, and production practices have limited it's 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 pearl millet grain producing areas, additional research on temperature stress effects on grain sorghum emergence and weed competitiveness is being conducted.

Domestic (Nebraska)

Velvetleaf Interference Effects on Interception of Photosynthetically Active Radiation (PAR) and Growth of Grain Sorghum - Samba Traore Dissertation

Research Methods

Studies of weed interference in grain sorghum [*Sorghum bicolor* (L.) Moench] are limited and have focused primarily on proportion of species, spatial arrangement of the crop, and timing of weed removal. Improved knowledge of crop growth parameters of sorghum hybrids and their response to weed interference could contribute to selection of cultivars with greater competitiveness with weeds. Velvetleaf (*Abutilon theophrasti* Medic.) interference with grain sorghum hybrids was evaluated in field experiments on Sharpsburg silty clay loam soils (fine smectitic, mesic Typic Arguidoll) during 1996 and 1997 at Lincoln, NE. The research objectives were (1) to determine the effects of velvetleaf interference on interception of PAR and growth of grain sorghum hybrids with different heights, (2) to evaluate the relationship between growth parameters and dry matter production of grain sorghum. 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

Medium height hybrids had greater leaf area indices (LAIs) and leaf area ratios (LARs) throughout the growing season and intercepted more PAR during the early part of the growing season. Interception of PAR was similar 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 (Figure 1) of the tall hybrid compensating for the lower LAI. Grain sorghum hybrids intercepted more light and produced more biomass in monoculture than in mixture, but the reduction in growth in 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 (Table 1). Correlations between plant height, LAI, relative growth rate and net assimilation rate with dry matter production decreased with progressing growth stage. 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.

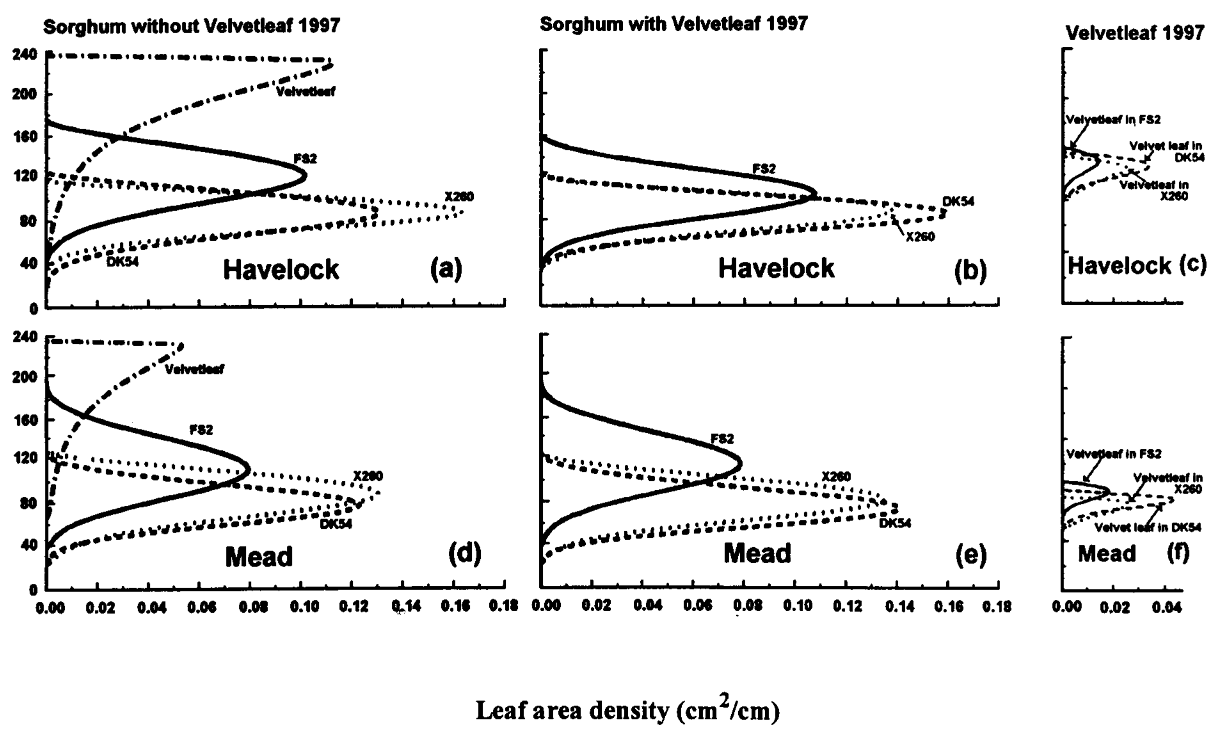

Figure 1. Leaf area density for grain sorghum hybrids without (a and d), and with velvetleaf (b and e), and velvetleaf (c and f).

Table 1. Pearson correlation coefficients and probability levels for grain sorghum dry weight with plant height, leaf area index, interception of PAR, leaf area ratio and net assimilation rate.

Growth stage	Plant height	Leaf area index	Interception of PAR	Leaf area ratio	Relative growth rate	Net assimiliation rate
GSI	0.93	0.98	0.27	-0.59	-0.88	-0.81
	<0.01	<0.01	0.11	<0.01	<0.01	<0.01
GSII	0.66	0.88	0.60	-0.86	-0.57	-0.37
	<0.01	<0.01	<0.01	<0.01	<0.02	<0.01
GSIII	0.53	0.57	0.32	-0.22	0.08	0.16
	<0.01	<0.01	<0.01	0.08	0.51	0.17
Growing season	0.88	0.89	0.68	-0.92	-0.92	-0.61
	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

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 genotpyes, and were thus classified as temperature stress resistant. San chi san had 28% less ACCO activity, produced 34% less ethlene, 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

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 which has low rainfall, short growing season, and efforts are being made to intensify wheat-fallow production systems by incorporating 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 12 to 15%. Pearl millet produced the higher yield when planted on June 1, but yield declines were small with planting as early as May 15 and as late as July 15 while grain sorghum had a narrower window for planting. Averaged over environments, grain sorghum produced approximately 0.4 Mg ha^{-1} more grain than pearl millet, but at planting dates after July 1, 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.

International
Niger

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

Research Methods

A randomized complete block designed experiment was conducted with plant spacing of 1m x 1m and 1.5m x 1m plant spacings with three thinning treatments of 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 digestibility and nutrient value. Grain and stover were harvested at the end of the growing season.

Research Results

Plant population and thinning treatments had no effect on grain or stover yield. Therefore, it is possible for farmers to harvest tillers for forage without adversely effecting grain yield or stover production. Forage value of harvested tillers and food quality of pearl millet grain are being determined, and the study is being continued during the 1999 growing season.

ROCAFREMI and Mali

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 pearl millet principal constraints of tillage, crop rotation, organic and inorganic fertilizer application, crop residue management, and use of improved pearl millet varieties; and regional studies were conducted on pearl millet grain yield response to application of organic and inorganic fertilizer. Specific treatment levels varied among countries, but could be summarized. In addition, INTSORMIL Project UNL-213 has conducted long-term cropping system and residue management studies at Cinzana and Koporo, Mali.

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 consistently increased grain yield by 10 to 19% in Ivory Coast, Mali and Niger (Table 2). 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 (Table 3). Although the treatment combinations used do not allow making definitive conclusions, the trend is that organic and inorganic fertilizers increase yields most when used together.

Table 2. Crop rotation with grain legume (cowpea or peanut) influence on pearl millet grain yields in West Africa.

	ROCAFREMI				INTSORMIL	
Cropping system	Burkina Faso	Ivory Coast	Mali	Niger	Mali	Weighted mean[1]
			kg ha^{1}			
Continuous	681	992	1297	942	1449	1225
Rotation	675	1089	1542	1125	1657	1404
Yield increase	0%	10%	19%	19%	14%	15%
Number of environments	2	2	3	4	11	22

[1] Mean weighted based on number of environments.

Table 3. Pearl millet grain yield response to organic and inorganic fertilizer application from ROCAFREMI Agronomy (P4) Regional Trials.

Burkina Faso			Mali			Niger			Senegal		
Fertilizer (Kind/Rate)	Yield kg/ha	Increase %	Fertilizer (Kind/Rate)	Yield kg/ha	Increase %	Fertilizer (Kind/Rate)	Yield kg/ha	Increase %	Fertilizer (Kind/Rate)	Yield kg/ha	Increase %
Zero	423	--	Zero	515	--	Zero	605	--	Zero	898	--
2.5 Tha manure	526	24	41-46-0 kg/ha	812	58	18 kg/ha P_2O_5	781	29	15-12-15 kg/ha[4]+43 kg/ha N	943	5
2.5 T/ha manure+13 Kg/ha P_2O_5 (200 kg/ha Rock Phosphate)	605	43	38-15-15 kg/ha[3]	798	55	18 kg/ha P_2O_5+23 kg/ha N	1093	81	30-24-30 kg/ha[4]+43 kg/ha N	998	11
12-12-12 kg/ha[1]	526	24	5 T/ha manure	634	23						
			4 T/ha manure +23 kg/ha N	734	43						
			23 kg/ha N+ 100 kg/ha Rock Phosphate	663	29						
Number of environments = 5			Number of environments = 11			Number of environment = 8			Number of environment -2		

[1] Only three environments, adjusted based on mean yields; 12-12-12 equals 75 kg/ha 15-15-15 fertilizer
[2] 100 kg/ha diammonium phosphate + 23 kg/ha N as urea
[3] 100 kg/ha 15-15-15 fertilizer + 23 kg/ha N as urea
[4] 75 and 150 kg/ha 20-16-20 fertilizer.

Networking Activities

Workshops

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

ROCAFREMI (West and Central Africa Pearl Millet Research Network) Agronomy (P4) Meeting, 5 - 8 April 1999, Ouagadougou, Burkina Faso.

Research Investigator Exchange

Visited research collaborators from Burkina Faso, Mali, and Niger during 30 March - 8 April trip to West Africa. This included on-site visits of research in Burkina Faso and Mali.

Co-major professor for Ph.D. degree for Samba Traore (1995-99). Also have had frequent interactions with Minamba Bagayoko concerning Ph.D. thesis research conducted with the University of Hohenheim and ICRISAT Sahalien Center. Have recruited Pale Siebou (Burkina Faso) and Nouri Maman (Niger) to start graduate studies in Jan. 2000.

Hosted at the University of Nebraska and worked with two ROCAFREMI Agronomy (P4) scientists (Taonda Jean Baptiste, Burkina Faso; Nouri Maman, Niger) on data analysis and interpretation for five-year report of research results.

Memorandum of Collaboration signed with INERA, Burkina Faso (8 April 1999) which allows INTSORMIL to initiate collaborative research.

Research Information Exchange

Actively participated in ROCAFREMI Agronomy (P4) meeting on research efforts, data analysis and interpretation, and report preparation, 5 - 8 April 1999, Ouagadougou, Burkina Faso.

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

Computer was purchased to assist in research efforts in Mali.

Publications and Presentations

Abstracts

Coulibaly, A., M. Bagayoko, S. Traore and S.C. Mason. 1998. Pearl millet yield and soil properties as influenced by crop residue management. Agron. Absts., p. 106.

Maranville, J.W., S.C. Mason and J.H. Sanders. 1998. Improving crop production practices in Sub-Saharan Africa: INTSORMIL approaches and perspectives. Agron. Absts., p. 45.

Stockton, R.D., S.C. Mason, S.A. Finlayson and P.W. Morgan. 1998. Ethylene effect on grain sorghum germination and early seedling vigor. Agron. Absts. , p.124.

Taonda, J.B., M.Nouri, A. Coulibaly, R. Akanvou, C. Ari and S.C. Mason. West African principal constraints research for pearl millet. Agron. Absts., (In Press).

Mason, S.C. and J.W. Máranville. 1999. Collaborative research programs enhance graduate education. Agron. Absts., (In Press).

Journal Articles

Nouri, M., 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. (In Press).

Nouri, M., S.C. Mason and S. Sirifi. 1999. Variety and management level influence on pearl millet production in Niger: I. Grain yield and dry matter accumulation. Afri. Crop. Sci. J. (In Press).

Nouri, M., S.C. Mason and S. Sirifi. 1999. Variety and management level influence on pearl millet production in Niger: N and P concentration and accumulation. Afri. Crop. Sci. J. (In Press).

Dissertations and Theses

Stockton, R.D. 1999. Ethylene involvement in grain sorghum germination and early seedling growth. Ph.D. Dissertation, University of Nebraska, Lincoln, NE. 110 pp.

Traore, S. 1999. Effects of genotypes and weed removal on the competitive ability of grain sorghum. Ph.D. Dissertation, University of Nebraska, Lincoln, NE. 208 pp.

Nutrient Use Efficiency in Sorghum and Pearl Millet

UNL-214
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Mr. Sidi Bakay Coulibaly - IER Physiologist, B.P. 258, Cinzana, Mali
Dr. Damba Traore, Sorghum Agronomist, IER, B.P. 258, Bamako, Mali
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Dr. Samuel Buah, Sorghum Agronomist, SARI, Tamele, Ghana

Summary

On-farm trials were conducted in Niger to study improved management consisting of applied fertilizers and use of tied ridges for water harvesting. Trials were located in three different agroecological zones having low, intermediate and high rainfall. However, this season more rain was received in the low rainfall region than the intermediate. Eleven farms participated and were used as replications within a region. Poor germination and plant development resulted in crop failure in the wet region. Grain yields in the dry zone were greater than in the intermediate zone due to rainfall differences. The new hybrid, NAD-1, produced greater yields than the variety when grown in tied ridges in the low rainfall zone. There was no difference in the intermediate zone. The variable and often stressful environment of 1998 made interpretation difficult. An additional on-farm trial conducted collaboratively with Dr. R. K. Pandey of the World Bank tested the NAD-1 hybrid, two plant densities, and five N treatments in the irrigated perimeters of Konni (loam soil) and Maradi (sandy soil). Three farmers participated at each location. The results showed that yields were higher in the loam soil location and yields were increased up to 120 kg N ha^{-1}. Partial factor productivity of a measure of return to farmers showed higher returns by using the NAD-1 hybrid versus an improved variety. Sandy soil required more N to reach equal yields to the loam.

Studies conducted on station in Niger which tested the effects of tied ridges, high plant population and five N rates, showed tied ridges increased yields substantially over flat beds. Nitrogen application improved yields up to 135 kg ha^{-1}, and the return to farmers was higher if N was used in conjunction with tied ridges and increased plant density. Rainfall in these tests was 547 mm in 1998. Another test where hybrid NAD-1 was compared to the varieties Sepan-82 and IRAT-204 confirmed that the hybrid out yields the varieties at all N fertilizer levels, and responded up to 180 kg N ha^{-1} in this test. The economic return to farmers was significantly greater when using NAD-1.

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 9%.

Greenhouse experiments conducted to test inherent chlorophyll differences on N responsiveness in sorghum showed that the maicillo line Lerdo Ligero (low chlorophyll) did not maintain as high photosynthesis as CK60 (high chlorophyll) under N stress. Further tests are needed, but it is unlikely that leaf chlorophyll per se is responsible for the observed lack of stress tolerance. In another test, two new Niger sorghum hybrids (NAD-1 and NAD-3) were compared to two improved lines (Sepan-82 and IRAT-204) for N responsiveness. In terms of photosynthesis and leaf stomatal conductance, there were no differences among the

genotypes even though these parameters were reduced with N stress. Further analysis of tissue N concentration and N use efficiency will be made.

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

On-farm Studies on the Use of Nutrients and Tied Ridges in Niger - Seyni Sirifi

On-farm studies on nutrients use and ridges were conducted in Niger during the 1998/99 cropping season. 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 about 400 mm of rain an average. Bengou location in the humid zone has usually an average rainfall of more than 600 mm. Two improved genotypes (NAD-1, a hybrid, 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 block was used where each producer was considered as a replicate and five replicates were planned to be installed in each location. Plots size was 4 m x 8 m and planting density was 41 675 hills (0.80 m x 0.30 m) with 0.80 mm between rows and 0.30 m between hills. Three plants were left per hill after thinning. During the 1998-99 season, rainfall received at Tillakaina, the dry location, was 456.7 mm in 31 days, while in Konni, in the intermediary rainfall zone, 398.5 mm in 29 days have been received. Rainfall in the dry location was higher than the one received in the immediate 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.

Trials conducted at Bengou, in the humid climate, failed due to bad germination and development. Their results were not analyzed, therefore, they were not included in the report. Results of Konni and Tillakaina trials were presented in Table 1 and concerned average grain and stover yields over replicate (farmer) and location. 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 than in the medium rainfall one. But 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. Morever, 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. 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 treat-

Table 1. Mean grain and stover yields from on-farm sorghum trials at two locations in Niger in 1998. Treatments consisted of three genotypes grown with ridges and tied ridges plus manure and inorganic nitrogen (improved) versus the same genotypes grown using traditional cropping practices.

Genotype	Treatment	Tillakaina		Konni		Average	
		Grain stover Kg ha^{-1}		Grain stover Kg ha^{-1}		Grain stover Kg ha^{-1}	
NAD-1	Improved (tied ridges)	2240	3734	432	4498	1336	4116
90SN7	Improved (tied ridges)	805	3923	769	7714	787	5818
Local	Improved (tied ridges)	1752	4688	106	4951	1384	4819
	Average	1598	4115	739	5721	1169	4918
NAD-1	Traditional (ridges)	1401	3176	602	4416	2003	3794
90SN7	Traditional (ridges)	968	3516	761	6242	864	4879
Local	Traditional (ridges)	2473	5009	794	5197	1633	5103
	Average	1614	3900	719	5285	1500	4592
NAD-1	Traditional	1614	3006	625	4766	1119	3886
902N7	Traditional	1571	3667	419	5744	995	4911
Local	Traditional	2236	4480	722	5099	1515	4789
	Average	1807	3718	589	5203	1210	4529

ments 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, in all locations, tied ridges performed better than traditional cultivation and genotype NAD-1 gave the highest yield. In 1998, on the contrary, the performance of genotypes were diverse and in some case the traditional and the local varieties tended to be more productive than the improved. Due to that contrasting situation, it's difficult to make any conclusion about the results of the 1998 study. It will be necessary to repeat that study next season in order to make appropriate recommendations about these technologies.

On-farm Sorghum Technology Evaluation to Enhance Sorghum Productivity in Niger - R.K. Pandey

Improving sorghum yield on farmers field in Sahelian environment is a primary goal of on-farm trials. Evaluating improved crop technologies with farmer participation under joint farmer-researcher managed trials provides an opportunity to farmers to learn about new technology and thus improve their farm income. An on-farm trial was conducted to evaluate sorghum technology (hybrid vs local variety Sepan-82) in two soil types (sand and loam) and two plant densities (low and high) at five N levels (0, 40, 80, 120 and 160 kg N ha^{-1}) in two irrigated perimeters in Konni and Maradi. Three farmers in each soil types were selected to evaluate the effect of cultivars, plant density and N rates on grain yield of sorghum. Data were analyzed as custom design with farmers as replications.

The crop was planted at 60 cm between rows and 25 and 37.5 cm between hills with 4-5 seeds per hill followed by manual thinning to achieve desired plant stands. The crop received 498 and 547 mm rain in the cropping season in Konni and Maradi, respectively, and was also occasionally irrigated when experiencing water stress. Half of the N was applied at planting and half at heading. The crop was hand weeded. Chlorophyll measurements were taken on fully expanded leaf at flowering as measure of N sufficiency. Data on grain yield, chlorophyll and partial factor productivity (PfP) over plant densities are presented (Table 2).

Grain yield was significantly higher in the loam soil compared to the sandy soil. Grain yield of both cultivars increased linearly up to 120 kg N per hectare. Chlorophyll meter readings as a measure of N sufficiency was higher as N level increased. Partial factor productivity as measure of return to farmers from N investment was higher for NAD-1 compared to Sepan-82 in the loam soil compared to the sandy soil. Greater N availability and reduced water stress in the loam soil provided better growing condition for higher grain yield. Further, farmers having sandy soil would require more N fertilizer to produce the same yield as the farmers of loamy soil.

The findings of this study suggested that in the Sahelian environment of Niger, improvement in sorghum productivity can be achieved by developing soil based management practices, particularly nutrient N, for optimizing grain yield of hybrids and open pollinated varieties. This may ensure greater resource use efficiency of resource poor farmers for grain production and maximize their farm profits.

Nitrogen Response of Sorghum as Influenced by Cultivars and Nitrogen Rates in a Sahelian Environment - R.K. Pandey

Low productivity of sorghum in a Sahelian environment demands examination of yield potential of sorghum cultivars at different N supply levels, where N is the major limiting production factor. Field experiments was conducted to examine yield potential of sorghum cultivars and nitrogen responsiveness on a sandy soil on a Lossa farm in Niger. Three cultivars namely IRAT-204 Sepan-82 and

Table 2. Grain yield and chlorophyll content and partial factor productivity as influenced by soil type, N application and cultivar in 1998.

Treatment	grain yield	chlorophyll	PfP, Konni	Grain yield	chlorophyll	PfP, Maradi
Loam Sepan-82						
0	978	35.7		1233	32.8	
40	1946	40.6	48.7	2033	36.4	50.8
80	2676	47.4	33.5	2793	42.9	34.9
120	3344	50.8	27.9	3720	49.9	31.0
160	3820	52.0	23.9	3413	51.9	21.3
Mean	2377	45.3	33.5	2558	42.8	34.5
NAD-1						
0	1248	30.2		1831	32.1	
40	2450	38.2	61.3	2333	36.7	58.3
80	3434	46.6	42.9	3286	44.4	41.1
120	4230	49.7	35.3	3920	49.3	32.7
160	4402	51.2	27.5	3980	52.2	24.9
Mean	2765	43.2	41.8	2980	42.9	38.8
Sandy Sepan-82						
0	873	26.7		960	29.0	
40	1449	36.8	36.2	1840	34.4	46.0
80	2158	46.7	27.0	2440	40.1	30.5
120	2732	49.6	22.8	2850	47.2	23.8
160	3256	51.6	20.4	3060	50.1	19.1
Mean	2214	42.3	26.5	2230	40.2	29.8
NAD-1						
0	1076	25.8		1140	27.7	
40	2074	32.4	51.9	2080	33.7	52.0
80	2632	44.8	32.9	2510	41.2	31.4
120	3534	49.3	29.5	3438	48.2	28.7
160	3481	50.1	21.8	3502	50.2	21.9
Mean	2619	40.5	34.0	2534	40.2	33.5
LSD (%)						
Soil type	329 NS			354 NS		
Cultivar	298 NS			311 NS		
N	319	6.3		304	5.9	
S x N	428 NS			462 NS		

NAD-1 were evaluated on five N levels; 0, 45, 90, 135 and 180 kg N ha^{-1}. The crop was planted on July 10, 1998 and received - 465 mm rainfall. Half of N was applied basally and half six weeks after planting. The crop was hand weeded. Chlorophyll was measured by the Minolta SPAD-500 at flowering.

The crop responded well to N fertilization. Significant differences were observed to N rates for both in hybrid and local cultivars. Mean yield of NAD-1 was 4165 kg ha^{-1} compared to 3122 kg ha^{-1} of Sepan-82 and 3136 IRAT-204. Grain increased almost linearly up to 180 kg N ha^{-1} in all three genotypes. Although NAD-1 produced numerically higher grain yield at zero N level compared to the other two genotypes, the full benefit in yield increase to better management was visible at higher N levels. Chlorophyll meter readings suggested increased leaf N sufficiency level occurred with N fertilization which improved potential grain yield. Partial factor productivity as a measure of return to farmers from N investment increased in NAD-1 compared to Sepan-82 and IRAT-204. (Table 3.)

The finding of this study suggested that in pursuit of improving sorghum productivity, benefit of introduction of hybrid technology can be realized fully if it is accompanied by simultaneous improved management which would include N use.

Sorghum Response to N Fertilizer in Relation to the Previous Crop in Mali - Abdoul Toure

Trials were conducted to test the effect of previous crop and different N rates on sorghum production in Mali. Sorghum was planted following peanuts, dolichos, cowpea, pearl millet, corn and sorghum at N rates of 0, 20, 40 and 60 kg ha^{-1}, and one treatment with 1 t manure. Two genotypes, CSM388 and N'Tenimissa were used. Results showed that sorghum yields were affected by the previous crop and genotype (Table 4). Corn was the best crop to follow and sorghum the worst. CSM388 outyielded N'Tenimissa an average of 449 kg ha^{-1} over all treatments. The positive effect of previous crop seemed to depend on its growth duration and/or its biomass production. Genotype CSM388 has

Table 3. Grain yield as influenced by cultivars and nitrogen rates 1998, Lossa, Niger.

Nitrogen ($Kg\ ha^{-1}$)	Grain yield ($Kg\ ha^{-1}$)				Chlorophyll meter readings			
	NAD-1	Sepan-82	IRAT-204	Mean	NAD-1	Sepan-82	IRAT-82	Mean
0	2097	1571	1317	1662	29.7	30.5	29.6	29.9
45	3076	2435	2651	2721	39.1	35.9	38.3	37.7
90	3656	3431	3598	3562	48.4	47.3	46.9	47.5
135	4933	4133	3970	4345	56.5	52.6	49.5	52.9
180	4762	4040	4148	4317	56.8	54.9	51.9	54.5
Mean	3705	3122	3136		46.1	44.2	43.2	
	LSD (0.05) Cultivars = 389 N = 381 C x N = NS				Cultivars = NS N = 4.8 C x N = NS			
	Partial factor productivity (kg grain/kg N applied)							
N Rate	NAD-1	Sepan-82	IRAT-204	Mean				
45	52.5	43.7	51.2	49.2				
90	33.8	29.8	32.6	32.1				
135	31.0	24.2	23.9	26.3				
180	24.0	18.4	18.7	20.4				

Table 4. Sorghum grain yield as influenced by previous crops and genotypes in the rainy season.

Previous crop	Genotypes		Differences
	CSM388	N'Tenimissa	
Sorghum	1492 C	1218 B	284*
Millet	1523 C	1229 B	295*
Peanut	1833 B	1337 AB	496*
Dolichos	1863 B	1373 AB	490*
Cowpea	1896 AB	1405 AB	313*
Corn	2095 A	1446 A	649*
Mean	1784	1335	449

* Significant at 5%; Means with the same letters are not significant at 5%.

high nutrient uptake efficiency compared to N'Tenimissa, and this may account for the yield differences.

There was a linear increase in yield up to 60 kg ha^{-1}. No significant difference in yield was obtained from 1 t ha^{-1} manure over that of the control (data not shown). Application of Malian rock phosphate increased overall yield by about 9%.

Domestic Research

Comparison of sorghums with genetic differences in leaf chlorophyll

Jerry Maranville, John Markwell, Gary Peterson

Changes in leaf chlorophyll in sorghum generally indicate corollary changes in leaf N. However, it is known that there are genetic differences in the amount of chlorophyll a given genotype can produce. It is not certain if those types having inherently less chlorophyll have the same N response characteristics as those with more chlorophyll. Sorghum line 'Lerdo Ligero', maicillo criollo sorghum with comparatively "yellow" leaves when grown under adequate N was compared to 'CK60' which has a dark green leaf. The study was conducted in pots in the greenhouse at two N levels (high and low) with eight replications. The low N medium (1 mg N kg^{-1}) caused N stress to be evident.

Results showed that the Ligero variety had 40% less chlorophyll in its leaves than CK60 when grown with adequate N (Table 5). There was no difference in carbon exchange rate (photosynthesis), however. When plants were put under N stress, Ligero lost 62% of its leaf chlorophyll and CK60 lost 56%. The CER was not reduced by the N stress in CK60, but Ligero values decreased by almost 50%. Our previous work has indicated a good correlation exists between leaf chlorophyll and leaf N in sorghum (INTSORMIL An. Rep., 1995, pp. 60-65). Leaf chlorophyll is not always a good predictor of photosynthesis and productivity, however. There is a good chance that the drop in photosynthesis shown by Ligero under N stress is due more to the disruption of carboxylation enzymes than the loss of chlorophyll per se. We have more experiments underway to study this further.

Nitrogen response of four sorghum cultivars - R.K. Pandey, Jerry Maranville.

In Sahalian environments, N use is low and soil is degraded, and sorghum yields are low. In order to improve sorghum yield, more productive cultivars that can use N more efficiently are needed. A glasshouse study was conducted to evaluate nitrogen response of four sorghum cultivars. A complete randomized design with five replica-

Table 5. Leaf chlorophyll of two sorghum genotypes measured by the SPAD-500 and by wet extraction, and photosynthesis from greenhouse grown plants at high and low N leaves.

Variety	N Level	SPAD chl μM m^{-2}	Lab chl μg cm^{2}	CER μM m^{-2} s^{-1}
CK60	High	1,766	83.4	18.57
	Low	783	35.6	21.24
Ligero	High	1,057	51.1	18.60
	Low	397	23.6	9.60

Table 6. Nitrogen response differences among Niger hybrids and open pollinated cultivars.

Treatment	Chlorophyll	Photosynthesis	Conductance
High N			0.2777a
NAD-1	49.32a	25.97a	0.2425ab
NAD-3	48.12a	22.21ab	0.2153ab
Sepan-82	47.00a	23.02ab	0.2521ab
IRAT-204	47.90a	26.69a	0.2521ab
Low N			
NAD-1	24.84b	19.72b	0.2073ab
NAD-3	23.34b	17.95b	0.1803ab
Sepan-82	21.62b	15.99b	0.1098b
IRAT-204	26.66b	13.63b	0.1281b

tions was used. Data on plant dry weight, leaf area, chlorophyll and photosynthesis were collected.

Significant differences between N levels were observed; however, differences among sorghum cultivars were not found (Table 6). At low N levels, there were no differences among cultivars for any trait. Higher photosynthesis was associated with greater conductance. Further analysis will be made on tissue N concentration and N use efficiency.

Networking Activities

Project UNL-214 is continuing collaboration with Dr. R.K. Pandey of the World Bank. Currently, Dr. Pandey is at the University of Nebraska doing research and writing manuscripts from collaborative studies in Niger. UNL-214 is paying Dr. Pandey's salary, and expenditures to date is $12,000. He will be at UNL through December, 1999.

A new MOU was drafted between INTSORMIL and SARI of Ghana, and UNL-214 is the primary focus of this new collaborative effort. Dr. Samuel Buah will be receiving funding to start agronomic studies in sorghum in the coming season.

UNL-214 is still working with World Vision International on consultation. The UNL-214 PI will make a trip to three African countries to review WVI studies at the expense of the InterCRSP funded program managed by Bean/Cowpea.

Publications

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Germplasm Enhancement
and Conservation

Breeding Sorghum for Increased Nutritional Value

PRF-203
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Summary

Four major achievements of this project will be cited.

Agrobacterium-Mediated Transformation of Sorghum

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.

Brown midrib (BMR) Sorghum-Sudangrass

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-Sudan 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-sudan 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. 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 sudan in W. Africa is be-

ing explored through collaboration with Dr. Issoufou Kapran. The value of forage in W. Africa is high and there is a chronic shortage of good quality forage which we believe can be partially alleviated by brown midrib sorghum sudan 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.

Seed Production of NAD-1 in Niger

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. That seed production be 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.

A Hybrid Seed Workshop for W. Africa, was held in Niamey, Niger on September 28 through October 2, 1998. The purpose of the workshop was to acquaint W. African sorghum and millet research scientists about the benefits of hybrid seed for W. 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 W. Africa and to assist the development of a private sector seed industry which brings many benefits to farmers in W. 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.ERA (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)

Transposon Tagging in Candy Stripe Material

Transposon tagging is a powerful method for identifying and isolating genes. Once a gene is mutated by insertion of a transposable element, this gene can be cloned using the transposable element as a probe. Thus, transposon tagging makes possible gene isolation on the basis of mutant phenotype, rather than relying on prior knowledge of the gene product. Tagging of genes can be done using endogenous transposable elements or transposable elements from other species. Nina V. Federoff demonstrated the applicability of plant transposable elements by cloning the *bronze* gene in maize. Since then, several plant genes have been isolated with the aid of transposable elements, including the cloning of the first disease resistance gene in plants.

The mutable pericarp color gene designated as "candy stripe" 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 from our perspective is that they can be used to identify agronomically important genes in sorghum. The probes are just now available which will allow us 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. A manuscript will be published in PNAS later this year describing the details of this research.

Objectives, Production and Utilization Constraints

Objectives

- 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.
- 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.
- 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.
- Improve forage quality of sorghum stover for better ruminant animal nutrition.
- 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-203 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.)

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 in itself a very popular variety among farmers in Niger. MR732 has good grain quality, excellent forage quality, and good yield potential with 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.

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 than 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 nine 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".

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 listing of graduate students who have completed degrees with Purdue INTSORMIL was presented in previous reports. Students can be divided into roughly four categories according to their current employment activities.

* Academic Appointments 7
* National Program Scientists 17
* Seed Industry Scientists 13
* International Center Scientists 9

During the past year, Mr. Carlos Carvalho from Brazil completed his Ph.D. degree and returned to the National Corn and Sorghum Program in Sete Lagoas, Brazil. He will be director of the biotechnology lab at this EMBRAPA research center. Lexington Nduulu is a graduate student from the Machakos Dryland Station in Kenya currently studying at Purdue. The identification of molecular markers which can be used to tag the high digestibility trait in sorghum will comprise the bulk of his Ph.D. thesis research.

Networking Activities

Workshops

The West African Hybrid Sorghum and Millet Workshop was held September 27 - October 2, 1998. Approximately 150 participants from 14 countries were in attendance. Several government officials participated and made favorable presentations. There is in fact a general consensus that the development of NAD-1 sorghum hybrid is one of the first significant contributions from the INRAN program to the people of Niger. There was general recognition of the valuable contributions made by INTSORMIL and Lee House, as an INTSORMIL consultant to the seed program. As a result of the workshop, there seems to be movement among the ICRISAT staff towards expediting their hybrid pearl millet program, which in fact has produced some good hybrids, but the technology has been pretty much on the shelf. Anand Kumar is an excellent pearl millet breeding with a strong interest in hybrids. A highlight of the meeting was the presentation by Mr. Barwale, from Mahyco Seed Company in India. He presented an excellent history of his experience in developing the private seed industry in India, which is now a one billion-dollar industry in India. His recount of his experience will be a highlight of the proceedings which is currently in preparation. 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 1998-99. 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. Issoufou Kapran will be attending a planning workshop in October 1999.

Germplasm and Research Information Exchange

Numerous requests for germplasm and information were received and distributed to collaborators in Africa, South Asia, and Latin America.

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Development and Enhancement of Sorghum Germplasm with Sustained Tolerance to Biotic and Abiotic Stress

Project PRF-207
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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 Year 20, we report on the results of two major studies conducted under PRF-207 that were recently published. The first is a summary of several recent publications on genetic analyses of drought tolerance using molecular markers. We employed marker analysis to identify QTL that correlate strongly with drought tolerance at specific stages. We then developed isogenic lines to test the phenotypic effects of genomic strongly associated with measures of agronomic performance in drought and non-drought environments. In most cases near-isogenic lines (NILs) contrasting for a specific locus differed in phenotypes as predicted based on earlier QTL analysis. Further analysis indicated that differences in agronomic performance may be associated with a drought tolerance mechanism that also influences heat tolerance.

In the second study, we assessed changes in concentration of phenolic compounds in sorghum grains during its development and to determine if changes in phenolic concentration play a role in fungal invasion of sorghum kernels. We observed that there is significant association between the concentration of certain phenols, particularly flavan-4-ols and proanthocyanidins and build up of major mold causing fungi. Infection of kernels by fungi increased with decline in concentration of tannins and flavan-4-ols suggesting that these compounds may play a significant role in mold resistance in sorghum.

Objectives, Production and Utilization Constraints

Objectives

Research

- To study the inheritance of traits associated with resistance to biotic and abiotic stresses 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-107 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

Selection and Genetic Analysis of Drought Tolerance in Sorghum

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 have 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. We summarize below the highlights of these findings:

Phenotypic Selection for Drought Tolerance

We have made a slow but significant progress via empirical breeding of sorghum for drought tolerance by breaking the trait of drought tolerance into specific phenological stages. Our approach has been to break down 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.

QTL Mapping and Analysis of Drought Tolerance

Molecular markers linked to QTL for drought tolerance could be used in increasing efficiency of breeding efforts to select sorghum germplasm with enhanced drought tolerance once these markers are identified through carefully monitored characterization of appropriate germplasm under stress conditions. Such an approach provides a more systematic mode for identifying specific traits that contribute to drought tolerance. Further analysis of these traits could lead to better understanding of the biological basis of drought tolerance. In the last several years, we undertook a number of studies toward this goal using a set of recombinant inbred (RI) sorghum lines especially developed for an array of interdisciplinary evaluation of the genetics and physiology of drought tolerance in sorghum. First, the RI lines were carefully evaluated for response to drought in a series of pre-flowering and post-flowering stress environments. Drought tolerance was estimated in several ways: evaluation of grain yield under drought, stability of yield, rate and duration of grain fill, seed weight, stay green and associated traits. Evaluation of the RI lines indicated segregation of drought tolerance during both developmental stages affirming its genetic basis and suggesting complementary interaction of loci from both parental sources. Second, the RI population was scored for the segregation of RAPD, RFLP, and SSR markers and these markers were ordered into a genetic map by linkage analysis and used to determine the contribution of the parental genotypes to each of the RI lines. Single factor analysis was used to identify QTL associated with yield and other measures of agronomic performance under drought and non-drought conditions. Several regions of the genome were associated with the expression of yield or yield components under pre-flowering and post-flowering drought, and under fully irrigated conditions. In each case, the marker allele associated with higher yield under fully irrigated condition was also associated with improved tolerance or agronomic performance under drought. On the other hand, two regions on two separate linkage groups were strongly associated with agronomic performance under pre-flowering drought but not under full irrigation. Similarly, two other regions of the genome on yet two other linkage groups were found to be associated with agronomic performance under post-flowering drought but not under full irrigation. These findings suggest that these loci mediate the expression of pre-flowering or post-flowering drought tolerance independent of mechanisms that control yield. Several QTL for stay green were identified on five linkage groups, however, QTL on three of these linkage groups were also positively associated with grain yield under non-drought conditions. This indicates that there may be a physiological link between the expression of stay green under post-flowering drought and grain yield under non-drought conditions.

Development of Near-isogenic Lines that Differ for Drought QTL

Although our QTL analysis identified regions of the sorghum genome that condition the expression of drought tolerance, it provided little information concerning the expression of individual QTL. Analysis of near-isogenic lines that differ at QTL can be an effective approach for the detailed mapping and characterization of individual loci. However, the use of NILs in analysis of important agronomic traits has been limited perhaps because of the time and effort required to develop these lines. We, therefore, developed a procedure for drawing NILs for any region of the genome that can be analyzed with molecular or other genetic factors. The procedure utilizes molecular markers to identify heterogeneous inbred families that are isogenic at most loci in the genome from NILs that differ for markers linked to QTL of interest. Using this procedure we developed NILs for several QTL associated with yield under drought environments and other morphological traits associated with drought tolerance.

