2001 Annual Report

INTSORMIL

Sorghum/Millet International Research

INTSORMIL

Sorghum/Millet Collaborative Reserach Support Program (CRSP)

Fighting Hunger and Poverty with Research
... a team effort

Funding support through the Agency for International Development

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Peter Esele earned his Ph.D. degree in plant pathology at Texas A&M University in 1991. As a sorghum and millet pathologist, Dr. Esele has conducted research on grain molds, Anthracnose in sorghum, and blast in finger millet at Uganda's Serere Agricultural Research Institute from 1981 to 2001. He served as Director of Research at Serere Agricultural Research Institute from 1992 to 2000 and was elected member of the Parliament of Uganda in July, 2001. Dr. Esele has been a collaborating research scientist in INTSORMIL since 1983 in sorghum and pearl millet research.

PD-ABU-890

Dr. John Axtell

The 2001 INTSORMIL Annual Report is dedicated to the memory of Dr. John Axtell in remembrance of his contribution to INTSORMIL and sorghum/millet research.

Dr. John Axtell, an outstanding scientist, member of the National Academy of Sciences and founding member of the INTSORMIL CRSP died unexpectedly on December 2nd, 2000. The following are highlights of his contributions as an INTSORMIL Principal Investigator. Because his contributions are significant and express the commitment which Dr. Axtell had for international development and research we in INTSORMIL are proud to acknowledge his contributions toward the improvement of grain sorghum in both the U.S. and developing countries.

- Dr. Axtell and his students demonstrated for the first time that tannins had a negative effect on protein availability, thereby diminishing nutritional quality of sorghum. This resulted in a shift in emphasis of sorghum breeding programs around the world toward low tannin sorghums. As a result, almost all sorghum varieties and hybrids developed and released for human consumption in the last 10 - 15 years have been of the low tannin types.

- Because of the discovery of the negative effects of tannins in human nutrition by Dr. Axtell and his colleagues, biochemists, geneticists, and food scientists investigated the various aspects of tannins and phenolic compounds in sorghum and food products.

- Dr. Axtell pioneered a successful research program that led to the identification of natural and induced high lysine mutants in sorghum.

- Dr. Axtell and his colleagues conducted an array of studies which clearly established that methods of food preparation can have dramatic effects on the digestibility of sorghum proteins. They developed the technique for determining the digestibility value of sorghum-based foods, *in vitro*. Then using their *in vitro* assay, they demonstrated that the proteins of various cereals behave differently when cooked, and that the cooking process was responsible for the decreased digestibility in sorghum. Working with cereal chemists, Dr. Axtell and his colleagues were also instrumental in developing highly digestible sorghum lines (*in vitro* digestibility values of up to 90%)

- Dr. Axtell made world-wide contributions to germplasm development. Varieties and populations of sorghum developed by Dr. Axtell and colleagues have been widely distributed to national research programs and international agricultural research centers where they have been widely utilized. Sorghum forages with the brown-midrib characteristic having high forage digestibility in sorghum forages are now commercially produced, based on research of Dr. Axtell and his colleagues.

- During his long and fruitful career, Dr. Axtell trained many graduate students and through their work as scientists, his legacy extends throughout the United States and many foreign countries.

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2001 Annual Report

Fighting Hunger with Research . . . A Team Effort

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

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Purdue University
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INTSORMIL Institutions are affirmative action/equal opportunity institutions.

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Introduction and Program Overview

Presently, worldwide, more than 800 million people are hungry and over one billion are desperately poor, and food demand is increasing rapidly. The majority of poor live in rural areas in developing countries and agricultural and food systems development is vital to economic growth; improving environmental quality; strengthening nutrition, health and child survival; improving the status of women; and promoting democratization. It is estimated that, between 1980 and 2030, the population of low- and middle-income countries will more than double–to seven billion, compared with one billion for high-income countries. In the next 35 years, 2.5 billion people will be added to the current population of 6 billion. More than 1.3 billion people today live on less than one dollar per day, and it is estimated that the number of hungry people will exceed one billion by 2020. The global population of underweight children below age five is expected to increase from 193 million in Year 2000 to over 200 million in Year 2020. *Increased production of cereals, which are crucial sources of food energy and other nutrients, is necessary to reduce world hunger.*

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

In developing countries of the semi-arid regions *sorghum and millet*, two important cereal grains, make the difference between food security and famine. In the United States, sorghum is important to the balance of trade, is an important feed in the production of beef, and is increasingly in demand as a raw material for food and as a renewable feedstock for production of fuel. In 2000, 58.5 Tg (million tons) of sorghum were produced world wide, of which 18.6 Tg were produced in Africa, mainly for direct consumption by humans, and 11.9 Tg were produced in the United States, mainly for livestock feed to produce meat for human consumption. In 1999, the United States exported 5.9 Tg of grain sorghum mainly for livestock feed, and in 1999, U.S. grain sorghum exports were worth $555 million. Large areas are planted to sorghum each year. For example, in 2000 sorghum was produced on 42.1 million hectares (ha, or 162,549 square miles, [sq mi]) worldwide, 21.6 million ha (83,398 sq mi) in Africa, and 3.1 million ha (11,969 sq mi) in the United States. About 500 million people worldwide depend upon sorghum for food, and most of these people are in developing countries where droughts and famine are common occurrences. *Clearly, sorghum production and utilization as food and feed are vitally important to developing countries and to the United States.*