Evaluation of NILs that Differ for Drought QTL

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 focussed 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. Agronomic evaluation of these NILs indicated large differences in yield and seed weight associated with each QTL marker. In most cases, NILs contrasting for as specific locus differed in phenotype as predicted by QTL analysis. Further analyses indicated that differences in agronomic performance may be associated with effects of heat tolerance, water status, and expression of stay green suggesting that these loci mediate the expression of drought tolerance via different biological mechanisms. This can be corroborated with careful physiological studies that can be more readily undertaken using NILs than random and unrelated 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 focussing on specific genomic regions associated with drought tolerance holds promise for developing a clearer understanding of the specific biological basis of this complex trait.

Grain Mold Resistance and Polyphenol Accumulation 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 landraces 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-4ols 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 9 weeks at 7-day intervals starting 7 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-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 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-deoxyanthocyanidins, the presence of these pigments did not differentiate mold-resistant and mold-susceptible genotypes. There was significant and negative correlation between concentration of proantocyanidins (tannins) and build up of major mold-causing fungi and visual mold rating indicating that this substance plays an important role in grain mold resistance in sorghum genotypes that produce it. The results also showed that the highest incidence of seed infection by fungi occurred between 25 and 35 days after anthesis. As the concentration of flavan-4-ols and proanthocyanidins in seeds of the different genotypes started to decline, percent seed infection on those genotypes showed proportional increases. This observation suggests that both flavan-4-ols and tannins play a significant role in mold resistance in sorghum. It is also possible that at an early stage of development, the seed might contain other secondary metabolites that have activity against fungi. Grain mold is caused by a diverse and dynamic group of fungi from different genera and it is unlikely that one or two mechanisms of resistance would be totally effective against all of them under all environmental conditions. Identifying different mechanisms of resistance to grain mold and incorporating them into agronomically important genotypes could provide a more lasting and effective solution to this major sorghum disease.

Networking Activities

Workshop and Program Reviews

Participate in African Dissertation Internship Awards Selection, Rockefeller Foundation, 18 May 1998, New York.

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

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

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

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

Participate in Regional Collaborative Research in Ethiopia and provide technical guidance to sorghum research in Ethiopia, 19-26 September, 1998.

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

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

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

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

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

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 project year:

Dr. Aberra Debelo, Nazret Research Station, P.O. Box 436, Nazret, Ethiopia

Dr. Paula Bramel-Cox, ICRISAT, India

Dr. Yilma Kebede, Pioneer, Manhattan, KS, USA

Dr. Brian Hare, Advanta, Pacific Seeds Pty Ltd, 268 Anzac Avenue, P.O. Box 337, Toowoomba, Qld 4350, Australia

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 or germplasm pool. Germplasm was distributed to cooperators in over 10 countries in 1998.

Publications

Refereed Papers

Menkir, A., P. Goldsbrough, and G. Ejeta. 1998. RAPD Based Assessment of Genetic Diversity in Cultivated Races of Sorghum. Crop Science 37:564-569.

Tuinstra, M., G. Ejeta, and P. Goldsbrough. 1998. Evaluation of Near-Isogenic Sorghum Lines Contrasting for QTL Markers Associated with Drought Tolerance. Crop Science 38:835-842.

Mohammed, A.H., G. Ejeta, L. G. Butler, and T. L. Housley. 1998. Moisture Content and Dormancy in *Striga asiatica* seeds. Weed Research 38:257-265.

Conference Proceedings

Axtell, J.D., I. Kapran, Y. Ibrahim, G. Ejeta, and D. Andrews. 1998. Heterosis in Sorghum and Pearl Millet. *In* Coors (ed) The Genetics and Exploitation of Heterosis in Crops. CIMMYT Press, Mexico City, Mexico

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Published Abstracts

Ejeta, G. 1998. Interdisciplinary Collaborative Research Towards The Control of *Striga*, p.46. Agronomy Abstracts. ASA, Madison, WI.

Mohamed, A., P.J. Rich, A. Melakeberhan, T. Housley, and G. Ejeta. 1998. An *in vitro* system for evaluating sorghum germplasm for post-infection *Striga* resistance mechanisms.p.76. Agronomy Abstracts. ASA, Madison, WI.

Ibrahim, Y., G. Ejeta, and W. E. Nyquist. 1998. G x E Interaction Analysis in Sorghum Using AMMI, p.79. Agronomy Abstracts. ASA, Madison, WI.

Ibrahim, Y., A. Melakeberhan, Y. Weerasuriya, N. Cisse, J. Bennetzen, G. Ejeta. 1998. Construction of a Sorghum Linkage Map and Identification of Loci Involved in *Striga* Resistance, p.156. Agronomy Abstracts. ASA, Madison, WI.

Invited Research Lectures

Ejeta, G. 1998. How Purdue Researchers Outwitted *Striga*. Presented at Workshop for Wabash Area Lifetime Learning Association, Morton Community Center, West Lafayette, April 1, 1998.

Ejeta, G., J.D. Axtell, B. Hamaker, and K. Ibrahim. 1998. INTSORMIL: A Win- Win Program for U.S. and Developing Country Agriculture. Presented at the Dean of Agriculture Team Award Ceremony, Purdue University, 12 May, 1998.

Ejeta, G. 1998. Strategies in Collaborative International Development Efforts in Plant Breeding. Presented at the Summer Institute for African Agricultural Research. 17 June, 1998, University of Wisconsin, Madison

Ejeta, G. 1998. Interdisciplinary Collaborative Research Towards the Control of *Striga*. Presented at the Symposium on CRSP: A Unique USAID Partnership with Higher Education. American Society of Agronomy, Baltimore, MD, 19 October 1998.

Germplasm Enhancement for Resistance to Pathogens and Drought and Increased Genetic Diversity

TAM-222
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Mr. Hector Sierra, Sorghum Breeder, Escuela Agricola Panamericana, PO Box 93, Tegucigalpa, Honduras

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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 late 1999.

Seed of over 2,000 entries from the Mali Sorghum Collection were introduced into the USA, and is being prepared at NSSL for the quarantine growout in St. Croix in winter 1999-2000.

Performance of stay green hybrids under severe post-flowering moisture stress showed that the stay green trait dramatically reduced lodging and produced higher yields than non-stay green hybrids.

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.

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. It 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

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, introduce into the USA.
- Identify and assist in developing new germplasm with resistance to grain mold, drought, head bug, 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

- 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 and breeding for improved resistance to drought. Sorghums with identified high levels of specific types of drought resistance in Texas have a similar response under drought in other countries of the world, including Sudan, Mali, Niger, and Honduras. Other adaptation traits such as grain quality, disease resistance, and grain yield must be combined with drought resistance to make a new cultivar useful.

Diseases are important worldwide and are often region or site specific. Most internationally important diseases are present and are serious constraints in Texas, especially downy mildew, charcoal rot, grain mold/weathering, head smut, and head blight. Other diseases such as anthracnose, leaf blight, rust, zonate, and gray leaf spot are also present in Texas. 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 where guinea type sorghums are almost exclusively grown. This quality problem is primarily due to the head bug/grain mold complex. Head bugs are the major constraint to the use of improved high yielding nonguineense type sorghums in much of West Africa. Head bug damage is often compounded by grain mold resulting in a soft and discolored endosperm, rendering it unfit for decortication and traditional food products. The early maturity of introduced types increases the grain deterioration problem. In southern Mali, late maturing, photoperiod sensitive sorghums are needed to assure grain maturity after the rainy season. In the drier northern areas of Mali and in Niger where drought stress is severe, earlier, less photosensitive material can be used, and drought tolerant Durra and Feterita sorghums perform well.

Mali and Niger are both drought prone areas where both pre- and post-flowering drought tolerance are important. Foliar diseases such as anthracnose and sooty stripe are important in the central and southern parts of Mali. 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 are a major constraint, 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. Improvement in the nonphotoperiod sensitive combine-type sorghum hybrids and varieties used over portions of Central America can occur directly from introduction of Texas adapted cultivars or hybrids.

There is a constant need in both host countries and the USA for conserving genetic diversity and utilizing 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 to produce sufficient food for increasing populations in 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 and 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 are made among various sources of pre- and post-flowering drought resistance and elite, high yielding lines. Progeny 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 to transfer QTLs into elite commercial and breeding lines. Selected advanced materials are incorporated into standard replicated trials for extensive evaluation at several location 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. We also work with NARS to assure 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 are sometimes 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

Thirty fully converted exotic lines and 30 partially converted bulks from the cooperative TAMU-TAES/USDA-ARS Sorghum Conversion Program released in late June 1998 were distributed and evaluated. Twenty-seven new fully converted lines and 70 partially converted lines were selected for release in 1999. Two new male sterile (A-lines), A807 and A1, were increased in a pre-release pilot increase in 1998. Several additional A-B pairs and R lines were 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.

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 season was very dry and extremely hot statewide with severe post-flowering stress in South Texas. No dryland plots were established at Lubbock due to lack of moisture. Good pre-flowering drought was obtained at Lamesa and Chillicothe, while quite good post-flowering ratings were attained at Lubbock and Halfway under limited irrigation. Breeding derivatives of the stay green line, B35 showed good stay green and outstanding lodging resistance. Sterilization of new B lines continued. Major diseases involved in the disease resistance breeding were charcoal rot, grain mold/weathering, downy mildew, head smut, anthracnose, and foliage diseases such as rust, zonate, and leaf blight.

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 season-long severe moisture stress. They showed good stay green ratings, no lodging, and yielded well (Table 1).

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), 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. Crosses and backcrosses were made using marker assisted selection (MAS) for stay green and greenbug resistance. Also, crosses and backcrosses were made with converted exotic lines to identify QTLs for yield and heterosis.

Table 1. Performance of selected stay green and non-stay green hybrids under severe drought, Corpus Christi, Texas, 1998.

Hybrid Designation/Pedigree	Stay Green Rating[1]	Lodging %[2]	Grain yield lb/A
A35*88V1080	2.7	0	3736
A35*Tx2908/R8503	2.7	0	3169
A35*90M50	2.8	0	3950
A35*90M17	3.0	0	3512
A35*89CC445	2.6	0	4097
A35*90EON362-4	2.9	1	3401
A35*Tx430	2.7	0	3341
A35*82BDM499	3.0	1	3676
A35*P37-3	3.1	1	3641
A402*88V1080*	3.2	0	3289
A409*88V1080*	3.1	0	3650
A403*88BE2668*	3.1	0	3465
Mycogen1506	2.7	0	4139
DeKalb DK 41y (Check)*	3.2	8	2723
A807*Tx2908/R8503**	4.6	48	2367
ATx399*Tx430**	3.5	4	3298
A1*Tx430**	3.8	10	3144
A1*P37-3**	4.3	15	2585
ATx631*Tx436**	4.4	21	2886

[1] Rating on 1 to 5 scale on premature leaf and plant death where 1 = completely green, 5 = death.
[2] Lodging was late season drought stress induced lodging associated with charcoal rot.

* = Moderate stay green hybrid
** = Non-stay green hybrid.

Several breeding progeny from crosses generated for Host County and USA use looked very good agronomically in Southern Africa in 1998-99. 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, ICSV1079, Sureño, Dorado, and 90EON328.

The Mali Sorghum Collection Growout in Mali was very successful and it is being processed at NSSL for a quarantine growout 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 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. Its 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, even though it exhibits some peduncle breakage.

Approximately 10 tons of N'Tenimissa grain was produced in increase plantings 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.

Other white, tan guinea breeding lines are being developed in Mali. They are tan-plant lines with excellent guinea traits, and are free of the peduncle breakage problem. Selection also continued among non-guinea type, tan-plant breeding lines with improved levels of head bug tolerance and grain mold resistance.

Excellent segregation for head bug resistance occurred in the F_3 progenies of the cross (Malisor 84-7*S34). However, Dr. Aboubacar Touré, 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.

Networking Activities

Workshops/Conferences

Participated in and chaired a session at the Regional Hybrid Sorghum and Pearl Millet Seed Workshop, Sept. 28-October 2, 1998, at Niamey, Niger. Interacted with leading scientists from West Africa, ICRISAT, and France.

Participated in and presented a paper at the WCASRN Workshop - Sustainable Sorghum Production, Utilization, and Marketing in West and Central Africa, April 19-22, 1999, at Lome, Togo.

Participated in the 1999 Sorghum Industry Conference and 21st Biennial Grain Sorghum Research and Utilization Conference (SICNA), February 21-23, 1999 at Tucson, Arizona, and co-authored one invited paper and three poster papers.

Research Investigator Exchanges

Traveled to Niger, Sept. 26-Oct. 2 for the Hybrid Seed Workshop and interacted with leading scientists from West Africa, ICRISAT, and France.

Helped coordinate the INTSORMIL EEP Review in Mali, October 4-7, 1998, and traveled to several IER Stations and on-farm sites, and to World Vision on-farm sites.

Traveled to Mali October 2-9, 1998 to evaluate and plan INTSORMIL/IER collaborative research.

Continued coordination of the introduction of the Mali Sorghum Collection into the USA and the plans for the growout of the Collection under quarantine in St. Croix the winter of 1999-2000.

Participated in the Sorghum Crop Germplasm Committee (SGC) as Ad hoc member, February 22, 1999, Tucson, Arizona.

Participated in and presented poster paper at the Annual American Society of Agronomy Meetings, October 18-22, 1998 at Baltimore, Maryland.

Participated in the Sorghum Biotech Partnership meeting (Cargill, Novartis, NC+, Crosbyton), April 12-13, 1999 at College Station, Texas.

Presented a talk, Breeding for Drought Resistance in Sorghum, at the USDA-ARS/TAMU-TAES Bushland Field Day, and to the TAES Wheat Breeding Group, August 12 and 13 respectively, at Amarillo, Texas.

Participated in INTSORMIL Technical Committee (TC) meetings, May 11-12, 1999 at Kansas City, Missouri.

Coordinated the visit and hosted Dr. Andrew Borrell, sorghum stress physiologist from Queensland, Australia, at Lubbock, Texas, June 28-July 2, 1999.

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.

Hosted many other visitors to Lubbock, including Medson Chisi, from Zambia, during the year.

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. A. Tunde Obilana, Sorghum Breeder, SADC/ICRISAT, Bulawayo, Zimbabwe.

Dr. Chris Manthe, Entomologist, DAR, Gaborone, Botswana.

Dr. B.N. Verma, Sorghum Breeder, Chilanga, Zambia.

Dr. Jeff Dahlberg, Sorghum Curator, USDA/ARS, Tropical Agriculture Research Station, Mayaguez, Puerto Rico.

Dr. L.E. Claflin, Pathologist, KSU-208, Kansas State University, Manhattan, KS.

Prof. D.J. Andrews, Sorghum/Millet Breeder, UNL-218, University of Nebraska, Lincoln, NE.

Dr. J.D. Eastin, Physiologist, University of Nebraska, Lincoln, NE.

Dr. Bob Klein, Geneticist, USDA/ARS - Texas A&M University, College Station, TX.

Dr. John H. Mullet, Biochemist, Molecular Biology, Texas A&M University, College Station, TX.

Dr. P.K. Subudhi, Molecular Biology, Texas Tech University, Lubbock, TX.

Dr. Fred Rattunde, Sorghum Breeder, ICRISAT, Bamako, Mali

Dr. Inoussa Akintayo, WCASRN Coordinator, WCASRN, ICRISAT, Bamako, Mali

Dr. Mitch Tuinstra, Sorghum Breeder, Kansas State University, Manhattan, KS

Dr. Ken Kofoid, Sorghum Breeder, KSU, Hays Experiment Station, Hays, KS

Germplasm and Research Information Exchange

Germplasm Conservation and Use

Continued to coordinate the work with the Mali Sorghum Collection, including plans for planting, seed increase, and completion of characterization of the growout of the complete Collection in St. Croix the winter of 1999-2000, and for the eventual distribution of seed to NSSL, ORSTOM, Mali and ICRISAT.

About 35 new exotic sorghums were selected for entry into the cooperative TAMU-TAES/USDA-ARS Sorghum Conversion Program in winter 1998-99. They included some cold tolerant lines from East Africa, and several elite cultivars from an old Ethiopia collection which were grown out (about 2,000 plots) in Puerto Rico.

Several recent introductions from Southern Africa were grown and evaluated in Puerto Rico and seed increased. The reported ergot resistant line, IS8525, was grown out and seed increased and crossed to several elite germplasm lines. Several photoperiod insensitive sorghum cultivars from the Sudan Collection were identified as promising sources of drought (mostly pre-flowering) resistance.

Twenty-seven new fully converted exotic lines from the cooperative TAMU-TAES/USDA-ARS Sorghum Conversion Program were selected for release in 1999, along with 70 partially converted lines.

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. Two new male sterile lines (A-lines) were increased as a pre-release pilot release, prior to their official release in 1999. 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, 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, Nicaragua, Mexico, Brazil, and Egypt.

Assistance Given

Joint evaluation of germplasm and nursery and test entry decisions was in collaboration 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.

Publications and Presentations

Abstracts

Rosenow, D.T., J.A. Dahlberg, G.C. Peterson, S.B. Coulibaly, A. Toure, H.F. Rattunde, and J.D. Chantereau. 1998. Characterization of the Mali Sorghum Collection. Agronomy Abs. p. 163.

Rodriguez-Herrera, R., W.L. Rooney, R.D. Waniska, D.T. Rosenow, and R.A. Frederiksen. 1998. Path analysis for grain mold resistance in sorghum. Agronomy Abs. p. 80.

Vietor, D.M., W.L. Rooney, D.T. Rosenow, and R.D. Powell. 1998. Carbon partitioning in stay green sorghum cultivars under water stress. Agronomy Abs. p. 92.

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Machado, S., E.D. Bynum, Jr., D.T. Rosenow, G.C. Peterson, T.L. Archer, R.J. Lascano, K. Bronson, E. Segarra, and L.T. Wilson. 1999. Spatial variability of sorghum yield: Site-specific interactions of soil, water, and pests. p. 13-14. In: Prec. of 21st Biennial Grain Sorghum Research and Utilization Conference. Feb. 21-23, 1999, Tucson, AZ.

Journal Articles

Crasta, O.R., W. Xu, D.T. Rosenow, J.E. Mullet, and H.T. Nguyen. 1999. Mapping of post-flowering drought resistance traits in grain sorghum: Association of QTLs influencing premature senescence and maturity. Molec. Gen. Genetics (in press).

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Miscellaneous Publications

Rosenow, D.T., J.A. Dahlberg, G.C. Peterson, L.E. Clark, A.J. Hamburger, P. Madera-Torres, and C.A. Woodfin. 1998. Release of 30 partially converted sorghum lines. 1998. International Sorghum and Millets Newsletter 39:82-84.

Peterson, G.C., D.T. Rosenow, and H.T. Nguyen. 1999. Breeding and marker-assisted selection-overcoming bugs and thirst. p. 25-30. In: Proc. of 21st Biennial Grain Sorghum Research and Utilization Conference, Feb. 21-23, 1999, Tucson, Arizona.

Pietsch, D., L. Synatschk, W.L. Rooney, and D.T. Rosenow. 1998. 1998 Grain Sorghum Performance Tests in Texas. Dept. of Soil and Crop Sciences Departmental Technical Report, DTR 98-08. 119 p.

Rosenow, D.T. 1999. INTSORMIL contributions to sorghum production and utilization in West and Central Africa. In: Proc. of WACSRN Workshop - Sustainable Sorghum Production, Utilization, and Marketing in West and Central Africa. April 19-22, 1999, Lome, Togo (in press).

Toure, Aboubacar and I. Kapran. 1999. Development of tan/white sorghum cultivars in West and Central Africa. In: Proc. of WACSRN Workshop - Sustainable Sorghum Production, Utilization, and Marketing in West and Central Africa. April 19-22, 1999, Lome, Togo (in press).

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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).

Sorghum lines resistant to sorghum midge that are suitable for hybrid production has been a primary research objective. In addition to pest resistance the lines should produce excellent grain yield potential under high pest density, acceptable yield with pest absent, and contain other needed traits including adaptation, foliar quality, etc.

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. Lines resistant to greenbug biotype I are in hybrid evaluation, and final selection and resistance evaluation. If the lines maintain resistance and produce agronomically acceptable hybrids they will be considered for release to private industry.

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 research to develop crop genotypes with enhanced environmental fitness suitable for use in more sustainable production systems is needed. Cultivars are exposed to stress concurrently or sequentially and a line with genetic resistance to multiple stresses will experience 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 multidisciplinary 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.

Among the major constraints to sorghum production in Sahelian Africa are: soil acidity, extremely deficient levels of N and P, spatially variable soil toxicity and limited available water. These factors frequently interact, with food shortages resulting. Solutions to these problems must meet site specific needs of soil, rainfall, resources, labor and capital.

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 conducted at nursery locations in Texas. This project supports collaborative research in three ecogeographic sites. Research in Mali is primarily for resistance to head bugs and identification of sorghum genotypes resistant/tolerant to soil toxicity. Research in Southern Africa is aimed at incorporating resistance to sugarcane aphid into adapted cultivars. Research 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.

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 also 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 LDCs but not in the USA, 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.

For soil toxicity research, diverse cultivars from the USA and other countries are evaluated in field nurseries at Cinzana, Mali. Lines which show promise are selected for further evaluation. Research on soil toxicity is hindered by the site specific nature of the problem, poor germination of experimental entries in nurseries planted for screening and evaluation, and no funds from the country budget assigned for the research.

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. Selected converted exotic sorghums were evaluated for resistance at Corpus Christi and College Station. 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.

Evaluation for sorghum midge resistance was hindered by the extremely hot, dry climate in 1998. As a result, sorghum midge population density was less than required for excellent evaluation. Seventy-three lines were evaluated for resistance to sorghum midge and agronomic desirability in the Midge Line Test (Table 1). Included were four susceptible and eleven resistant checks, and 59 experimental breeding lines. Most resistant checks and experimental lines were significantly less damaged than the susceptible checks. The most resistant checks were not significantly less damaged than several experimental entries. Sorghum midge density was greater at Corpus Christi (MDR=2.3) than at College Station (MDR=3.0).

The primary sorghum midge resistance source is TAM2566 (SC175-9) a partially converted zera zera (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. Many of the selections derived from these lines have excellent resistance and agronomic traits. Several were selected to test in hybrid combination.

The converted exotic sorghum collection has formed the basis for the sorghum midge resistance breeding program in the United States. Based on evaluation of the converted exotic collection in a non-replicated trial at Corpus Christi and College Station to evaluate for additional sources of resistance, 47 converted lines were selected for more extensive evaluation. The lines were evaluated in a replicated trial at Corpus Christi and College Station. Based on analysis of the data, several lines were identified with potentially useable resistance. However, agronomic characteristics will hinder use of the lines in the breeding program. One line selected for additional use is IS12611C (SC111-14E), a converted zera zera with tan plant, white pericarp, and excellent foliar traits.

Combining ability for yield potential and sorghum midge resistance was studied to evaluate advanced germplasm for use as hybrid parents. A major constraint to production and use of sorghum midge resistant hybrids has been the lack of superior lines which possess excellent resistance and grain yield potential under pest infestation, and excellent grain yield potential in the absence of the pest. Release of A/BTx639, A/BTx640, and A/BTx641 represent significant progress in development of sorghum midge resistant hybrids. Improvement is now needed in R-lines to provide additional heterosis and superior agronomic traits. To develop a useful sorghum midge resistant hybrid the grain yield level has to be increased 10 to 15%.

Grain yield and midge damage rating for entries in the Midge Hybrid Test at College Station are shown in Table 2. The standard resistant check is ATx2755*Tx2767 (MDR=2.0, grain yield=4035 kg ha^{-1}) and the standard susceptible check is ATx2752*RTx430 (MDR=4.7, grain yield=2772 kg ha^{-1}). Most experimental hybrids produced

Table 1. Rating of sorghum lines in the Midge Line Test for midge damage and desirability, 1998.

	Midge damage rating[1]		Desirability[2]	
Pedigree	CC[3]	CS[3]	CC	CS
7BRON138/7MLT45/((SC62-14*Tx2782)-B12-CC1-CC1*Tx2878)-SM18	1	3.7	2.7	2.7
94ML68/7BRON131	1	1	2.4	2.5
7BRON143/7MLT53/(MR118-3-RS-CC2-CS1-CS1-SM1*Tx2882)-SM15	1	2.3	2.3	2.7
(MR127-92M5*MR114-90M11)-SM2	1	1.3	2.2	2.2
Tx639	1	3	2.4	2.5
97M2/7BRON135/7ML48	1	3	2.4	2.4
7BRON139/7MLT49/(Tx2872*Tx2880)-SM10	1	2	2.4	2.4
B94-7	1	4.7	2.4	2.5
97M3/7BRON136/7ML48	1	1.3	2.9	2.7
7BRON147/7MLT44/((SC62-14*Tx2782)-B12-C11-C1`1*Tx2878)-SM17	1	2.7	2.5	2.4
7BRON132/7ML5TR/((SC228-14*Tx2767)-2-B2-BM2-LM2*Tx2876)-CM4	1	1.7	2.6	2.7
((SC572-14*SC62-14)-C12-CC1-CC1*Tx2885)-CM14	1	3.3	2.3	3.1
(MR127-92M5*MR114-90M11)-SM17	1.3	2.3	2.5	2.4
Tx640	1.3	2.7	2.5	2.4
Tx2880	1.3	1.7	2.8	2.7
((MB120C-BM5-CS2-CS1-SMBL-LMBK)*MB108B/P.G.)-SM5	1.3	3	2	1.8
B94-15	1.3	7	2.3	2.3
Tx2882	1.3	1.7	2.3	2.2
(((Tx2767*SC693-14)-B6-L1-BM1-CC1)*Tx272)-SM3	1.3	2	2.2	2.2
(PM12713*Tx2882)-CM7	1.3	1.7	2.5	2.5
7BRON145/7MLT58/(MB108B/P.G.*MB110-49-B2-CC2-CC1-LMBK)-BM10	1.3	6	2.3	2.4
(Tx2880*SC170-6-17)-SM15	1.3	2	2.4	2.4
7BRON134/7MLT56/(PM12713*Tx2766)-CM2	1.3	1	2.3	2.4
97M14/7BRON153/7ML63	1.3	1.3	2.3	2.2
Tx2782	1.5	2	3.1	0
(Tx2782*BM108B/P.G.)-CM10	1.5	2	2.6	2.6
97M1/7BRON134/7ML56	1.7	1.3	2.3	2.3
97M7/BRON141/7ML51	1.7	2.7	2.8	2.9
7BRON154/7MLT65/(Tx2882*89CC132)-CM53	1.7	4	2.3	2.5
(MR127-92M5*MR114-90M11)-SM2	1.7	1.3	2.3	2.3
(PM12713*Tx2880)-CM5	1.7	2	2.4	2.5
7BRON155/7MLT61/(Tx2767*((SC572-14*SC62-14)-B5-L1-BM1-CM1))-SM5	1.7	2.3	2.2	2.2
(MR112B-92M2*Tx2880)-SM17	1.7	3.3	2.5	2.6
7BRON157/7MLT67/(PM212713*Tx2880)-CM5	1.7	4	2.6	2.8
MR112B-92M2*Tx2880)-SM31	1.7	2	2.7	2.5
B94-14	1.7	6.3	2.3	2.4
MB108B/P.G.	2	1.7	1.8	1.8
(MR112B-92M2*Tx2880)-SM17	2	0	2.7	0
(((SC572-14*SC642-14)-B17-L1-CC1)*Tx2872)-SM1	2	2	2.6	2.9
97M17/7BRON157/7ML67	2	3.7	2.6	2.9
(88B885/(Tx623*CS3641)*TX2782)-BM8	2	3	2.2	2.3
B94-17	2	7	2.2	2.3
(((SC572-14*SC62-14)C12-BM1-BM1-BM1-LMBK)*Tx2767)-CM7	2	4.3	2.4	2.2
Tx641	2	4.3	2.3	2.3
7BRON156/7MLT66/(MR112-90M5*73O366)-CM4	2	2.7	2.3	2.2
7BRON158/7MLT68/(PM12712*Tx2880)-CM5	2	2.3	2.9	2.6
(PM12713*Tx2880)-CM7	2	3	2.5	2.5
((MB126e-BM3-BM2-CC2-SMBKMLBK)*MB108B/P.G.)-CM9	2.3	4.3	2.4	2.3
7BRON133/7MLT55/((SC228-14*Tx2767)-2-B2-BM2-LM2*Tx2876)-CM4	2.3	1.3	2.6	2.4
97M13/7BRON152/7ML62	2.3	1.7	2.4	2.3
7BRON153/7MLT63/(TX2882*6E0374)-CM9	2.3	2.3	2.5	2.6
97M9/7BRON146/7ML64	2.3	3	2.4	2.5
97M18/7BRON159/7ML69	2.3	1	2.6	2.5
((MB126E-BM3-BM2-CC2-SMBK-LMBK)*MB108B/P.G.)-SM5	2.3	3.5	2.1	2.7
94ML66/7BRON131	2.7	4	2.6	2.7
B94-6	2.7	3.3	2.5	2.6
((MB230C-BM5-CS2-CS1-SMBL-LMBK)*MB108B/P.G.)-SM5	2.7	3	2.2	2
7BRON129/7MLT34/((MB110-21-L1-BM2-CC1*Tx623)-CM8	2.7	2.7	2.4	2.3
(MR127-92M5*MR114-90M11)-SM17	3	2.3	2.4	2.6
97M16/7BRON156/7ML66	3	3.1	2.3	2.2
(TX2882*SRN39)-CM3	3.3	1	2.9	2.1
97M10/7BRON149/7ML60	4	1	3	2.4
7BRON141/7MLT51/(MR114-90M11*Tx2880)-SM5	4	3.5	3.1	2.9
(((SC572-14*SC62-14)-C12-BM1-BM1-BM1-LMBK)*Tx2767)-CM19	4	4	2.8	2.4
7BRON137/7MLT43/(PM11344*Tx2782)-CS-24	4.7	3.3	3.8	3.6
Tx623	5	3	2.6	2.3
(((SC572-14*SC62-14)-B7-CM1-BM2-BMBK)*6EO362)-SM6	5.3	2.7	2.5	2.8
Tx2767	5.3	2.3	3.5	3
Tx430	5.7	3.1	2.3	2.4
Tx3042	5.7	1	3.1	3.3
Tx378	7	2	3	3.3
MR114-90M11	8	2.3	0	2.9
(Tx2882*89CC132)-CM53	9	3	3.2	3.5
$\bar{x}$	2.3	2.3		
LSD_{05}	1.9	4		

1 Rated on a scale of 1 = 0-10%, ...9 = 91 = 100% of kernels that failed to develop.
2 Agronomic desirability rated on a scale of 1 = most desirable up to 5 = least desirable.
3 CC = Corpus Christi; CS = College Station.

Table 2. Grain yield, midge damage, and agronomic characteristics of hybrids in the Midge Hybrid Test at College Station, Texas, 1998.

Hybrid	Yield kg ha^{-1}	MDR[1]	Days 50% anthesis	Height	Exsert	IB[2]	DES[3]
				------- cm -------			
ATx640*97M18	5077	2	70	154	9	1.9	2.2
ATx640*RTx430	4667	2.3	61	109	9	1.8	2.3
ATx640*97M7	4547	1.7	64	111	9	1.8	2.7
ATx2755*97M18	4543	2	69	147	14	1.9	2.3
ATx640*97M17	4343	1.7	62	120	12	1.9	2.7
ATx2755*97M1	4293	1.7	65	118	14	2.9	2.7
ATx640*97M10	4224	2.3	62	104	6	1.7	2.2
A94-6*Tx2767	4209	2	66	126	9	1.5	2.3
ATx640*97M3	4175	2.3	62	114	9	2.2	2.6
A97-7*Tx2767	4073	2	62	119	12	1.7	2.5
ATx640*Tx2767	4061	2	65	119	12	1.8	2.3
ATx2755*Tx2767	4035	2	63	111	11	1.7	2.5
ATx640*97M13	4032	1.3	64	109	11	2.1	2.2
ATx2755*97M2	4013	1.7	61	103	5	3.2	2.3
A94-14*Tx2767	4001	2	61	120	9	1.7	2.4
ATx2755*97M9	3988	2.7	62	105	5	2.2	2.2
ATx640*97M14	3875	1.7	64	107	11	1.9	2.3
ATx641*Tx2767	3872	2	62	117	10	1.7	2.3
A94-6*Tx2882	3840	2.3	66	96	7	1.9	2.3
A94-17*Tx2882	3825	3	58	98	8	1.7	2.3
A94-17*Tx2767	3640	2.3	62	116	8	1.8	2.2
ATx639*Tx2882	3615	2.7	59	101	9	1.8	2.4
ATx640*97M16	3592	2	63	110	10	1.9	2.4
A94-15*Tx2880	3585	2	58	104	6	1.7	2.1
ATx640*97M1	3581	1.7	66	129	13	2.9	2.5
ATx639*Tx2767	3579	2.3	62	118	8	1.7	2.7
A94-17*Tx2880	3577	2	57	108	8	1.7	2.4
ATx2755*Tx2880	3547	2.3	60	95	7	1.9	2.5
ATx2755*97M10	3539	3	60	96	6	1.7	2.3
ATx640*94ML66	3523	1.3	62	102	10	2.1	2.6
ATx640*Tx2882	3479	1.7	63	102	7	1.9	2.3
A94-15*Tx2882	3467	2.7	58	99	6	2	2.2
ATx2755*Tx282	3431	2.3	63	95	9	2	2.2
ATx639*Tx2880	3399	2.7	57	107	8	1.9	2.5
A807*RTx430	3351	4	58	113	7	1.5	2.2
A94-14*Tx2882	3304	3	58	104	8	105	2.4
ATx2755*97M17	3272	2	61	104	13	2	2.4
ATx640*Tx2880	3249	1.3	58	103	7	1.7	2.3
ATx2755*97ML68	3232	2.7	59	97	5	2.4	2.2
ATx641*Tx2882	3213	2.3	59	97	7	2.2	2.2
A94-7*Tx2882	2920	3	60	98	7	2	2.7
ATx2755*97M3	2908	3.7	58	95	7	2	2.6
A94-15*Tx2767	2901	2.7	62	115	9	1.6	2.4
ATx2755*97ML66	2897	1.7	60	98	5	1.8	2.4
ATx641*Tx2880	2844	2	58	106	5	1.7	2.2
ATx2752*Tx2783	2821	2	63	108	6	2.7	2.9
ATx2752*RTx430	2772	4.7	60	100	3	1.7	2.5
A94-6*Tx2880	2567	3	63	107	6	1.6	2.6
ATx639*97ML66	2532	3.3	58	102	5	1.9	2.7
A94-7*Tx2880	2332	3	58	100	6	2	2.8
ATx2755*RTx430	2321	2	61	97	7	1.3	1.3
A35*RTx430	2177	4.3	63	118	10	1.7	2.3
ATx399*RTx430	2157	6.3	60	92	4	1.6	2.3
A1*Tx2862	2067	5.3	65	119	7	2.4	2.3
ATx639*RTx430	1996	0	61	152	2	0	0
ATx641*RTx430	1751	2.3	61	108	6	1.2	1.5
ATx3042*Tx2737	753	6.7	58	104	5	1	1.5
Mean	3396	2.5	61	109	8	1.9	2.3
LSD .05	1096	1	2	7	3	0.5	0.5
C.V	23.8	30.8	1.8	5	30	19	15.1

[1] MDR = Rated on a scale of 1 = 0-10%, ...up to 9 = 91-100% of kernels that failed to develop.
[2] IB = Insecticide burn (phytotoxicity) rated on a scale of 1 = no phytotoxicity, ... upt to 5 = 100%
[3] Agronomic desirability rated on a scale of 1 = most desirable, ..., to 5 = least desirable.

significantly more grain than the susceptible checks. Although no experimental hybrids produced significantly more grain than ATx2755*Tx2767, eleven hybrids produced more grain. Seven of the top hybrids contained ATx640 as the resistant parent. ATx640 is one of the most recent releases for sorghum midge resistance and will produce excellent hybrids in late planting regardless of whether sorghum midge are present. Differences at College Station (average grain yield of 3396 kg ha^{-1}) under moderate pest density represent grain yield potential under conditions more likely to be encountered in producers fields.

Selections were made to continue development of germplasm resistant to biotype E, I, and K greenbug. New R-lines resistant to biotype E continue to produce excellent hybrids. The lines represent a range of plant types including tan plant, white pericarp and tan plant, red pericarp. Other favorable traits include wide adaptation and resistance to several diseases. Several lines could be used to develop food type sorghums with improved biotic stress resistance.

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. Selections to develop biotype I/K resistant lines were made in many populations. Screening against biotypes I and K greenbugs identified genotypes that contain moderate resistance to both biotypes. Resistance to biotype I and K is controlled by different genes and a moderate level of resistance to both biotypes is emphasized in the selection criteria. Many crosses to introgress resistance gene(s) into an array of elite germplasm were made.

Molecular biology research identified molecular markers resistant to biotype C, E, I, and K greenbug. For this research (Ph.D. dissertation of C.S. Katsar) TAM-223 and TAM-225 collaborated with Dr. A.H. Paterson to provide unique training in breeding, entomology and molecular biology. Significant new understanding of the nature of greenbug resistance resulted from this research. Nine molecular markers on eight linkage groups were identified for resistance to greenbug. Two markers on different linkage groups were identified for biotype C resistance derived from SA7536-1. For biotype C resistance derived from Capbam two markers on different linkage groups were identified. One marker for biotype C resistance was common to both SA7536-1 and Capbam. For biotype E resistance derived from Capbam three markers on two linkage groups were identified. For resistance genes in PI550607 one marker for biotype C, three markers for biotype E, and three markers for biotype K were identified. For PI550607 the markers for each biotype were on different linkage groups. A low level of greenbug resistance was identified in a susceptible cross with BTx623 as a parent. This could lead to identification of additional resistance genes with small effects that enhance greenbug resistance. Greenbug resistance is not simply inherited but is multigenic and mostly quantitative, the number of resistance loci found ranging from one to five (depending on the population). The relationship between greenbug resistance in sorghum, wheat, and barley was also studied. Correspondence exists between greenbug resistance in the different species. This could lead to strategies of gene management or deployment to improve durability of resistance. Additional populations are in development to conduct fine mapping activities as a prelude to cloning.

For the marker-assisted selection research, crosses and backcrosses to incorporate greenbug resistance and post-flowering drought tolerance into a single genotype were made. Three greenbug resistance sources are used: Capbam through Tx2783, PI550607, and PI550610. The source of post-flowering drought tolerance is the cross B35*Tx7000. Molecular analysis using RFLP markers will identify genotypes that contain greenbug resistance genes and QTLs for drought resistance. 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 to compare the efficiency of marker-assisted selection versus traditional selecting in this project.