Millets, which include several types such as pearl millet, finger millet and proso millet, are cereal crops even better adapted to arid ecosystems than is sorghum, and pearl millet is a staple for 300 million people worldwide. Most of these people are in countries within semi-arid regions where malnourishment is a persistent problem. In 2000, 36.0 million hectares (138,997 sq mi) of millets were harvested worldwide, of which 20.1 million ha (77,606 sq mi) were harvested in Africa, and 149,740 ha (578 sq mi) were harvested in the United States. In 2000, the amount of millets harvested worldwide was 27.2 Tg, of which 13.5 Tg were harvested in Africa and 166,000 Mg (thousand tons) were harvested in the United States. Millets are crops used mainly for direct consumption by humans in developing countries, and the millets are used mainly for feeding livestock, particularly poultry, in developed countries. Pearl millet is an important cereal crop which provides food energy and other nutrients to hundreds of millions of people in areas which currently suffer from malnutrition, particularly Africa and southern Asia. *The United States and all other participants in the World Food Conference have a stake in promoting the production and utilization of sorghum and pearl millet to help end hunger, particularly in Africa.*

In October 1999, the International Food Policy Research Institute (IFPRI) noted that in both developed and developing countries, the rate of increase in cereal yields is slowing from the days of the Green Revolution, partly due to reduced use of inputs like fertilizer and partly due to low levels of investment in agricultural research and technology. In *World Food Prospects: Critical Isssues for the Early Twenty-First Century,* IFPRI points out that "without substantial and sustained additional investment in agricultural research and associated factors, it will become more and more difficult to maintain, let alone increase, cereal yields in the longer term. The gap in average cereal yields between the developed and developing countries is slowly beginning to narrow, but it is widening considerably within the developing world as Sub-Saharan Africa lags further and further behind the other regions . . . ." In its *2020 Global Food Outlook Report,* IFPRI observes that "Cultivating more and more land will not solve Sub-Saharan Africa's food security problems for the long-term. Between 1967 and 1997, the region expanded cereal cultivation by 31 million hectares and roots and tubers cultivation by 8 million hectares. This rate of expansion is not sustainable; therefore, higher crop yields are needed to reduce malnutrition in Africa."

Agricultural research provides benefits not only to producers of agricultural products but also to processors and consumers of agricultural products. Agricultural research has proven itself continuously as providing improvements which yield products of greater quantity and quality, as well as improved health to consumers and broad-based economic growth which goes beyond producers and consumers. In the *U.S. Action Plan on Food Security – Solutions to Hunger,* published in March 1999, the United States government states that one of the ways that the United States plans to contribute to the global effort to reduce hunger is by the United States' continuing commitment to support international agricultural research through the Collaborative Research Support Programs.

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

INTSORMIL's vision for 2001-2006 is to focus research of multidisciplinary, international teams of scientists to serve the economic and nutritional needs of the human populations which depend on sorghum and pearl millet for food and feed when the lack of water limits food and feed production. These teams will work on a regional basis to develop the technology to improve the economic well-being, nutrition, and health of people in both developing countries and the United States. Thus, the Sorghum and Millet Collaborative Research Support Program (INTSORMIL CRSP) conducts collaborative research using partnerships between U.S. university scientists and scientists of the National Agricultural Research Systems (NARS), IARCs, PVOs and other CRSPs. INTSORMIL is programmatically organized for efficient and effective operation and captures most of the public research expertise on sorghum and pearl millet in the United States. ***The INTSORMIL mission is to use collaborative research as a mechanism to develop human and institutional research capabilities to overcome constraints to sorghum and millet production and utilization for the mutual benefit of the U.S. and Less Developed Countries (LDCs).*** Collaborating scientists in NARS developing countries and the U.S. jointly plan and execute research that mutually benefits all participating countries, including the United States.

INTSORMIL takes a regional approach to sorghum and millet research in western, southern, and eastern Africa, and in Central America. INTSORMIL focuses resources 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. In addition, scientists of the Agricultural Research Service of the U.S. Department of Agriculture at Tifton, Georgia participate in INTSORMIL. What were formerly referred to as "host" countries are now referred to as "collaborating" countries to indicate the closer and more collaborative relationships that have developed between the United States and those countries as a result of all that has been accomplished during the past twenty-two years of the INTSORMIL CRSP.

Because sorghum and millet are important food crops in moisture-stressed regions of the world, they are staple crops for millions in Africa and Asia, and, in their area of adaptation, sorghum and millet have a distinctly competitive advantage to yield more grain than other cereals. As wheat and rice products have been introduced to urban populations in developing countries, traditional types of sorghum, because of some quality characteristics, have not been able to effectively compete with wheat and rice products. However, as a result of research by INTSORMIL researchers and others, improved, food-quality sorghums produce grain that can be used for special ethnic and dietary products as well as for traditional food products. Special white sorghums developed by INTSORMIL collaborative research in Mali have improved characteristics which allow preparation of high-value food products made of as much as 100% sorghum which can compete successfully with wheat and rice products in village and urban markets. Couscous made from food-quality, hybrid sorghum is being market tested in Niger. The development of both open-pollinated and hybrid sorghums for food and feed with improved properties such as increased digestibility and reduced tannin content 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 United States. Improved varieties and hybrids of pearl millet, like improved lines of sorghum, can be grown in developing countries, as well as the United States, and have great potential for processing into high-value food products which can be sold in villages and urban markets, competing successfully with imported wheat and rice products. These developments are results of the training and collaborative, international scientific research that INTSORMIL has supported both in the United States and collaborating countries.