For soil toxicity research at Cinzana a 17 entry paired plot experiment was developed and sent to Mali. All entries in the test were specifically requested by Dr. Mamadou Doumbia, IER soil chemist. The experiment was planted in the soil toxicity site on the Cinzana station and in a farmers field adjacent to the Cinzana station. Research in soil toxicity continued to be hindered by poor germination in the sites selected for the study.

Work with Malian collaborators to develop improved guinea type varieties with higher yield potential, superior grain traits, tan plant, and other needed plant traits continued. One tan plant, white seeded line named "N'Tenimissa" has consistently shown excellent grain yield and agronomic traits. It is currently in on-farm tests prior to release.

A 50-entry test for sugarcane aphid resistance was sent to Southern Africa in collaboration with TAM-222, TAM-228, and TAM-225. The test was evaluated for resistance to sugarcane aphid in a greenhouse screening and for resistance to sooty stripe at Golden Valley, Zambia (Table 3). For sugarcane aphid resistance, nine experimental entries sustained no more damaged than the resistant checks (SDSL89426, WM#322, FGYQ353, TAM428, FGYQ336, CE151, WM#177, Ent. 62/SADC, and Sima). For sooty stripe resistance, only three entries expressed resistance. However, no experimental entries were resistant to both sugarcane aphid and sooty stripe. Sugarcane aphid resistant breeding materials are in development for the collaborative program. Resistance sources including TAM428, CE151, WM#177, Sima (IS23250), SDSL89426, FGYQ336 have been intercrossed or crossed

Table 3. Rating of sorghum lines for resistance to sugarcane aphid based on aphid severity and aphid damage at Gaborone, Botswana, and for sooty stripe at Golden Valley, Zambia.

Pedigree	Aphid severity[1] 21 DAP[3]	Aphid severity[1] 27 DAP	Aphid damage[2] 21 DAP	Aphid damage[2] 27 DAP	Sooty stripe
(Macia*TAM428)-HD1 (F7)	1.0	1.0	1.0	1.0	5.0
PGRC/E#222879	1.3	1.0	1.0	1.0	3.5
SDSL89426	1.3	1.5	1.0	1.0	3.0
WM#322	1.3	1.0	1.3	1.0	4.3
FGYQ353	1.3	1.0	1.0	1.0	3.8
GR128-92M12/(GR105*(R5646*SC326-6))	1.3	1.0	1.3	1.0	4.5
TAM428	1.3	1.5	1.0	1.0	4.0
(CE151*BDM499)-LD17	1.3	1.5	1.0	1.0	4.0
FGYQ336	1.5	1.0	1.0	1.0	2.5
CE151	1.5	1.0	1.0	1.0	5.0
WM#177	1.5	1.0	1.3	1.0	3.5
(Macia*TAM428)-LL2	1.5	1.0	1.0	1.0	5.0
PGRC/E#222878	2.0	1.5	2.0	1.5	2.0
PGRC/E#69414	2.0	1.5	1.5	1.5	2.5
Ent. 62/SADC	2.0	1.0	1.3	1.0	2.0
Sima (IS23250)	2.0	2.0	1.3	1.5	3.0
60B124/(GR134-/(GR104*((Tx432*CS3541)*SC326-6)))	2.0	2.5	1.0	1.0	5.0
GR127-90M39/(GR105*((Tx432*CS3541)*SC326-6))	3.0	5.5	2.3	5.5	3.8
(Macia*TAM428)-LL7	3.0	2.6	3.0	2.1	3.0
(CE151*BDM499)-LD17 (F8)	3.3	2.0	3.0	1.5	2.8
(Macia*TAM428)-LL9 (F6)	3.5	3.5	3.0	2.5	2.5
Macia	3.5	6.0	3.0	6.0	1.8
GR127-90M41/(GR105*((Tx432*CS3541)*SC326-6))	3.5	5.5	2.8	5.5	4.3
87EO355/(TAM438*(Tx432*CS3541))	3.5	5.5	3.0	5.5	4.0
MR114-90M11	4.0	6.0	4.3	6.0	5.0
(Macia*Dorado)-HD4 (F7)	4.3	5.5	4.0	5.0	2.5
(87EO266*TAM428)-HF4 (F4)	4.5	5.5	4.0	4.5	5.0
(TAM428*SV1)-HD10 (F87)	4.8	6.0	3.8	6.0	4.0
(87EO366*TAM428)-HF2 (F4)	4.8	5.5	3.8	4.5	5.0
5BRON131/(80C2241*GR108-90M30)	4.8	6.0	4.8	6.0	4.0
6BRON167/((87BH8606-4*GR127-90M46)-HG21)	4.8	5.0	4.5	3.0	4.5
(87EO366*WSV387)-HD25	5.0	5.5	4.0	5.0	4.3
7ML67/(PM12713*Tx2880)	5.0	6.0	4.5	6.0	5.0
5BRON135/(Tx2862*6EO361)	5.0	6.0	5.0	6.0	4.0
(86EO351*Macia)-HL25 (F4)	5.0	6.0	5.0	6.0	3.8
86EO361/(R5646*SC326-6)	5.0	6.0	5.0	6.0	3.0
4ML69/(PM12713*Tx2766)	5.0	6.0	4.8	6.0	3.0
4ML68/((SC228-14*Tx2767)*Tx2876)	5.3	6.0	5.0	6.0	4.5
6BRON168/(88C445*Tx2862)	5.3	5.5	5.0	4.5	4.0
5BRON155/((87BH8505-4*GR127-90M46)-HG30)	5.5	6.0	5.3	6.0	3.0
6OB122/GR132A	5.5	6.0	5.3	6.0	5.0
7ML42/(PM11344*Tx2767)	5.5	6.0	5.3	6.0	5.0
5BRON151/(7EO366*GR107B-90M16)	5.5	6.0	5.3	6.0	5.0
82BDM499/(SC173*SC414)	5.5	6.0	4.5	6.0	3.0
Segaolane	5.5	6.0	6.0	6.0	2.5
5BRON154/((87BH8606-4*GR127-90M446)-HG10)	5.8	5.5	5.5	4.0	3.0
5BRON139/(6EO361*GR107-)	5.8	6.0	5.5	6.0	2.0
6BRON161/(7EO366*Tx2783)	5.8	6.0	5.5	6.0	4.5
6BRON156/(88C445*Tx2862)	5.8	6.0	5.5	6.0	4.5
MR126/(MR37/(Tx2746*SC423)*Tx430)	6.0	6.0	6.0	6.0	3.0

1 Rated on a scale of 1 = no aphid population buildup, up to 6 = plants 100% covered by aphids.
2 Rated on a scale of 1 = no plant damage, up to 6 = all plants dead.
3 DAP = Days after planting.

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, Texas for initial selection. 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.

Networking Activities

Workshops

Participated in the Workshop on Hybrid Seed Production in West Africa, 28 Sep. - 2 Oct. 1998, Niamey, Niger. Participated in discussion regarding development of a hybrid seed industry in West Africa and observed field production of the parental lines and hybrid.

Participated in the 1999 Sorghum Industry Conference held in conjunction with the Biennial Grain Sorghum Research and Utilization Conference co-sponsored by the Sorghum Improvement Conference of North America (SICNA), 21-24 February 1999, Tucson, AZ.

Research Investigator Exchanges

Niger - 28 Sep. - 2 Oct. 1998. Participated in the West Africa Regional Hybrid Sorghum and Pearl Millet Seed Workshop. Participated in discussion regarding development of a hybrid seed industry in West Africa and observed field production of the parental lines and hybrid.

Mali - 2-9 Oct. 1998. Participated in the External Evaluation Panel Review of collaborative activities between IER and INTSORMIL. Evaluated field research at Sotuba and Cinzana, and on-farm trials conducted by World Vision in the Bla region. Met with representatives of the ICRISAT West Africa Program to discuss current and future collaboration.

South Africa/Botswana - 5-11 April 1999. Met with collaborators at the ARC - Grain Crops Institute (Potchefstroom) to discuss initiation of research on sugarcane aphid resistance. Evaluated research for ergot, sugarcane aphid resistance, and other entomological problems. In Botswana, discussed research on sugarcane aphid resistance. Evaluated research conducted by the DAR sorghum program and production of the sorghum hybrid BSH-1 and parental lines.

Honduras/Nicaragua - 3-8 May 1999. In Honduras, participated in discussions with representatives of the Escuela Agricola Panamericana (EAP), Zamorano, concerning future direction of the collaborative sorghum research program. Met with representatives of DICTA to discuss Government of Honduras participation in the research program. Met with USAID representatives to discuss INTSORMIL participation in Hurricane Mitch relief. In Nicaragua, met with representatives of INTA to discuss continued collaboration. Met with USAID to discuss INTSORMIL activity in Nicaragua. Met with representatives of the Universidad Nacional Agraria (Managua) and the Universidad Nacional Autónomia de Nicaragua (León) to discuss potential collaboration with INTSORMIL. Met with representatives of PROMESA to learn of their activity and discuss how INTSORMIL can contribute to their project.

Mr. Travis Taylor, Texas Grain Sorghum Board Executive Director, several occasions

Germplasm and Research Information Exchange

Germplasm Conservation 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, Australia., South Africa, Botswana, Zimbabwe, and Zambia. Entries in the All Disease and Insect Nursery (ADIN) were evaluated at many locations domestically and internationally.

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.

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, Department of Plant Pathology and Microbiology, Texas A&M University, College Station, TX 77843 (TAM-224).

Dr. L. W. Rooney, Cereal Chemistry, Department of Soil and Crop Sciences, Texas A&M University, College Station, TX 77843 (TAM-226).

Dr. G.N. Odvody, Plant Pathology, Texas A&M Research and Extension Center, Route 2 Box 589, Corpus Christi, TX 78406-9704 (TAM-228).

Dr. R. D. Waniska, Cereal Chemistry, Department of Soil and Crop Sciences, Texas A&M University, College Station, TX 77843.

Dr. W.L. Rooney, Sorghum Breeding, Department 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. J.A. Dahlberg, Sorghum Breeding and Germplasm, USDA-ARS, Tropical Agriculture Research Station, 2200 Avr. Pedro Albizu-Campos, Suite 201, Mayaguez, PR 00680-5470 (Now Research Director, National Grain Sorghum Producers).

Dr. R.G. Henzell, Sorghum Breeding, Hermitage Research Station, via Warwick, QLD 4370, Australia.

Dr. A.H. Paterson, Molecular biology, Department of Soil and Crop Sciences, Texas A&M University, College Station, TX 77843 (Now at the Univ. of Georgia).

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Breeding Pearl Millet and Sorghum for Stability of Performance Using Tropical Germplasm

Project UNL-218
David J. Andrews
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Mr. S.A. Ipinge, Millet Breeder, Ministry of Agriculture, Water and Rural Development, P.O. Box 144, Oshakati, Namibia
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Drs. T. Hash and K.N. Rai, Millet Breeders, and Dr. Paula Bramel-Cox, Genetic Resources, ICRISAT, Patancheru P.O. AP 502 325, India
Dr. Anand Kumar, Millet Breeder, ICRISAT, Sahelien Center, BP 12.404, Niamey, Niger.
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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 produce 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 as a forage crop in intensive agriculture. However, pearl millet has a more nutritious grain than sorghum, and so 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 5 tons of grain/ha in 3 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 in sorghum and to produce the adapted plant type needed to grow pearl millet as a combine feed grain crop; to identify sources of useful traits and develop methods to consistently select for them; and to provide students thesis topics from the on-going re-

search 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 was begun 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 is also done 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 was sent to Niger.

In the U.S., both applied and basic research is conducted on both crops. Good progress was made in developing pearl millet hybrid parents which show high levels of heterosis, lodging resistance and early maturity. Basic research on the new A_4 cytoplasmic male sterility system (CMS), and recently, in collaboration with ICRISAT, the A_5 system was continued. These appear to offer significant advantages in breeding and producing hybrids both in the U.S. and tropical areas. Studies with the same (isonuclear) pearl millet hybrids with A_1, A_4 or normal cytoplasm, showed evidence 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. I 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_{egp} and A_{av} 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. This ingrogression continues to provide new genetic diversity for early and full season grain hybrids in the U.S. including white grain-tan plant food quality hybrids. Work continued using developed screening methods, on using sources of genetic resistance 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 US 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.

For Sorghum

- Continue to produce and evaluate hybrid parent lines for Botswana (in collaboration with ICRISAT/SMIP/Zimbabwe).
- To produce and release parental lines for food quality hybrids for the USA.
- To develop screening methods, and study inheritance of seedling heat tolerance.

Constraints

Pearl millet and sorghum are major food crops in low resource semi-arid (LRSA) subsistence farming in Africa and Asia. LRSA production is limited by both agronomic and non agronomic (negligible capital, small and fragile markets, competing imported cereal grain prices and social factors). Principal agronomic constraints are lack of plant nutrients and 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 yields. Improving production conditions in LRSA agriculture has proved difficult mainly because of cost and risk involved to the individual farmer and because 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) to increased food production. However, 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 in developing countries. Hybrids however do attract private enterprise and all this entails in providing farmers with quality seed. In the last few years, attitudes have changed in regard to the hybrid concept in developing countries and their local production and sale to farmers is now viewed as desirable and possible.

Hybrids 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 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 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 with conventional CMS or protogyny seed parents.

Research Approach and Project Output

Research Methods

The general approach for both crops is to create diversity 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 used in collaborative breeding projects in host countries to select for adaptation there, and also in the U.S. to incorporate new genetic diversity into lines for release. 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 CMS system in sorghum but both A_1 (Tift 23A_1 cytoplasm) and increasingly 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 be used then to detect existing or introduced R_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, Zambia (see Southern Africa regional 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 can be advantageous.

Sorghum germplasm arising from Iskender Tiryaki's M.S. thesis (see last annual report) will be evaluated both for production performance and germination cool tolerance. The inheritance of seedling heat tolerance in sorghum using a simplified lab screening technique is being studied by Peter Setimela for his Ph.D. dissertation. A food quality B-line sorghum population based on genetic male sterility gene ms_7 is being produced by random mating.

Research Findings

Pearl millet

Dr. K. N. Rai, from ICRISAT continued his research at University of Nebraska -Lincoln (UNL) on the utility of A_1 and A_4 CMS systems with the support of a research grant from the Mahyco Seed Company, Jalna, India. Cold susceptibility at flowering, production performance, and inheritance of male fertility restoration were studied. When day/night temperatures were lowered to 18°C day/10°C night (12 hr each), differences due to cytoplasm were found between isonuclear hybrids made in A_1 A_4 and B (normal cytoplasm). Proportion of viable pollen (87-92%), pollen production score, 3.8 - 3.9 (5.0 best) and selfed seed set (54-63%) was reduced for hybrids produced in normal and A_4 cytoplasm, but was lower (respectively 67%, 34% and 2.7%) for the A_1 hybrid. This reduction combined with the longer protogyny period of A_1 hybrids, contributed to the low open pollinated seed set which has been experienced with A_1 hybrids at low flowering temperatures. A_4 cytoplasm does not appear to increase vulnerability to cool temperatures.

A test was conducted at Mead, Nebraska and ICRISAT, Hyderabad, India to compare performance of the A_1, A_4 and B (normal) cytoplasms in isonuclear hybrids produced by crossing three seed parents with three restorers (Table 1). Comparisons for all traits was not possible because the restorers were not completely dual restorers as intended. However, some clear results emerged. 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 better, which is explainable if cytoplasm/nuclear interactions contribute to heterosis. A further indication that this can occur derives from an A_1 or A_4 hybrid apparently being better than the same hybrid made in normal cytoplasm. This finding, that cytoplasm/nuclear interaction may contribute to hybrid yields, is of considerable importance not only for pearl millet, but for other crops where CMS hybrids are possible. Cooperative experiments are planned with ICRISAT adding A_5 CMS hybrids. An additional result was that A_4 hybrids are about one day earlier in flowering and (not shown in Table 1) have a shorter protogyny period, both of which are useful effects of A_4 cytoplasm. In another experiment, examination of R_4 male fertile/male sterile segregation ratios in sterile cytoplasm, showed that male fertility restoration in the A_4 CMS system in the single cross and backcross studied was due to a single dominant nuclear gene.

Mr. S. A. Ipinge, from Namibia, while studying hybrid breeding methods in the UNL pearl millet program, measured the direct effects (Xenia) of pollen genotype on seed size. Prior research had shown when a mixture of selfed (created by sibbing) and crossed seed is created on the same head, using a single dose of mixed pollen, then the crossed

Table 1. Mean grain yield, time to 50% flowering, and selfed seedset in cytoplasmically different isonuclear hybrids of pearl millet. Mead, Nebraska 1998 summer; and Patancheru, India 1998 rainy season[1].

	Grain yield (t ha^{-1})			Days to 50% flowering			Selfed seedset (%)		
Hybrid combination	A1	A4	B	A1	A4	B	A1	A4	B
Mead, 1998 summer season									
293 × 16R1R4	4.41	3.64	3.46	60.3	58.8	60.8	6	62	84
× 58001R1	3.73	3.65	3.60	61.8	58.5	61.0	92	2	94
× 68A4R4	3.07	2.75	3.07	58.5	57.0	57.3	1	46	76
413 × 16R1R4	3.08	3.62	3.89	61.3	60.0	61.0	57	86	92
× 58001R1	2.76	3.40	3.11	63.0	61.8	63.5	95	16	94
× 68A4R4	3.64	3.28	3.49	57.5	57.0	58.3	1	54	90
378 × 16R1R4	3.23	2.67	2.93	62.0	61.8	62.5	2	91	64
× 58001R1	2.82	3.72	3.08	66.5	65.3	66.0	95	15	95
× 68A4R4	3.23	2.92	2.98	64.0	63.3	63.8	10	75	85
SEd		±0.329			±0.80			±6.5	
Mean	3.33	3.30	3.29	61.6	60.4	61.6	40	50	86
SEd		±0.11			±0.27			±2.2	
Patancheru, 1998 rainy season									
293 × 16R1R4	2.96	2.74	-	42.5	42.0	—	59	88	—
× 58001R1	2.92	3.00	—	42.5	43.0	—	64	21	—
× 68A4R4	2.57	2.32	—	41.8	40.8	—	1	59	—
413 × 16R1R4	2.82	1.94	—	45.0	45.3	—	86	94	—
× 58001R1	2.68	2.57	—	45.5	44.8	—	92	1	—
× 68A4R4	2.55	2.67	—	41.5	40.3	—	26	35	—
378 × 16R1R4	2.47	2.35	—	46.3	45.8	—	59	93	—
× 58001R1	2.31	2.79	—	48.5	45.8	—	91	2	—
× 68A4R4	2.43	2.37	—	46.3	45.3	—	6	62	—
SEd	±0.149			±0.55			±7.3		
Mean	2.63	2.53	—	44.4	43.6	—	54	50	—
SEd	±0.05			±0.18			±2.4		

[1] Data compiled by Dr. K.N. Rai, ICRISAT

(hybrid) seeds could be up to 10% heavier than adjacent self pollinated seeds. The question remained whether this represented a just reallocation of growth resources between the two seed types within the head, or a net gain.

Using a dominant white grain color marker (pollen from a white seeded parent produces white seed on a gray seeded female), Mr. Ipinge studied seed weight and head harvest indices (HHI = grain weight/head weight) in crosses between two lines and two hybrids, one of each pair being grey seeded (used as female), the other white. Thus when a grey seeded line is pollinated with a mixture of its own pollen (from another tiller or sister plant) and white male pollen, the color of the resulting seed indicates whether it is self pollinated (grey) or cross pollinated (white, hybrid seed).

White (hybrid) seed was significantly heavier (13%) in the mixture on the female line, but although white seed was slightly heavier (3%) than grey in the mixture on the female hybrid, the difference was not significant (Table 2). All heads used in comparisons had full seed set. The selfed seed in the mixtures was not lighter than seed on 100% selfed heads, indicating that increase in hybrid seed weight was not at the expense of selfed seed weight.

Because average head weights could not be compared, due to the very large number of hand pollinations required to remove sampling bias, the alternative approach of comparing head harvest index (HHI) was used. Since the structure of the head is fixed prior to pollination, different increases in seed weight on a head after pollination will be reflected by a change in the ratio or percentage of grain weight to total head weight (HHI).

Differences in HHI were significant between selfed and 100% crossed heads, both in lines and hybrids. HHI of L1 × (L1 + L2) (see Table 2) was not as high as expected but not statistically lower than L1 × L1. H1 × (H1 + H2) was not significantly different from either selfed or hybrid heads, but was intermediate in value as expected.

Pollen genotype increased seed size in the female line and thus xenia affects may substantially contribute to seed yield in hybrid seed production, through increased seed size. The results suggest but do not prove a similar effect occurs between hybrids, where theoretically it would, on average be about half that between lines. As with any kind of heterosis, the magnitude of any xenia effect would be expected to vary with specific combinations. For it to have practical value, it would have to occur between hybrids with similar yields. Further experiments are planned.

Table 2. Pearl millet grain weight Xenia tests. 100 seed weights from heads of grey seeded parents when self pollinated, crossed with pollen from a white seeded male parent, or pollinated with a mixture of own (grey) and male (white) pollen.

Parents		100 seed weights (gm)			
			Crosses		
Crosses and sibs	HHI* %	Sibs (= selfs)	Mixed Pollen Grey seed	Mixed Pollen White seed	White pollen white seed
INBREDS					
L1 × L1 (sib)	60.9	0.73			
L1 × (L1 + L2)	59.3		0.74	0.84	
L1 × L2	67.4				0.87
L2 × L2 (sib)	54.4	1.18	0.06		
LSD (0.05)	3.78				
HYBRIDS					
H1 × H1 (sib)	68.1	0.74			
H1 × (H1 x H2)	71.2		0.89	0.92	
H1 × H2	71.4				0.79
H2 × H2	69.6	1.04	0.06		
LSD (0.05)	2.84				

*HHI = Head harvest index = (head grain wt/head wt) x 100
L1 = Line 413B small grey seed, used as female
L2 = Line 68Bw large white seed used as male
H1 = Hybrid 378-2A x 086R small grey seed, used as female
H2 = Hybrid 59043A_4 w x 1163R_4w large white seed, male.

Support for the breeding of locally adapted hybrids in Namibia, Zambia and Mali were 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.

We have continued to improve pearl millet parental lines, many in both A_1 and A_4 CMS systems, for combining ability and lodging resistance. New early hybrids in the 1998 test yielded up to 26% more than the check, and a late hybrid gave 69% more (Table 3). The lodging scores, taken one month after harvest on parts of plots left for that purpose, also show large improvements. Seed parents NM-1 through NM-5 and restorers NM-6R and NM-7R were released in May 1998. Release of seed parent 59043 A_1 and A_4 among others, is planned in 1999. The Crosbyton Seed Company Texas, successfully produced some 1,000 lbs of four pearl millet grain hybrids, and intends to continue production of two or three of these in 1999.

An isonuclear set of seed parents in A_1, A_4, A_5, A_{egp}, and A_{av} is nearing completion so that the parental and hybrid attributes of these cytoplasms can be directly compared. Restorers for A_5 (R_5) A_{egp} (R_{egp}) and A_{av} (R_{av}) have been discovered in advanced lines. One released male parent, NM-7R (see Table 3) is a multiple restorer on all cytoplasms except R_4, which is being backcrossed in.

In the spring of 1998 at Lincoln, field cold tolerance for early germination of 25 pearl millet entries (3 populations and their top crosses and 11 parental lines) was evaluated in a replicated test. Seedling emergence was recorded beginning at 11 days after planting at a 5 cm depth in soil temperatures of 15-16°C. Good cold tolerance was identified in populations NPM3Sid and NCD_2 and parental lines 1Rm and 4Rm (Figure 1). Lines NM-1 and NM-3 showed moderate levels of cold tolerance while NM-7R was cold susceptible. In additional field screenings, seedling cold tolerance was found in derivatives of three other populations (NPM-1, NFPM-1, and 2800A_4 R_4) and two seed parent lines (59668 A_4 and 59037-2 A_4).

Pearl millet plants often sustain early damage from a variety of causes, grazing, insects, heat, sand blasting and as happened to a regional test in the U.S., hail damage prior to boot stage. Pearl millet is known to exhibit recovery from such events, and we conducted an experiment where mowing 10 cm from 25 day old plants, simulated early damage. The results in Table 4 show that in the early planting, only one of the five millet hybrids showed yield loss, probably because it was the earliest. In the later planting there were no significant yield reductions in pearl millet due to mowing but the two later maturing hybrids gave significantly higher yields, mainly due to higher head numbers (data not shown). Pearl millet shows remarkable tolerance to early defoliation (where growing points are not damaged), and may respond by producing more heads/m^2.

Sorghum

The generation of tan plant food quality seed parents and male parents continued. Hybrid tests in 1998 identified five

Table 3. 1998 Pearl Millet A1/A4 Grain Hybrid Yield Test - Lincoln, NE. Performance of top 10 entries and check, out of 25 entries.

Hybrid	Grain yield kg ha^{-1}	Bloom days	Height cm	Lodge[1] %
57135 A_1 × 91-2085 R_1	6960	83	126	30
NM-5 A_1 × NM-6 R_1[2]	5210	73	117	34
59043 A_1 w × NM-7 R_1	5060	74	116	31
59043 A_4 w × 1163 A_4 R_4 w	4800	68	113	44
59043 A_1 w × 91-2085 R_1	4800	68	120	36
NM-5 A_4 × 57028 A_4 R_4 w	4720	81	118	30
89-0083 A_4 × 9R_4/4R_4	4650	69	118	54
NM-1 A_1 × NM-7 R_1	4610	67	114	15
59043 A_1 w × NM-7 R_1	4420	75	125	53
59043 A_4 w × 57028 A_4 R_4 w	4420	83	108	18
2068 A_1 × 89-0083 R_1[3]	4120	66	128	89
Mean (25 entries)	4300	73	115	43
LSD 0.05	955	4.4	8.6	38

[1] Measured on plot borders 1 month after harvest
[2] NM-1 through NM-7 released May, 1998.
[3] Check entry
w = white seeded

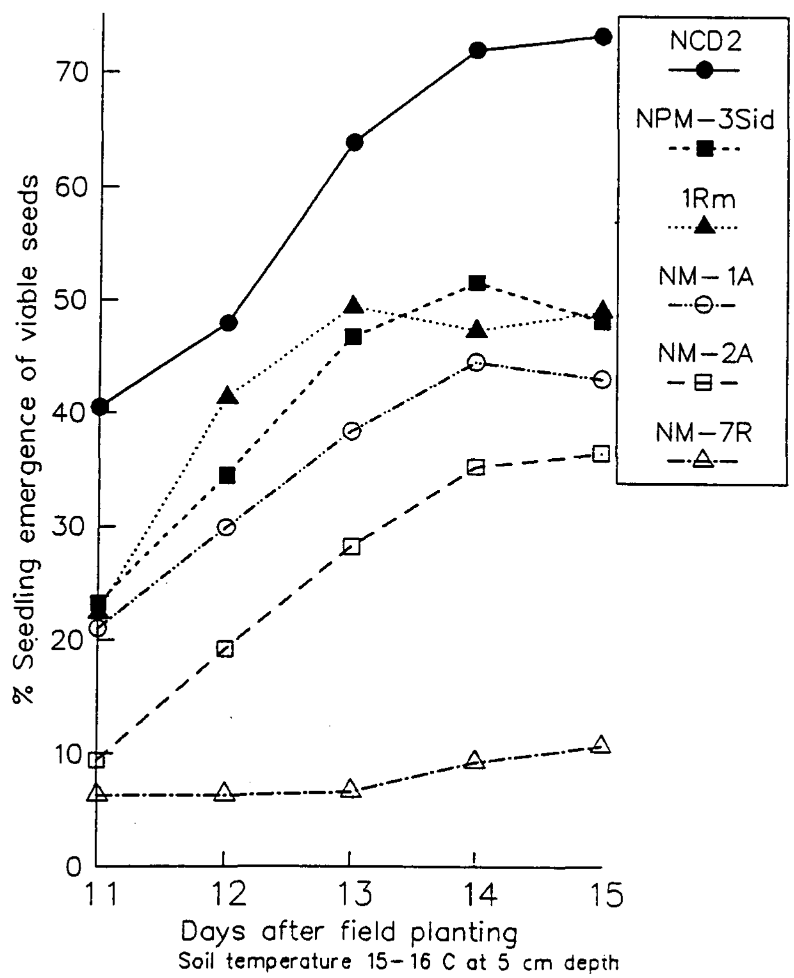

Figure 1. Pearl millet seedling field emergence of cold tolerant and susceptible varieties in 1998.

Table 4. Mean days to bloom and grain yield of pearl millet and sorghum hybrids with no mowing and mowing at 25 days after planting on 6-18-98 and after planting on 7-2-98 at Mead, Nebraska.

	June 18 planting				July 2 planting			
	Bloom days		Grain yield kg ha^{-1}		Bloom days		Grain yield kg ha^{-1}	
	No mowing	Mowing	No mowing	Mowing	No mowing	Mowing	No mowing	Mowing
79-2068A × 89-0083R	55.0	55.6	3770	3850	63.6	64.0	2930	3310
HGM-100	70.6	73.6	2260	3020	79.0	76.3	1830	2820
54025A$_4$ × 6RM	70.6	71.6	2770	2870	80.3	80.0	1440	1940
58074A$_4$ × 6RM	53.3	55.3	3550	2890	65.6	66.3	2400	2270
NM-5A × NM-6R	59.6	61.0	3650	3430	69.0	70.0	3310	3090
DK 18 sorghum	54.3	55.3	6470	6280	67.3	68.7	4620	3820
Mowing LSD (0.05)	1.1		460		0.8		440	
Hybrid LSD (0.05)	0.8		270		0.7		230	

Table 5. Sorghum collaborative hybrid test 98-13 Mead. Three seed parents (DJA) x 11 restorers (JFP) plus checks. Yield, days to bloom and height of seven best hybrids, checks and average effects of the three test seed parents.

Hybrid	Yield (kg /ha^{-1})	Bloom (days)	Height (cm)
N298A × 5R*	9630	78	167
N298A × 8R*	9500	78	165
N298A × 7R*	9430	79	155
N272A × 5R*	9310	80	165
N298A × 6R*	8990	77	160
N272A × 7R*	8850	80	152
N285A × 5R*	8800	80	145
Pioneer 8500 (ck)	8000	77	130
N122A × Tx430 (ck)	7510	79	137
Mean (33 entries)	7840	80	138
LSD (0.05)	1110	2.7	13
Seed parents (Hybrid averages)			
N298A	8180	78	151
N285A	7790	80	143
N272A	7740	81	134
LSD (0.05)	325	0.8	3.8

* Food quality hybrid
ck = check

or six potential seed parent releases and two or three new tan plant male parents. Hybrid tests now planted in 1999 will provide definitive data. A collaborative test with Dr. Jeff Pedersen, USDA-UNL tested a set of 11 tan plant male parents (JFP) on 3 tan plant seed parents (DJA) (Table 5). One seed parent N298A, gave on average, significantly better hybrids than others. There were also significant differences for general combining ability among male parents. Line 5R (a TX430 × E35-1/E35-1 derivative) gave the best hybrid with each seed parent. The top hybrid, N298A × 5R, a tan plant food quality type, gave 18% more grain yield than the best commercial hybrid.

Results from Peter Setimela's continuing research on sorghum seedling heat tolerance (using extent of recovery growth after a heat shock of 50°C for 10 min.), indicates tolerance is mostly recessive. For tolerant hybrids therefore both plants should carry heat tolerance. However test crosses showed that the contribution of heterosis to hybrid seedling heat tolerance can vary between hybrid combinations.

Networking Activities

Workshops

Program speaker, INTSORMIL/ICRISAT/INRAN West African Sorghum and Pearl Millet Hybrid Seed Production Workshop, Niamey, Niger, Sept. 23 - October 1, 1998.

Contributor, ASA Annual Meeting, Baltimore, Maryland, 18-24 October, 1998.

Research Investigator Exchanges

Dr. K.N. Rai, Senior Millet Breeder, ICRISAT, Patancheru. Visiting scientist at UNL Nebraska, January-December, 1998, primarily working on pearl millet CMS systems.

Mr. S.A. Ipinge, Senior Millet Breeder, MAWRD, Okashana, Namibia. Visiting research scholar, May - October, 1998, hybrid breeding techniques and xenia effects.

Germplasm and Information Exchange

Supplied three seed parents and two male parents to Niger for production of sorghum hybrids selected in INRAN tests.

Supplied eight U.S. seed companies requested sorghum releases.

Supplied seed of base crosses to Mali which will allow an existing Mali pearl millet top cross protogyny hybrid to be produced by the A_4 CMS system.

Supplied seed of initial crosses needed to convert Namibia MKC pearl millet variety to an R_4 restorer male parent, and two MKC test hybrids.

Provided Namibian pearl millet breeding program with belt head thresher.

Provided information to Zambian pearl millet breeding program on R_4 hybrid breeding.

Received 49 pearl millet lines from ICRISAT India, 7 from ICRISAT Niger and 22 from ICRISAT/SMIP program, Zimbabwe.

Publications and Presentations

Presentations

Andrews, D.J., J.F. Rajewski and K. N. Rai. New Cytoplasmic Male Sterility Systems for Hybrids in Pearl Millet, West African Sorghum and Pearl Millet Hybrid Seed Production Workshop, Niamey, Niger, Sept. 23 - Oct. 1, 1998.

Andrews, D.J., J.F. Rajewski, K.N. Rai and Fabien Juetong. 1998. Advantages of A4 male-sterile cytoplasm in breeding grain hybrids of pearl millet. Paper presented at ASA meeting, 18-24 October, 1998, Baltimore.

Rai, K.N., D.J. Andrews, J.F. Rajewski. 1998. Potential of A5 male-sterile cytoplasm for breeding forage and grain hybrids of pearl millet. Poster presented at ASA Meeting, 18-24 October, 1998, Baltimore.

Andrews, D.J. and J.F. Rajewski. 1998. Breeding grain pearl millet for the U.S. Agron. Abstr. p. 44.

Rajewski, J.F., D.J. Andrews, G.W. Burton, G.J. Cuomo, D.L. Klinkebiel, and W.D. Stegmeier. 1998. Photoperiod sensitive pearl millet forage hybrids utilizing dwarf grain type seed parents. Agron. Abstr. p. 81.

Rajewski, J.F. and D.J. Andrews. 1998. Pearl millet grain hybrid response to early and mid season defoliation. Agron. Abstr. p. 82.

Proceedings

Govila, O.P., K.N. Rai, K.R. Chopra, D.J. Andrews, and W.M. Stegmeier. 1998. Breeding pearl millet hybrids for developing countries - Indian experience. *In:* Rosenow, D.L. et al. Proc. Int'l Conference on Genetic Improvement of Sorghum and Pearl Millet. Lubbock, TX, September 23-27, 1996. pp. 97-118.

Johnson, J.W., W.D. Stegmeier, D.J. Andrews, D.T. Rosenow, R.G. Hanzell and R.L. Monk. 1998. Genetic resistance to lodging. *In*: Rosenow, D.L. et al. Proc. Int'l Conference on Genetic Improvement of Sorghum and Pearl Millet. Lubbock, TX, September 23-27, 1996. pp. 481-489.

Rai, K.N., K. Anand Kumar, D.J. Andrews, S.C. Gupta, and B. Ouendeba. 1998. Breeding pearl millet for grain yield and stability. *In* Rosenow, D.L. et al. Proc. Int'l Conference on Genetic Improvement of Sorghum and Pearl Millet. Lubbock, TX, September 23-27, 1996. pp. 481-489.

Crop Utilization and Marketing

Chemical and Physical Aspects of Food and Nutritional Quality of Sorghum and Millet

Project PRF-212
Bruce R. Hamaker
Purdue University

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Summary

In the past year, studies have continued on couscous processing, development of a more rapid, high sample throughput protein digestibility screening assay, and the fundamentals of stickiness in sorghum foods and how to control it. A new study was initiated, with a Kenyan graduate student, with the goal of finding methods to increase the amount of sorghum/millet flour that can be used in composite bread. Two scientists from our group participated in the West African Regional Sorghum and Millet Hybrid Seed Workshop held in Niamey in September 1998, and we planned and moderated the utilization section held on the third day. The major achievement from this year's work was the development of a new, simpler screening assay for identification of sorghum lines with high protein digestibility. The assay is currently being used in a collaboration with J. Axtell's group to screen progeny from crosses between normal and highly digestible/high lysine sorghum genotypes. This work was done with the financial assistance of the Texas Grain Sorghum Board.

Sorghum protein and starch digestibilities in livestock animals have been shown to be slightly lower than for other feed cereals, and are substantially lower in cooked porridges fed to children. Previous work done in this laboratory (Kirleis' and Hamaker's groups) showed that the protein bodies of sorghum, that encapsulate about 70% of total grain protein, are difficult to digest and become even more resistant to digestion following cooking. The high protein digestibility sorghum found in this laboratory has dramatically different, irregularly-shaped protein bodies resulting in easy access of proteases to the storage protein, called kafirins. The screening assay is based on the principle that the major storage protein, α-kafirin, digests away very quickly in the highly digestible sorghum. A new assay was developed using the principle that solubilized kafirin proteins can be precipitated to form a turbid suspension. Relative turbidity can be quantified using a visual wavelength spectrophotometer. Following an hour digestion with the protease, pepsin, the undigested proteins were extracted, precipitated with trichloroacetic acid, and the amount of remaining α-kafirin was measured based on relative turbidity of the suspension. Turbidity values were inversely correlated to digestibility. This very simple approach has resulted in a screening assay that can be performed by a lab technician. High throughput of at least 100 samples per day was achieved.

Studies in Niger and at Purdue continued with the goal of optimizing sorghum and millet-based couscous processing for eventual commercial production by small-scale entrepreneurs. The project this year purchased a small commercial-scale sorghum/millet decorticator and flour mill for the Niger laboratory. This, and the building of a fairly large scale solar drier, completed the couscous processing unit at INRAN/Niger. Optimization studies, for the production of a high quality competitive product and for high product output, were begun and will be finished in the next project year. Processed couscous, made from the hybrid NAD-1, will be market tested. At Purdue we have identified a soluble component from couscous that is highly correlated to product stickiness. Stickiness is an undesirable feature in couscous and is a problem in a number of sorghum cultivars. We have further characterized the component and studied its origin.

In a new study started this year, we have investigated methods to incorporate higher quantities of sorghum flour into wheat-based composite breads. This addresses the need to find ways to utilize processed flours in Africa and at levels in composite bread that would make its incorporation economically worthwhile. Currently, acceptable composite flour breads can be made only at about 15% sorghum substitution. In a model study, we have shown that addition of preconditioned corn storage protein, zein, which is analagous to sorghum kafirin, to 20% sorghum/wheat composite flour notably increases dough elasticity and bread loaf volume. Further studies will show whether sorghum proteins will behave similarly, and whether proteins can be made available in sorghum flour to contribute to dough viscoelasticity. Sorghum (or millet) flour could then hypothetically be added with wheat flour at higher levels than can presently be achieved.