Although significant advances have been made in improvement and production of sorghum and millet in the regions of developing countries 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 maintains a flexible approach to accomplishing its mission. The success of the INTSORMIL program can be attributed to the following strategies which guide the program in its research and linkages with technology transfer entities.

- **Developing institutional and human capital:** INTSORMIL provides needed support for education of agricultural scientists in both developing countries and the United States. The results of this support include strengthening the capabilities of institutions to do research on sorghum and millet, development of collaborative research networks, promoting and linking to technology transfer and dissemination of technologies developed by research, and enhancing national, regional, and global communication linkages. A major innovative aspect of the INTSORMIL focus is to maintain continuing relationships with scientists of collaborating countries upon return to their research posts in their countries. They become members of research teams of INTSORMIL and NARS scientists who conduct research on applications of existing technology and development of new technology. This integrated relationship prepares them for leadership roles in their national agricultural research systems and regional networks in which they collaborate. *From a strategic standpoint, the education of agricultural scientists of developing-country scientists by INTSORMIL contributes to the economic and political stability of developing countries, through cultural ties and long-term scientific collaboration. These scientist-to-scientist bonds help enable the collaborating countries to achieve economic growth necessary to becoming more significant trading partners with their neighbors and the United States. Strategically for the United States, it is crucial to maintain a cadre of scientists knowledgeable about sorghum and millet both within and outside the United States to assure the safety and growth of these two crops in the United States, since both crops are native to Africa.*

- **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, promotes natural control of arthropod pests and diseases of sorghum and millet, and develops resource-efficient cropping systems. Moreover, INSORMIL develops integrated pest management programs, develops cultivars with improved nutrient and water use efficiencies, and evaluates impacts of sorghum/millet technologies on natural resources and biodiversity.

- **Developing research systems:** Collaboration in the regional sites in countries other than the United States has been strengthened by using U.S. and NARS multi-disciplinary research teams focused on unified plans to achieve common objectives. INTSORMIL scientists provide global leadership in biotechnology research on sorghum and pearl millet. The outputs from these disciplinary areas of research are linked to immediate results. INTSORMIL uses both traditional science of proven value and newer disciplines such as molecular biology in an integrated approach to provide products of research with economic potential. These research products which alleviate constraints to production and utilization of sorghum and pearl millet are key elements in fighting hunger and poverty by providing means for economic growth and improved health. New technologies developed by INTSORMIL collaborative research are extended to farmers' fields in developing countries and the United States through partnerships with NGOs, research networks, extension services and the private sector. In addition, economic analysis by INTSORMIL researchers plays a crucial role by enabling economic policymakers to more intelligently consider policy options to help increase the benefits and competitiveness of sorghum and pearl millet as basic food staples and as components of value-added products.

- **Supporting information networking:** INTSORMIL research emphasizes working with both national agricultural research systems and 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, with the ultimate goal being economic and physical well-being to those involved in production and utilization of these two important cereals.

- **Promoting demand-driven processes:** INTSORMIL economic analyses focus on prioritization of research, farm-level industry evaluation, development of sustainable food technology, processing and marketing systems, all of which are 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 or millet for food. Research products transferred to the farm will spur rural economic growth and provide direct economic benefits to consumers. INTSORMIL assesses consumption shifts and socioeconomic policies to reduce effects of price collapses, and does research to improve processing to yield products of sorghum and millet which are attractive and useful to the consumer. Research by INTSORMIL agricultural economists and food scientists seeks to reduce effects of price collapse in high yield years, and to create new income opportunities. 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 in the semi-arid tropics. There is international recognition by the world donor community that national agricultural research systems (NARS) in developing countries must assume ownership of their development problems and move toward achieving resolution of them. The INTSORMIL program is a proven model that empowers the NARS to develop the capacity to assume the ownership of their development strategies, while at the same time resulting in significant benefits back to the U.S. agricultural sector. These aspects of INTSORMIL present a win-win situation for international agricultural development, strengthening developing countries' abilities to solve their problems in the agricultural sector while providing benefits to the United States.

Administration and Management

The University of Nebraska (UNL) 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, events and accomplishments of INTSORMIL during the past year occurred in the United States and collaborating countries.

- Dr. John Axtell, sorghum breeder at Purdue University, passed away.
- Dr. George Teetes, entomologist at Texas A&M University retired.
- Dr. Richard Fredriksen, plant pathologist at Texas A&M University, retired.
- Dr. Jerry Maranville, plant physiologist at the University of Nebraska, retired.
- Dr. Darrell Nelson, Board Member from the University of Nebraska, was elected President of the American Society of Agronomy.
- Dr. Frank Gilstrap replaced Dr. Bobby Eddleman as Board Member from Texas A&M University.
- Dr. Stephen Mason, agronomist at the University of Nebraska, received the 2000 L.K. Crowe Outstanding Undergraduate Advising Award.

The 2000-2001 Technical Committee was elected. Its members are:

- Dr. Gary Peterson, Chair, Texas A&M University (Southern Africa Regional Program Coordinator)
- Dr. John Sanders, Vice Chair, Purdue University (Agronomy/Physiology)
- Dr. Henry Pitre, Secretary, Mississippi State University (Plant Protection)
- Dr. Bruce Hamaker, Purdue University (Economics/Utilization)
- Dr. Gebisa Ejeta, Purdue University (Horn of Africa Regional Program Coordinator)
- Dr. Wayne Hanna, USDA-ARS (Plant Breeding)

- Dr. Stephen Mason, University of Nebraska (Central America Regional Coordinator)

- Dr. Aboubacar Touré, Institut de Economie Rurale, (Mali Coordinator)

- Dr. Peter Esele (Uganda Coordinator).

- INTSORMIL, INIFAP, ICRISAT and other sponsors held the Global 2000 Conference, Sorghum and Pearl Millet Diseases III, in Guanajuato, Mexico, September 23 - 30, 2000.

- INTSORMIL and the Institut Senegalais de Recherches Agricoles (ISRA), the national agricultural research system of Senegal, signed a Memorandum of Understanding, providing the institutional framework to strengthen INTSORMIL collaborative research in Senegal.

- The INTSORMIL External Evaluation Panel completed the five-year, in-depth program review.

- The INTSORMIL Five-Year Grant Extension Proposal was completed and submitted to USAID.

- INTSORMIL made its presentation for a five-year grant extension and was recommended for continuation, March, 2001.

- INTSORMIL completed negotiations with USAID/Mozambique, resulting in a grant being awarded to fund graduate education of ten Mozambican agricultural scientists by a number of CRSPs; INTSORMIL was selected by the CRSP directors to manage the graduate education program.

- The U.S. Southern Africa Regional Coordinator and the INTSORMIL Associate Program Director attended the 15th Sorghum and Millet Improvement Program (SMIP) Steering Committee Meeting at ICRISAT/Matopos, Zimbabwe, October 4-5, 2000 and visited collaborating scientists in Namibia, Zambia, Mozambique and Zimbabwe.

- INTSORMIL investigators, the Program Director and the Associate Program Director attended the annual meeting of the American Society of Agronomy and presented papers regarding INTSORMIL collaborative research, November 5 - 9, 2000.

- The Program Director and the Associate Program Director represented INTSORMIL at the meeting of the CRSP Council Steering Committee, Otter Rock, Oregon, July 23-25, 2000.

- The Associate Program Director represented the nine CRSPs at the National Stakeholders' Workshop on Rural Development Sector Strategy for Nigeria in Abuja, Nigeria, February 1 - 3, 2001

- INTSORMIL contributed to an exhibit on the nine CRSPs presented at the Fourth Annual Agricultural Research and Education Exhibition and Capitol Hill Reception in Washington, D.C., March 6, 2001. The Program Director and Associate Program Director represented INTSORMIL.

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

* INTSORMIL 2000 Annual Report, INTSORMIL Publication 00 -1

* INTSORMIL 2000 Annual Report Executive Summary, INTSORMIL Publication 00 - 2

* Sanders, J. and D. McMillan. Agricultural Technology for the Semiarid African Horn–Country Studies. INTSORMIL Publication 00 - 3

* "Inside INTSORMIL" Newsletter, January 2001, INTSORMIL Publication 01 -1

* INTSORMIL Policy and Operating Procedures Manual, INTSORMIL Publication 01 - 2

* Lowenberg-DeBoer, J. and T. Sullivan. Feasibility Study on the Use of Sorghum and Millets in Animal Feeds–Study Tour, Kenya, Ghana, Mali and Senegal. INTSORMIL Publication 01 - 3

* Sanders, J. and D. McMillan. Agricultural Technology for the Semiarid African Horn–Synthesis and Country Studies, revised. INTSORMIL Publication 01 - 4

Education

Within INTSORMIL's regions of collaborative research and the United States, education of collaborating scientists contributes to the capability of each collaborating country research program to stay abreast of economic and ecological changes which alter the balance of sustainable production systems. The strengthening of collaborating country research institutions contributes to their capability to predict and be prepared to meet the challenges of economic and ecological changes which affect production and utilization of sorghum and millet. A well balanced agricultural research institution must prioritize and blend its operational efforts to conserve and efficiently utilize its natural resources while meeting economic needs of the population in general and the nutritional needs of both humans and livestock. To this end, education is an extremely valuable component of development assistance.

Year 22 Education (July 1, 2000 - June 30, 2001)

During Year 22, 2000-2001, there were 33 students from 17 different countries enrolled in an INTSORMIL advanced degree program and advised by an INTSORMIL principal investigator. Approximately 51% of these students came from countries other than the USA. The number of students receiving 100% funding by INTSORMIL in 2000-2001 totaled 13. An additional 20 students received partial funding from INTSORMIL.

Conferences and workshops are an important means of continuing education for scientists doing research on sorghum and millet. During Year 22, INTSORMIL supported several workshops, the largest of which was Global 2000: Sorghum and Pearl Millet Diseases III at Guanajuato, Mexico, September 23-30, 2000. One hundred thirty participants from twenty-two countries attended the workshop at which they learned about worldwide state-of-the-art research on diseases of sorghum and pearl millet. One individual participated in the ROCARS Mid-Term Network Evaluation in Mali, West Africa. In addition, a number of scientific writing workshops were offered by an INTSORMIL PI in Manhattan, KS, South Africa, Mali, Malaysia, Egypt, and Uganda. About 330 individuals improved their scientific writing skills by participating in these workshops. Another benefit of the conferences and workshops sponsored by INTSORMIL is that they increase the sharing of information, a key factor in developing more efficient research strategies and in more efficiently carrying out research. Of the participants at these conferences and workshops, INTSORMIL funded 60 and provided partial funding for the participation of 419.