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 Couscous

Work has continued both at Purdue and INRAN, Niger to optimize couscous processing procedures to achieve a high quality commercializable sorghum or millet couscous for the urban West African marketplace. In earlier work, A. Aboubacar, former Nigerien doctorate student and now post-doctoral research associate, installed an entrepreneurial-scale couscous processing unit (1996 report) with the central mechanized agglomerator designed and fabricated at CIRAD, France by J. Faure (Figure 1). As reported last year, the couscous unit and products produced were exhibited and demonstrated at a regional agricultural research exposition in Ouagadougou, Burkina Faso by M. Oumarou and M. Moussa of INRAN. As flour quality is critical to obtaining high quality couscous, and many other processed cereal products, a decorticator and hammer mill were purchased in this project year for INRAN/Niger and IAR/Ethiopia.

Much of this year's couscous activities at INRAN/Niger were focused on optimization of couscous yield and quality. The largest constraint in couscous production using the entrepreneurial-scale unit was unacceptably low yield of couscous using the mechanized agglomerator. Studies were conducted to better control and optimize water content of the wetted flour, application technique, and agglomerator speed and angle. Couscous yield, as measured by the amount of couscous obtained in one pass through the agglomerator, increased from about 70% to about 95%. Both sorghum and millet couscous quality was improved by controlled decortication (removal of bran layer), by repeated washing of the decorticated grain, and by decreasing solar drying exposure. Very good consistent quality couscous was obtained. At the hybrid workshop held in Niamey in September 1998, the participants were invited to the Cereal Quality Laboratory at INRAN and couscous prepared using the mechanized unit was served. Questionnaires were given and responses were quite positive regarding the couscous quality.

Investigation into the Sorghum Couscous Component Responsible for Stickiness

Stickiness, probably the most 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. Producing a commercial couscous with good cooked texture is critical in establishing a product market. Of eight sorghum varieties, six of which are used in Niger, a wide difference in couscous stickiness was mea-

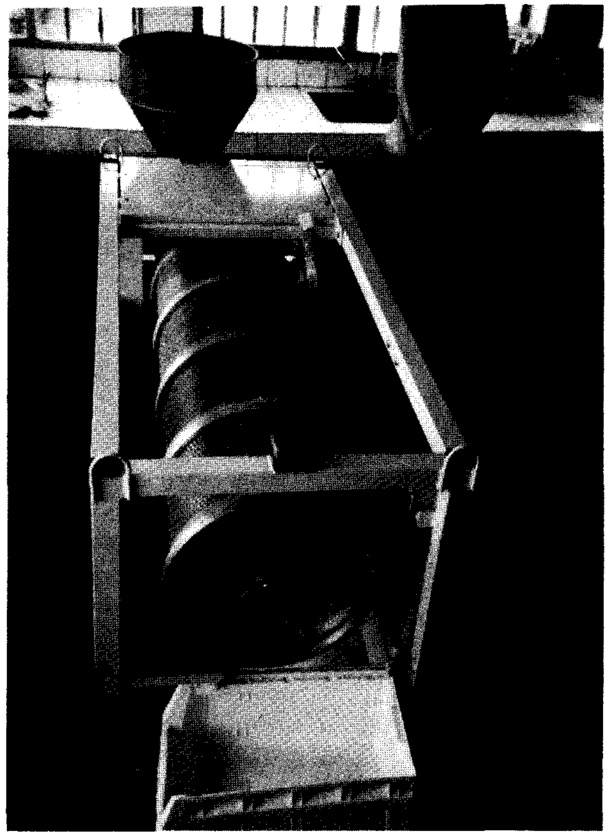

Figure 1. Picture of the couscous agglomerator that is the central part of the entrepreneurial-scale couscous unit set up at INRAN/Niger. The agglomerator was designed and fabricated by CIRAD/France and purchased through the INTSORMIL Niger project.

sured. As part of a longer range effort to control stickiness and select varieties with low degree of stickiness, a study was conducted at Purdue to identify the causative agent for couscous stickiness and to determine its origin.

It was found that the stickiness of couscous was positively correlated to the amount of a very low molecular weight water-soluble branched starch fraction in the rehydrated couscous ® = 0.86, $P<0.01$) and to the amount of starch damage in the flour ® = 0.89, $P< 0.01$). Such a low molecular weight starch component has not been reported before in the literature for any cereal products. Its odd makeup suggests that it is not a native component of the grain, but instead is likely produced during grain processing. Its high correlation to starch damage, that occurs during grain milling, at least suggests that different cultivars are more or less susceptible to fragmentation of starch during milling. Accordingly, pending other studies on the origin of this component, breeding lines could be chosen for optimum couscous processing quality (and possibly other processed food qualities) based on susceptibility to starch damage or some other criteria.

The branched starch component had a low molecular weight corresponding to the low end of the amylose range. Its debranching profile (debranching into linear glucan chains) showed a three-fraction pattern characteristic of debranched amylopectin. Rehydrated couscous soluble components extracted at 30°C for 30 min were separated through a low-pressure size exclusion system using a Pharmacia S-300HR (2,000 – 100,000 Da MW range) column. Any amylopectin or amylose present eluted at the void volume, and the low molecular weight branched fraction eluted as a series of unresolved peaks. When the flour used to make the couscous was similarly extracted and separated, a profile similar to couscous was obtained. This flour fraction debranched with isoamylase followed by size-exclusion chromatography, using Biogel P-10, shows an elution profile similar to the one of couscous. Therefore, it was conclusively shown that the starch component found within couscous that highly correlated to stickiness was also present in the flour. These results suggest that the milling process may generate the identified component.

The low molecular weight branched starch fraction from flour was also debranched with β-amylase (digests only external starch chains down to the branching points) and separated by size-exclusion chromatography. The limit dextrin fraction (representing 55% of total carbohydrate) created a broad chromatographic peak that tailed until the maltose elution peak (representing 33% total carbohydrate). From these data, we concluded that the low molecular weight branched starch fraction correlated to couscous stickiness originates in the flour. The finding that the fraction appears to be composed of a range of varying size amylopectin molecules supports a view that starch damage may be responsible for the presence of the branched starch compound. Ball-milling experiments varying the amount of damaged starch are in progress.

As part of this project, we also developed a simplified, and less expensive, separation method for amylopectin and amylose. The system employs a typical high pressure HPLC pump and refractive index detector, but, instead of a series of four HPLC columns, uses only an intermediate pressure chromatography column (Pharmacia) with Sephacryl S500 HR packing. This repackable column contains about $75 of chromatography media making it a cheap alternative to more expensive conventional columns.

Sorghum with High Protein Digestibility

We previously reported (1994-98 INTSORMIL annual reports) on the identification of sorghum lines within J. Axtell's high lysine population that have 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.

A New Rapid Assay to Identify Highly Digestible Sorghum Cultivars

The discovery in our laboratory of highly digestible sorghum cultivars prompted the need for the development of a rapid assay to screen breeders' lines for protein digestibility. This complementary work to INTSORMIL PRF-212 was funded by the Texas Grain Sorghum Board. In last year's report, a screening assay based on disappearance due to pepsin digestion of the α-kafirin protein was introduced. The screening assay used electrophoretic gels to visualize loss of α-kafirin and results on the highly digestible sorghum mutant showed excellent ability to identify this trait. However, the relative sophistication and expense of electrophoresis as a screening technique, prompted further studies to develop a simpler, cheaper, and higher throughput assay.

Microtiter BCA Assay

We first developed a simple colorimetric assay using bicinchoninic acid (BCA) to quantify the amount of protein remaining after 1-hour pepsin digestion of sorghum flour. The lower the amount of remaining protein indicated the more digestible the cultivar. We have further refined the BCA assay on a microtiter plate which makes it possible to analyze more samples in a day. Using 87 sorghum samples, we found a correlation coefficient of $r = 0.92$ between the BCA assay and our recently developed electrophoresis assay. More importantly, two distinct populations of normal and highly digestible sorghum cultivars were obtained when the results of the BCA assay were compared to those of the electrophoresis-based assay. With this assay, highly digestible sorghum cultivars were defined at an absorbance cut-off. We estimate that about 120 samples can be assayed in a day using the BCA assay as compared to 60 samples with the electrophoresis-based assay.

Turbidity Assay

We have recently developed a turbidity-based assay that is even quicker and more efficient than the BCA assay. The procedure used in the BCA assay consists of precipitating protein with 72 % trichloroacetic acid (TCA) solution, centrifuging the precipitate, dissolving the protein pellet in a buffer and reacting with BCA reagents. The absorbance of the resulting purple-colored solution is then read at 562 nm. In the turbidity assay, protein remaining after 1-hour pepsin digestion was extracted with a buffer and an aliquot precipitated with 72 % TCA. The absorbance of the turbid solution was read at 520 nm. Addition of TCA to the protein solutions resulted in a quick turbidity development that reached a plateau at about 5 min for highly digestible cultivars and 10 min for normal cultivars. In both cases, the turbid solutions were stable for at least 1 hour. These results indicate that by using the turbidity assay, considerable amount of time could be saved, more samples analyzed and use of costly chemical reagents avoided. Even more importantly, a comparison between the BCA and turbidity assays indicated that the turbidity assay is more efficient than the BCA assay in distinguishing highly digestible from normal cultivars. As shown in Figure 2 there is at least a 3-fold increase in absorbance values from highly digestible to normal cultivars with the turbidity assay, whereas with the BCA assay, differentiating between the two cultivars is done at a very close absorbance cut-off. 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 (Figure 2). Current work is focused on converting the turbidity assay to a microtiter 96-well plate type assay. This will both minimize sample size and increase the sample throughput per day.

Improving Grain Quality of Highly Digestible/High Lysine Sorghum

As reported previously, a problem with initial lines of Axtell's high-lysine population identified with the highly digestible trait was that grains were mostly floury endosperm. In a screening of approximately 40 breeding lines, generated from crosses made between the mutant and normal hard endosperm cultivars, lines were identified with the highly digestible trait that contained what we have termed a "vitreous core" endosperm. In other words, a vitreous (hard, glassy) endosperm arises in the central part of the kernel and, in essence, forms a vitreous interior cap. Cross sections of such grain show a typical soft floury endosperm at

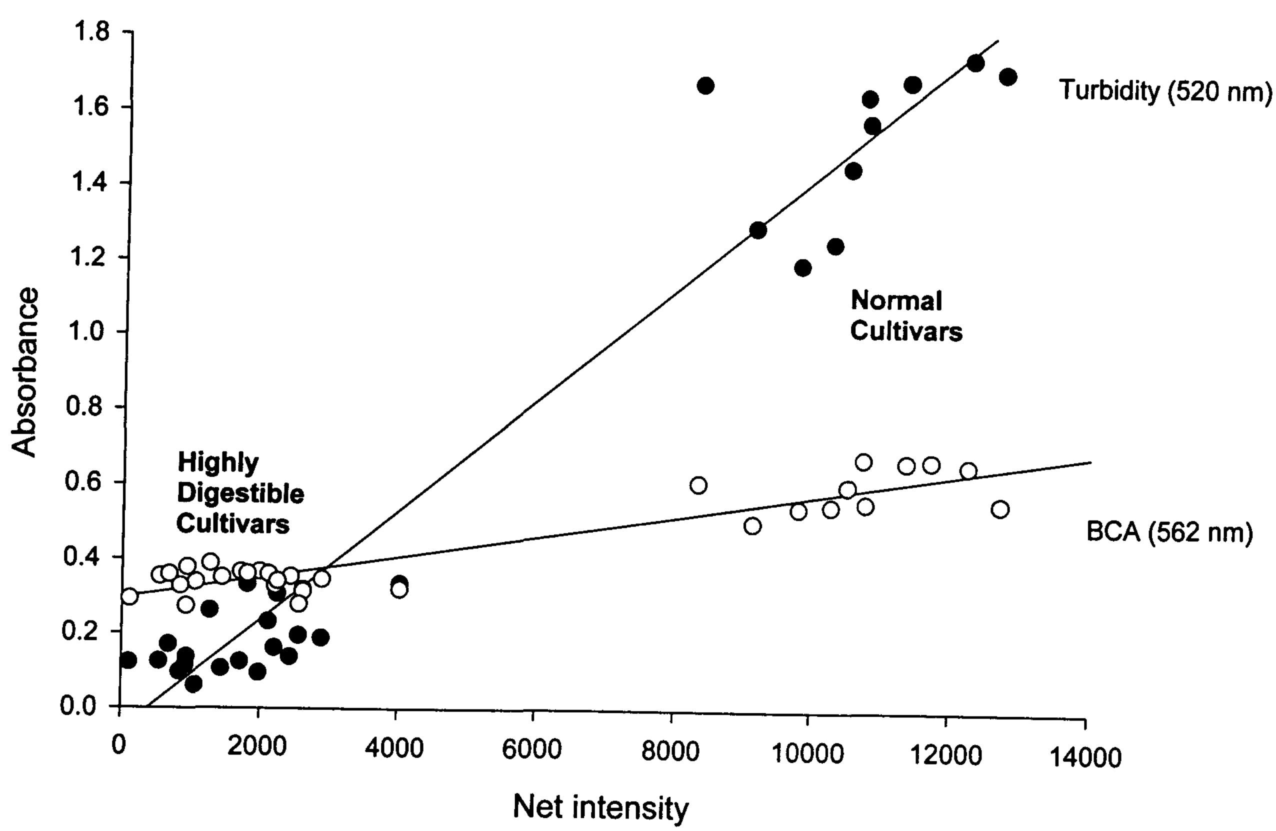

Figure 2. Comparison of BCA (colorimetric) and turbidity protein digestibility screening assays as compared to the previously developed electrophoresis-based screening assay. Improved ability to discriminate highly digestible cultivars is demonstrated by the turbidity assay.

the center of the kernel, surrounded by vitreous endosperm, that is then again surrounded by a dense floury endosperm at the periphery of the grain. Last year, we reported that this grain has milling quality not too different from normal vitreous grains, however further work needs to be done. Selections were made last fall at the Purdue Agronomy Farm for highly digestible grains containing higher fill of vitreous endosperm. In some cases, vitreous fill accounted for approximately 70% of endosperm area. Stability of this trait over different environments is still in question, and studies have been planned with Axtell's group to address it. They are also studying heritability of the trait and whether the highly digestible trait is linked with high lysine content. Details of their study are given in their section of this report.

Potential of Increasing Levels of Sorghum Flour in Wheat Bread Composites

The overall objective of this study was to increase the substitution rate of sorghum flour in sorghum-wheat composite dough system for bread making. Sorghum-wheat composite flours show drastically reduced performance in bread making systems when levels increase above 15-20% sorghum. In previous work, it was shown that maize zein protein, the storage protein analagous to sorghum kafirin, when mixed with starch and heated to 35°C formed a viscoelastic dough. This slight heating above what is termed the glass transition temperature of the protein, allows for it to be flexible and to form interactions with other proteins. Our hypothesis was that sorghum protein, if made available, may be able to participate in the viscoelastic fibril network formation of wheat gluten that is responsible for the leavening of bread. This could then permit sorghum flour content to be increased in wheat/sorghum composite breads. Sorghum kafirins, as well as maize zeins, are encapsulated in rather rigid structures called protein bodies that would make the proteins unavailable for such contact, however use of milling techniques or the highly digestible cultivars would possibly make the proteins available.

In this study, the role of analogous prolamins, corn zeins, on the viscoelastic properties of the composite flour dough was examined in order to observe the potential effect of kafirins in dough formation. Mixograph curves of decorticated sorghum/wheat composites, run at 35°C (above the glass transition temperature of zein), were notably improved with addition of zein. Mixograph peak height increased and mixing time decreased uniformly in 10 and 20% composite flours with increasing concentrations of zein. For example, at 20% sorghum flour substitution, the mixogram peak height increased from 3.76 to 4.4 and 5.92 cm while mixing time decreased from 5.24 to 3.1 and 2.56 min with addition of 5 % and 10% zein, respectively. At 10% zein addition, the dough mixograph curve approached the profile generated by 100% wheat flour.

These data suggest that if kafirin could be made available, then it would contribute to the formation viscoelastic doughs. Further studies show an increase in loaf volume with increasing amounts of added zein at fixed sorghum substitution. At 20 % sorghum substitution loaf volume increased from 715.8 without zein to 739.2 and 809.2 cc at 5% and 10% added zein respectively. Dough extensibility studies done using the instron in the compression mode indicated an increase in elongation force with increasing amounts of added zein at a fixed extension (Figure 3). The higher the force required to obtain the extension the higher the extensibility. This is the first reported evidence that non-wheat proteins can contribute to bread making properties as indicated by dough strength and loaf volume. Further work to determine the interaction of zein and gluten proteins in the composite flour system is ongoing. Future work will determine if kafirin can practically be made accessible and be used to positively affect loaf properties.

Networking Activities

Workshops

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

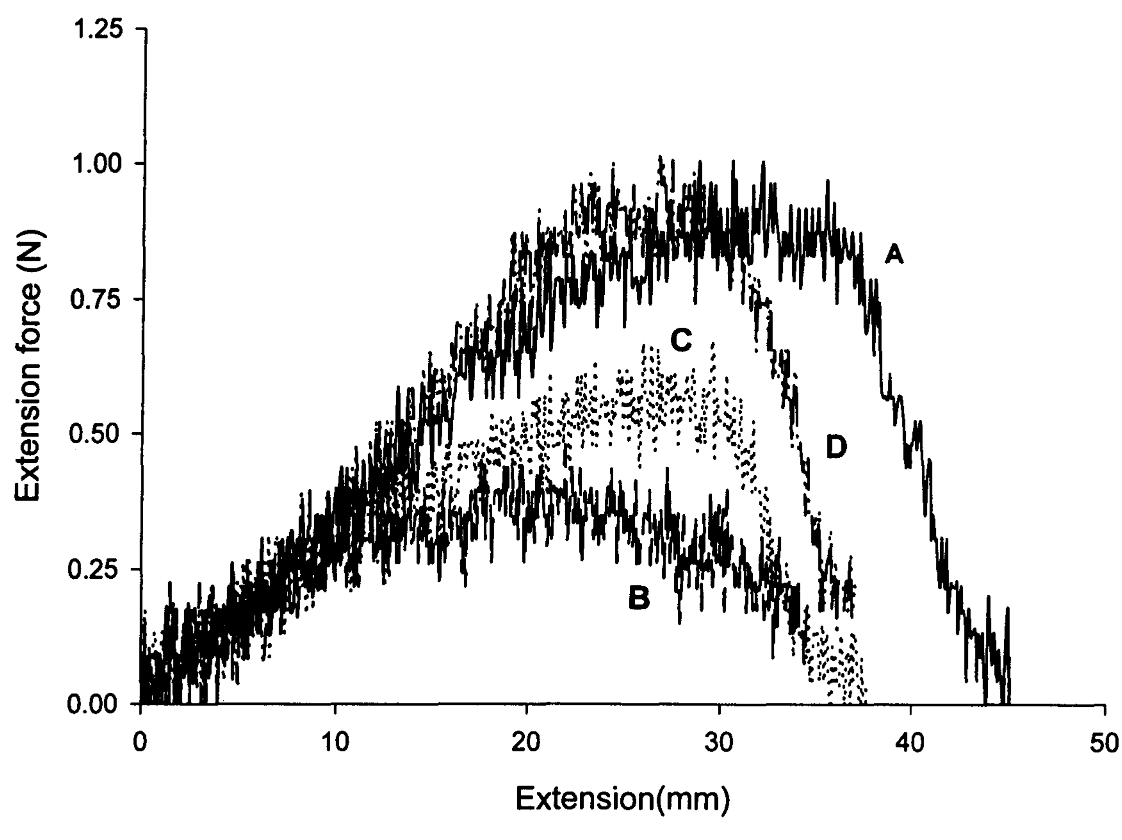

Figure 3. Extensibility plot of 20% sorghum/wheat dough with added maize zein protein at levels of 0, 5 and 10% (B-D), respectively. A is the control 100% wheat flour dough.

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 also participated in an annual planning and evaluation meeting for the P5 project "Millet Promotion Through Improvement of Processing Technologies" of the West and Central Africa Pearl Millet Research Network (ROCAFREMI), March 1999 in Dakar, Senegal. The focus of the project is on processing of locally grown millet to products for sale to urban consumers. In the same trip, INRAN couscous processing collaborators – M. Oumarou, M. Moussa, S. Kaka – were visited and plans were made for final optimization and completion of the couscous processing unit. A market testing study was designed by C. Nelson, J. Ngeunga, and B. Hamaker.

Research Investigator Exchange

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.

Purdue staff working on INTSORMIL-related projects (A. Aboubacar, C. Huang, G. Zhang) attended and presented research findings at the annual American Association of Cereal Chemists meeting in Minneapolis, MN in October 1998.

Publications and Presentations

Abstracts

Batterman-Azcona, S.J. and B.R. Hamaker. 1998. Microstructural changes occurring in protein bodies and α-zeins during corn processing. Scanning 20:182.

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Elkin, R.G., E. Arthur, B.R. Hamaker, J.D. Axtell, M.W. Douglas, and C.M. Parsons. 1998. The nutritional value of a highly digestible sorghum cultivar for broiler chickens. Poultry Sci. 77(suppl. 1):87.

Journal Articles

Aboubacar, A. and B.R. Hamaker. 1998. Physicochemical properties of flours that relate to sorghum couscous quality. Cereal Chem. 76:308-313.

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Batterman-Azcona, S.J., J. Lawton, and B.R. Hamaker. Effect of specific mechanical energy on protein bodies and α-zeins in corn flour extrudates. Cereal Chem. 76:316-320.

Rahmanifar, A. and B.R. Hamaker. 1998. Potential nutritional contribution of Quality Protein Maize in poor communities: A close-up on children's diets. Ecol. Food Nutr. (In press).

Aboubacar, A. and B.R. Hamaker. 1998. Branched soluble starch as a determinant of sorghum couscous stickiness. J. Cereal Sci. (In press).

Proceedings

Hamaker, B.R., and J.D. Axtell. 1998. Nutritional quality of sorghum and pearl millet. In Proceedings of the International Genetic Conference on Sorghum and Pearl Millet, D. Meckenstock (ed.), University of Nebraska, Lincoln.

Dissertations and Theses

Batterman-Azcona, S.J. 1998. Microstructural and chemical changes in corn protein bodies and α-zeins during processing and their effect on texture. Ph.D. diss.

Food and Nutritional Quality of Sorghum and Millet

Project TAM-226
L.W. Rooney
Texas A&M University

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Professor John R.N. Taylor, Head, Food Technology Department, University of Pretoria, Pretoria, South Africa

Summary

We have conducted extensive multi-location, multi-year trials to evaluate the abrasive milling properties and factors affecting dry milling of sorghum. 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.

White food sorghum flour can be substituted for 50% of the wheat flour in Mexican cookie formuli. The effect of particle size and sandiness of sorghum flour were reduced by using 5% pregelatinized corn starch with 95% sorghum flour in cookies. The texture was equivalent to wheat flour cookies. Pregelatinized sorghum could be used as well.

Noodles from 100% sorghum flour were similar to rice noodles but the dry matter losses during cooking were higher. A noodle making procedure that could be used to make nonwheat noodles for special gluten free diets was devised. Factors affecting noodle quality of sorghum were determined.

Heterowaxy sorghum grain has advantages for use in tortillas and baked snacks to improve the texture. Waxy grain has excellent functional properties but grain yields are low.

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

Two Ph.D., two B.S. and one short term trainee completed work on sorghum and joined the food industry in Mexico, USA and Nicaragua. Three new graduate students joined our research team.

Research in Honduras demonstrated that food sorghums produced acceptable tortillas. This work conducted by Mr. J. Bueso using the commissary tortilleria at EAP and is used as part of increased educational activities in food technology.

A workshop organized by Professor Taylor, University of Pretoria, Dr. Janet Dewar, CSIR, and Lloyd Rooney, TAMU, was hosted by the 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.

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.

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 critically affect the significance of other attempts to improve the crops. If the grain cannot be processed and consumed for food, 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 village 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. That is why it is imperative that the plant improvement programs develop cultivars with good quality for value- added processing at the local level. In addition, we must promote a system of marketing identity-preserved grains as value-added products for urban consumers.

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.

Utilization of Sorghum in Noodles

Commercial Noodles Characterization.

Commercial wheat and non-wheat starch based noodles were characterized for their texture, structure, pasting and cooking properties. Non-wheat noodles had higher initial viscosity than the wheat noodles; starch gelatinization plays an important role in their processing and texture. Non-wheat starch based noodles also had significantly lower dry matter losses than the other noodles. The sorghum flour noodles had higher dry matter losses than the other non-wheat noodles and were similar to those in wheat noodles.

Cooked non-wheat starch based noodles had a clear appearance and a chewy, rubbery texture while cooked wheat noodles were more opaque and less chewy. ESEM evaluation indicated that uncooked wheat and non-wheat noodles had distinctive external and internal structures. The interior of the wheat based noodles was composed of gelatinized but intact starch granules suspended in a thin gluten matrix. The interior structure of the non-wheat noodles was determined by the strength of the gelatinized, starchy matrix combined with the amount of shear forces exerted on the noodles during processing. The non-wheat noodles tended to be harder to fracture than the wheat noodles; melted starch may produce stronger noodles than starch/protein combinations.

Sorghum Noodle Characteristics

Three white food sorghums, ATx631*RTx436, ATxARG*RTx436, and SC283-14, were decorticated, milled into flour and processed into 100% sorghum noodles. Flour, water, and salt (1%) were preheated using two pre-heating steps (hot-plate or microwave oven) and dried by three methods: air-dry method (23°C, 48 hr); single-stage (60°C, 30% RH, 3 hr) or two-stage (60°C, 100% RH for 2 hr followed by 60°C, 30% RH for 2 hr). Sorghum flours with smaller particle sizes yielded the best noodles. The microwave preheating method produced better noodles than the hot-plate method. Stronger and firmer noodles, dry or cooked, were prepared using two-stage drying compared to the other drying methods. Fine flour that was preheated using a microwave oven and dried using the two-stage method produced the best noodles with moderate (10%) dry matter loss. Optimized processing conditions yielded sorghum noodles with good qualities when properly cooked. The cooking time had to be carefully controlled. Overcooking caused high dry matter losses and crumbly noodles. The heterowaxy sorghum flour did not produce acceptable noodles. The hard endosperm sorghum produced the best noodles in terms of texture after cooking and dry matter losses were taken into account. Particle size, color, presence or absence of black specs and type of sorghum affected noodle properties significantly. Whole grain flours did not produce acceptable noodles due to poor taste, dark color, poor texture and high dry-matter losses during cooking.

Effect of Waxy Sorghum on Food Processing

Waxy and heterowaxy sorghums have excellent properties for some food systems alone or in combination, including steam flaking, micronizing for granolas and ready-to-eat breakfast cereals, inhibition of tortilla staling and improvement in texture of baked tortilla chips and extrudates. In other foods, waxy sorghum does not work and is often a liability. We have shown that white waxy sorghum could be a good ingredient in foods. This is especially true since no white waxy corn hybrids are available. However, the waxy sorghum hybrids are characterized by relatively low grain yields and cannot be produced economically compared to nonwaxy sorghum hybrids. Some commercial heterowaxy hybrids are grown in limited quantities currently and are available for identity preserved production. Thus, sorghums with enhanced amylopectin content could be available at competitive prices.

Specialty Tortilla Chips

A black sorghum grain cooked at alkaline pH produced tortilla chips with a very intense, blue (black) color that was better than the best blue corns produce. The grain has the highest level of polyphenols we have found in sorghums. It could be used in a niche market for production of reduced cost high-quality "blue" tortilla chips and related products. A brown sorghum produced dark tortilla chips and tortillas. The color of tortillas and chips is affected significantly by pH. Several bright red sorghums are being evaluated for potential production of a bright red, natural tortilla chips. These sorghums have exceptionally high levels of total phenols, especially anthocyanins, that are equal to the level of phenols in blueberries and grapes.

Sorghum Flour in Cookies

Numerous inquiries concerning use of sorghum flour in baking have been received from Mexican food processors. Therefore, we initiated research on production of cookies and related products from 100% sorghum flour and blends with wheat flour or corn starch. The effect of substituting sorghum flour (SF) with native starch (sorghum and corn), utilizing flours with different levels of damaged starch (high, medium and low), and fractionating the flour into fine and coarse particles on cookie quality was evaluated. Addition of vital wheat gluten (WG) and pregelatinized corn starch (PCS) was also evaluated for cookie quality and texture. A Mexican cookie formulation was used to reduce variation in spread and height of cookies.

The effects of damaged starch, particle size and the addition of native starch affected cookie quality. Cookies made with 100% fine sorghum flour particles were fragile and crumbly. SF alone can be substituted for up to 50% of the wheat flour (WF) and still produce acceptable cookies. SF ground through the Udy mill (higher damaged starch) produced cookies with better subjective and objective texture. Doughs were easier to handle and cookies were not as fragile or crumbly as those produced with flour milled in the Quadrumat Senior mill (Table 1). The force required to bend cookies at 0.25 mm was higher for Udy milled flours (those with damaged starch) but not as high as WF alone or SF + PCS (Figure 1).

Substitution of 15 or 30% isolated (undamaged) sorghum or maize starches for sorghum flour resulted in gritty cookies with a fragile (crumbly) texture. Microscopy analysis showed that there was no continuous phase of melted starch holding the crumb of the 100% SF cookie together, so it simply fell apart when touched. SF containing higher amounts of damaged starch significantly improved the quality of the cookies over sorghum alone, and had a greater effect on quality than flour particle size or the addition of native starch (Table 1). The addition of 5% pregelatinized corn starch (PCS) or 10% wheat gluten (WG) improved the cookies even more and made them resistant to breakage during handling. PCS in the flour produced a harder cookie than the WG or the WF formulations (Figure 1). Microscopy analysis of the cookies with PCS indicated that the gelatinized starch formed a continuous film that held the crumb together more effectively, functioning much like gluten does in the system. The cookies with PCS also did not have the charac-

Table 1. Physical properties of Mexican style cookies made with 100% sorghum flours, at different levels of particle size, with and without wheat gluten and purchase compared to 100% wheat flour cookie.

Sample	Flour properties		Moisture	L	Color[c]		Young's Modulus[d]	Diameter[e]
	D.S.[a] (%)	PSI[b]	%		a	b	(Kpa)	(cm)
Wheat flour control	7.2	1.3	6.5	79.8	0.6	22.1	14.0	6.8
Sr. Mill SF[f] : low damaged starch	7.2	1.18	5.7	81.7	-0.9	23.6	3.8	7.0
50% fines[g]	-	1.26	4.9	81.7	-0.8	23.6	4.2	7.0
100% fines[g]	-	1.34	4.7	82.6	-0.3	23.1	4.4	6.9
1x Udy milled SF[h]: medium damaged starch	11.4	1.18	4.4	78.7	1.0	23.3	11.6	6.9
50% fines[g]	-	1.25	4.0	78.8	1.1	23.3	10.2	6.8
100% fines[g]	-	1.33	3.9	79.9	0.9	22.5	7.9	6.8
2x Udy milled SF[h]: high damaged starch	16.0	1.2	3.9	77.6	0.8	20.0	9.7	6.9
50% fines[g]	-	1.26	3.5	78.0	0.9	20.8	12.3	6.9
100% fines[g]	-	1.32	3.6	77.9	0.7	21.2	7.4	6.8
95% SF + 5% VWG[i]	15.2	-	4.76	77.51	1.34	23.65	14.8	6.9
95% SF + 5% PCS[i]	20.0	-	5.14	76.77	1.12	23.12	25.9	6.9
LSD	0.8[j]	0.03[j]	1.6[j]	0.7[j]	0.3[j]	0.9[j]	4.5[j]	

1 Damaged starch as percent in flour. AACC method 70-30A.
2 PSI (particle size index) = S a_ib_i/total weight of flour; where a_i = overs on each sieve, and b_i = sieve #/100; sieves used were US standard testing sieve #40, #70, #80, #100, and #120. Pan assigned 1.4 for PSI calculation.
3 Cookie color. Colorimeter (CR-310 Minolta Co., LTD. Ramsey, NJ).
4 Young's modulus = $(4Fa^3)/3dpD^4$, where F is peak force (N), a is the length of the beam (4.5 cm), d is the bending distance, and D is the diameter of the cookie.
5 Cookie diameter. Values are means of 6 observations.
6 Sorghum flour from Sr. mill operation.
7 50% fines= regular flour substituted with 50% particles passing the #100 sieve, 100% fines= 100% particles passing #100 sieve.
8 Sorghum flour from 1 and 2 step Udy mill operation.
9 Additives: VWG= vital wheat gluten, PCS= pregelatinized corn starch.
10 Significant values 0.05 alpha level.

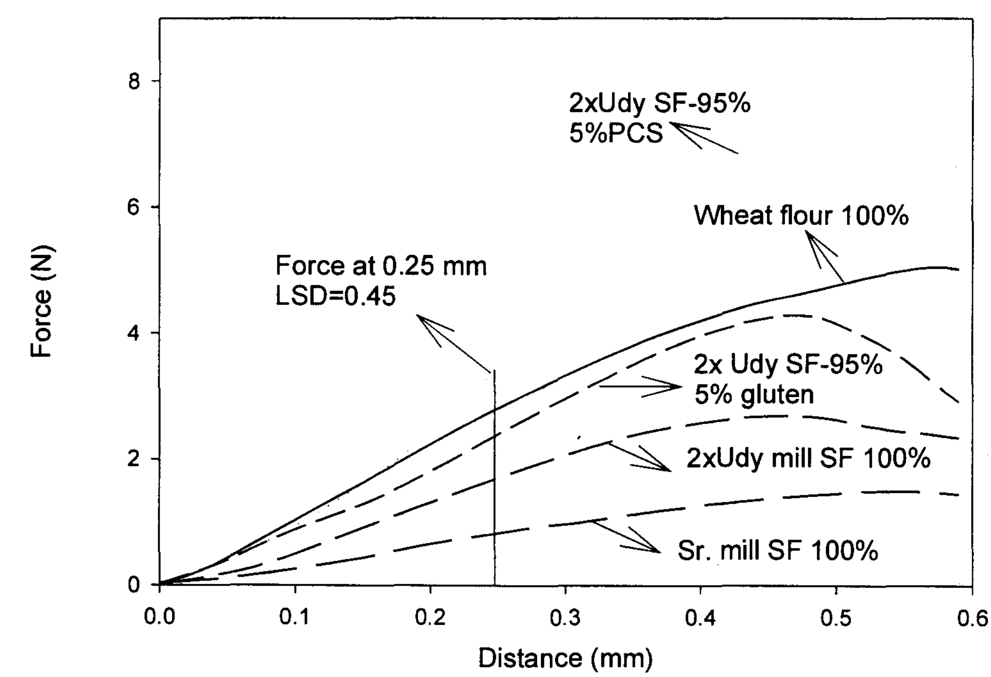

Figure 1. Bending force for Mexican style cookies containing sorghum flours, gluten and PCS compared to 100% wheat flour.

teristic dry, fragile, gritty texture of sorghum cookies. The PCS coats the large particles of sorghum flour, making them less noticeable in the mouth.

A descriptive panel (trained) and a consumer panel (untrained) were used to evaluate cookie texture and acceptance. Blends used for cookies evaluated by the trained panel were: control (100% WF); 100% SF (2xUdy); 50% WF-50% SF and 5% PCS-95% SF. The 100% SF cookie had the highest fracturability. Addition of 5% pregelatinized corn starch significantly reduced grittiness and improved adhesiveness and cohesiveness. 50% WF-50% SF produced acceptable cookies that were judged very similar to the 5% PCS-95% sorghum flour cookies.

For the consumer panel, a chocolate chip formulation using 100% WF or 95%SF-5% PCS cookies was baked. The chocolate chip cookie made with 95% SF-5% PCS was preferred over the control by 35% of the panelists. A discriminative test using Brysselkex cookies showed that some consumers preferred 5% PCS-95% SF and 50% WF-50% SF cookies over wheat control because they were softer. Panelists were able to detect differences between cookies made with 100% WF and the cookies containing SF.

Our data clearly indicate that sorghum flour can be used effectively in a wide variety of cookies substituting for up to 50% of the wheat flour. With special formulations higher levels of sorghum can be utilized. Increasing the damaged starch in SF significantly improves cookie texture; it increases dough viscosity and decreases moisture loss during baking. The bland flavor and light color are advantages of sorghum over maize for use in composite flours. It is likely that pregelatinized sorghum flour could be used instead of PCS. The three point bending test effectively evaluates the cookie crust; it does not measure the inside texture of the cookie. Thus a combination of subjective and objective measurements are required.

Sorghum Bran in Bread

Yeast leavened bread containing 10% high tannin sorghum bran has an excellent color and flavor, and contains high levels of phenols and dietary fiber. The catechin equivalents are complexed in the bread and cannot be analyzed; their ability to serve as antioxidants are being tested. Special high tannin, black, red and brown sorghums can be processed to produce yields of 10 to 25% bran fractions with total phenols and catechin equivalents equal to or higher than those contained in similar servings of grapes and blueberries. This research continues; it offers continued potential for phytochemically fortified nutraceuticals from sorghum.

Economics and availability of good quality sorghum flour are critical factors limiting use of sorghum. High prices for wheat stimulate interest in sorghum that is sometimes short lived when wheat prices drop. However, over the long term, good quality sorghum will be used in composite flour products because it has a bland flavor which does not mask other flavors like the strong flavor of maize does, and it provides an economical choice for use in functional foods as a chemoactive agent.

Sorghum Starch, Malting and Brewing Studies

Dr. Serna-Saldivar, ITESM, Monterrey, Mexico, is continuing to investigate brewing and starch properties of sorghum with our collaboration. He has two students initiating research in that 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.

Commercial Food Products Available in USA

Sorghum flour and grits are sold to special ethnic and dietary markets by two mills in Texas. Some commercial hybrid seed companies in the USA have expanded their efforts to produce white, tan plant, food-type hybrids. Significant quantities of food-type sorghums are available in commercial storage. Due to low grain prices much of it has not been sold, which discourages its continued segregation in the market. However, food-type hybrids are given a small premium by some feedlots in West Texas.

Composition and Quality Attributes of Commercial Food Sorghum Hybrids

Commercial food sorghums grown in 1997 and 1998 were analyzed for composition, physical and milling properties. The protein and fat content of food type sorghums averaged 10.7 and 3.4%, respectively (Table 2). The milling properties of food-type sorghum hybrids grown under commercial production were compared with a standard red hybrid. 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 the 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.

The advantages of the food type sorghums over red sorghum is illustrated in Figures 2 and 3 which compare the yields of decorticated grain with the color measured with a Minolta colorimeter. In Figure 2, the decorticated grains were ground into flour and the color was measured. We used an L value of 85 as typical of a very high quality white flour. Then, the yield of flour at L values of 85 was compared (Table 3). In Figure 3, we compared the same thing except the decorticated grain (grits) was not milled into flour. The color is more apparent for grits so an L value of 70 was used as the standard for acceptability. The yields of decorticated grain to achieve acceptable quality flours and grits vary significantly with the red sorghum having substantially reduced yields, especially for whole decorticated grain.

Table 2. Analyses of commercial food sorghums grown in West Texas in 1997 and 1998.

Sample	Protein (%)	Fat (%)	Test wt. (lb/bu)	TKW (g)	Density (g/cc)	Floaters (%)	Grain yld (%)	Decorticated kernel color L	a	b
Warner 902W	9.9	3.3	61.6	26.1	1.37	28	83.6	67.5	1.2	22.9
Jowar - 1	10.4	3.3	61.5	26.5	1.38	32	83.0	67.8	1.1	22.4
W902 (#1)	10.1	3.3	60.7	27.4	1.37	59	71.8	68.4	1.1	23.7
W902 (#2)	10.0	3.3	60.5	30.0	1.37	52	72.8	68.4	1	23.3
W528 #1	11.3	3.4	60.9	29.8	1.35	65	74.6	67.7	1.7	20.4
Red	13.1	3.5	59.5	29.8	1.36	70	74.5	63.3	3.6	20.9
Warner 902W-1*	10.9	3.3	61.2	27.9	1.35	—	84.0	68.1	1.2	20.9
Warner 902W-2*	12.8	3.4	59.1	33.1	1.34	—	83.8	65.0	3.4	18.5

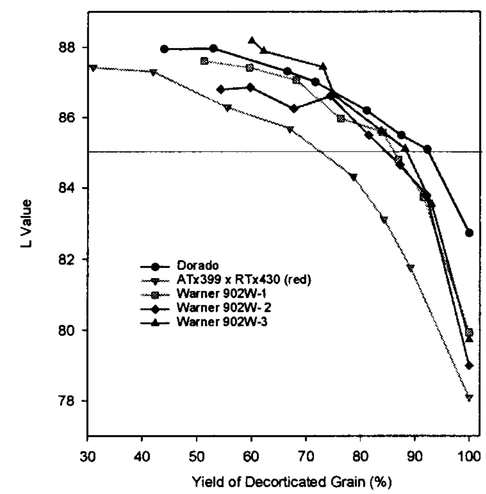

Figure 2. L Value of ground decorticated grain vs. yield of decorticated grain of five sorghums.

Yields of flour and grits of the white food sorghums (W-902W) were inversely related to the amount of weathering. Dorado had bright white grain free of weathering. Thus, for critically important milling comparisons the adjustment of yields to a constant lightness value provides useful information.

We evaluated the International Food Sorghum Trials grown in several locations in Texas during 1990 to 1998 for kernel properties and milling properties. We have used abrasive milling techniques so our conclusions may not hold for roller milling or crushing of sorghum hybrids. However, 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.

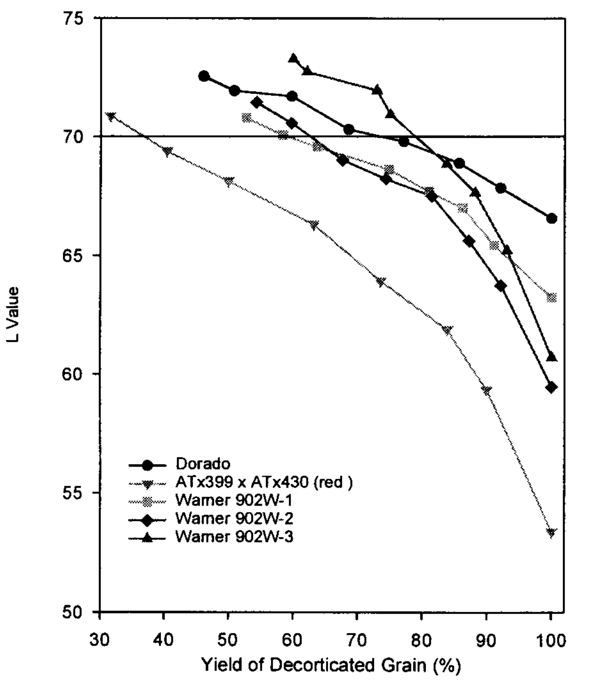

Figure 3. L Value of unground decorticated grain vs. yield of decorticated grain of five sorghums.

Table 3. Yield of flour and decorticated sorghums adjusted to constant L value.

Sample	Grain yield[1]	% Decorticated Grain yield[2]	Grain yield[3]
ATx399*RTx430	75.0	38.0	78.6
Dorado	93.0	73.0	81.1
Warner 902W-1	86.0	57.0	84.0
Warner 902W-2	84.0	62.0	81.5
Warner 902W-3	88.0	79.0	83.8

[1] Sorghum flours (Udy mill) adjusted to equal L values of 85.0
[2] Whole decorticated grains had L values of 70.0
[3] Decorticated grain yields at 4.0 min milling-standard procedure.

* 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.

Role of AFP in Minimizing Grain Molding of Sorghum

Grain molds and weathering greatly affect utilization quality of sorghum. We are continuing to evaluate the role of AFPs in mold resistance. Previous research demonstrated that several proteins with antifungal activity (AFP) are in sorghum pericarp, germ and endosperm. The AFP content increases during caryopsis development, peaks at physiological maturity, and decreases during desiccation. A mixture of AFPs was inhibitory to grain mold fungal species; whereas, each AFP was less inhibitory when evaluated separately.

Grain mold resistance correlated to AFP levels in the caryopsis at physiological maturity. Among these sorghums we observed resistant cultivars containing low AFP and tannins; several susceptible cultivars had high AFP levels. We stressed 10 sorghums with fungal inoculation in the field; the resistant cultivars responded by increasing or maintaining AFP content while the susceptible cultivars had lower levels of AFP.

We designed an experiment to determine the responses of sorghum caryopses to in vitro stress. Caryopses were collected from a resistant (Dorado) and a susceptible (TX2536) sorghum at 15, 30 and 50 days after anthesis (DAA). We stressed caryopses with wounding, soaking or the combination of these and measured AFP in whole caryopsis and hand-separated pericarp, germ and endosperm fractions. AFP levels were greater for resistant than susceptible sorghums for most treatments. All treatments caused more change in AFP in caryopses at 30 DAA compared to 15 or 50 DAA. Wounding caryopses (30 DAA) increased chitinase and sormatin in the endosperm and chitinase in the germ (Figure 4). Soaking generally decreased amounts of AFP in all tissues. In the combined treatment wounding increased chitinase and sormatin and decreased glucanase. Evidence of increased AFP induction or extractability in sorghum caryopsis in response to stress was documented. Even though the amount of AFP per caryopsis is similar to or less than in other tissues, the pericarp contains higher concentrations of AFP than the germ (2 to 4 times) or endosperm (12 to 20 times).

There were differences in how tissues accumulated or lost AFP in this study. The tissues had greater responses in chitinase and sormatin levels compared to glucanase levels after soaking and wounding. Chitinase was more inducible in the resistant cultivar than in the susceptible cultivar. The change in AFP levels in tissues was significant in the endosperm and sometimes in the pericarp. In general, wounding (dry or soaked) caused increased chitnase and sormatin synthesis while soaking resulted in a change in the distribution and in some losses due to leaching. Hence, this study supports the concept that sorghum AFPs contribute to the overall defense mechanism of the caryopsis against fungal infection.

We are working with Drs. Bill Rooney and Raul Rodriguez to determine molecular markers for grain mold resistance. We are in the process of analyzing data and interpreting the results.

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 if not impossible.

Networking Activities

Southern Africa

L.W. Rooney traveled to Pretoria South Africa to participate in the INTSORMIL Sorghum End Use Quality Assessment Workshop. The organizers of the workshop were Professor (Dr.) John R. Taylor, Head, Food Science Department, University of Pretoria, Dr. Janice Dewar, Scientist, CSIR, Pretoria and Professor Lloyd W.

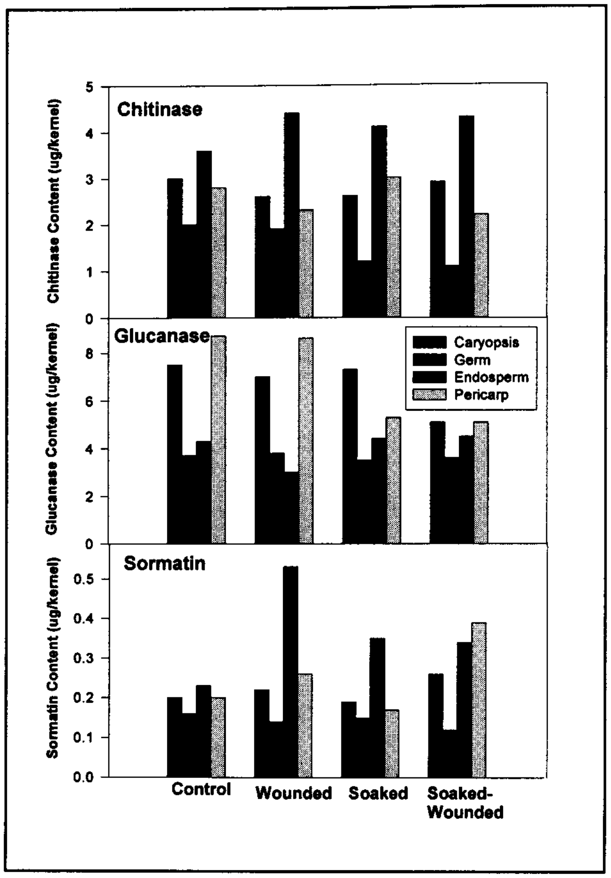

Figure 4. Effects of treatments on chitinase, glucanase and sormatin levels in sorghum caryopsis and tissues (average over cultivar and age).

Rooney, Food Science, Texas A&M University. There were 36 participants in the workshop which lasted three and one half days including information on sorghum composition, structure, genetics and quality attributes for malting and brewing, dry milling and processing into a wide variety of foods. Industrial companies represented ranged from South African Breweries to very small brewers, maltsters, farmers and grain brokers, plus university and food research institutes in Botswana, Zimbabwe, Kenya and other countries.

Several participants were graduate students in the Food Science Department at the University of Pretoria from other African countries. These students are participating in the Regional Master of Science programs which consists of joint programs between CSIR and University of Pretoria. Thus, the workshop reached into many countries of Africa by educating these future leaders in the potential of sorghum as food and industrial ingredients. The ARC Summer Grains Institute at Potchefstroom participated. Mr. Apie Pretorious, Agronomist, ARC led an excellent field trip to the Summer Grains Research Center facilities. They are processing sorghum hybrids grown in replicated trials into dry milled products. Their facilities complement those at CSIR and University of Pretoria. Great potential exists for a strong collaborative effort among these groups. This workshop included a tour of a large sorghum brewery.

Major conclusions were that excellent information is available on malting and brewing quality of sorghum. Very little is known about dry milling properties, or how to define and assess them. New sorghum hybrids are lacking and unlikely to be developed by private industry because the market is insufficient to justify such research. Sorghum products are taxed (14%) while maize is not taxed. Unless the tax is removed sorghum has difficulty competing with maize.

Research Activities at University of Pretoria

Several graduate students are conducting research on aspects of sorghum utilization with Professor Taylor and Dr. Dewar. Ms. Trust Beta is nearing completion of her Ph.D. on processing sorghum with high levels of polyphenols into foods. She has included dry milling, malting and brewing studies of local Zimbabwean sorghum cultivars. Her work has been cooperative with the Matopos grain quality lab in Zimbabwe. She is also working on starch properties at the University of Hong Kong with Professor Harold Corke.

Ms. Leda Hugo, Mozambique, is a Ph.D. student at University of Pretoria working on composite breads made from sorghum milled products. She is a professor at University of Eduardo Mondlane University and completed her M.S. at Texas A&M University.

Lloyd Rooney serves as the external examiner for the M.S. thesis of Mr. Joseph Wambugo from Kenya who is working on weaning foods from sorghum. Several students from various countries in Southern Africa discussed their research projects. There is a great opportunity to provide information to these future African food industry leaders on the properties, advantages and disadvantages of sorghum and millets in local food systems. For example, it is not understood that larger quantities of sorghum flour can be added to wheat than corn flour because of the bland flavor of sorghum. The relative advantages and disadvantages of sorghum and millet are unknown; even the dark brown or red sorghums would have advantages over maize in certain products.

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. Mr. Jorge Medina, EAP senior from Nicaragua, completed his undergraduate research thesis on processing of Sureño sorghum into table tortillas using the tortilleria in the commissary at EAP. The overall acceptance of sorghum tortillas by the students in preference trials was good. Mr. Medina was funded from TAM-226 for a three month educational program in the Cereal Quality Lab where he processed Sureño and other sorghums into tortillas. He conducted objective measurements to compare the texture and staling of corn and sorghum tortillas. His research confirmed our earlier work with maize tortillas that the RVA could be used to monitor staling of tortillas. His texture and RVA data clearly showed how rapidly starch changed in tortillas from both corn and sorghum. He returned to Nicaragua where he accepted a position in the food industry.

We provided several hundred pounds of decorticated food sorghum to Mr. J. Bueso, EAP, for extrusion experiments in Honduras. A student partially funded by INTSORMIL is conducting a senior research project to evaluate extrusion of sorghum. We will acquire a small stone grinder for Mr. Bueso to utilize in tortilla processing experiments. Plans to evaluate different sorghum lines were crushed by the loss of nurseries and infrastructure due to hurricane Mitch. Mr. Bueso is scheduled to start his Ph.D. program at TAMU with TAM-226 funding in January 2000. Current plans include his completion of course work on campus with most research conducted at EAP. Special experiments would be conducted on the TAMU campus as required.

The EAP CITESGRAN program has increased activities in food science teaching, research and out reach in Central America. We hope to assist them with workshops on tortillas from maize and sorghum and other topics, e.g., extrusion. Nolvia Zelaya, M.S. Student from Honduras, is working on tortillas in our laboratory and is available for these activities.

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, texture. Dr. Serna has written a Spanish textbook on cereal quality and technology that is a popular text in Spain and Latin America. He covers sorghum and all the other cereals in his text. His Ph.D. and subsequent experience was funded from INTSORMIL. His activities extend our knowledge of sorghum into many areas of the world.

Mali

N'Tenimissa (one new white, tan plant, locally adapted photosensitive sorghum cultivar specifically designed for value-added processing in Mali) has some agronomic problems; however, it is liked by farmers for its tô quality. Ms. Berthe and others in the IER Food Technology laboratory have been testing N'Tenimissa in a wide variety of food products. The real key is to produce large enough quantities of grain for value-added processing. 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. Identity-preserved grain production is required. 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.

The laboratory in Mali provides information on milling and other quality attributes which can be used for selection. Dr. A. Toure, IER sorghum breeder, is expediting the breeding and testing program.

Global 2000, World Vision and other groups are collaborating in Mali to evaluate maize and sorghum production and utilization. Our information on weaning foods with increased caloric density using malt is being tested in villages by IER food lab through a grant from the Novartis Foundation.

Sorghum Market Development Activities

The Grain Sorghum Producers Association has market development activities to capitalize on the new food sorghums for use in value-added products in Mexico, Central and South America. Our research activities on composite flours, tortillas, snacks and other food products from sorghum was presented at U.S. Grain Council sponsored value-added market development workshops in Mexico and Manhattan, Kansas. The interest in sorghum flour use was stimulated by recent high prices in wheat flour. Since wheat prices have decreased drastically the short-term interest is nil, but there is a long-term interest in sorghum for human food since it is a major crop in Mexico.

The concept of identity-preserved production and marketing of grains is expanding significantly in value-added corns. The development of white food-type, waxy, heterowaxy and nonwaxy sorghums fits into these marketing schemes.

North America

Several papers were presented at the annual American Association of Cereal Chemists conference in Minneapolis, MN. L.W. Rooney presented sorghum quality/utilization discussions to Texas Sorghum Producers Board Members, to sorghum production conferences in San Antonio and Edna, Texas, to U.S. Grain Council market development teams and to many visitors from Mexico, Australia, Mali, Niger, Botswana, Honduras, Guatemala, El Salvador, China and Japan.

Our laboratory conducted short courses on practical snack foods production and maize quality evaluation in which sorghum utilization was part of the program. We presented five poster papers at the National Sorghum Utilization and Research Conference in Tucson Arizona. Ms. M. Leon-Chapa, M.S. student in our lab, won third prize in the Graduate Student research paper contest for her presentation on "Sorghum utilization in cookies".

Training, Education and Human Resource Development

Mr. Jorge Medina, EAP food science graduate, spent three months in our laboratory to conduct research on tortillas from sorghum and maize. In addition, he participated in our workshop on practical snack food production from maize and sorghum.

Monterrey Institute of Technology: our collaboration with Dr. Serna-Saldivar, Head, Food Science Department., 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 has conducted sorghum/maize quality research. He is teaching cereal quality/technology classes to many students from Latin America.

Three graduate students worked on INTSORMIL related research, with partial financial support.

Two Ph.D., and two B.S. scientists and one trainee completed their programs and returned to Honduras, and Mexico. Two were employed in the U.S. food industry, one each in Mexican and Nicaraguan food industry and one at the university. Projects included milling properties, tortilla quality, snack foods and baked products from white sorghum flour.

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Strategic Marketing of Sorghum and Pearl Millet Food Products in West and Southern Africa

Project UIUC-205
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Summary

The project conducted a preliminary study on "Prospects for a Pearl Millet and Sorghum Food Processing Industry in the West African Semi-arid Tropics". The preliminary study is based on secondary data about grain demand and supply in the region. It provides a picture of marketable surplus and urban demand that contributes to an understanding of demand for processed products and the available supply of grain for processing. This work began in September, 1998 and was completed in March 1999. In April 1999 a presentation on "Prospects for a Pearl Millet and Sorghum Food Processing Industry in the West African Semi-Arid Tropics" was made at the ROCARS meeting in Lome, Togo.

Work was initiated on valuing the attributes of millet in the preparation of tô and couscous in Niger. A survey was prepared and administered beginning 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. The INRAN food scientists are attempting to correlate attributes valued by consumers with chemical attributes that can be measured in the lab.

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. The research is in its startup phase. The progress during the year has included: the establishment of a collaborative working relationship with a researcher from the region; the definition of a collaborative research plan; the identification of a population of producers to sample; and the construction of a survey instrument to collect data on the sampled farm households.

Objectives, Production and Utilization Constraints

The first full year of this project was 1998-99. The PI made his first visits to western and southern Africa in late July of 1998. The objective of these visits was to learn about constraints to the marketing of sorghum and pearl millet food products in the two regions, to network with other researchers in the region, and to establish a collaborative research project in southern Africa.

The objectives of the visit relate to the objectives of the project. The overall objective is to identify the elements needed to create a successful coordinated marketing channel from farm to processor to consumer, and 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; and coordinated supply of identity preserved grain from farmers to processors. The research in west Africa is currently concentrating on the area of demand for characteristics. The research in southern Africa is currently concentrating on farmer adoption of varieties.

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 on attributes will demonstrate a methodology for identifying the attributes that are most valuable to consumers. In most cases, these will be the attributes of most value to processors too.

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 keys 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 conducting 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.

Networking Activities

Workshops

Carl Nelson participated in the SADC/ICRISAT SMIP review and planning meeting held in July 1998 in Harare, Zimbabwe. This was Nelson's first trip to the region. Initial contacts were made with researchers from the NARS and from ICRISAT/Bulawayo. During the meeting, Nelson learned of Tebogo Seleka of the Botswana College of Agriculture. Nelson meet with Seleka in the week following the SMIP review and planning meeting. Subsequent email communication led to the establishment of a collaborative research arrangement with Seleka.

Carl Nelson participated in a food processing workshop of ROCEFREMI held in Dakar, Senegal in March 1999. The workshop provided an opportunity to learn about processing activities that are developing throughout the region. Several food processors of millet food products in the Dakar area were visited during the workshop. Initial information was gathered to form a basis for a formal survey of food processors in the Dakar area, and in the area around Ougadougou, Burkina Faso.

Jupiter Ndjeunga presented a paper entitled "Prospects for a Pearl Millet and Sorghum Food Processing Industry in the West African Semi-Arid Tropics" at a ROCARS meeting held in Lomé, Togo in April, 1999.

Publications and Presentations

Miscellaneous Publications

Nelson, C. and J. Ndjeunga. "Prospects for a Pearl Millet and Sorghum Food Processing Industry in the West African Semi-Arid Tropics", paper presented to ROCARS annual meeting, Lomé, Togo, April, 1999.

Host Country

Program Enhancement

Central America Regional Program

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Collaborative Program

Institutions

* 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
* Mississippi State University

Organization and Management

The INTSORMIL Central American Regional Program is based at the Panamerican Agricultural School (EAP), Zamorano, Honduras. This location provides 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 provides an ideal location from which to conduct research and training. The Direccion de Ciencia y Tecnologia Agricola (DICTA) provides Government of Honduras research support by use of the LaLujosa Experimental Station at Choluteca. Nurseries and trials are planted at Zamorano and Choluteca. The program is currently managed by Dr. Raúl Espinal in collaboration with Hector Sierra and Rafael Mateo. The program has extensive ties with private seed industry and developed the first multi-location Central American region sorghum performance test to provide unbiased hybrid performance data in a range of environments. Texas A&M University is developing collaboration with Christiani Burkard (Guatemala), the largest local seed company in Central America.

The major goal of the program is to develop high yielding photoperiod sensitive sorghums. Much of the breeding activity has been on improvement of indigenous landrace varieties unique to Central America called maicillos criollos. These sorghums are widely planted in the semi-arid regions of Central America and used as a maize substitute for making tortillas. Research is conducted in sorghum breeding, entomology, plant pathology and cereal quality. Primary support for the breeding program is from Texas A&M University. Entomology research is conducted by Mississippi State University and the Department of Plant Protection. Previous research has dealt primarily with insect complexes in the maicillos. Research to study sorghum midge (*Stenodiplosis sorghicola*) in Nicaragua has been initiated. Pathology research has been conducted by Texas A&M University in collaboration with the Department of Plant Protection. During 1997-98 research in cereal quality was initiated between Texas A&M University and the CITESGRAN program.

Change in personnel is allowing a more broad-based regional program to develop. While research is still conducted in breeding and evaluation of improved maicillo criollos for small producers, increased emphasis is given to grain quality and evaluation of improved maicillo in tortilla. Results will be used to aid in developing improved quality maicillo. Entomology activity has expanded to include sorghum midge on photoperiod insensitive varieties in Nicaragua. Additional activity in Nicaragua includes evaluation of breeding lines from Texas A&M University. Discussions have been initiated with two universities in Nicaragua, UNA-Managua and UNAN-Leon, regarding development of collaborative ties with INTSORMIL.

Three types of grain sorghum are grown in Central America. Maicillos are grown on hillsides primarily by very small producers in a maize intercropping system. Primary growing region for the maicillos is the steep hillsides of the Pacific regions of Honduras, Nicaragua, Guatemala, and El Salvador. Maicillo research is conducted by the Honduras program. Small to medium producers frequently grow varieties, and many small Nicaraguan producers are interested in varieties. The INTA sorghum program does research on improved varieties. Large producers grow hybrids produced by private industry.

INTSORMIL through the CLAIS network, strengthens sorghum research in Central American countries. This collaboration has 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 in multiple localities. Private companies use this trial to take advantage of the increasing demand for hybrids by providing better hybrids adapted to tropical conditions.

Financial Inputs

Primary financial support for the program is from the INTSORMIL Central America regional budget. For FY1997-98, the regional budget was $80,000. Funds in the amount in $53,000 were transferred to EAP for program operation. The funds support 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 are funded. All INTSORMIL funds transferred to Honduras are managed by the EAP. The remaining Central American Regional funds are at the M.E. and used for travel, supplies, equipment, repairs, and maintenance of the regional program. INTSORMIL collaborates with the Soil Management CRSP on 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. Six testing locations were utilized in 1998-99. The performance trial generated an income of $7,200 in 1998-99. EAP supports the research through facilities, land, financial management and general supervision of the program operations. DICTA supports the research by providing land and facilities at the La Lujosa Experimental Station, Choluteca.

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) was provided to the PROMESA project in Central America. Collaboration with the Soil Management Program is to measure the effect of soil conservation techniques on sorghum productivity on steepland areas of southern Honduras.

A MOU with INTA in Nicaragua was signed in May, 1998. Initial research activity in Nicaragua centered on entomology graduate research on sorghum midge. Additionally, several tests from Texas A&M University were sent to INTA for evaluation and selection. Discussions for additional collaborative activity in Nicaragua were initiated with the Universidad Nacional Agraria (Managua), and the Universidad Nacional Autonoma de Nicaragua (Leon). A Memorandum of Understanding (MOU) with each institution should be signed during 1999-2000. The INTA sorghum program emphasizes photoperiod insensitive germplasm. Collaboration with INTA will broaden the impact of INTSORMIL activity in Central America by providing better access to the range of sorghum grown in the region.

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 kg 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 maicillos. These tropical sorghums are three to four meters tall, drought tolerant, and photoperiod sensitive. Although maicillos have very low yield they are widely 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 but uniform cultivars.

The inability of maicillos to respond to management practices with increased grain yield is a primary constraint to increased production. Before new technologies like soil and water conservation can improve soil fertility and become economically feasible, the genetic potential of cultivars to respond with increased grain production must be enhanced. 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 must occur. Other high rainfall areas with different precipitation patterns need appropriate sorghum types to take advantage of better environments for biomass production.

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 southern Honduras. This severe erosion reduces crop productivity by decreasing the amount of nutrients available for plant growth. It also increases the likelihood of crop failure due to drought by decreasing the amount of topsoil which reduces soil moisture storage. In response to intensifying land use pressure on hillsides in southern Honduras, some farmers have adopted soil conservation techniques but the majority still practice traditional agriculture. Previous research of planting enhanced maicillos on steepland areas with soil conservation techniques showed dramatic increases in sorghum yield.

Alternative uses for sorghum need to be developed to encourage sustainable growth including both improved maicillos and commercial hybrids. White grain, tan plant color sorghums are well adapted to Central American food and feed systems. Innovative processing systems to increase starch digestability and maximize net energy intake, like extrusion and flaking, need to be incorporated into the system to produce better and more efficient animal rations based on sorghum. Human consumption needs to be promoted, especially in tortilla related products and extruded snacks. There are sufficient superior grain quality sorghums to be used in human food systems and opportunities have to be identified and pursued.

Imports of maize hinder further development of the sorghum industry and sorghum research in Central America. During the 1999 Guatemala PCCMCA meeting some seed company representatives expressed concern about the future of sorghum production in countries like Guatemala and Panama that import huge quantities of maize. Subsidized grains not only cause a negative effect on sorghum producers and production but create a grain dependency within these countries.

Plant Breeding Research - Hybrids

In 1998, evaluation of commercial hybrids was conducted in Mexico, Guatemala, Honduras, Nicaragua, Panama and Dominican Republic. This testing program is an important tool for sorghum seed companies and producers. It provides producers with reliable hybrid performance data. Seed companies are able to evaluate hybrids in a range of environments against other hybrids. Five companies participated in the test: Asgrow, Cargill, Cristiani Burkard, DeKalb and Pioneer. (In 1999 an additional company, Kelly Green International, is interested in evaluating hybrids in the performance trial.) Results were published and distributed among sorghum scientists and collaborators during the PCCMCA meeting held in Guatemala City in April 1999.

Eighteen hybrids were evaluated in the 1998 trial (Table 1). Countries and number of locations per country are: Guatemala (1), Honduras (2), Nicaragua (2), Panama (2), Mexico (1), and Dominican Republic (1). Average grain yield over locations was 4.0 t ha^{-1}. The most consistent hybrid was DK 69 at 4.8 t ha^{-1}. DK 69 was the top yielding hybrid in Honduras, Nicaragua, and Panama.

Collaboration with Cristiani Burkard, Guatemala for germplasm evaluation continued. The Texas A&M University INTSORMIL sorghum breeding programs provided

Table 1. Average grain yield performance of 18-grain sorghum cultivar over nine locations in Mesoamerica during 1998 (t ha^{-1}).

Hybrid	Company	Average	Guatemala	Honduras	Nicaragua	Panama	Mexico	Dominican Republic
DK 69	DeKalb	4.8	3.3	4.4	6.2	6.2	8.6	0.1
X 9714	DeKalb	4.6	3.6	2.2	5.7	6.1	9.4	0.6
Cuarzo	Asgrow	4.5	4.1	2.7	4.3	6.3	9.6	0.3
MX 7337	Asgrow	4.5	3.7	2.9	4.1	5.9	9.3	1.1
DK 68	DeKalb	4.4	2.3	2.8	5.2	6.0	9.2	1.0
CB 8971	Cristiani	4.4	3.5	2.5	4.6	6.6	8.9	0.8
CB 2966	Cristiani	4.2	4.8	1.8	2.9	5.7	9.8	0.7
Marfil	Asgrow	4.2	3.8	2.6	3.6	6.2	9.0	0.5
XS 379	Pioneer	4.2	3.5	3.1	4.0	5.8	8.1	0.8
MX52277	Asgrow	4.2	3.9	3.1	4.1	5.7	8.1	0.7
AS 63147	Asgrow	4.0	2.7	2.3	3.5	5.7	9.0	0.8
X 784	DeKalb	3.9	3.3	2.2	3.7	6.2	8.1	0.3
CB 8973	Cristiani	3.8	3.8	2.1	2.8	5.5	8.3	0.5
XM 5287	Asgrow	3.8	3.8	2.3	2.9	5.4	7.9	0.7
XS 475	Pioneer	3.5	2.5	2.0	2.7	5.7	7.4	0.7
Mercurio	Cargill	3.5	2.4	2.4	3.2	5.6	7.4	0.3
5560	Cargill	3.2	2.8	1.9	2.3	5.6	6.6	0.5
DK 33	DeKalb	3.1	3.1	2.1	2.1	4.6	6.6	0.5
Average		4.0	3.4	2.5	3.8	5.8	8.4	0.6

Locations: Guatemala = 1, Honduras = 2, Nicaragua = 2, Panama = 2, Mexico = 1, Dominican Republic = 1.

several tests for evaluation of experimental germplasm to obtain information on potential commercialization on U.S. developed germplasm in Central America. In June 1998 the following tests were provided for evaluation: All Disease and Insect Nursery (ADIN), Grain Weathering Test (GWT), International Food Sorghum Adaptation Trial (IFSAT), Drought Hybrid Test (DHT), and the Drought Line Test (DLT). Data was obtained on reaction to four diseases (rust, zonate, grey leaf spot and anthracnose), overall desirability, and grain yield. Grain quality was rated in the GWT. Cristiani Burkard is interested in obtaining several advanced lines to evaluate in hybrid combination for possible use. A similar set of tests was provided to Cristiani Burkard in June 1999 for evaluation.

To initiate collaboration with INTA the following tests were provided for evaluating in Nicaragua: 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. Little data was collected due to excessive rainfall (600mm) during a 10 day period of flowering. The rainfall interfered with pollination (causing blasting) and grain development. However, in the GWT three entries were selected for potential use: 97GWO117, 97BRON305, and 97CA2258. Similar tests were sent to INTA in June 1999 for evaluation in the 1999 growing season.

Enhanced Maicillos

Enhanced maicillos are sorghum lines obtained from crossing photoperiod-sensitive landraces (maicillos criollos) with elite sorghum lines from ICRISAT and Texas A & M University that express outstanding adaptation to the maize/maicillo intercropping system. Nurseries of enhanced maicillos are planted at Zamorano and La Lujosa. Advanced materials are then evaluated in the International Improved Maicillo Trial (EIME). Last year the EIME, consisted of 27 entries and was planted in two locations in Honduras: Zamorano and Choluteca. Superior EIME entries are evaluated in on-farm demonstration plots. Due to excessive rainfall caused by Hurricane Mitch data was obtained from the Zamorano location only. Average grain yield was 1743 kg ha^{-1}, and the top check was San Bernado III at 3439 kg ha^{-1}. The only enhanced maicillo with greater yield than the checks San Bernado III or Porvenir was DMV 221.

Entomology Research

The *lepidopterous* 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 20% of the sorghum production and maize as high as 35% by using the recommended practices. 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.

Sorghum midge remains the most serious pest in Nicaragua. Ing. Johnson Zeledon a graduate student from MSU is studying the dynamics of the population and means of control. Zamorano published a technical bulletin about Locust of Sorghum and Maize. This publication highlights the research of Dr. Pitre and graduate students to identify sorghum pests in southern Honduras.

Grain Quality Research

The Honduras program has historically concentrated most of its effort on improving the agronomic and processing characteristics of the maicillos criollos. Beginning in January 1998, enhanced maicillos (named dwarf maicillo varieties or DMV) that show good agronomic traits in the EIME trials are being evaluated for grain quality, nutritional composition, and masa and tortilla quality at Zamorano. This research is in close collaboration with the Texas A&M University Cereal Quality Laboratory. 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 (Table 2). Sureño was selected as the standard because of its wide acceptance for tortilla.

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. 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 the two hybrids have excellent quality traits and should be considered good materials for food processing (Table 2). 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. Variability in chemical composition among cultivars evaluated was low (Table 3).

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 per-

Table 2. Physical properties of selected Dwarf Maicillo Varieties compared to commercial hybrids and to a standard food-type variety (Sureño).

Cultivar	Density (g/cc)	1000-Kernel Weight (g)	TADD Hardness[1] (%)	Floaters[2] (%)	Color (L)[3]
Sureño	1.39	26.0	12	32	62.5
DMV 218	1.39	25.9	24	43	62.8
DMV 210	1.38	25.3	27	63	58.7
DMV 213	1.39	26.1	27	94	64.3
DMV 226	1.38	30.1	35	52	56.3
DMV 223	1.37	22.8	64	81	55.9
MX 7124	1.38	23.9	27	43	57.1
DMV 219	1.38	19.0	32	71	63.2
DMV 198[d]	1.38	23.9	20	27	54.8
DMV 137	1.39	30.4	22	35	55.8
DMV 228	1.39	20.6	31	69	61.6
DMV 221	1.38	20.4	27	69	58.8
DMV 179	1.39	25.2	22	37	57.3
DMV 222	1.38	25.3	49	61	59.0
Lerdo Ligero	1.38	23.0	47	98	56.6
DMV 225	1.39	24.9	34	45	54.1
DMV 224	1.40	25.3	31	37	56.3
DMV 238	1.40	25.8	24	43	58.7
DMV 239	1.39	26.0	22	56	61.3
DK69	1.38	27.3	22	32	56.3
LSD P=0.05	0.0053	1.9	3	13	1.9

[1] % decortication in soft grains is higher than in hard ones.
[2] % of grains that float on a solution of $NaNO_3$ adjusted at a specific gravity of 1.275g/cm3. The higher the % of floaters the softer the grain is.
[3] L axis of the tristimulus scale used by the Minolta chroma meter. L value: 0=black, 100=white

Table 3. Nutrient composition of selected improved maicillos (DMV), two commercial hybrids, a maicillo criollo and Sureño.

Cultivar	Dry matter[1]	Carbohydrates	Protein %	Fat	Fiber
Sureño	87.6	69.1	11.3	3.5	3.7
DMV 218	83.5	66.0	11.4	3.8	2.3
DMV 210	83.7	65.6	11.0	3.8	3.3
DMV 213	82.6	63.4	11.5	3.7	4.0
DMV 226	84.3	64.9	11.7	3.9	3.8
DMV 223	85.9	69.1	10.8	3.8	2.2
MX 7124	86.5	72.9	9.3	3.9	0.4
DMV 219	82.3	63.7	11.8	3.8	3.0
DMV 198	85.8	71.1	9.8	3.9	1.0
DMV 137	86.1	70.5	10.4	3.9	1.3
DMV 228	82.8	64.2	11.6	3.8	3.2
DMV 221	84.0	66.7	10.8	3.8	2.7
DMV 179	84.7	67.2	10.7	3.8	3.0
DMV 222	86.7	70.7	10.2	3.9	1.9
Lerdo Ligero	82.8	63.2	11.9	3.8	3.9
DMV 225	84.9	67.7	10.9	3.9	2.4
DMV 224	87.9	73.1	9.9	3.9	1.0
DMV 238	87.2	72.2	9.9	3.9	1.2
DMV 239	86.3	70.4	10.2	3.9	1.8
DK69	85.4	70.6	10.3	3.9	0.6
LSD P=0.05	1.1	2.7	0.4	0.1	1.0

[1] All dry matter components are expressed on a wet basis.

formance. The inability of the grinder to produce a finer masa affected the texture and rollability of the tortillas in general.

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,

Table 4. Organoleptic and physical properties of tortillas made with 100% sorghum compared to 100% corn tortillas.

Cultivar	Aroma*	Appearance	Texture	Rollability	Taste
Corn (H-29)	8.4	8.4	7.1	7.5	7.7
Sureño	6.0	7.5	4.0	5.0	4.0
DMV 218	7.3	6.5	6.5	5.5	6.7
DMV 210	7.3	5.8	5.8	4.6	6.7
DMV 213	7.0	5.7	5.8	5.0	6.8
DMV 226	6.5	6.4	5.4	5.4	6.8
DMV 223	5.7	7.2	6.4	4.8	6.4
MX 7124	6.0	5.5	5.5	2.0	4.5
DMV 219	6.0	4.5	4.5	1.0	4.5
DMV 198	6.5	4.0	4.0	1.0	6.5
DMV 137	5.7	5.0	4.5	2.4	5.8
DMV 228	5.5	4.5	4.5	1.5	5.5
DMV 221	5.0	4.0	4.0	2.0	4.5
DMV 179	5.0	4.5	4.5	3.0	1.5
DMV 222	5.0	4.8	5.4	3.8	6.6
Lerdo Ligero	3.7	2.7	3.2	2.8	3.4
DMV 225	3.2	2.3	2.6	2.8	5.4
LSD P=0.05	2.0	2.01	2.4	2.0	1.7

* Rating scale: 1=strongly dislike, 2= dislike, 3=unacceptable, 4= neither like or dislike, 5= slightly good, 6= acceptable, 7=good, 8=very good, 9=excellent

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 may be the best choice since it combines high grain yield with good tortilla quality.

Tortillas made with 100% DMV 219 staled at a similar rate than 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 Viscoanalizer 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 our evaluation of the improved maicillos. Further research will be concerned with studying the factors that may accelerate the staling of sorghum tortillas compared to corn tortillas.

Mutual Research Benefits

Many production constraints are similar between Central America and the USA 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. Germplasm exchange will contribute to development of novel genetic combinations with multiple stress resistance, wide adaptation, and improved food quality.

Institution Building

Equipment and Other Support

INTSORMIL ordered a Jeep Grand Cherokee for use in Central America. The vehicle will be used primarily by graduate students to conduct research at diverse locations in Honduras and Nicaragua.