Another important category of education which INTSORMIL supports is non-degree research activities, namely post-doctoral research and research of visiting scientists with INTSORMIL PI's in the United States. During Year 22, six female scientists and twelve male scientists improved their education as either post-doctoral scientists (4) or visiting scientists (14). Their research activities were in the disciplines of plant breeding, food quality/utilization, economics, plant pathology, and *Striga* physiology. These scientists came to the United States as post-doctoral scientists or visiting scientists from Argentina, Botswana, Brazil, El Salvador, France, the Gambia, Hungary, Mali, Nicaragua, Niger, and the United States.

Networking

The Sorghum/Millet CRSP Global Plan for Collaborative Research includes workshops and other networking activities such as newsletters, publications, the exchange of scientists, and the exchange of germplasm. The INTSORMIL Global Plan is designed for research coordination and networking within ecogeographic zones and where relevant between zones. The Global Plan:

- Promotes networking with IARCs, NGO/PVOs, Regional networks (ROCAFREMI, ROCARS, ASARECA, SADC/SMINET, SADC/SMIP and others) private industry and government extension programs to coordinate research and technology transfer efforts.

- Supports INTSORMIL participation in regional research networks to promote professional activities of NARS scientists, to facilitate regional research activities (such as multi-location testing of breeding materials), promote germplasm and information exchange, and facilitate impact evaluation of new technologies.

- Develops regional research network, short-term and degree training plans for sorghum and pearl millet scientists.

Over the years, established networking activities have been maintained with ICRISAT in India, Mali, Niger, Central America and Zimbabwe; SAFGRAD, WCASRN, WCAMRN, ASARECA, ECARSAM and SMIP/SMINET in Africa; CLAIS and CIAT of Central and South America and SICNA and the U.S. National Grain Sorghum Producers Association for the purpose of coordinating research activities to avoid duplication of effort and to promote the most effective expenditures of research dollars. There also has been efficient collaboration with each of these programs in co-sponsoring workshops and conferences, and for coordination of research and long-term training. INTSORMIL currently cooperates with the ICRISAT programs in East, Southern, and West Africa, with WCASRN and WCAMRN in West/Central Africa and with SMIP/SMINET in Southern Africa. Sudanese collaborators have provided leadership to the Pan African *Striga* Control Network. INTSORMIL collaboration with ROCAFREMI in West Africa has much potential in allowing INTSORMIL utilization scientists to collaborate regionally. ROCAFREMI is a good mechanism for promoting millet processing at a higher level than has been seen before in West Africa. During the last four years, INTSORMIL, the Bean/Cowpea CRSP and World Vision International have been working with NARS researchers and farmers in five countries under the West Africa Natural Resource Management Project, creating and using a technology-transfer network in West Africa. INTSORMIL will continue to promote free exchange of germplasm, technical information, improved technology, and research techniques.

Regional Activities and Benefits

West Africa

This was certainly a year of transition for the West Africa regional activities with the passing away of John Axtell. Several accomplishments for the year indicate continued emphasis of INTSORMIL on a regional approach to strengthen research capabilities and use research to fight hunger and poverty in West Africa.

A meeting of INTSORMIL investigators was held in Niamey, Niger in March 2000 to review projects, discuss future plans and strategies, and develop new collaborative research in northeastern Nigeria. These new collaborative research activities, at the Lake Chad Research Institute and University of Maiduguri in Nigeria, will focus only on millet and will add to the hybrid millet breeding and millet utilization work with ICRISAT (Dr. Gupta) at the university there. Another meeting was held in the Spring of 2001 to bring in additional regional investigators and complete strategic planning for the regional thrust.

In the Niger hybrid sorghum project, research on development of new improved hybrids is coming to fruition with a number of improved hybrids for early maturity and good grain quality. Seed production, a hurdle to overcome in making hybrids a realization, is progressing with the organization of a seed association. Possible collaborations with other projects (e.g., the Millet and Sorghum Initiative funded by IFAD and others) will help this effort.

The Niger utilization project on processing of high quality flours and agglomerated products (mainly couscous) has progressed with one-half of the market study completed. Results are very positive in terms of responses to commercial potential of NAD-1 hybrid sorghum couscous. Public exhibitions also took place in 2000 and 2001 that have raised public awareness of the sorghum/millet processing unit, breeding of hybrid sorghum, and seed production activities. NGO's were visited to begin to try to get financing for commercial units. The next step is clearly to initiate commercial processing of couscous and flours, and this may require some additional financing. Carl Nelson assisted in the design of the market study and Jupiter Ndjeunga traveled to Niger to assist with design and implementation.

Projects on entomology, agronomy, and pathology are all active in Niger and have made significant contributions to developing varieties of sorghum resistant to midge, developing tied-ridge technology appropriate to Nigerien cropping systems, and improving our knowledge of the biology of sorghum nematodes. Scientists in all disciplines in Niger, Nigeria and Burkina Faso are in need of U.S. collaborators, particularly in entomology and plant pathology. Steve Mason has agreed to assist Seyni Serifi in agronomic research in Niger. Dr. Mason also has two students at Nebraska from the region (Niger and Burkina Faso). Researchers in economics continue to be active. Tahirou Abdoulaye, a graduate student at Purdue, has done significant field research in Niger, primarily on fertilizer adoption. INTSORMIL began collaborative research with plant pathologists, agronomists, and plant breeders in Burkina Faso.

The successful use of N'Tenimissa flour by a private bakery in Mali to make a cookie using some sorghum flour was important and demonstrated that new improved food quality cultivars can stimulate new commercialization of sorghum based products. Most recently, 100% sorghum biscuits are being made by IER and various individuals in Bamako. Marketing of the 100% sorghum biscuits is being done by ROCARS to popularize the product in a number of countries in West and Central Africa.

Collaborative research was initiated in Ghana and Senegal, and a MOU was approved with ISRA in Senegal. There was much interest and desire in both countries to expand the initial collaboration to additional scientists and research areas, but it appears that funding will be difficult to obtain for any major program growth in the near future. Several other countries expressed intense interest in April at the ROCARS meeting in Mali on how they could get involved in INTSORMIL. The expansion into new countries is a good move, but we must be careful to not create unrealistic expectations in the four new countries in West Africa in which INTSORMIL is beginning to devote more resources, or those and other countries may perceive INTSORMIL's PIs as not being able to deliver.

Horn of Africa

In Year 22, under the auspices of IGAD with funds provided by USAID/REDSO/EA, a major study assessing the state of dryland research in the Horn of Africa region was conducted under the leadership of Dr. John Sanders and in cooperation with a number of agricultural scientists from the Horn of Africa.

The survey provides extensive documentation regarding dryland agriculture in the region, technologies available, and research gaps that can be addressed through future research. A stakeholders' workshop is planned for later in the year to discuss the results of this study and to develop a dryland research agenda for the Horn of Africa.

Dr. John Sanders and his graduate student, Negga Wubneh, also completed a field study on the assessment of the impact of *Striga*-resistant sorghum varieties and associated technologies recommended for use in Ethiopia by INTSORMIL. These technologies include *Striga*-resistant varieties, nitrogen fertilization, and tied-ridging as a moisture conservation measure. Analysis and publication of this field study are expected to be completed in early 2002.

On-going collaborative research has progressed in each of the countries, namely Ethiopia, Eritrea, Kenya and Uganda; the results from each of these studies is documented in this report. INTSORMIL investigators in each country have taken keen interest in collaborating with U.S. investigators where partnerships have been developed. Because of expanded collaborative involvement in several countries, more U.S. investigators are needed to provide collaborative linkages with scientists in the region. New investigators joining INTSORMIL are expected to take advantage of the opportunities for collaboration in the Horn of Africa, where host country scientists and programs continue to appreciate and welcome technical support provided by collaborating scientists in the United States.

Southern Africa

Most activities were carried out as planned. Some logistical constraints hindered the research effort. However, research is on-going and, depending on the program, continues to make good progress toward objectives and has produced results that are important to increasing the production and quality of end-products of sorghum and pearl millet in Southern Africa.

Hybrid parents have been bred for sorghum and are nearing completion for pearl millet. A large amount of sorghum breeding material and varieties in use have been characterized for resistance to major diseases and sugarcane aphid. Multi-location testing of sets of such lines provides strategic ecogeographic information on distribution and severity of diseases. Factors influencing the incidence and control of sorghum ergot are now better understood, leading to better control of the disease, especially in hybrid production fields. Food quality research can lead to increased use of sorghum in various products. Linking variety qualities to specific end uses is proving to be very important.

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

Central America

The Central America program continues to evolve from a program focused on Honduras to a more regional program with increased activity in El Salvador and Nicaragua. Concurrent with this evolution has been increased collaborative research in plant pathology and agronomy. The research activities planned at the INTSORMIL Research Planning Meeting in October, 2000 were successfully implemented. After completion of the 2001 year research, a conference will be held to report research results and plan collaborative research activities The major programming challenge for 2002-2006 is to match activities to the available budget, and to develop more interdisciplinary activities. Graduate education of scientists in national programs is needed, but identification of candidates who are proficient in English with firm commitments to work in national programs is difficult, and funding is limited. On the whole, given the short time in the present collaborative model in Central America, the program is functioning well due to the commitment of scientists in the region.

Regional Benefits by Technical Thrust

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

Germplasm Enhancement and Conservation

Breeding sorghum varieties and hybrids for use in developing countries and the United States requires proper recognition of the major constraints limiting production, knowledge of germplasm, and an appropriate physical environment for evaluation and testing. Successful breeding efforts also require knowledge of mode of inheritance and association of traits that contribute to productivity as well as tolerance to biotic and abiotic stresses. Germplasm exchange, movement of seeds in both directions between the United States and collaborating countries, involves populations, cultivars, and breeding lines which carry resistance to insects, diseases, the parasitic weed, *Striga*, drought, and which are tolerant to edaphic stresses, one of which is soil acidity. Research and germplasm development activities in INTSORMIL attempt to address these essential requirements.

INTSORMIL/Purdue project (PRF-207) addresses major biotic and abiotic constraints (drought, cold, grain mold, and other diseases) that limit productivity of sorghum in many areas of the world. Over the years significant progress has been made in some of these areas. Superior raw germplasm have been identified, mode of inheritance established, chemical and morphological traits that contribute to productivity as well as to tolerance to these stresses have been identified. Selected gene sources have been placed in improved germplasm background, some of which have already been widely distributed. Training of NARS scientists is an important component of our research and development effort.