Training and Education

During 1998, INTSORMIL awarded a half tuition scholarship to two EAP students. Eduardo Rivera (Nicaragua) is conducting research on comparison of parasitoids and predators populations of the sorghum panicles in two different cropping systems in southern Honduras. Rivera is working under the supervision of Dr. Ronald Cave, an entomologist. Jorge Medina (Nicaragua) evaluated tortilla quality of enhanced maicillos. Belen Prado, another fourth-year student from the Zamorano Food Science program evaluated the remaining three improved maicillos and Lerdo Ligero. She will also work on developing an expanded breakfast cereal made with a combination of sorghum grits and defeated soy flour via extrusion.

In 1999, the project awarded two Zamorano students a half tuition scholarship to conduct research on steepland areas of southern Honduras. Claudia Urrutia (El Salvador) will evaluate the use of rock wall terraces and their influence on an intercrossed system and maize-maicillo productivity. Beatriz (Ecuador) will begin research this year studying the effect of soil conservation in two localities of southern Honduras and the Yeguare region.

Mario Carrillo, a Nicaraguan student is pursuing a M.S. degree in entomology at Mississippi State University. Mr. Carrillo is evaluating insect management strategies in traditional and improved sorghum and maize production systems in fields with flat or gentle slope land in southern Honduras. Johnson Zeledon another Nicaraguan graduate student from MSU is studying the relationship and management of sorghum midge (*Stenodiplosis sorghicola*) on sorghum in Nicaragua. Mr. Zeledon will continue monitoring sorghum midge populations in Nicaragua during this year.

Travel and Networking

Dr. Henry Pitre evaluated research in Honduras and Nicaragua in October 1998.

Hector Sierra and Rafael Mateo traveled to Colombia to attend the ICRISAT meeting on November 1998. During this meeting the future collaboration and evaluation of new genotypes from ICRISAT Program was discussed.

Hector Sierra traveled to Baltimore, MD in the United States in October 1998 to present a poster at the Agronomy Society Meeting.

Hector Sierra, Rafael Mateo and Javier Bueso traveled to Guatemala in April 1999 to attend the PCCMCA meeting.

Dr. John Yohe, Dr. Tom Crawford, and Dr. Gary Peterson visited Honduras and Nicaragua in May, 1998. In Honduras discussion were held with EAP, DICTA, and USAID regarding INTSORMIL activity and future direction. In Nicaragua discussions were held with INTA to strengthen collaboration, and communication was established with UNA and UNAN regarding potential collaborative activity.

Networking

Strong collaboration has developed between the sorghum program and other organizations 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. This collaboration has been on-going for many years and has been critical to testing new technologies in producers fields. New collaboration has been established with NARS/ICRISAT/CIAT to evaluate sorghum and millet for tolerance to acid soils. The program continues to provide and evaluate promising materials with different private and government institutions. New collaborative organizations such as the Spanish Peace and Development are working with small-scale farmers in sustainable agriculture. DICTA is sponsoring a program with medium size ranchers to improve productivity. As part of the technology transferred DICTA technical personnel are recommending the use of improved sorghum cultivars developed by the program such as Sureño. Sureño is a promising alternative to feed cattle in the semi-arid conditions of southern Honduras.

Research Results

A complete list of research results can be found in the 1997-98 Annual Report.

Collaboration between breeding and entomology identified improved maicillo genotypes with superior grain quality and processing traits.

Publications and Presentations

Mateo, R and P. Paz. 1998. Grain sorghum performance test for the PCCMCA. (In Spanish). Tech. Rep. No. AG-9901. Escuela Agricola Panamericana, El Zamorano, Honduras.

Pitre, Henry, H. E. Portillo, D. H. Meckenstock, M. T. Castro, J. I. Lopez, R. Trabanino, R.D. Cave, F. Gomez, O. Vergara y R. Cordero. 1999. La langosta del sorgo y el maiz. Zamorano Academic Press. El Zamorano, Honduras, 133pp

Sierra, H and R. Mateo. 1998. The Honduras Sorghum Program and INTSORMIL Collaboration. NARS/ICRISAT/CIAT meeting. La Libertad, Colombia.

Bueso, J. and Medina, J. 1998. Evaluation of tortilla quality of five enhanced Maicillos [*Sorghum bicolor* (L.) Moench]. Sorghum meeting PCCMCA. Guatemala. Guatemala.

Medina, J. 1998. Evaluation of tortilla quality of five enhanced Maicillos (Sorghum bicolor L. Moench) (In Spanish). Ingeniero Agronomo Thesis. Escuela Agricola Panamericana.

Horn of Africa

Gebisa Ejeta
Purdue University

Coordinators

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Semere Amlesom, Eritrea Country Coordinator, Division of Ag Research and Extension Services, P.O. Box 10438, Asmara, Eritrea
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 relatively new initiative to regionalize our collaborative research efforts in Eastern Africa. Before the start of the current regional effort, INTSORMIL had had a productive collaborative program with the Agricultural Research Corporation (ARC) in Sudan. This collaboration 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 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 MOA, 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 becoming the 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. Sharaf 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 Woldewahid, 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 – Peter Esele, 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 Area 1000 ha	Sorghum Yield kg ha^{-1}	Sorghum Production 1000 mts	Millet Area 1000 ha	Millet Yield kg ha^{-1}	Millet 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
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 2-3 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

Kenya: C.K. Kamau

Background

The INTSORMIL Collaborative Research support program was born out of need by U.S. Government and scientists in particular to help solve some of the recurrent problems constraining food production in Least Developed Countries (LDCs). Sorghum and millet are the crops of choice because of their drought tolerance. They are suitable for semi-arid areas where world's poorest farmers are found. Another consideration was poverty alleviation among the farmers in the semi-arid regions. To satisfy these needs, a multi pronged approach is adopted as follows:

- Train LDC scientists to solve agricultural problem through research by working with experienced U.S. scientists.
- Train the LDC scientists in an identified agricultural problem area of mutual interest to both LDC and the USA.
- In so doing, solve problems in LDCs especially in the identified area of mutual interest and collaboration.

Kenya Agricultural Research Institute (KARI) like other LDCs in the Horn of Africa region prepared a proposal to INSORMIL in the area of *Striga* and food quality which was accepted and approved.

The statement of work/objective under this subgrant and the proposal were:

1. Screen high diastatic power sorghum germplasm for adaptation to Kenya.

2. Test adapted germplasm for yield in sorghum National performance trials.

3. Carry out proximate analysis especially reducing sugar and fat content in promising lines.

4. Identify traits that are correlated to malting quality for use during early generation screening.

5. Release the best two sorghum varieties for cultivation and use by the brewers.

6. Create expanded market for sorghum in Kenya.

7. Survey and collect local sorghum germplasm suitable for malting.

8. Develop hybrids with good malting and clear beer production.

***Striga* Component Work Objectives**

The statement of work/objectives were later amended to include the following objectives in the area of *Striga.*

1. Conduct field screening for *Striga* resistance in sorghum lines developed at Purdue for adaptation to growing conditions in Kenya.

2. To assess impact of integrated use of *Striga* resistant sorghum varieties in combination with nitrogen fertilization and water conservation measures.

3. Initiate breeding efforts on transfer of *Striga* resistance from various sources into adapted Kenyan sorghum varieties.

4. Train Kenyan scientists on laboratory methods for screening for resistance to *Striga* in sorghum.

To start this collaborative work an initial advance of US $5000 was dispatched to KARI to facilitate the *Striga* research at the Regional Research Centre in Kakamega, and the food grain activities in Katumani.

During the short-rainy season in 1998 (November 98 - Feb 99) sorghum and millet experiments were planted in two sites, Katumani and Kiboko. The experiments planted at Katumani were:

Objective 1 and 2

National Performance trials (Sorghum)16 entries replicated 4 times

Advanced yield trials (Sorghum) 26 entries replicated 3 times.

Preliminary yield trial (Sorghum) 60 entries replicated 2 times.

Malt quality yield trial (Sorghum) 16 entries replicated 3 times.

Breeding nursery	F_3 - 36 lines
	F_4 - 86 lines
	F_5 - 20 lines
	F_6 - 18 lines

Dry-land selections (drought nursery) 42 lines.

Experiments planted at Kiboko were:

National performance trials (Sorghum) 16 entries replicated 4 times.

Regional yield trials (Sorghum) 26 entries replicated 3 times.

INTSORMIL food grain trials (Sorghum) 42 entries replicated 2 times.

Preliminary yield trial (Sorghum) 60 entries replicated 2 times.

Similar activities were undertaken for pearl millet. Generally the season was very poor, despite the fact Katumani has relatively cooler weather and high rainfall compared to Kiboko. Consequently a harvest was achieved for all experiments with quite a number of entries failing to produce grain which is acceptable in a breeding program. When we planted at Kiboko, the expectation was that if rainfall was poor the crop could be supplemented with irrigation.

This was not possible because the irrigation pump at Kiboko broke down. The total rainfall was 142 mm which was poorly distributed. Consequently the data collected in this test site is unreliable.

During the 1999 long-rainy season (March–September 1999), the number of entries planted were reduced through selection based on data collected at Katumani. Very promising entries were advanced to high stages of yield testing. Of particular interest in this collaboration is the malt quality sorghum trial. In this trial the entries SDSH-378, SDSH-513, Red Swazi and SDSL-88298 were advanced to National Performance Trials. Data collected on the INTSORMIL Food Grain trial is not reliable due to the poor season at Kiboko; consequently the entries in this trial could not be advanced to higher stages of yield testing.

Objective 3 and 4

Out of the successful entries in Katumani 400-500g of grain have been sampled for proximate analysis. Laboratory procedures have been prepared and necessary chemicals bought except for two. Counterpart funds ran out before two important chemicals were bought. These chemicals will be bought using INTSORMIL funds. Malting tests will be conducted alongside proximate analysis tests as soon as the two chemicals are bought.

Objective 6

Our social economist is in the process of preparing a questionnaire to use with the brewers. This objective is pending completion of the questionnaire.

Objective 7

In our opinion, this objective would be implemented better with knowledge gained from the other objectives. It is therefore pending until we have results from the aforementioned objectives.

Objective 8

Work relating to this objective started late last year but due to the bad season, the results are not reliable. We will need to continue to depend on INTSORMIL to provide testing materials for hybrids since our national program does not have a hybrid component. Two kits or more will greatly increase our chances for success.

At Katumani, the starting point was to clear outstanding debts as the check translated to money after all the required processes in April 1999 while work had started in July 1998. The main debt was in casual payrolls as follows: December 1998 at Katumani site, November 1998 at Kiboko site, February 99 at Katumani site, and January 99 at Kiboko site.

Striga Component: International _Striga_ Nursery

Objective 1-4

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 to this parasitic weed are estimated to range between 65% and 100% (Dogget, 1965 Ejeta et al., 1993). Of late *Striga* has been reported to extend to non-traditional areas (Orodho and Kiriro, 1994). 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. Scientists in the U.S. have made a breakthrough in a rapid laboratory screening method for sorghum resistance to *Striga*. The immediate objectives of the International *Striga* nurseries are:

1. Conduct field screening for *Striga* resistant sorghum lines developed at Purdue for adaptation to growing conditions in Kenya.

2. To assess impact of integrated use of *Striga* resistant sorghum varieties in combination with nitrogen fertilization and water conservation measures.

3. Initiate breeding efforts on transfer of *Striga* resistance from various sources into Kenya Sorghum varieties.

4. Train Kenyan scientists on laboratory methods for screening for resistance to *Striga* in sorghum.

In this set of objectives only objective number 1 is earmarked for this collaboration, others being long-term. The International *Striga* trial was not planted last season (November 1998 - March 1999). The implementing officer for this component did not have any funds from any source. He had however planted the *Striga* nursery the previous season (March – September 1998). A copy of the collected data was forwarded to the HOA Coordinator.

Because of lack of funds, the planting of the *Striga* trials were delayed in Kakamega. The crop is presently in milk stage and doing well. However, the *Striga* plants looked very small. If these plants do not grow very fast, then they might not be able to cause the desired effect.

Issues requiring attention

1. In Kenya, rainfall is bimodal in nature; thus there are two growing seasons in a year. Efficiency could be intensified in screening for adaptation in both the food quality and *Striga* resistance if test kits could be sent twice a year. The most appropriate timing would be February for the long rainy-season and September for the short-rainy season. Two or more kits for each trial can greatly enhance chances of success.

2. There is need to budget for a computer to allow information storage and retrieval. Much time is wasted in attempting to borrow a computer.

3. It is proposed that the work objective on data collection be delayed until we gain experience from results of the previously mentioned objectives.

Eritrea: Tesfamichael Abraha

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 is from 1998, carried out in the western lowland (Shambuko) and in the highland (Mendefera).

Objectives

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.

Materials and Methods

Low-land cultivars

Twenty-six 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' plots 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.

Selected low-land cultivars.

Eight sorghum varieties, received from INTSORMIL/ Purdue University (International *Striga* Resistant Nursery), 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.

Progress to Date

One of the better characterized mechanisms of resistance against *Striga* is the host root's low production of chemical compounds that *Striga* seeds require as a stimulant for germination (Worsham, 1987).

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 amount of stimulants suffered to a lesser degree by this parasitic weed.

Varieties with entry numbers 8579 and 8568 were with no *Striga* at all and Varieties with entry numbers 8557and 8580 were with very few number of *Striga*.

Varieties with entry number, 8552, 8556, 8566, 8577 and 8555 sustained fewer *Striga* and at the same time gave good

Table 3. Screening low-land sorghum cultivars for their resistance against *Striga*.

No.	Treatment	Plant height (cm)	Panicle size (cm)	Stand count	*Striga* count/plot		Yield (Q/ha)
					1st count	2nd count	
1	8551	133	26.25	38	3	40	22.72
2	8552	150	28.75	59	2	28	39.19
3	8553	143	30.00	37	3	13	23.72
4	8554	148	32.50	29	1	15	24.76
5	8555	137	30.50	54	0	18	29.43
6	8556(control)	130	29.75	56	0	12	33.24
7	8557	134	29.00	33	1	4	15.21
8	8558	100	27.75	43	10	65	18.98
9	8559	138	30.00	55	10	75	25.29
10	8560	127	19.50	46	32	66	15.60
11	8563	138	29.50	40	9	169	26.04
12	8564	129	28.25	41	26	196	23.34
13	8565	132	29.75	49	25	181	25.78
14	8566	136	29.25	48	3	36	29.85
15	8568	138	23.00	57	0	0	13.77
16	8571	111	28.00	40	4	36	18.35
17	8572	117	25.75	39	1	22	24.09
18	8573	134	34.50	41	0	12	26.44
19	8574	128	23.75	34	8	43	17.73
20	8575	267	30.75	67	15	148	35.43
21	8576	129	27.75	52	12	84	26.10
22	8577	150	26.50	44	2	120	29.68
23	8578	153	24.75	42	1	21	20.42
24	8579	108	25.25	38	0	0	21.38
25	8580	111	25.50	27	0	5	12.34
26	PATO	223	22.00	25	10	12	22.23
LSD0.05							12.08
SE							6.07
CV %							35.87

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

Research Equipment

A laptop computer was purchased in Ethiopia by EARO for use by the EARO/INTSORMIL Principal Investigators for their field work.

Table 4. Screening selected cultivars of sorghum for their resistance against *Striga*

No.	Treatment	Sorghum stand count/plot	*Striga* count/plot	
			1st count	2nd count
1	8551	56	7	155
2	8552	79	14	126
3	8553	32	17	185
4	8554	38	7	299
5	8555	52	25	206
6	8556(Local-Bazenai)	91	6	251
7	8557	52	24	347
8	8558	48	2	314
9	8559	75	16	299
LSD0.05%				129.9
SE				106.15
CV %				53.59

Travel

Gebisa Ejeta traveled in September to accompany the INTSORMIL External Evaluation Panel's review of the HOA program. Dr. Sanders also traveled to Ethiopia but he and Gebisa were unable to visit Tigre since the fields were in the war zone of the Eritrea/Ethiopia conflict.

Dr. Aberra Debelo, EARO Deputy Manager and Country Coordinator visited Purdue University in June.

Networking

The Intergovernmental Authority on Development (IGAD) covers seven countries of the Horn of Africa (HOA) namely, Djibouti, Eritrea, Ethiopia, Kenya, Somalia, Sudan and Uganda. IGAD has the mandate to undertake a wide array of development activities ranging from conflict prevention, management and resolution, food security and environmental protection, to infrastructure development. 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.

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 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.

In 1997 we signed MOUs with Ethiopia, Kenya, Uganda and Eritrea following discussions initiated during the workshop in November. 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.

This year, INTSORMIL was requested by IGAD (Intergovenmental Authority on Development) to undertake a survey project on "Promoting Sustainable Production of Drought Tolerant High Yielding Crop Varieties through Research and Extension.

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 USA. 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 some 500,000 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 were released to the seed industry in the U.S.

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 USA. 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. These 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 about 200 farmers.

- An integrated *Striga* control study including the three *Striga* resistant selections, nitrogen fertilization, and tied-ridges was planned for implementation starting with 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 stalkborers was initiated and the necessary baseline data generated.

- We also held a Traveling Workshop in Ethiopia and Eritrea for our regional collaborators. The workshop allowed for exchange of ideas and establish understanding for undertaking regional sorghum and millet research collaboratively.

Mali

D.T. Rosenow
Texas A&M University

Coordinators

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Dr. Aboubacar Toure, Sorghum Breeder, Host Country Coordinator, IER, B.P. 438, Sotuba, Bamako, Mali

Collaborative Program

Program Structure

The program in Mali, a coordinated effort between INTSORMIL and IER, is multi-disciplinary and multi-institutional in scope and includes all aspects of sorghum and millet improvement, production, and utilization. Each Malian scientist develops research plans cooperatively with an INTSORMIL counterpart and in concert with and as a part of the overall IER Mali research plan. Major INTSORMIL collaborators travel to Mali annually during the critical period of the crop year to consult, review progress, and plan future collaborative activities with their Malian counterparts. Occasionally, IER scientists travel to the USA for research review and planning. These plans are reviewed by the country coordinators, consolidated, and coordinated with IER research project plans for approval or modification. This insures that the research fits into the annual overall IER strategic plan. The plans then become part of the annual Amendment to the MOA.

Memorandum of Agreement

The original Memorandum of Agreement formally establishing INTSORMIL collaboration with IER and allows transfer of funds was signed in Mali on October 10, 1984. A revised MOA was signed in 1996 at the beginning of the current INTSORMIL 5-year Grant. The annual Amendment to the MOA, which consists of the 1998-99 work plan and budget (Amendment #15), was developed jointly by the country coordinators in April-June 1998, and approved by IER and INTSORMIL in July, 1998.

Financial Input

The USAID Mission has provided significant financial support to the total IER research program, of which sorghum and millet are a part, through the SPARC Project which ended in June 1997. Approximately 50% of the yearly Mali Country Budget is transferred directly to Mali from the INTSORMIL Management Entity. The remainder is retained at the M.E. and used for major equipment purchases, supplies, IER scientist travel, IER scientist short term training, or special needs as they arise. Also, some individual U.S. INTSORMIL investigators transfer pass-through funds to Malian counterparts or purchase equipment or supplies for Mali directly from their project funds.

Collaborating Institutions

Institute of Rural Economy (IER), Bamako, Mali
Texas A&M University
University of Nebraska
Purdue University
Kansas State University
USAID/Bamako
ICRISAT/WASIP/Mali
WCASRN (Regional Sorghum Network) (ROCARS)
InterCRSP (World Vision Int.)

Research Disciplines and Collaborators

Germplasm Enhancement - Sorghum - Aboubacar Toure, Abdoulaye G. Diallo, Mody Diagouraga (millet), Keriba Coulibaly (Sikasso), IER; D.T. Rosenow, G.C. Peterson, G. Ejeta, D.J. Andrews, INTSORMIL; S.B. Coulibaly, TTU/TAMU student, IER (Breeding).

Crop Protection Systems - Entomology - Yacouba Doumbia, Mde. Diarisso Niamaye Yaro, IER; G.L. Teetes, INTSORMIL.

Crop Protection Systems - Pathology - Mamourou Diourte, Mde. Diakite Mariam Diarra, Ousmane Cisse, IER; R.A. Frederiksen, INTSORMIL.

Crop Protection Systems - *Striga*/Weed Science - Bourema Dembele, Cheickna Diarrra, IER; G. Ejeta, INTSORMIL.

Crop Production Systems - Agronomy/Physiology/Soils - Adama Coulibaly, Abdoul Wahab Toure, Mamadou Doumbia (Soil Lab) IER; S.C. Mason, J.W. Maranville, INTSORMIL; Samba Traore, UN student, (IER (Weed Science/Agronomy).

Utilization and Quality - Mde. Aissata Bengaly Berthé, Mde. Coulibaly Salimata Sidibe IER; L.W. Rooney, INTSORMIL.

Economics - Bakary S. Coulibaly, IER (Purdue student); J.H. Sanders, INTSORMIL.

On-Farm Trials and InterCRSP - Aboubacar Toure, Oumar Coulibaly, IER; Philippe Dembele, World Vision; D.T. Rosenow, J.W. Maranville, INTSORMIL.

Sorghum/Millet Constraints Researched

Production and Utilization Constraints

Yield level and stability in sorghum/millet production is of major importance in Mali where food production is marginal in the presence of a rapidly growing population. Low and unstable yields are the result of complex interactions of low soil fertility (particularly nitrogen and phosphorus), drought stress, diseases, insect infestations, *Striga*, and lack of availability of improved cultivars.

Head bugs and associated grain molds adversely affect sorghum yield and grain quality, and are a major constraint to the development of improved high yielding sorghum cultivars. *Striga* is a major constraint for both sorghum and millet. Other major constraints are phosphorus and nitrogen deficiency, water stress, and millet head miner infestations.

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 higher rainfall areas. Grain prices which cycle between high and low yield-level years are a deterrent to adoption of improved technology.

Transformation of sorghum and millet grain into new shelf-stable foods and industrial products is needed to encourage local production of grains and to enhance agribusiness activities involving sorghum and millet.

Efforts are concentrated to strengthen research on breeding, crop physiology, soil and water relationships, entomology, pathology, *Striga*, food processing, and food technology, marketing, and technology transfer. An effort to develop new food products from cereals and legumes is emphasized. Selection for enhanced drought resistance is a major concern. Major activities involve the introduction and use of new genetic materials in breeding programs to develop cultivars to increase or stabilize grain yields with desirable food quality.

New Opportunities

Newly developed tan-plant Guinea-type breeding cultivars, especially N'tenimissa, have been tested on-farm and offer an opportunity to develop new food products and industrial products which could enhance demand and stabilize prices. New commercial products using sorghum and millet are being developed and marketed. Work to develop *Striga* resistant sorghums and photoperiod sensitive late maturing sorghums to escape head bugs and molds was expanded the last five years. Extensive on-farm trials of new cultivars has been initiated with World Vision and with the InterCRSP Technology Transfer Project. An MOU between INTSORMIL and WCASRN (regional sorghum network) presents opportunities for technology transfer in sorghum across West Africa. A similar MOU with ROCAFREMI (millet regional network) offers similar opportunities in pearl millet. Cooperation with scientists especially Niger and Burkina Faso should lead to a more regional approach in West Africa.

Research Progress

Details of much of the research related to Mali are presented in individual PI project reports in this publication. This Mali Country Annual Report will emphasize research done by the IER in Mali.

Sorghum Breeding

The sorghum breeding program in IER is a large and diverse program. While Dr. Aboubacar Toure was on a two-year Rockefeller Foundation Post Doc Fellowship on sorghum biotechnology at Texas A&M, Jan. 1996 to July, 1998, Sidi Bekaye Coulibaly (Agronomy/Physiology) was named to head the IER sorghum breeding program. Dr. Toure returned to Mali in July, 1998 to again head the sorghum breeding program. Sidi Bekaye Coulibaly departed in August, 1998 to Lubbock, Texas to begin a Ph.D. program in sorghum breeding jointly with Texas Tech and Texas A&M.

The IER sorghum breeding program does extensive crossing and intercrossing among elite introductions, improved non-guinea and guinea derived breeding lines, and elite local cultivars. It utilizes genetically diverse germplasm from around the world resulting in much genetic diversity in the breeding program. Extensive use is made of ICRISAT developed lines and elite lines from the USA. Emphasis in the program centers on improving the head bug/grain mold resistance of high yielding tan-plant non-guinea breeding lines, guinea by non-guinea intergrades, and on developing tan-plant true guinea cultivars. Breeding for the dry northern areas also involves some crosses with local Durras from the area and early Caudatum derivatives from Senegal.

A standard system of moving progenies along at the different locations is in place and understood by the technicians. After the F_2, progenies are separated into early, medium, and late maturing groups and then selected and advanced at appropriate sites. Early materials are selected at the lower rainfall, more northern sites of Bema and Cinzana, while medium maturity materials are grown at Sotuba, Sougoula and sometimes Cinzana. Late maturing progenies are evaluated mainly in the southern, high rainfall sites of Farako (Sikasso) and Kita. Yield trials of advanced breeding lines also are divided into these three general maturity groups and corresponding sites. Yield tests typically involve Preliminary and Advanced Trials.

New breeding crosses are made annually, sometimes in the winter off-season. In 1998, 72 new crosses were made. From the F_2s planted at Sotuba, Cinzana, and Bema in the 1998 rainy season, 794 single-plant selection were made to advance by the pedigree method. Eighty-nine F_3 families (1986 entries) were grown at Sotuba, Cinzana and Bema with 609 panicles selected within 48 families at Sotuba, 228 panicles within 37 families at Cinzana, and 151 panicles within 25 families at Bema.

Also evaluated were F_4 and F_5 generations according to maturity group. The early F_4 progenies were evaluated at Bema and Cinzana. We selected 49 panicles at Bema among 12 families, and 114 panicles within 23 families at Cinzana. Medium F_4 progenies evaluated included 206 entries derived from 25 families at Sotuba and Kolombada. The 128 late F_4 progenies were evaluated at Farako and Kita. In the F_5 early materials, 10 families at Bema from 18 families, and 11 families in 12 families at Cinzana were selected. The medium F_5 progenies were evaluated and 19 lines derived from 9 families at Sotuba and 7 lines from 9 families at Kolombada were selected. A total of 14 lines were selected for late F_5 progenies at Longorola and Kita.

In the Advanced Elite Early Maturity Test, 32 entries were evaluated at Bema and Cinzana. At Cinzana, the highest yielding entry was 95-EPRS-GII-101 (Malisor 84-7*CE151) with 2271 kg ha^{-1}, while at Bema, 95-EPRS,GII-1047 (Bagoba*ECSV-1171) ranked first with 1500 kg ha^{-1}. The Advanced Elite Medium Maturing Test was grown at Sotuba, Kolombada, and Cinzana and contained 49 advanced breeding cultivars. The highest yielding entry of Kolombada was 95-EPRS-GII-1015 (Malisor 84-7*Nagawhite) with 2467 kg ha^{-1}. At Sotuba, 97-SB-F5-DT-138 ranked first with 3633 kg ha^{-1} followed by 95-EPRS-GII-1085 with 2967 kg ha^{-1}. At Cinzana, high variability resulted in no significant differences in yield. It was decided that 95-CZ-F4P-98 and 95-CZ-F4P-99, two previously promising lines derived from N'Tenimissa* Tiemarfing are too late maturing for the medium zone (Sudan) and would need to fit into southern Mali. In the Advanced Late Maturing Test with 14 breeding lines, the highest yield entry at Kita was 96-5B-CS-F6-4 (Malisor 84-7*IPS0001), while at Farako (Sikasso), 96-SB-CS-F6T-11 gave the highest grain yield.

Based on 3 years data from the Advanced Early Test three new lines, 95-EPRA-GII-105 (Malisor 84-5*CE151), 95-EPRA-GII-114 (ICSV-1079*Tx2883) and 95-EPRA-GII-1047 (Bagoba*ICSV-117), will be advanced to on-farm tests in 1999. Also, two new entries 98-SB-F2-78 and 98-SB-F2-82 both from ((Bimbiri Soumale* S34)*Malisor 92-2) will be tested on-farm. After 3 years of evaluation, 2 lines were selected from the Advanced Medium Maturity Test for on-farm testing in 1999, 95-EPRS-GII-1015 (Malisor 84-7* Nagawhite) and 95-EPRS-GII-1030.

Pearl Millet Breeding

A pilot protogyny hybrid program was initiated in collaboration with D.J. Andrews. The locally developed top cross hybrid (Civarex 9105*Trombedie) was produced by the protogyny method, which utilizes the difference in timing between stigma exsertion and receptivity and pollen production on the same panicle to achieve crossing. This method requires careful timing and a fairly uniform female. Production of hybrids is much easier if the parents are converted to a CMS system, but the A1CMS system does not work well where parents are populations, but the populations work well with the new A4CMS. The collaborative program is converting CVX9015 to an A_4 male sterile population (two backcrosses) and Trombedie to an R_4 population (the initial cross).

The Preliminary Test of 54 agronomically elite synthesis and varieties was grown at Cinzana and Koporo. At Cinzana, the three highest yielding varieties were F5G3 Sanioba 03*Youna 30, F5G4 Sanioba 03*Youna 30, and Indiana 05 *Sanioba03 with 4485, 4389, and 4048 kg ha^{-1} respectively, as compared to the local check with 3806 kg ha^{-1}. At Koporo the highest yielding variety was F5G23 Mil Labbe*Niou Kouniou OUGOU with 2151 kg ha^{-1}.

Entomology

Research activities for 1998 were focused essentially on head bug screening for identification of new resistance sources and the evaluation of plant extracts as insecticide.

Studies were conducted on resistance varieties (preliminary and advanced experiments) to head bugs at Sotuba Station, and in on-farm tests of six improved varieties in five villages (Ouendja, Sikouna, Seribougou, Segue and Sangoué) near Cinzana.

In the first preliminary experiment 93-EP-F6-GII-5 and 93-SP-EP-GII-1026 had better yield than Malisor 84-7, but the same head bug damage visual score of 1.5 while the varieties 93-SP-EP-F6-GII-15, and 93-SP-EP-F6-GII-27 scored 1.75. All had less grain mold than Malisor 84-7.

In the second preliminary experiment, 94-EPRS-GII-1136, 94-EPRS-GII-1016 and 94-EPRS-GII-108 scored 2 but their yields were similar to that of Malisor 84-7. In the third preliminary experiment, 95-EPRS-GII-1047, 95-EPRS-GII-1030 and 95-EPRS-GII-1014 had a lower head damage score than Malisor 84-7, but the same visual score to grain mold.

In the advanced experiment all six varieties (90-CZ-CS-TX-2, 90-CZ-CS-TX-12, 90-CZ-CS-TX-6, 90-CZ-CS-TX-1, PR 2566 (2-5) (7-9) and PR 2562) had similar resistance to head bug as the control Malisor 84-7.

The insecticide efficacy tests on head bug conducted at Sotuba and Cinzana Station showed that Decis and Diazinon were more efficient against head bugs than any of the three rates of phorbol ester.

Observations of head bug damage in on-farm trials again indicated much less head bug damage than on Research Stations. N'Tenimissa showed little to only mild damage on-farm, while it was extensively damaged on research stations. Sorghums, however, with high susceptibility to head bugs showed extensive damage on-farm even in the presence of apparently relatively low infestations. More research on the head bug ecology and damage in farmers fields is needed.

Pathology

Studies were conducted on anthracnose at Samanko (20 km west of Bamako), on seedling diseases at Farako (405 Km South) and Sotuba, and on covered smut at Katibougou (60 km north) and Cinzana (250 km northeast) during the 1998 rainy season.

Results on the screening of 67 sorghum breeding lines at Samanko indicated that only 2% of the accessions showed high resistant to foliar anthracnose (severity score ≤ 2), 80% were resistant (score $\geq 2 < 3$), 16% were susceptible (score $> 3 < 6$) and 2% were very susceptible (score > 6). Ratings of the grain for anthracnose indicated that 15% of the accessions were very resistant, 48% resistant, 30% susceptible, and 7% very susceptible.

Results on local plant pesticides confirmed the effectiveness of *Canavalia ensiformis* in controlling covered smut at three locations. At Katibougou, this plant species in combination with other local plants pesticides showed good control of smut during the 1998 rainy season and these plant parts will be tested again in 1999. *Canavalia ensiformis* and *Securidaca longipedonculata* are two indigenous plant pesticides being tested in on-farm trials and will soon be released to farmers for seed dressing products.

Agronomy/Physiology

Trials were conducted to test the effect of previous crop and different N rates on sorghum production in Mali. Sorghum was planted following peanuts, dilichos, cowpea, pearl millet, corn and sorghum at N rates of 0, 20, 40 and 60 kg ha^{-1}, and one treatment with 1 t manure. Two genotypes, CSM388 and N'Tenimissa were used. Results showed that sorghum yields were affected by the previous crop and genotypes. Corn was the best crop to follow and sorghum the worst. CSM388 out yielded N'Tenimissa an average of 449 hg ha^{-1} over all treatments. The positive effect of previous crop seemed to depend on its growth duration and/or its biomass production. Genotype CSM388 has higher nutrient uptake efficiency then N'Tenimissa, and this may account for the yield differences. There was a linear increase in yield in different N rates up to 60 kg ha^{-1}. No significant difference in yield was obtained from 1 t ha^{-1} manure over that of the control. Application of Malian rock phosphate increased overall yield by about 9%.

Studies were conducted to evaluate the effects and interactions of cropping systems and nitrogen rates on millet and cowpea yields. Among the cropping systems tested, millet yields in millet-cowpea rotation and in millet-cowpea intercrop were by far the best. Millet yield increases, due to rotation with cowpea led to 31% increase in biomass, 34% in heads, 29% in grain weight compared to continuous millet. All nitrogen treatments above 40 N kg ha^{-1} gave higher grain and head yield than those of the check and 20 N kg ha^{-1}.

Cowpea production in millet-cowpea rotation and continuous cowpea had the highest yield among all the treatments. There was a highly significant cowpea fodder yield response to nitrogen levels. There was no significant cowpea pod and grain yield response to nitrogen applications. Grain yields obtained from the use of public garbage manure, cow manure, compost of organic material are similar but greater than that of the check with a 45% yield increase. Millet residues management treatments did not influence yield.

Research in Mali and by the West and Central Africa Pearl Millet Research Network (ROCAFREMI) indicates 10 to 19% yield increase when rotating pearl millet with cowpea or peanut across the region, while other production practices appeared to be more site specific. 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.

Weed Science/Striga

Twenty-four selected lines from Dr. G. Ejeta, Purdue University were used in the *Striga* evaluation trials at Cinzana in 1998. The results did not show any statistical differences among entries but visual observations on *Striga* infestation at maturity indicted that the Purdue lines had very little *Striga* infestation.

Soil Toxicity/Acid Soils

In a study of adaptation of sorghum genotypes to acid soil conditions, several sorghum exotic genotypes, breeding lines, local cultivars, and improved varieties were tested for tolerance. The screening was conducted on plot F9 of the toposequence of the Cinzana station. The properties of the sandy, mixed, hyperthermic Plinthic Paleustalf soil were: clay % (5% in surface to 18% at 150 cm); pH (H_2O) (5.5 in surface 26 cm to 4.6 in 101-150 cm depth); Organic C (%) (0.13 to 0.16), CEC (0.90 in 0 to 35 cm, to 2.35 in 101-150 cm); and Al(%) (saturation in % of ECEC) (34 in 0-26 cm to 41 in 101-150 cm). Bagoba, OH 84-3/5, Gadiaba/cz, and El Mota were the most tolerant genotypes. At least 50% of the plants of these genotypes produced grain. These are local cultivars well adapted to low rainfall, acid, and sandy soils of Niger, Northern Nigeria, and Northern Mali. The first three cultivars are Durras, while El Mota is a Caudatum. However, they do not have acceptable grain quality traits for use in the major sorghum zones of West Africa where Guineense type sorghums are commonly used. Improved and exotic genotypes IS 9277 and MN 408 also showed some tolerance to this soil problem.

Improved and exotic genotypes included in this study have different abilities to stand acid soil conditions through accumulation of low or high concentrations of one or more of the following elements: Mn, P, Si, and Al. Future screening will include testing these mechanisms under different acid soils conditions (either sorghum, cowpea or peanut as preceding crop). In addition, promising sorghum genotypes of the on-going breeding program would be tested for tolerance to acid soil conditions.

Grain Quality/Utilization

Forty-eight samples of sorghum from Sotuba (Advanced Yield Trial EADT), 30 from Cinzana, 25 from Bema (97-BE-DT), 30 from Bema (EADT) and 24 from Mara were characterized by analyzing them for tô consistency, color vitreousness, one thousand kernel weight, density and ash. The parameters affecting grain quality were good in general. Decortication yield varied between 86% to 64%. Tô consistency and color were good for the majority of the samples.

Studies were conducted in cooperation with commercial bakeries in Bamako, two of medium size in Segou, one large scale confectionerie in Bamako (GAM) General Alimentaire du Mali, and six pastries. To produce the composite flour for evaluation sorghum (N'Tenimissa) grains were cleaned of stones and dirts, dehulled with a plate mill, washed and sun dried. The dried grains were milled in a Cormall Grinder which is a hammer mill and then sieved (about 120 mesh). Composite flour was made as follows: bread - 80% wheat, 20% sorghum; snacks - 80% wheat, 20% sorghum; 70% wheat, 30% sorghum; 60% wheat, 40% sorghum.

Marketing of products was done with the assistance of Food Technology Laboratory because the bakeries/confectioneries were unwilling to market the products through their established marketing channels as a result of change in product. Questionnaires were administered to determine consumers response on the products (organoleptic tests) and reaction of the bakeries/confectioneries on the suitability of using sorghum composite flour for baking. Profitability of using wheat/sorghum composite flour was determined using input-output and cost-benefit analysis.

Bread and three confectionery products (cakes, doughnut and buns) were pilot produced in the Food Technology Laboratory (LTA). The same products were produced by the bakeries and confectioneries. Organoleptic tests were conducted on the products. The same products were then produced by the bakeries and confectioneries.

The results show that bread of acceptable quality was produced from wheat flour substituted with 15% sorghum flour. The organoleptic assessment among consumers in Bamako and Segou for appearance, taste and smell of the bread rated well. Even though the smell was rated well there was a tint of raw sorghum smell. Texture was rated low due to the coarse nature of the sorghum flour which was not as fine as the wheat flour. Generally 78% of the test population accepted and were prepared to buy the bread if produced on a regular basis compared to 22% who declined to eat bread produced from composite flour. Seventy percent rated the overall quality of bread produced from 80:20% wheat/sorghum composite flour as either very good or good.. Shelf life varied between 1-2 days compared to 2-3 days of bread from pure wheat flour. Acceptability of snacks were higher than for bread. The principal organoleptic parameters were rated very high (>60%) for the three snacks.

It was observed by the bakeries that the bread from the composite flour rises well however tends to collapse as it is fed in the oven thereby decreasing in size. Bread was not as spongy and therefore breaks more easily than bread from pure wheat. A third problem is the fineness of the flour.

On-Farm Trials

IER scientists conducted on-farm trials of early maturing, medium maturing, and late-maturing cultivars. Results were not very reliable, and mostly non-significant, with rather low yields. Generally, the local check yielded about the same as the improved cultivars. Results from the World Vision on-farm trials in the Bla area were not available.

Socio-Economic

In Bakary Coulibaly's M.S. research in Mali on the effects of devaluation on food consumption patterns in urban Bamako, it was found that sorghum and millet were substitutes for imported rice and wheat, but were not substitutes for domestic rice. The amount of substitution was small, and the overall change in the consumption pattern was modest. The substitution could not be explained using relative price changes since the net effect of devaluation and changes in rice tariffs was to increase the relative price of sorghum and millet to rice. The substitution is explained with changes in household income, which declined with devaluation. Lower incomes caused households to increase consumption of the traditional cereals since they were still cheaper than rice in absolute terms. 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.

Several new sorghum and millet technologies have been developed and tested in Mali. Results from agricultural stations and on-farm trials have been well documented and show that large yield increases can be expected from the new technologies. Previous INTSORMIL research by Ousmane Coulibaly has shown that the new technologies increase producers' incomes and that the potential for adoption exists. To date, however, adoption of the new technologies remains minimal.

The on-going Ph.D. research by Jeff Vitale in Mali is to determine the economic impacts of alternative policies for increasing the adoption of sorghum and millet technologies. The policies include expanding the seed supply industry, improved rural infrastructure, and increased cereal demand from rising incomes and from expanded processing activities.

In a study across semi-arid Sub-Saharan, it was found that 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 apparently will be necessary for substantial yield increase. Improved cultivars alone are unlikely to have a significant sustainable yield effect to reduce poverty in semiarid Sub-Saharan Africa.

Technology Transfer

Two surveys in the Segou region showed that the technology adopted to the greatest extent was use of the seed treatment Apron Plus® on pearl millet which improves stand establishment and reduces downy mildew problems. In one of the surveys the communities 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. It was concluded that greater 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.

Mutual Benefits

All research results reported should benefit Mali and surrounding countries of West Africa where similar production constraints occur. The use of the tan-plant N'Tenimissa should have benefit in the Guinea growing areas of West Africa. Information on sources of improved food quality and food type sorghums should be useful in improving overall quality of U.S. sorghum grain. Several Malian breeding lines show excellent grain yield potential, leaf disease resistance, and excellent grain quality in Central America, Puerto Rico, and South Texas.

Institution Building

INTSORMIL provided various field and laboratory research equipment including computers, printers, pollinating bags, and breeding supplies to the IER collaborate program. Training in computer use was provided by G.C. Peterson.

Several Malian students at INTSORMIL institutions will make important contributions upon their return to Mali. Dr. M. Diourte in pathology at KSU and Dr. N. Diarisso in entomology at TAMU returned to Mali in 1997. Mde. Salimata Sidibe Coulibaly returned with a M.S. in food technology from North Carolina A&T and is now working in the cereal technology lab. The soil research component in IER was strengthened with the return of Dr. M. Doumbia (M.S. and Ph.D.-TAMU, Soil Management CRSP) who is now Director of the IER Soil Laboratory. Samba Traore (Ph.D.-UN) returned to Mali the early summer of 1999.

Students in training include Mamadou N'Diaye at Ohio State in entomology, Niabe Teme, completing his B.S. and then M.S. at Texas Tech, and Sidi Bekaye Coulibaly at Texas Tech/Texas A&M in breeding, in July 1998. Adama Coulibaly (M.S.-KSU) assumed the responsibility of Minamba Bagayoka in millet agronomy, and is the National Coordinator in Mali for pearl millet.

Funding from INTSORMIL for training of Dr. Moussa Traore (Ph.D.-Nebraska) former physiologist and Mali Country Coordinator, and former Permanent Secretary to Minister of Agriculture was huge in the reorganization and current operation of IER. The contribution of Dr. Oumar Niangado, former Director General of IER, has also been significant. He is a former INTSORMIL collaborator and millet breeder, and was instrumental from the beginning in INTSORMIL's collaboration in Mali. Dr. Aboubacar Touré, Ph.D. from TAMU in breeding is currently serving as INTSORMIL Country Coordinator, is a member of the INTSORMIL Technical Committee, and is also Head of the Mali national sorghum program.

INTSORMIL travelers to Mali during the year included: Drs. D.T. Rosenow and G.C. Peterson, sorghum breeders; Dr. G.L. Teetes, entomologist; all from Texas A&M; Drs. J.D. Maranville and S.C. Mason, agronomists and Prof. D.J. Andrews from Nebraska; J.H. Sanders, economist, from Purdue. Dr. John Yohe, INTSORMIL Program Director, Dr. John Swanson, USAID (Washington) INTSORMIL Project Manager, and three INTSORMIL External Evaluation Panel (EEP) members, Dr. Richard Hahn, Dr. Larry Busch, and Dr. Walter De Milliano also visited Mali. Dr. R.A. Frederiksen conferred with his Malian collaborator at the Hybrid Seed Workshop in Niger.

Networking

The research accomplishments in Mali are immediately and directly transferable to most countries in West Africa. Work on sorghum and millet food technology applies to Africa and many areas of the world. Head bugs are common to West Africa while drought and grain mold are world-wide problems. Exchange of elite germplasm with useful traits is an excellent means of networking among breeders.

Efforts are underway to utilize existing networks to extend technology to the region in both sorghum and millet. Steve Mason has participated in the ROCAFREMI (pearl millet network) meetings to develop collaborative activities with the millet network. Jerry Maranville and Darrell Rosenow have represented INTSORMIL at the WCASRN (sorghum network) General Assembly meetings and Darrell Rosenow has visited with the Steering Committee and Coordinator. These contacts resulted in a MOU between INTSORMIL and WCASRN being signed in mid 1997 establishing guidelines on collaboration. The new tan-plant Guinea cultivar developed in Mali was entered in the WCASRN trial over West Africa in 1997 and 1998.

All key Malian scientists traveled to Niger, September 25 - 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. Berthe, Aboubacar Toure, 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 and regional INTSORMIL - Host Country activities.

There has been a long history of collaboration with ICRISAT in Mali, and collaboration has been excellent with Drs. H.F.W. Rattunde, J.C. Chantereau, and A. Ratnadass. Arrangements were made to procure seed for the planting, seed increase, and characterization of the Mali Indigenous Sorghum Collection in Mali in 1997, in a collaborative effort among INTSORMIL, IER, ICRISAT, ORSTOM (France), CIRAD (France) and USDA-ARS. Seed was obtained from ICRISAT (India), ORSTOM (France), USA, CIRAD, and Mali programs (IER and ICRISAT), arranged, and packaged and planted at both the Cinzana Station and Samanko (ICRISAT Center) in 1997. The Collection was characterized, and selfed seed harvested, and seed was carried to the USA for introduction. The seed has all been catalogued and is being prepared for a quarantine growout seed increase, and completion of characterization in St. Croix the winter 1999-2000.

The identification of molecular markers for head bug resistance is another collaborative activity involving the Rockefeller Foundation (which funded Dr. Aboubacar Toure as a Post Doc with Texas A&M, but worked in a biotech lab at Texas Tech), INTSORMIL, CIRAD, and ICRISAT (A. Ratnadass). The CIRAD component in France utilizes a biotech lab in France. The populations were screened for head bug resistance at Cinzana, Sotuba, and Samanko, and jointly evaluated by IER, INTSORMIL, and ICRISAT/CIRAD scientists. The identification of useful markers could have a major impact across West Africa where head bugs are a serious problem.

World Vision conducted on-farm trials in 1996 using N'Tenimissa as well as some *Striga* resistant lines from Purdue. Collaboration with World Vision increased in 1997 and 1998 with the implementation of the new InterCRSP (INTSORMIL, Bean-Cowpea) West African Project on Technology Transfer. Newly developed cultivars will be broadly distributed and evaluated in on-farm trials.

Research Accomplishments

INTSORMIL has been in Mali informally since November of 1979, with a formal MOU signed with IER in 1984. The program has interacted with ICRISAT-WASIP, WCASRN (ROCARS), ROCAFREMI, TROPSOILS, IER, Ceiba-Geigy, and CIRAD. USAID-Mali has supported the program in the past with moral and financial support. A significant accomplishment has been a major improvement in the capability of IER to conduct sorghum/millet research in Mali. IER is recognized as having one of the best overall sorghum/millet research programs in Sub-Saharan Africa. Accomplishments for the entire life of the project have been detailed in previous annual reports with some key items highlighted here along with new results:

- 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 effort upon yield.

- Research by ROCARFREMI indicates a 10 to 19% yield increase when rotating pearl millet with cowpea or peanut across Mali, while other production practices appear to be more site specific. This research also showed grain yield increases due to 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.

- The cultivars Bagoba, OH 84-3/5, Gadiaba/CZ, and El Mota were the most acid/toxic soil tolerant genotypes. IS9277 and MN 4508 also showed some tolerance.

- The Mali Sorghum Collection (2,543 plots) of indigenous cultivars from Mali was successfully grown in 1997, was characterized and seed increased and packaged for distribution. A smaller tentative Working Collection was identified. There was greater diversity in the collection than anticipated. The entire Collection will be grown in quarantine at St. Croix in Winter 1999-2000, seed increased, and characterization completed.

- The new white-seeded, tan-plant Guinea type breeding cultivar, N'Tenimissa, performed well in on-farm trials. Its yield is equal to or slightly superior to the local checks. It had good farmer acceptance regarding yield and food use, even though it does show some peduncle breakage. It is not quite as good as local cultivars in head bug resistance, but based on observation in on-farm trials it appears to be good enough at the on-farm level.

- Grain quality analysis of N'Tenimissa shows it to be intermediate in decortication yield and hardness between local cultivars and non-guinea breeding lines. Tô color and consistency were equal to that of locals.

- Two new white, tan, true Guinea breeding lines were identified, 96CZ-F4-98 and 96CZ-F4-99, from the cross (N'Tenimissa * Tiemarfing), and seed increased for on-farm evaluation in 1998. These appear equal to locals in grain traits, but with tan-plant color. They are too late for the middle zone at Mali.

- Several mutant-derived Guinea type, breeding lines developed by the Dr. Alhousseini Bretoudeau, a geneticist at the Agriculture School at Katiabougou, showed promise for nitrogen-use-efficiency and grain yield.

- Rotation of pearl millet with cowpea again increased grain and stover yield as reported in previous years. Crop rotation combined with low amounts of nitrogen fertilization results in the most efficient use of fertilizer nitrogen.

- Seven-year averages show that crop residue incorporation slightly increased pearl millet grain and stover yields, while crop residue removal adversely affected cowpea yields.

- 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.

- World Neighbors' employees indicate widespread adoption of an early season improved (mass selected) sorghum (CSM219) and three improved pearl millet cultivars (IBV8001, Composite Souna Sagnon, and Benkadinyo) in the Segou area. They also reported farmer use of improved manure management and improved intercropping systems.

- Bread made with 5-10% N'Tenimissa sorghum flour was preferred over wheat/corn flour. Cookies made with 5% and 10% N'Tenimissa flour by GAM were good quality regarding taste, but the manager had some concern over black specs in the product, apparently due to some mixture with grain from non-tan-plants. Some women associations and small entrepreneurs are processing sorghum crunch for selling.

- Several *Striga* resistant lines from Purdue evaluated in Mali showed good *Striga* resistance, but had inferior grain quality compared to local cultivars.

- F_3 progeny of the cross (Malisor 84-7 * S-34) for molecular marker analysis of head bug resistance showed excellent differentiation for head bug damage.

- Nine new sorghum breeding progeny showed head bug resistance equal to that of Malisor 84-7.

- 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.

- INTSORMIL trainees are now in key administrative and research positions in Mali.

- The adverse effect of head bugs on the grain/food quality of sorghum across the guinea type sorghum growing area of West Africa was first recognized and documented in Mali.

- Head bugs and grain molds combine to cause devastating loss in grain yield and quality especially of introduced types.

- 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.

- An easy, efficient method of screening for head bug resistance using bagged vs. non-bagged heads has been developed and can be used to evaluate a large number of entries with little effort.

- 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 possess excellent guinea traits and yield potential.

- *Striga* resistance using lab screening to *S. asiatica* in the USA works under field conditions to *S. hermonthica* in Mali.

- Genetic tolerance to low pH related soil toxicity problems has been demonstrated, and tolerant varieties identified (Bagoba, Babadia Fara, and Gadiaba).

- Crop rotation of pearl millet (or sorghum) with cowpea (or peanut) enhanced grain yield of pearl millet (or grain sorghum) = 25% (17 to 30% Range), and cowpea (or peanut) = 5% (0 to 16% Range).

- Intercropping pearl millet (or sorghum) with cowpea (or peanut) increased land use efficiency by 14% (9 to 37% Range).

- Without fertilizer application, all tested cropping systems (including legume rotations) mine the soil of nutrients.

- Application of N fertilizer and P fertilizer increases pearl millet (and sorghum) grain yields. [Example: 40 kg ha^{-1} N increased pearl millet grain yield at Cinzana by 17% (6 to 35% range)].

- Nitrogen use efficiency (NUE) of improved sorghum cultivars has been better than local cultivars at higher N rates, while local cultivars had better NUE at zero and very low N rates.

- The combination of cowpea and millet flour (1-3) significantly improved the nutritional status of young children. This technology has been transferred to villages, especially in the Cinzana area.

- Parboiling can convert sorghum and millet into acceptable shelf-stable products.

- Mileg, a weaning food using primarily millet flour has been developed by private enterprise and marketed in stores in the Bamako area. The product was developed using technology developed in the IER Cereal Technology Laboratory.

- 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 & Niger Country Coordinator, Agronomy Department, Lilly Hall, Purdue University, W. Lafayette, IN 47906

Collaborative program

INTSORMIL/INRAN hired an administrative assistant, Ms. Guimba Nana Maimouna, 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), and analyzing interactions between input-output market development and adoption of new millet and sorghum technologies in Niger.

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 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 is supervising 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 September 28 through October 2, 1998 in Niamey. Participants included representatives from various NGOs and PVOs, NARS and CGIARs, as well as seed producers and seed production specialists from the U.S., India, Zambia, Nigeria, Burkina Faso and Niger.

Partial funding support was also provided by the McKnight and Rockefeller Foundations, the W. African Regional Sorghum (ROCARS), Millet (ROCAFREMI) Networks and ICRISAT.

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 submit a preliminary budget which is then incorporated within the total country program in consultation with the INRAN country coordinator.

Sorghum/Millet Constraints Researched

Production and Utilization Constraints

Drought, insect pests, long smut and *Striga* are the major constraints in Niger. Extremely high soil temperature leads 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 tuwo preparation.

Research Methods

The collaborative research program in Niger includes the following: sorghum and millet breeding, entomology, agronomy, pathology, physiology, food quality, and economics. Research methods appropriate for each of these disciplines are used for this research program.

Examples of Research Progress

Cereals Quality and Processing - M. Oumarou, M. Maiga, A. Aboubacar, and B. Hamaker

The couscous processing unit fabricated at CIRAD, France, is installed in the Cereal Quality Laboratory (LQC) at INRAN. The unit consists of a flour agglomerator (rouleur), a solar dryer, a couscous steamer, and a plastic sealer for packaging. The unit is being used to improve processing techniques to produce good quality couscous from millet and sorghum and mixture with peanut and other legumes. The unit has also been used as a demonstration and testing tool to local entrepreneurs who are interested in commercial production of couscous.

Studies on sorghum and millet couscous using the couscous processing unit continued this year. Two studies were conducted: the first, on the influence of flour-to-water ratio on couscous granule size distribution, and the second on improvement of flour and couscous color through fermentation. Flours from two sorghum cultivars (NAD-2 and Sepon-82) and two millet cultivars (Souna III and HKP) were used. Flours were produced manually using a mortar and pestle - decortication and milling at commercial mills were avoided because of the difficulty in obtaining pure flour due to contamination by flours from other sources.

Results of the first study indicate that the proportion of couscous of a particular granule size that can be obtained with the rouleur (flour agglomerator) is strongly influenced by the amount of water used for agglomeration and by cultivar type. It was previously reported (1997 report) that the manner of couscous consumption used in Niger varies according to granule size. The findings of this study suggest that by controlling the amount of water for flour agglomeration, couscous of desired granule size can be produced and marketed separately.

In the second study, fermentation was found to considerably improve the color of couscous from the millet cultivars and Sepon-82, whereas it had little effect on the color of NAD-1 couscous.

With funding from INTSORMIL, a grain decorticator and flour mill fabricated at URPATA (Senegal) have been purchased and are to be installed at the INRAN Cereals Laboratory.

Sorghum Breeding/Hybrid Seed Activities - Dr. Issoufou Kapran, Habou Kano, Siraji Moumouni, Sabiou Mahaman, Dr. Issaka Mahaman, Illa Bawa, Moussa Oumarou, Dr. Lee House, Dr. D.T. Rosenow, Dr. D. Andrews, Dr. B. Hamaker, Dr. John D. Axtell, Dr. Gebisa Ejeta

Sorghum improvement through breeding of early maturing and high yielding hybrids and varieties remains high priority. High yields are needed to cope with the food needs of a growing population in an environment where the cropping season is erratic and local varieties low yielding. Constraints facing sorghum production include drought, poor soils, insect pests (especially midge and headbugs), disease including long smut, and *Striga*. It is also very important that improved materials have acceptable food quality for preparing local food products as well as for the context of commercial food products.

For the past five years we have identified seed production as a key area for the breeding program for strengthening a sustainable sorghum production in the country. Therefore in 1998, there was an emphasis on seed-related activities while a few trials and observation nurseries were conducted on station.

Hybrid Seed Production

- **training in hybrid seed production techniques** was organized at six different locations across the country, and was attended by more than 200 participants coming from farming communities as well as research and extension stations. Trainees clearly appreciated the opportunity and indicated in a questionnaire which topics deserved more emphasis for future sessions.

- **production of parental seed** is essential for hybrid seed production to expand. The female parent of NAD-1 hybrid was increased at the INRAN Lossa station as well as at Jirataoua where farmers were contracted. In total more than three tons of A-line seed were harvested, cleaned and stored for the 1999 growing season. This represented an insurance of hybrid seed production over more than 300 hectares.

- **NAD-1 hybrid seed production** was undertaken by private individuals, farmer cooperatives, and the research station. Total production was estimated in the ten tons of which two were produced by INRAN. This was below expectation for current needs, however production was steadily moving from research into private hands. This activity underlined the needs for a great number of technicians to help farmers, for farm machinery to improve and expand land own by most of the producers, and for infrastructures leading to better handling and storage of seed produced. Nevertheless it was noticeable that field techniques for hybrid seed production were quickly being mastered by farmers, for example at the Jirataoua irrigated perimeter seed yield was superior to 1.7 t ha^{-1}.

- **a workshop on hybrid sorghum and millet seeds** was organized in late september at Niamey and proceedings are in progress. Beyond the successful attendance by experts from many west african countries, from the USA, France, and India, the workshop focused the attention of local people and government on the availability of improved varieties and seeds for increased food production. Increased requests for hybrid seed and for training in seed production were sent to INRAN following the workshop.

Sorghum trials and breeding nurseries

- **nursery of new sorghum hybrids**: despite the superior performance of NAD-1, we are actively looking for new hybrid combinations, to offset the low visual quality of NAD-1 in heavy rainfall areas, and to find earlier maturing hybrids for more dryland farming, and with parents that nick better for possible dryland seed production. Hybrids from various sources as shown in Table 1 were placed in observation nurseries at different locations .

- Genotype x planting date influence on long smut infection: long smut disease is a problem in the dry environment of Niger, and from empirical observations it may be more serious on female parents in hybrid seed production fields. We were interested in learning whether the susceptibility of the female parent of NAD-1 was (totally) genetic or if an escape mechanism would be available through planting dates. A trial was conducted at Maradi/SEHA with four replications and six entries including two A-lines, two hybrids, one R-line, and a local check. Planting was done every two weeks between June 1 and August 15, i.e., six plantings. The design was a split-plots with dates as a main factor and entries within dates as subfactor. Data consisted of flowering dates, number of infested panicles and grain yield in each plot. Preliminary results for three entries and three planting dates are shown in Table 2.

These results suggest that no entry was immune but ATX623 appears to be more susceptible. This result confirms empirical observations. In addition there is a tendency towards an increase in the level of infection with later planting dates for all entries. Impact on grain yield remains to be established, however it would appear important to breed for resistance because later planting dates are actually preferred for the purpose of seed quality (maturity after rains).

Mutuality of Research Benefits

Use of drought tolerant materials from Sahelian countries, including Niger, have been used extensively by the private and public sectors in the USA. The principal benefit to Niger will be an efficient and productive research program at INRAN through training and collaborative research activities of INRAN staff.

Institution Building

The Cereals Laboratory at INRAN has now been equipped with a flour mill and decorticator to optimize the quality of the flour to improve the quality of the couscous. Two varieties of sorghum (NAD-1 and Sepon 82) and two varieties of millet (SOUNA III and HKP) have been screened for their couscous making abilities.

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.

Table 1. Sorghum hybrids placed in observation nurseries in Niger in 1998.

Designation	Source	Number of entries	Location
Purdue A-lines × INRAN R-lines	INRAN	17	Lossa, Kollo, Maradi
Purdue & Nebraska A-lines × MR732	Purdue Nebraska	10	Lossa, Konni, Maradi
Food grain hybrids from Purdue	Purdue	54	Lossa, Kollo
Food grain hybrids from TAMU	TAMU	50	Lossa, Kollo
TOTAL		131	

Table 2. Influence of sorghum genotype and planting date on long smut infection.

	ATX623	ABON34	MR732
Ave 50% fl.	68 days	75 days	77 days
Date of planting		Infested panicles (%)	
June 1	9	29	5
June 15	25	6	5
July 1	40	8	21
July 15	42	24	39
Average infestation	29	17	18

Several US PIs and INRAN trainees traveled to Niger:

Lee House	7/16/98 – 08/07/98
David Drake	9/26/98 – 10/08/98
Katy Ibrahim	9/22/98 – 10/14/98
Hama Boukary	9/22/98 – 10/03/98
John Axtell	9/22/98 – 10/03/98
Lee House	9/22/98 – 10/10/98
Gebisa Ejeta	9/22/98 – 10/03/98
Bruce Maunder	9/22/98 – 10/03/98
Bruce Hamaker	9/22/98 – 10/03/98
John Sanders	2/22/99 – 02/27/99
Adam Aboubacar	9/22/98 – 10/03/98
Bruce Hamaker	3/16/99 – 03/20/99
Tahirou Abdoulaye	9/22/98 – 10/03/98
Lee House	5/20/99 – 06/05/99

Currently, there are four Nigerien students being trained in U.S. institutions. They include: Adam Aboubacar, Post-doctorate Food Sciences, with B. Hamaker at Purdue; Kadi Kadi, M.S. entomology, with F. Gilstrap and George Teetes at TAMU; Issoufou Kollo Abdourahmane, Ph.D. pathology, with R. Frederiksen at TAMU; A. Tahirou, Ph.D. agricultural economics, with J. Sanders at Purdue University.

Networking

The major constraint for adoption of new technologies in W. 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. INTSORMIL's major contribution was the W. African Regional Hybrid Seed workshop which was held in Niamey September 27 to October 2, 1998. This workshop highlighted the important contribution that can be made by a seed industry and offered opportunities for W. African countries to share experiences. One of the major foci of the meeting will be hybrid seed production for sorghum and millet as well as other crops.

Research Accomplishments

Entomology - Mr. Hamé Abdou Kadi Kadi, Dr. Ousmane Youm, Dr. Frank E. Gilstrap, Dr. George L. Teetes, and Dr. Bonnie B. Pendleton,

During Year 20, main activities were academic types, including courses and thesis writing and defense for fulfillment of the requirements for a Master of Science degree at Texas A&M University. As part of a larger research effort to assess the impact of natural enemies on millet head miner abundance, life table analysis was used to improve understanding of the biology and distribution of mortality of millet head miner in the laboratory. Millet head miner survival and development were compared under controlled conditions in the laboratory and in exclusion cages in the field. Drs. Gilstrap and Youm provided full support for research conducted at ICRISAT-Niger during Year 18 and 19. Financial support from Texas A&M/Entomology (INTSORMIL/TAM-225B) was used for thesis research and writing. Dr. Youm, ICRISAT entomologist, allocated the research facilities (field, laboratory equipment, and supplies) and other local support needed. Drs. Teetes and Pendleton, entomologists at Texas A&M University, provided valuable advice, office and computer access, administrative and financial support throughout graduate studies. Some administrative, financial, and logistical support was provided by INRAN-Niger.

Millet Constraints Researched

Millet production constraints

Millet head miner, *Heliocheilus albipunctella* de Joannis, has been the major insect pest of pearl millet, *Pennisetum glaucum* (L.) R. Br., since 1972-1974. Millet head miner larvae bore in spikes of pearl millet and cause severe crop loss, as much as 81% in Niger, and low millet grain quality. Grain loss was estimated at 6% for pearl millet variety 'IVSP-78' (Guevremont 1982). Different management tactics have been tested, including cultural and chemical controls, to reduce damage by millet head miner in West Africa (Gahukar et al. 1986). However, most management tactics are impractical or expensive. Therefore, finding alternative strategies are important for managing millet head miner in the Sahel.

Materials and Methods

Research was conducted during the 1996 and 1997 cropping seasons at the ICRISAT Sahelian Center in Niger.

Laboratory Studies

Laboratory research focused on assessing survival and development of millet head miner cohort reared only on Bio-Serv® # 9782 diet and three millet-based diets (i.e., early exserted millet, middle-flowered millet, and soft-dough millet). Experiments were conducted using adults (1♀:1♂) from a laboratory colony or captured in light traps. Adults were placed in oviposition cages containing freshly cut millet spikes as stimulant for females to oviposit eggs. Collected eggs were held in a petri dish for hatching. Using a brush, larvae were put individually in plastic cups containing 15 ml of artificial diet and/or millet-based diet. Survival, fecundity, oviposition period, and cohort development of millet head miner were assessed until individuals died. Rearing chambers were maintained at 24, 26, 28, and 30 ± 1°C, a photoperiod of 12:12 (L:D), and 70% RH.

Field Cage Exclusion Studies

Seed of 'HK' was planted in a field on three different dates. Exclusion cages were used to assess millet head miner survival, fecundity, and cohort development in exclusion cages in the field. Wire framed cages were 70-90 cm long x 30 cm diameter and covered with fine cotton-mesh screen. Each cage was placed over a selected spike at the booting stage 24 hours prior start of experiment. A pair (1♀:1♂) of millet head miner adults from laboratory colony was released into the cage at sundown to coincide with the time millet head miner adults become active in the field. Daily, a dissecting microscope was used to examine cut spikes for eggs. Survival, fecundity, length of oviposition period, and cohort development of millet head miner in the cage were assessed until individuals died.

Another experiment was conducted by placing each cage over a spike exserted 5-10 cm. Spikes were infested artificially at different times with laboratory-collected eggs. A brush was used to place eggs within each millet spike to avoid eggs accidentally being dislodged. Spikes were checked to assess the number of eggs that hatched. Mean cohort development and number of days of survival for millet head miner were estimated on pearl millet spikes.

Research Accomplishments

Laboratory Studies

Longevity of millet head miner females was longer and more affected by temperature than was that of males. Millet head miner females reared in the laboratory at 24°C, the coolest temperature tested, lived a mean of 4.0 days, 0.8 day longer than the male longevity of 3.2 days. The longevity of females declined by ≈ 0.2 day for each 2°C increase in temperature. Oviposition period of millet head miner was significantly longer at 28°C, 3.2 days, than at 24°C, 2.3 days, or 30°C, 2.7 days. Females in the laboratory tended to oviposit more eggs at higher than lower temperatures, but not significantly more. During both years, many eggs were oviposited and hatched at 28°C in the laboratory.

When millet head miner cohorts were fed Bio-Serv® diet, mean developmental times in days from eggs to adults were less at 28 and 30°C. More individuals of millet head miner cohorts survived when fed Bio-Serv® than any of the millet-based diets. Survival to the adult stage was greatest (5.4%) at 30°C. When fed early exserted millet diet, mean developmental time from eggs to adults was least and percentage of survival greatest, 2.3, at 26°C than at the 3 other temperatures. Developmental times were shortest and survival greatest when millet head miner cohorts fed middle-flowered millet diet were reared at 28 and 30°C. Millet head miner cohorts fed soft-dough millet diet developed fastest and survived best to the adult stage when reared at 24°C.

Developmental times from eggs to adults were longest (51.1-55.4 days) when millet head miner cohorts were fed Bio-Serv® diet and shortest (40.2-50.2 days) 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 exserted millet diets, respectively. 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. The next best diet to rear millet head miners could be soft-dough millet diet at 24°C because only 40.2 days were required for cohorts to develop and 2.6% of the cohort survived to become reproductive adults.

Field Cage Exclusion Studies

Millet head miner females and males survived in exclusion cages in the field for 3.1-4.0 and 3.2-3.8 days. Each female oviposited means of 29.6 and 44.9 eggs in 1996 and 1997, but the number of eggs oviposited differed by the time pearl millet was planted during the season. Fecundity of millet head miner in the field was 2-4 times lower than that in the laboratory. Mean numbers of days of oviposition in the field, 2.4 and 3.1 days in 1996 and 1997, respectively, were similar to those in the laboratory.

In 1996, mean percentages of survival of different millet head miner life stages were greater on early (33.6%) than late-planted pearl millet in the field (16.8%) but less than the 66.8% estimated under controlled conditions in the laboratory. Developmental time from eggs to neonates required only 5.0 days on pearl millet planted on 6 June or late, 7 July. But, a significantly longer developmental time of 6.9 days was required for millet head miner on pearl millet planted on 21 June.

Most eggs developed into medium larvae (18.8%), prepupae (5.6%), and pupae (1.8%) on pearl millet planted on 6 June 1996. Developmental times were longest on pearl millet planted 6 June — 13.7 days to medium larvae, 22.2 days to prepupae, and 27.8 days to pupae. Millet head miner required a similar number of days (24.3) to develop to prepupae in the laboratory.

In 1997, the percentage of neonates that developed was inversely proportionate to the amount of eggs placed on a pearl millet spike. Percentages of eggs that developed into neonates were greater, 89.0 and 92.5 and 96.0 and 91.5, when 5 and 10 eggs were placed on spikes of pearl millet planted on 23 June and late, on 16 July, respectively. When 15 or 20 eggs were placed on spikes, 70.5-77.0% survived to become neonates on pearl millet planted in the field on the 3 dates. These percentages were similar to that estimated in the laboratory, 66.8%. Developmental times from eggs to neonates were 5.0-6.7 days on pearl millet planted in the field on the 3 dates in 1997.

Percentages of eggs that developed into medium larvae, 47.0-73.0, prepupae, 26.3-54.5, and pupae, 6.5-21.3, were greater on pearl millet planted 23 June than on pearl millet planted later in 1997. In the laboratory, 41.3% of millet head miner developed into medium larvae.

Suitability of food and environmental conditions affected fecundity and development of millet head miner in the laboratory and 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%. In the field, time pearl millet was available influenced millet head miner cohort survival and developmental times. 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 recommendable management tactic to reduce survival and damage by millet head miner in the Sahel.

Cereals Quality and Processing - Mr. Moussa Oumarou, Mr. Kaka Saley, Mr. Moustapha Moussa, Drs. Genevieve Fliedel, Issoufou Kapran, B. Hamaker and Adam Aboubacar

Sorghum and Millet couscous are prepared and consumed daily among most families in Niger and other parts of West Africa, but the local quality and the quantity cannot meet the demand.

The progressive urbanisation and the devaluation of the CFA have created high demand for local food products, therefore a processing technology is urgently needed to promote the production and consumption of sorghum and millet couscous which have specifications desired by consumers.

The cereal lab at INRAN and the Food Science Department at Purdue University have initiated a small processing unit for research on sorghum and millet couscous, in order to identify sorghum and millet varieties that can be processed into couscous and also the possibilities of optimizing efficiently the processing equipment.

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.

Specific Objectives

Improve the quality of the flour using modern decortication and milling techniques.

Optimize the couscous agglomerator. The rationale is to increase couscous quality, yield and also the possibility of reducing the cost of the agglomerator.

Increase the capacity of drying the flour and the couscous.

Develop a marketing plan to transfer the technology to the beneficiaries.

Materials and Methods

Decortication and milling have been carried out manually.

Mixing of flour/water was done with a food mixer (Kenwood electronic) and mixing time was 3mn/kg of flour. Granulation has been carried out with the agglomerator (telemecanic, CIRAD) adjusted at 36 rpm and the granulation time was about 4mn/kg.

Cooking stove using butane gas with a couscousier (Nigeral) has been used to steam the couscous for 30mn and a solar dryer (ONERSOL) was used to dry the flour and the steamed couscous for 48 hours.

The average values of the parameters determined are summarized in Table 3.

The study revealed the possibility of processing sorghum and millet couscous. Still efforts will have to be made to optimize efficiently the processing equipment, to complete the product development and to initiate a marketing test. Such initiative may be a starting point for innovation, promotion and consumption of sorghum and millet couscous of good quality.

Table 3. Average values of parameters determined.

Parameters	Samples			
	NAD-1	Sepon 82	Souna III	HKP
Yield of decortication (%)	73	67	70	69
Yield of dried flour (%)	50.14	55	54.84	58
Particles size of dried flour (mm)	0.1-0.2	0.1-0.2	0.1-0.2	0.1-.02
Ash Content of flour (%)	1.2	0.97	0.81	1.07
Hydration of flour approximate. (%)	58-65	60-72	45-55	50-55
Particles size of couscous (%)	1-2	1-2	1-2	1-2
Yield of dried couscous (%)	65.2	73.82	83.47	72
Moisture of dried couscous (%)	6.67	6.65	6.83	7.09

The ongoing research has been presented at the technological exhibition in Burkina Faso from March 30th to April 5th, 1998 and at the Regional Hybrid Seed Workshop organized by INRAN/INTSORMIL/ICRISAT from September 28th to October 2nd, 1998.

Economics - Tahirou Abdoulaye and J. Sanders

During this fiscal year, our activities included participating in the Regional Hybrid Sorghum and Pearl Millet Seed Workshop in Niger; presenting a paper at the USAID sponsored conference at Iowa State University; and thesis research work

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[1] 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 USA 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 has completed his course work for the Ph.D. program. His 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.

A journal article was submitted to Agricultural Systems by Tahirou Abdoulaye and J. Lowenberg-DeBoer. The article is from Tahirou's Master thesis work, which was funded by INTSORMIL. The paper examines the intensification process of agricultural production in south central Niger (Birni N'Konni area) and the potential role of modern and traditional inputs in the process of intensive input use.

Agronomy - Millet - Nouri Maman, Drs. Botorou Ouendeba, Salvador Fernandez-Rivera, Mr. Moustapha Moussa, and Dr. Stephen Mason

The focus of this research is on the effect of plant density and pre-harvest of tillers on late maturing pearl millet productivity and feeding quality

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 pearl millet have been developed by Dr. Botorou with INTSORMIL support and are being 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 animal 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.

[1]In the long run, prices decline because production costs per output unit decreases with technological change. So, both farmers and consumers will benefit.

Objective

The main objective of the study is to develop specific crop production practices for Maiwa pearl millet which take into account the increasing integration of crop production and animal husbandry. To do so the intermediate objectives are:

- to evaluate the effect of plant population on grain yield and quality;
- to determine the effect of pre-harvest of tillers on grain yield and quality;
- to determine the nutritive value of pre-harvest tillers as animal feed.

Materials and Methods

Experimental design: Randomize Complete Blocks Design with 4 replications.

Treatment design: 2 x 3 factorial
Factor A: Plant density:
A_1 = 1m x 1m
A_2= 1.5m x 1m
Factor B: Thinning:
B_1 = 2 plants/hill thinning 14 days after planting
B_2 = T1 + tillers harvest 65 days after planting (DAP)
B_3 = T1 + tillers harvest 85 DAP

Fertilizer application: 100 kg SSP ha^{-1} (18 kg P_2O_5) before planting and side dress application of 100 kg urea ha^{-1} (46 kg N).

Data collection

- harvest of tillers leaving only those which could produce panicles at 65 DAP for B_2 and 85 DAP for B_3. The harvested plant will be dried, weighed, ground and analyzed for digestibility and nutrient concentration for animal feeding (ILRI Lab/ICRISAT);

- grain yield;

- total biomass;

- food quality analysis of grain.

Statistical analysis: Analysis of Variance (ANOVA) and mean separation using the general linear model (GLM) procedure of the SAS.

Results and Discussion

In 1998, the study was conducted under good rainfall condition. There were no major pest problem except for downy mildew, probably because the seeds were not treated with Apron-plus® fungicide as recommended before sowing.

As indicated in the treatment design, additional thinning was done at 65 and 85 days after planting. The amount of dry matter harvested were:

At 65 days after planting:

- plant density 1 (1m x 1m): total 136 kg ha^{-1}; 105 kg ha^{-1} of leaves and 31 kg ha^{-1} of stems.

- plant density 2 (1.5m x 1m): total 131 kg ha^{-1}; 102 kg ha^{-1} of leaves and 29 kg ha^{-1} of stems.

At 85 days after planting:

- plant density 1: total 199 kg ha^{-1}; 164 kg ha^{-1} of leaves and 35 kg ha^{-1} of stems;

- plant density 2: total 150 kg ha^{-1}; 123 kg ha^{-1} of leaves and 27 kg ha^{-1} of stems;

In both cases there were no significant difference between the two densities and the effects of these treatments are presented in Table 4. Statistical analysis indicated that there were no plant density*thining interaction, thus, individual mean effect are presented in the same table. The overall grain yield mean was 1352 kg ha^{-1} and total dry matter yield mean was 10 330 kg ha^{-1} and harvest index was 0.13.

The effect of additional thinning, at both 65 et 85 DAP, on grain yield and total dry matter production was not significant. This implies that it is possible for farmers to harvest some of tillers for animal feeding with no risk on expected yield. However, a second year study is necessary with more tillers harvested at the indicated periods.

As the hypothesis was that it may be possible for farmers to harvest these amount for animal feeding, 80 samples of both leaves and stems were sent to ILRI/ICRISAT Sadoré for analysis of: dry matter (DM), organic matter (MO), digestibility, NDF et ADF. The results of this analysis are not available yet.

Plant density effect is significant with the narrowest row plant density (1m × 1m) having the lowest number of panicles per hill than the largest row plant density, 1.5m × 1m (2.9 vs 4.1, $p<0.01$). However, the difference in grain yield is not significant, 1331kg ha^{-1} vs 1375 kg ha^{-1}. This conforms to previous studies which indicated that the largest plant density is better for Maiwa pearl millet because of its tillering capacity. Contrary to the two previous variables, the narrowest row plant density produced more total biomass ($p = 0.04$) than the largest plant density with 11 090 kg ha^{-1} vs 9 570 kg ha^{-1} and has the lowest harvest index 0.12 vs 0.16 (Table 4).