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

- Improved yield (for all collaborating countries)
- Improved drought tolerance (Africa and drier areas of Latin America)
- Acid soil tolerance
- *Striga* resistance (West, Eastern Africa, and Southern Africa)
- Midge and greenbug resistance (Latin America)
- Downy mildew resistance (Latin America and Botswana)
- Anthracnose resistance (Latin America and Mali)
- Charcoal rot and lodging resistance (Africa and drier areas of Latin America)
- Head smut and virus resistance (Latin America)
- Foliar disease resistance (for all collaborating countries)
- Improved grain quality characteristics for food and industrial uses (for all collaborating countries)

The commitment of INTSORMIL to integrated pest management of insect pests and pathogens has produced new lines of sorghum useful to commercial breeders and seed companies for both marketing hybrids and developing more advanced hybrids. Germplasm obtained and evaluated for resistance to economically important insect pests was used to combine insect resistance with other favorable plant traits. Germplasm was identified for advanced testing with resistance to selected insects and diseases, and will contribute to production of widely adapted, high yielding hybrids. Techniques of molecular biology are being used to help understand the inheritance of resistance to greenbug. Results from molecular mapping of sorghum are being used in marker-assisted selection studies for greenbug resistance and post-flowering drought tolerance.

INTSORMIL has been working since the mid-1980's to help Niger develop a hybrid seed industry. Beginning with initial experiments with hybrid sorghum in the 1980s, INTSORMIL scientists of Niger and the United States have collaboratively developed a hybrid sorghum, NAD-1, which is well adapted to conditions in Niger, yields higher than most local varieties and has acceptable qualities for consumers. Following a hybrid sorghum and millet workshop held by INRAN, INTSORMIL and ICRISAT in Niamey in 1998, our private-sector partners in Niger, with the cooperation and support of the public sector, have made significant progress in the production and sale of NAD-1 hybrid sorghum seed. 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 keeping the seed producers' association outside of the formal structure of the government. INTSORMIL thinks this is an encouraging development which should be nurtured. Third, the demand for hybrid seed far exceeds the supply even though the seed is sold at approximately eight times the price of grain. The important distinction between seed and grain is now recognized in Niger. We estimate that 60 tons of hybrid seed will be produced this year in Niger. A great deal of this seed production will be on small farms. During the past year, Nigerien and American food scientists in the INTSORMIL program have collaborated on pilot-plant production of high-quality flour, couscous, and degué (a breakfast food) from NAD-1 hybrid sorghum. INTSORMIL agricultural economists are surveying consumer preferences to provide useful information for marketing of these improved sorghum products.

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

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

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

Producing improved seed that seed companies and farmers can use, INTSORMIL researchers in developing countries and the United States have collaborated to develop improved, high yielding varieties and hybrids. Progeny were identified that combine several needed favorable traits into a single genotype. Advanced selections are being evaluated using 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–in this case, improved germplasm–developed by INTSORMIL has been adopted by private industry and used in hybrid production and breeding programs. Impact assessment studies have consistently shown a high rate of return on investment from research conducted by this project.

In pearl millet breeding, in the first year of the project for the cytoplasm/genotype crosses INTSORMIL was able to obtain consistent results from Niger, India and the USA. The grain yields of the population hybrids compared to their land race parents were similar to what was expected. However, the lower-than-expected yields due to non-adaptability of the population hybrids in the locations tested was unexpected. In the future, the collaborative research of INTSORMIL millet breeders will need to produce population hybrids among locally adapted genotypes. The principal investigator doing pearl millet breeding in Georgia has decided to maximize impact by having visiting scientists spend time with him during the pollinating season. The visit from Moussa Sanogo was beneficial for him and he will get a publication in the International Sorghum and Millet Newsletter from the visit.

Good progress was made in achieving the objectives of INTSORMIL's project for germplasm enhancement for resistance to pathogens and drought and increased genetic diversity (TAM-222). The Mali Collection effort was essentially completed and some very unique elite-appearing exotic cultivars were identified. Broad-based germplasm development and distribution continued and showed promise in Mali, Nicaragua, El Salvador, Zambia, and South Africa. A good portion of the PI's time is devoted to evaluating, identifying, and deciding which germplasm lines and parental lines to release and how to release various materials. A larger number of releases is anticipated this next year.

INTSORMIL's project for germplasm enhancement for resistance to insects and improved efficiency for sustainable agricultural systems (TAM-223) progressed in all research areas. Germplasm was obtained and evaluated for resistance to economically important insect pests. Selections were made to combine insect resistance with other favorable plant traits. Germplasm was identified for advanced testing with resistance to selected insects and diseases that will contribute to production of widely adapted, high yielding hybrids. Results from molecular mapping are currently used in marker-assisted selection studies for greenbug resistance and post-flowering drought tolerance. Collaboration with LDC scientists resulted in progress to develop improved, high-yielding varieties or hybrids. Progeny were identified that combine several favorable traits into a single genotype. Advanced selections are being evaluated by 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 is increasing.

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

Sustainable Production Systems

In West Africa, INTSORMIL's main collaborative agronomy research activities have been focused in Mali and Niger. However, a memorandum of understanding was signed in 1999 with IN.E.R.A., the NARS of Burkina Faso, and collaborative research was initiated in Burkina Faso. INTSORMIL also participates in the West and Central African Sorghum and Millet Research Networks. In research conducted during the past four years, it was determined that high-yielding grain sorghum genotypes that are tall or have high vertical leaf area distribution can be more competitive with weeds and, therefore, be a useful component of integrated weed management programs. Studies on management of late-maturing Maiwa pearl millet in southern Niger were initiated. Because this variety of pearl millet tillers profusely, it provides a unique opportunity to integrate grain production for human consumption and forage production to support livestock. Initial results 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.