Table 4. Effect of plant density and thinning on late maturing pearl millet (Maiwa) in 1998 at Bengou INRAN station (Niger)

Treatments	Number of panicles/hill	Grain yield	Total biomass yield	Harvest index
		-------- kg ha^{-1} ---------		
Plant density (P D)				
1m x 1m	2.9	1331	11 090	0.12
1.5m x 1m	4.1	1375	9 570	0.16
LDS (5%)	0.5	230	14 00	0.06
Thinning				
14 DAP	3.4	1377	10 110	0.17
14 DAP & 65 DAP	3.8	1398	10 350	0.14
14 DAP & 85 DAP	3.3	1283	10 530	0.12
LDS (5%)	0.7	82	1710	0.08
Probability F-test		------ P > F ------		
P D	<0.01**	0.69	0.04*	0.16
T	0.27	0.66	0.87	0.42
P D*T	0.25	0.41	0.06	0.48
CV (%)	17.6	19.6	15.5	50.8

1 DAP = Days after planting

Conclusion

This study was conducted for only one year and first results indicate that interesting cropping system recommendations for Maiwa pearl millet with emphasis on crop production and animal husbandry can be drawn after two years of study. We are therefore planing to conduct the same study in 1999 with additional crop management factors.

Agronomy - Sorghum - Seyni Sirfi and Jerry Maranville

On-farm studies on nutrient use and ridges were conducted in Niger during the 1998-99 cropping season. 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 8 m and planting density was 41,675 hills (0.80 m x 0.30 m) with 0.80mm between rows and 0.30 m 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. Results of Konni and Tillakaina trials are presented in Table 5 and average grain and stover yields over replicate (farmer) and location. 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 than in the medium rainfall one. But 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 compared to 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.

Table 5. Mean grain and stover yields from on-farm sorghum trials at two locations in Niger in 1998. Treatments consisted of three genotypes grown with ridges and tied ridges plus manure and inorganic nitrogen (improved) versus the same genotypes grown on traditional growing practices.

		Tillakaina		Konni		Average	
		Grain stover kg ha-1		Grain stover kg ha-1		Grain stover kg ha-1	
Genotypes	Treatments						
NAD-1	Improved (tied ridges)	2240	3734	432	4498	1336	4116
90SN7	Improved (tied ridges)	805	3923	769	7714	787	5818
Local	Improved (tied ridges)	1752	4688	1016	4951	1384	4819
Average		1598	4115	739	5721	1169	4918
NAD-1	Improved (tied ridges)	1401	3176	602	4416	2003	3794
90SN7	Improved (tied ridges)	968	3516	761	6242	864	4879
Local	Improved (tied ridges)	2473	5009	794	5197	1633	5103
Average		1614	3900	719	5285	1500	4592
NAD-1	Traditional	1614	3006	625	4766	1119	3886
90SN7	Traditional	1571	3667	419	5744	995	4911
Local	Traditional	2236	4480	722	5099	1515	4789
Average		1807	3718	589	5203	1210	4529

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, in 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 case 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. It will be necessary to repeat this study next season in order to make appropriate recommendations about these technologies.

Pathology - Issoufou Kollo Abdourhamane

This research focuses on Acremonium wilt (*Acremonium strictum*) of sorghum in Niger: Association with nematodes and Effect of nitrogen and liming.

Association of *Acremonium strictum* with *Pratylenchus zea*

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 1990's, 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 the Konni area. Although the disease is generally more serious on the improved cultivars there are cases where even the landraces 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 was 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 landrace 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 thouroughly 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 (Figure1). The high susceptibility of this hybrid to acremonium wilt is evident. With the landrace 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 effect the incidence of acremonium wilt in either 1997 (which is a droughty year) or in 1998 (Table 6). 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.

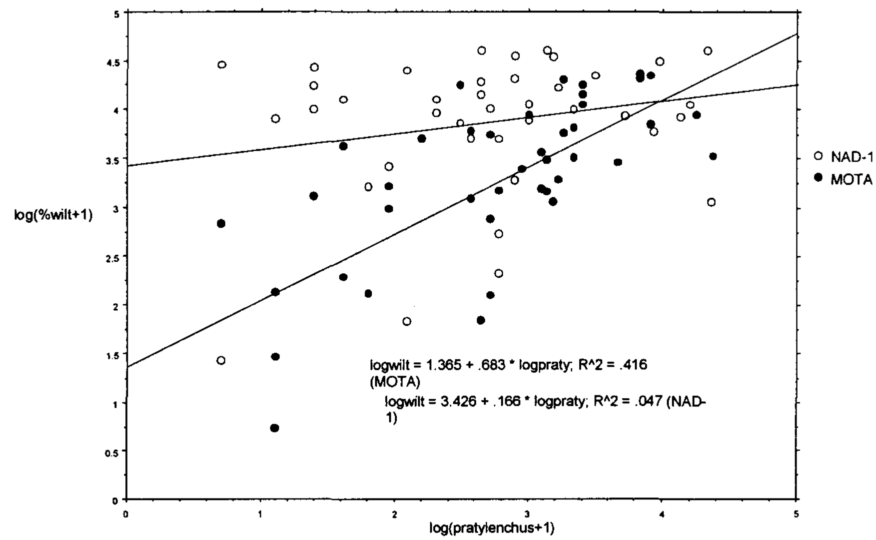

Figure 1. Relationship between *Pratylenchus zea* and acremonium wilt on sorghum in Niger, 1997 cropping season.

Table 6. Effect of nematicide application on acremonium wilt incidence in sorghum and yields of sorghum. In a farmer's field in Niger, cropping 1998.

Nematicide	Plants/plot		Percent wilt		Plants harvested		Grain yield kg/plot	
kg a.i/ha	NAD-1	MOTA*	NAD-1	MOTA	NAD-1	MOTA*	NAD-1	MOTA*
Counter								
1.1	56	82	65.22	28.24	29	37	0.55	0.62
2.2	55	84	61365	16.73	27	45	0.42	1.52
3.3	58	96	39.23	20.51	28	54	0.54	1.73
Furadan								
2.0	56	74	76.37	21.10	35	37	0.63	1.01
4.0	38	83	84.89	18.53	28	44	0.29	1.66
6.0	45	98	80.56	26.35	28	53	0.31	1.63
Control	47	71	78.64	17.19	28	29	0.40	0.86

* differences are significant at the 5% probability level.

Effect of liming and Nitrogen forms on the development of acremonium wilt of sorghum

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 known to influence soil borne diseases. The objective of this experiment was to study the effect of nitrogen form and lime on the development of acremonium wilt on sorghum.

The experiment was conducted at the Konni research station during the 1997 and 1998 cropping seasons (Data for 1997 are shown here, Tables 7, 8 and 9). The hybrid NAD-1 was used. Two levels of limestone was used, 0 and 1 t ha^{-1}. Limestone was obtained from 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 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 6 replications. Disease incidence was monitored and yield components were measured.

Stand was significantly improved by lime and nitrogen (Table 7). The interaction between the nitrogen and lime was not signifiçant. The control treatments had the lowest number of plants; the best stand was obtained with CAN (Table 8). Although the wilt incidence was highest in the control plots (Table 8), the 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 significative at 5% level. However, the effect of lime was significant

Table 7. Analysis of variance for the effects of liming and nitrogen source on the development of acremonium wilt and yield of sorghum. Konni reseach Station 1997.

		Mean square				
Source	df	Plant/plot[1]	%Wilt[2]	Plants harvested[3]	Straw yield kg/plot[4]	Grain yield kg/plot[5]
Block	5	0.088	0.007	186.183	0.756***	0.020
Lime	1	0.531***	0.022*	588.00**	0.178	0.050**
Nitrogen source	3	0.126**	0.014	409.861***	0.135	0.017
Lime × Nitrogen source	3	0.023	0.005	201.556*	0.444*	0.036**
Error	35	0.043	0.007	85.793	0.144	0.011

[1]cv=5.12% [2]cv=27.19% [3]cv=22.30% [4]cv=14.24% [5]cv=11.85%
*** signficant at 0.01 probability level
** significant at the level of 5% probability
* significant at the level of 10% probability.

Table 8. Means for stand establisment as affected by liming and the different forms of nitogen, Konni, Niger 1997.

Lime stone (t ha-1)	Plants/plot	%Wilt	Plants harvested
0.0	52 B	33A	38B
1.0	64 A	24A	45A
Nitrogen form			
69 kgN/ha (urea)	59 AB	20A	40B
69 kgN/ha (CAN)	64 A	29A	48A
Manure 20 T ha-1	60 AB	33A	44AB
Control	50 BC	33A	35BC

Means followed by the same letter are not significantly different at the 5% level of probability.

Table 9. Means of sorghum grain and stover yields as affected interaction between liming and form of nitrogen.

Lime stone (T ha-1	Nitrogen form	Grain yield (kg/plot	Stover yield (kg/plot)
0.0	69 kg N/ha (urea)	5.875AB	0.619B
	69 kgN/ha (CAN)	6.083AB	0.700BA
	Manure (20 t ha-1)	7.417A	0.779BA
	Control	7.500A	0.754BA
1.0	69 kgN/ha (CAN)	7.750A	0.910A
	69 kg N/ha (CAN)	8.042A	0.883A
	Manure (20 t ha-1)	4.792B	0.913A
	Control	7.125A	0.613B

Means followed by the same letter are not significantly different at the 5% level of probability.

and the effect of nitrogen form was highly significant (Table 7). 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 (Table 9). 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.

These data were obtained during the 1997cropping season. The 1998 data is being analyzed and compared with those of 1997. This comparison is important because 1998 had excellent rainfall. 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.

Work on Long smut

In collaboration with the Breeding program, we have decided to continue our screening program for resistance to long smut. In addition, we have decided to investigate the effect of planting time and the rain pattern on the incidence of long smut on sorghum. Specific details of these trials are not presently available.

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Southern Africa Region (Botswana, Namibia, Zambia, Zimbabwe)

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Collaborative Program

Organization

Each project is planned in conjunction with NARS collaborators. Where SADC/ICRISAT/SMIP (called SMIP hereafter) has scientists in the research discipline, these are also involved.

Six research projects were conducted in the Southern Africa region in 1998/99. They were:

98-1 *Breeding:* Development of R_4 hybrids, using popular Namibian and Zambian pearl millet varieties.

98-2 *Pathology:* Disease management research, identification and use of resistance to sorghum diseases.

98-3 *Food quality:* Sorghum food quality research.

98-4 *Pests:* Pest management and resistance to sugarcane aphid and integrated pest management in Botswana and South Africa.

98-5 *Production and Marketing:* Identification of factors limiting commercial production and marketing of sorghum in Botswana.

98-6 *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 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.

The Planning Process

Research projects in breeding, pathology, pests and food quality were based on ongoing linkages. Production and marketing, and ergot research projects are new this year, 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 Règional Research and Technology Transfer program (SMINET) to ensure full integration with other sorghum and pearl millet research and technology transfer in the region.

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, to some extent and very economically, address some of these constraints through increasing yield levels and matching grain qualities to meet end-use requirements. However, market channels still need development, 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 . Foods Botswana and other companies cannot acquire sufficient quantities of high quality sorghums for processing. A strong need exists for developing a system of identity preserved production, marketing and processing. Drought stress and charcoal rot are major constraints to sorghum production in Botswana, together with sugar cane aphid damage. In Zambia, leaf pathogens (leaf blight, anthracnose and sooty stripe) are severe. Sorghum ergot is prevalent through the region, and may be severe in hybrid seed production fields.

Constraints Addressed by Project Objectives

Breeding: Raise yields through developing A_4 CMS pearl millet hybrids with local adapted varieties as male parents in Namibia, and Zambia.

Pathology: Identify adapted, agronomically desirable sources of resistance to drought stress and charcoal rot to include sources with additional 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: Evaluate qualities of Zimbabwean sorghums, examine methods of using high polyphenol sorghums in foods through dry milling, malting and brewing.

Pests: Identify, evaluate, and incorporate sugarcane aphid resistance into sorghum varieties and hybrids adapted to Southern African agricultural systems. Develop integrated pest management strategies for controlling sorghum insect pests in Southern Africa.

Production and Marketing: Through structural village and market surveys, to identify sorghum and pearl millet production and marketing/utilization constraints, first in Botswana, then regionally.

Ergot: Reduce the risk of ergot through analyses of weather data, and develop control strategies including host plant resistance 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 U.S. through joint research. Germplasm flow is useful in both directions. Basic research from the U.S. 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 U.S., or find new resistance to existing pests. Sorghum ergot disease, which recently entered the U.S. from South America, is a case in point. Prior research in South Africa on sources of resistance and 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 are often synonymous with aspects of livestock feed values.

Examples of Findings

Breeding

Namibia. At UNL further backcrosses were made to develop an A_4 CMS version of SMIP seed parent line 88006, and R_4 restorer versions of Okashana, and the MKC variety. Seed of some experimental hybrids were made which were also evaluated in the Mexico winter nursery (where days are as short as in Namibia). Hybrid 8401 A_4 x MKC was exceptional. It was noted that MKC does naturally contain R_4 restorer genes. Seeds of all the above were sent to Namibia and were planted in December, 1998 for evaluation. R_4 crosses were identified, and a 'winter nursery' is planned (August 1999) in Namibia to more rapidly advance the parental development.

Zambia. The pearl millet breeding program at Kaoma initiated a comprehensive A_4 hybrid breeding project this year. Prior research has shown that hybrids are both somewhat earlier (a drought avoidant advantage) and up to 20% higher yielding than varieties. A range of 19 regional lines were evaluated as potential seed parents and eight leading Zambian varieties as male parents. Using bulk pollen, the male parents were crossed on to the two best seed parents. These will be examined in the SMIP off season nursery for occurrence of restorer genes. However, the male parents were also crossed to an A_4 R_4 source supplied from UNL which ensures that their conversion to R_4 restorers can be completed.

At SMIP Matopos, testcross hybrids made with R_4 lines derived from NMP-3 R_4 population were grown in an observation nursery.

Pathology

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 was only adequate to assess susceptibility and not resistance. Dr. Obilana has increased seed of these materials representing most countries of the SADC region. Seed is sufficient for multiple location plantings so plans are being formulated for grow outs at more disease-intensive nursery locations in Zimbabwe, Zambia, and South Africa. Insect response (sugarcane aphid) may also be included at another South Africa location.

In 1998-99, 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. The primary location for disease evaluation in 1999 was Golden Valley, Zambia which had very high levels of sooty stripe and moderate levels of anthracnose. Most newly introduced materials had a high susceptibility to either or both sooty stripe and anthracnose; some of these sorghums may still be of value in other SADC regions if foliar pathogens are not a limiting production factor. SC326-6 derived material like 86EON 361 and 86 EON362 continued to be impressive across Zimbabwe and Zambia but even these developed higher than normal levels of sooty stripe at Golden Valley. 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. Unfortunately, several entries were extremely susceptible to sooty stripe at Golden Valley and did not appear to have good adaptation to the region. However, other entries did have both acceptable adaptation and at least moderate resistance to sooty stripe.

Several drought resistant materials either new or previously tested in Botswana were selected for evaluation at that location and two similar subsets were to be evaluated in Matopos, Zimbabwe and Golden Valley, Zambia. Many of these materials had or were also being evaluated for sugarcane aphid resistance. Drought prevented a planting at Sebele in Botswana and 56 of 103 cultivars established in a late-planting at Matopos had "days to physiological maturity" that were similar to or less than Macia, a parental standard. Sooty stripe was the most prominent disease in the subset planted at Golden Valley with EO366 crosses being generally susceptible and those of SRN39 generally resistant. Derivatives of several crosses with Macia 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 this location. This indicated it was possible to use multilocational testing to identify cultivars that had both broad adaptation to the SADC region and resistance to major disease and insect pests

Virus reactions in the International Sorghum Virus Nursery (ISVN) at the Pandamatenga Research Station 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. He is also evaluating additional live virus specimens recently collected in South Africa in April 1999.

Food quality

Several graduate students are conducting research on aspects of sorghum utilization with Professor Taylor and Dr. Dewar. Ms. Trust Beta is nearing completion of her Ph.D. on processing sorghum with high levels of polyphenols into foods. She has included dry milling, malting and brewing studies of local Zimbabwean sorghum cultivars. Her work has been cooperative with the Matopos grain quality lab in Zimbabwe. She is also working on starch properties at the University of Hong Kong with Professor Harold Corke.

Ms. Leda Hugo, Mozambique, is a Ph.D. student at the University of Pretoria working on composite breads made from sorghum malt and milled products. She is a professor at University of Eduardo Mondlane University and completed her M.S. at Texas A&M University.

Lloyd Rooney serves as the external examiner for the M.S. thesis of Mr. Joseph Wambugo from Kenya who is working on weaning foods from sorghum. Several students from various countries in Southern Africa discussed their research projects. There is a great opportunity to provide information to these future African food industry leaders on the properties, advantages and disadvantages of sorghum and millets in local food systems. For example, it is not understood that larger quantities of sorghum flour can be added to wheat than corn flour because of the bland flavor of sorghum. The relative advantages and disadvantages of sorghum and millet are unknown; even the dark brown or red sorghums would have advantages over maize in certain products where the dark color would be acceptable.

Pest Management

A trip was made in April, 1999, to South Africa and Botswana by Drs. Teetes and Peterson to establish a collaborative research program for Southern Africa directed at development, evaluation, and deployment of sorghum genotypes resistant to the sugarcane aphid, *Melanaphis sacchari*, and develop a plan to implement IPM strategies for sorghum insect pests. Primary collaborators are Dr. C.S. Manthe, DAR entomologist, and Dr. J. van den Berg, ARC/GCI entomologist. Drs. Manthe and van den Berg have conducted research on numerous insects of sorghum in Southern Africa. 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-222, TAM-228, and TAM-225. The test was evaluated for resistance to sugarcane aphid in a greenhouse screening and for resistance to sooty stripe at Golden Valley, Zambia. For sugarcane aphid resistance, nine experimental entries sustained no more damage than the resistant checks (SDSL89426, WM#322, FGYQ353, TAM428, FGYQ336, CE151, WM#177, Ent. 62/SADC, and Sima). For sooty stripe resistance, only three entries expressed resistance. However, no experimental entries were resistant to both sugarcane aphid and sooty stripe. Sugarcane aphid resistant breeding materials are in development for the collaborative program. 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_1's to adapted cultivars were made. The germplasm was planted at Corpus Christi, Texas for initial selection. 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 included tan plant, white pericarp, and appropriate height and maturity.

Research on developing resistance to sugarcane aphid will be increased for 1999-2000. INTSORMIL, through the Texas A&M University breeding/entomology program, will provide to regional scientists a replicated 50-entry test for evaluation for resistance to sugarcane aphid and local adaptation at sites to be determined by regional collaborators. 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

This project is in its startup phase. The progress during the year has included the establishment of a collaborative working relationship with a researcher from the region, the definition of a collaborative research plan, the identification of a population of producers to sample, and the construction of a survey instrument to collect data on the sampled farm households.

Carl Nelson made initial contacts with sorghum/millet researchers in the region in July, 1998. First contacts were made at the SADC/ICRISAT planning and review conference held in Harare, Zimbabwe the week of July 27, 1998. Those contacts led to some coordination of research with David Rohrbach of ICRISAT – Bulawayo. For example, Rohrbach already had plans to survey sorghum processors in Botswana. Therefore a duplicate survey of processors was avoided.

Following the Harare conference Nelson spent a week in Botswana gathering preliminary information about sorghum processing in Botswana. During the week Nelson was introduced to Dr. Tebogo Seleka, of the Botswana College of Agriculture. Following the introduction, arrangements for collaborative research were negotiated through electronic mail. Nelson returned to Botswana in March 1999 to initiate the collaborative research on the production and marketing constraints in Botswana.

A student from the Botswana College of Agriculture is expected to start the agricultural economics graduate program at Illinois in January 2000. Dr. Seleka is helping recruit a recent graduate with a strong academic record.

Ergot

The aim of the current study is to develop a multi-variate model which will incorporate as many of the relevant variables affecting ergot severity in hybrid seed production systems. Initially, these include the production of viable pollen by pollinator parents under a range of weather conditions, 'nicking', distance from the pollen source and weather during the infection period. The study is being conducted over a range of areas representative of climatic zones including 4 areas in South Africa, and production areas in Zimbabwe and Zambia.

Due to late funding, trials were only planted at four localities in South Africa namely Cedara (Kwazulu Natal), Bethlehem (Free State), Potchefstroom (North West Province) and Hazyview (Mpumalanga) during the current season. Trials consist of blocks of 19 rows, 25 m in length. The outer two rows of each block were male-normal pollinator rows while the inner 15 rows were male-sterile (A-line). Rows were spaced 1.2 m apart with an intra-row spacing of ± 10 cm. At each end of each block, and at right angles to the test-rows, two rows of male-sterile lines were planted three weeks prior to the planting of blocks. At flowering these rows were artificially inoculated with a *C. africana* spore suspension (*ca* 10^6 spores per ml) to serve as spreader rows.

At each locality blocks were planted at three planting dates from the end of November to early January to create a range of ergot potentials during flowering. On each date, two blocks were planted, one using PAN8564 and the other NK283 as pollinators. The date of 50 % flowering was determined for each row. At anthesis of pollinator rows, pollen was randomly collected from each 5 m row length for assessment of pollen viability and mean pollen viability was determined for each row. Approximately four weeks after flowering of each block, heads in each row were visually assessed for percentage seed set and ergot severity.

Abnormally high temperatures and drought stress during flowering at various localities resulted in 5 of the 12 plantings having to be abandoned due to poor flower emergence and drought damage. The relationship between pollen viability and pre-flowering minimum temperature (days 23-27 pre-flowering) in the remaining seven blocks is shown in Figure 1. NK283 was more cold sensitive than PAN8564, showing an approximately linear decrease in pollen viability with decreasing temperature. Pan 8564 on the other hand showed little decrease in pollen viability even as minimum temperatures declined to approximately 14°C. Weather conditions were such that sufficiently low temperatures were not experienced to reduce pollen viability significantly

Abnormal weather conditions and insufficient prior data on the relative behavior of males and females resulted in poor 'nicking' with males flowering from three to eight days before females depending on locality and planting

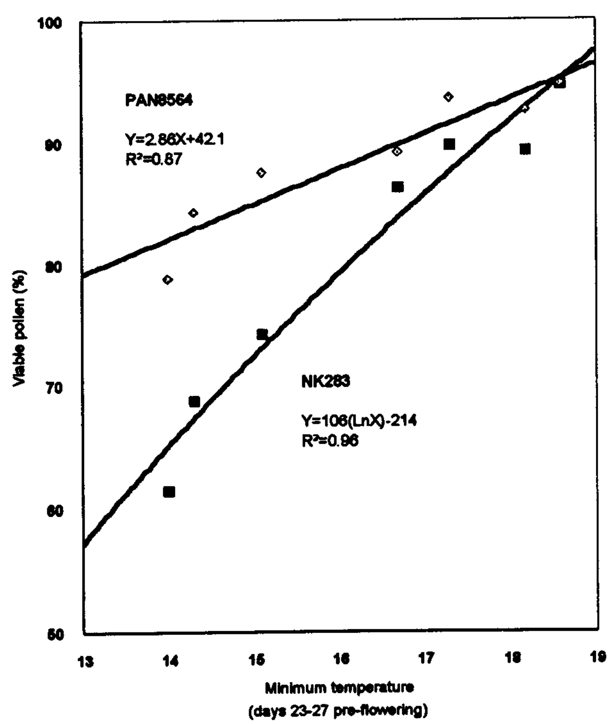

Figure 1. Relationship between viable pollen (%) produced by the pollinator parent and pre-flowering minimum temperature (°C).

date. However, at all localities mean seed set was higher in PAN 8564 than NK 283 pollinator blocks which could possibly be attributed to the greater pollination efficiency of the former.

Due to high daily maximum temperatures at each locality during early post-anthesis (Tmax > 29 °C), ergot severity in pollinator rows was low despite high inoculum pressure supplied by spreader rows (ergot severity in the latter > 70 %). In contrast, despite the high temperatures, the absence of high pollen pressure due to poor 'nicking' resulted in ergot severities in male-sterile lines being high (Figure 2). The relationship between 'nicking', pollinator and distance from the pollinator rows is given in Figure 2. Except for Bethlehem blocks (Figure 2 a,b) all female rows yield high ergot severities. At Bethlehem a gradient was evident with distance from the pollinator rows. The figures suggest that beyond 3-4 rows from pollinators, a sharp increase in ergot severity can be expected. Wind direction also played a role as indicated by the skewed distributions of disease on either side of the block.

Analysis of the relationship between ergot severity and weather conditions has yet to be completed. This has been confounded by poor pollen pressure and a limited range of temperatures during the pre- and post-anthesis period. It appears that in the absence of pollen, the relationship between temperature/humidity is less precise than previous models developed for self-pollinating genotypes suggest and that the disease is able to develop over greater range of conditions in male-sterile genotypes.

Institution Building

Funding Support and Equipment

The MOU with the SMIP program was signed in October, 1998. INTSORMIL collaborative research projects will become fully integrated in the SMINET research and development program for the Southern African region.

A head and small plot belt thresher was provided to the Namibian pearl millet breeding program at Okashana Research Station.

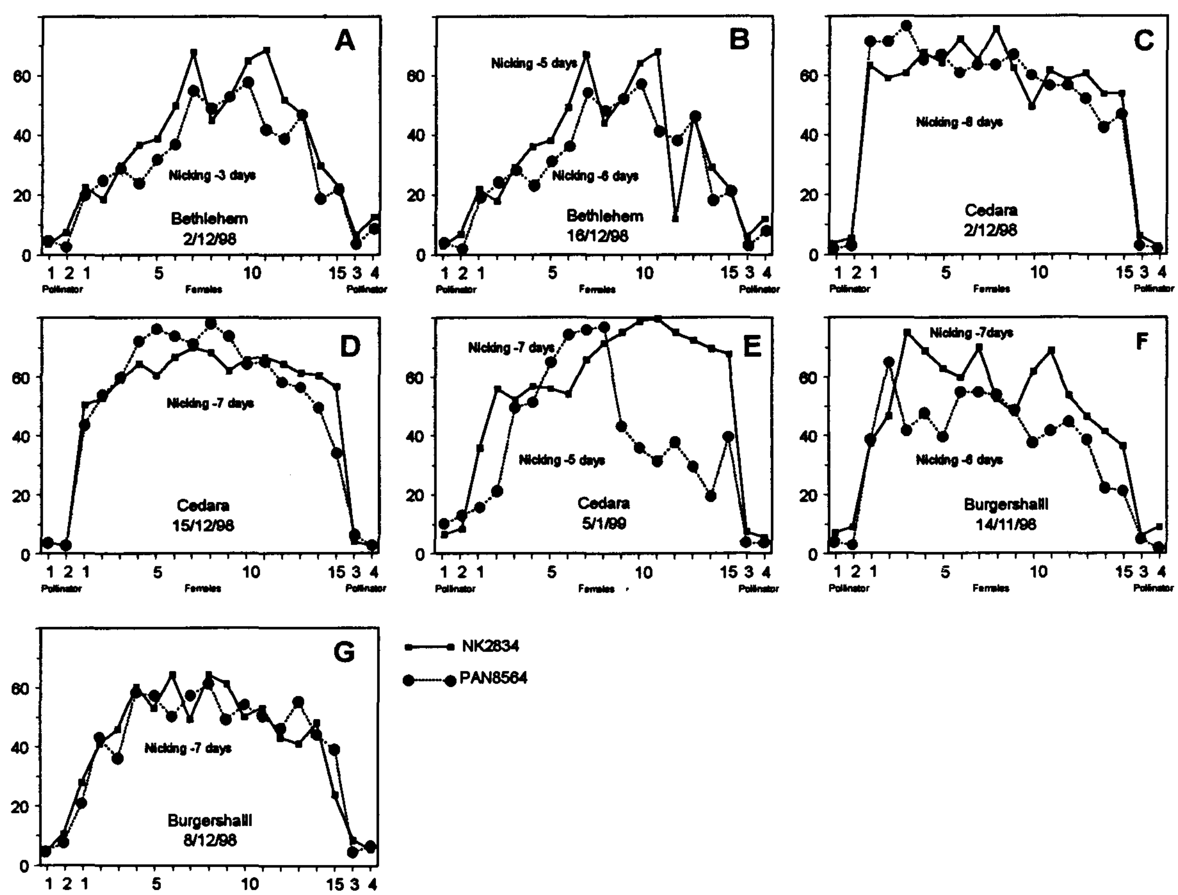

Figure 2. Ergot severity (vertical axis) associated with pollinators NK283 and PAN8564 and distance (horizontal axis, rows) from the pollinator parent at various localities and planting dates.

Four computers and two printers were being purchased for collaborators in Zambia and Botswana.

Training of Host Country Researchers

Ms. Trust Beta, Zimbabwe, continued a 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 part subsistence costs were provided by INTSORMIL.

Mr. Peter Setimela, sorghum breeder, Department of Agricultural Research, Sebele Research Station, Botswana, continued his Ph.D. program 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 hybrid breeding techniques.

Host Country and U.S. Scientist Visits.

The INTSORMIL External Evaluation panel, Dr. Fran Bidinger (ICRISAT) and Walter DeMilliano, accompanied by Dr. John Yohe, Director of INTSORMIL, John Swanson USAID-Washington, Dr. Darrell Nelson (INTSORMIL Board, (University of Nebraska) and David Andrews, Southern Africa Regional Coordinator, visited Nambia, Zimbabwe and Botswana February 1 - March 13, 1999.

Dr. Carl Nelson attended a SADC/ICRISAT planning and review meeting in Harare, Zimbabwe and then 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 December 1998 as co-organizer of the Sorghum End Use Quality Assessment Workshop held December 1-4 and visited ARC/GCI Potchefstroom.

Gary Petersen and George Teetes visited South Africa and Botswana for pest research in April, 1999.

Gary Odvody traveled to Southern Africa April 5-22, 1999 to evaluate nurseries and determine future collaborative research activities in Zimbabwe, (SMIP scientists and national sorghum breeders in Bulawayo, PPRI/DRSS in Harare) Zimbabwe, Golden Valley Zambia, DAR in Sebele and Pandamatenga, Botswana, and the Grain Crops Institute in Potchefstroom, South Africa.

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 commenced a six month visiting researcher program with the pearl millet breeding program at the University of Nebraska.

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 now 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 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 Univ of Pretoria and CSIR in South Africa in April, 1999 at which there were 36 participants, including industrial representatives. A field trip was arranged to ARC/GCI Potchefstroom. Major conclusions were that while excellent information is available on malting and brewing quality of sorghum, very little is known about dry milling properties, or how to define and assess them. New sorghum hybrids are lacking and unlikely to be developed by private industry because the market is insufficient to justify the research costs. Sorghum products are taxed (14%) while maize is not taxed. Unless the tax is removed, sorghum will continue to be at a disadvantage competing with maize in milled food products.

Research Accomplishments

Breeding

Seed was sent from UNL-218 and planted by Mr. Ipinge in Namibia-1998 to complete the third cross to develop two A_4 CMS Namibian pearl millet topcross 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 UNL in hybrid breeding in October 1998, and a belt thresher was supplied for his breeding program in Namibia.

Pathology

More disease nurseries with diverse components and goals were planted than originally planned. These nurseries and related activities provide important gains in improved cultivar development and understanding of local and regional pest resistance requirements. However, inclusion of newly selected sorghums and nurseries delayed seed shipments sufficiently so that at some locations drought patterns and other factors prevented or lessened the value of some nurseries. Also, the increased number of INTSORMIL and NARS scientists involved in this integrated nursery program screening for adaptation and multiple pest resistance makes strategic planning more imperative but difficult. Perhaps the greatest gain from these collaborative activities is their promotion of regional institutional development and networking through increased research and communication linkages among scientists from NARS, SMIP and INTSORMIL.

Food Quality

INTSORMIL co-sponsored the Sorghum End Use Quality Workshop at the University of Pretoria December 1-4, 1998 and continued to support the Ph.D. program of Mrs. Beta. Her research on high tannin sorghums indicate treatment with NaOH prior to roller milling can reduce tannin levels to an acceptable level for food use.

Pests

Sources of resistance to the sugar cane 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

This was the first year of work on the research project. 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; identify specific research projects for collaboration; and 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.

Ergot

Late funding allowed only South Africa trials to be conducted on ergot research but the experiences from those trials will be highly beneficial in the subsequent regional trials planned for 1999-2000. Abnormally high temperatures, drought, and different dates of planting were associated with variable numbers of days to pollen shed for the male pollinators used in this study. Sometimes there was a poor synchronization of pollen shed from the pollinators and blooming of male-sterile sorghums. Experimental design was changed to eliminate this problem from experiments to be established next year in South Africa and other collaborating SADC countries.

Planned Accomplishments

All projects were active and reached their planned goals.

There were several significant achievements this year:

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.

Two further projects on production and marketing constraints and on ergot were started.

The regional collaborative program was reviewed by the INTSORMIL External Evaluation Panel February 1, 1999 to March 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.

The INTSORMIL Southern Africa collaborative research project is now well structured to address many of the regional constraints to sorghum and pearl millet production and utilization, and is now fully integral with other regional sorghum/millet activities, from the planning stage to co-funding agreed research projects.

Publications

Axtell, J., Kapran, I., Ibrahim, Y., Ejeta, G., and Andrews, D.J. 1999. Heterosis in sorghum and
pearl millet. *In* Coors, J.C. (ed.), The Genetics and Exploitation of Heterosis in Crops. ASA, Madison, WI.

Beta, Trust, Lloyd W. Rooney, Lillian T. Marovatsanga and John R.N. Taylor. 1999. Phenolic
compounds and kernel characteristics of Zimbabwean sorghums. J. Sci. Food Agric. 79:1003-1010.

Training

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 23 different countries were enrolled in an INTSORMIL advanced degree program. Approximately 74% 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 1998-99, 25% of all INTSORMIL graduate participants were female. Twenty of the total 51 students received full INTSORMIL scholarships. An additional 12 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.

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 1998-1999 there are 18.

In addition to graduate degree programs, short term training programs have been designed and implemented on a case by case basis to suit the needs of host country scientists. Four post doctoral scientists and five visiting host country scientists were provided the opportunity to upgrade their skills in this fashion during 1998-1999.

The following table is a compilation of all INTSORMIL training activities for the period July 1, 1998 through June 30, 1999.

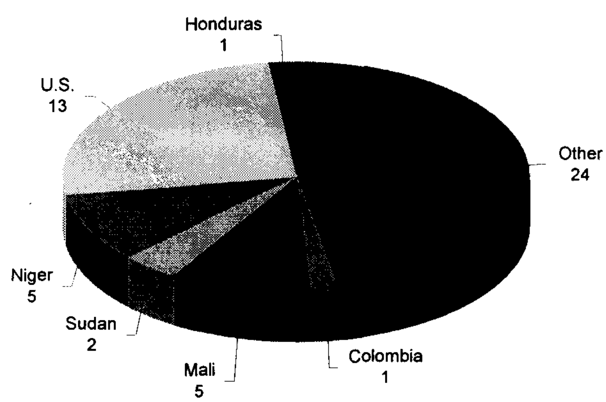

Figure 1. Participants by Country

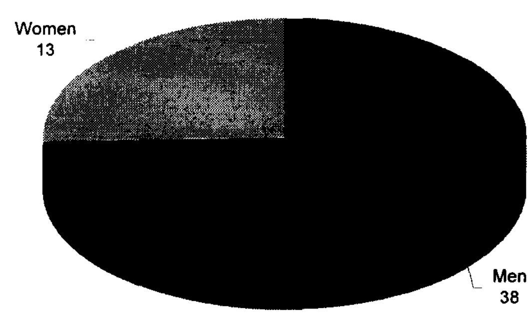

Figure 2. Participants by gender

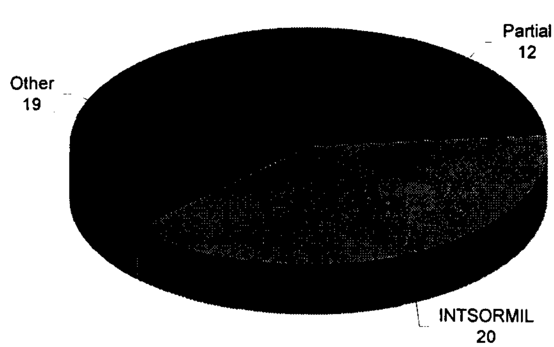

Figure 3. Source of Funding

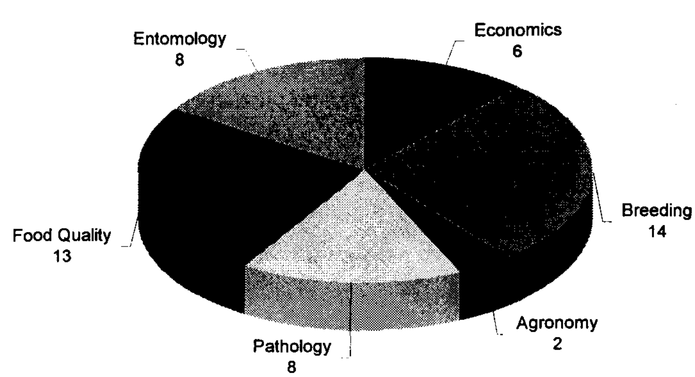

Figure 4. Discipline Breakdown

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

Appendices

INTSORMIL Sponsored and Co-Sponsored Workshops 1979 - 1999

	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
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

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
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

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
DICTA	Direccion de Ciencia y Tecnologia Agricola - Mexico
DR	Dominican Republic
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
DARE	Division of Agricultural Research and Extension - Eritrea
DRA	Division de la Recherche Agronomique, IER Mali
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
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
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.ERA	Institut d'Etudes et de Recherche Agricoles Agricultural Research Institute
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	Institute Nigerien du Recherche Agronomic, Niger
INTA	Instituto Nicaraguense de Technologia Agropecuaria
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
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 Alimenticios
PI	Principal Investigator
PL480	Public Law No. 480
PNVA	Malien Agricultural Extension Service
PPRI/DRSS	Plant Protection Research Institute/Department of Research and Specialist Services
PRF	Purdue Research Foundation
PRIAG	Regional Program to Strengthen Agronomical Research on Basic Grains in Central America
PROMEC	Program for Research on Mycotoxicology and Experimental Carcinogensis, South African Medical Research Council
PROMESA	Proyecto de Mejoramiento de Semilla - Nicaragua
PSTC	Program in Science & Technology Cooperation
PVO	Private Volunteer Organization
RADRSN	Regional Advanced Disease Resistance Screening Nursery
RARSN	Regional Anthracnose Resistance Screening Nursery
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
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