This project has been extremely productive in graduate education of West African collaborating scientists; agronomic research which has led to publication in scientific journals, the publication of extension bulletins, and the transfer of improved practices to pearl millet producers; and strengthening the activities of the West and Central Africa Pearl Millet Research Network. In the USA, the project has documented the potential for pearl millet as a new grain crop in the Great Plains, and developed production practice recommendations for planting date, row spacing, and nitrogen fertilizer application. During the past year, research activities have expanded from West Africa to Central America. The pending merger of the West and Central Africa Pearl Millet and Grain Sorghum Research Networks has potential to enhance project activities. Nebraska research on pearl millet is severely constrained by the lack of a pearl millet breeding program in the Great Plains, and the lack of private sector investment in developing pearl millet as an alternate grain crop.

INTSORMIL's project on nutrient efficiency in sorghum and pearl millet completed activities in all countries as planned. On-farm trials successfully demonstrated the value of using new hybrids, inorganic fertilizer and tied ridges to conserve moisture which is now being adopted in certain regions of Niger. Contacts were made between NARS scientists in Ghana, Mali and Niger and WVI personnel as expedited by the UNL-214 PI. Collaboration between and among these individuals should result in greater efficiency for extending new technology. The underlying physiological mechanism for NUE was determined to be a key enzyme in the photosynthesis pathway. This discovery was published in a major journal.

In the project, Economic and Sustainability Evaluation of New Technologies in Sorghum and Millet Production in INTSORMIL Priority Countries (PRF-205), the Senegal and Mali reports for the three-country study of the potential impacts from new technologies and supporting policies were completed. The final report on Niger is well advanced and will be completed in early 2002. This Niger project has been partially supported by ICRISAT. The farmer decision-making model was the same across these three countries and the technologies similar so the comparison and contrast will be instructive. This field research is on schedule with the synthesis of the three country results due out in 2002.

The two-volume, six-country study of the potential of new dryland technologies in the Horn has been published and distributed. A workshop on these results will be held in the fall of 2001. Finishing this report was delayed as key personnel were not allowed into the Sudan and the time frame given by IGAD turned out to be too short for the desired scope of the report.

The fieldwork for the study on the diffusion of *Striga*-resistant sorghum cultivars and associated technologies was completed in Tigray, Ethiopia in this fiscal year and the report on this will be available in 2002. The perennial problem of this fieldwork on diffusion and impact analysis is transportation. The agricultural service of Tigray National Regional State contributed transport vehicles in support of this activity..

Sustainable Plant Protection Systems

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

Witchweeds (*Striga* spp.) are obligate parasitic weeds of significant economic importance. Control methods available to date have been costly and beyond the means of farmers in developing countries. While combining several control measures may be necessary to eradicate *Striga*, crop losses to *Striga* can be effectively minimized through host-plant resistance. In the INTSORMIL project, *Striga* Biotechnology Development and Technology Transfer (PRF-213), the goal has been to exploit the unique life cycle and parasitic traits of *Striga* to develop sorghum lines that are resistant to *Striga* because of disrupted interaction between the parasite and the host. INTSORMIL's *Striga* research program is progressing well. Investigators in Project PRF-213 have made significant advances in our pursuit of understanding the biology of host parasite interaction in *Striga* parasitism. The collaborative research team has exploited the biological relationship between *Striga* and its hosts in identifying and characterizing mechanisms of *Striga* resistance in sorghum. The work is exemplary and provides parallel for similar gains in maize and other crops. Collaborative linkages with ICRISAT and several NARS have been developed and strengthened. Training of NARS scientists is an important component of INTSORMIL's *Striga* research and development effort. Seed supply is likely to be a bottleneck in efforts to promote an expanded cultivation of these varieties. However, INTSORMIL received additional support in Year 22 to cooperate with the NARS of Ethiopia to organize and deliver a sorghum production technology package in *Striga*-affected areas in Ethiopia. This technology project will include multiplication of well-adapted, *Striga*-resistant sorghum, acquisition and packaging of fertilizer, production of plows to make tied ridges, training of trainers, and, finally delivery of the seed, fertilizer, plows and training to farmers.

INTSORMIL's project on agroecology and biotechnology of fungal pathogens of sorghum and millet from the Greater Horn of Africa (KSU-210) has changed its geographic focus to Central America. A short course was conducted at Kansas State for two scientist collaborators, Ings. Reina Guzman and Sergio Pichardo. The laboratories in the host countries are being updated very slowly and much improvement remains as El Salvador and Nicaragua were involved in political strife for nearly twenty years. The objectives of the collaborative project are on schedule as were initially planned.

Sorghum and maize are important grain crops for human consumption and animal feed in developing countries in Central America. The crops are damaged each year by soil inhabiting insects, stem borers, caterpillar defoliators, and panicle feeding insects that contribute to reduced yields of both crops on farms in this region. The complex of defoliators and sorghum midge are considered to be the most damaging to these crops in Honduras and Nicaragua, and annually cause extreme damage to the crops. Research in Honduras in 2000 resulted in partial explanation for differences in occurrence of the principal insect pest constraints to sorghum and maize production in contrasted hillside and coastal plain production systems. The limited success was due to the harsh environmental conditions experienced in the experimental areas. The damage to both crops and ultimately the complete sorghum crop destruction limited or prevented yield measurements for the experimental treatments. Nevertheless, the information obtained in 2000 on the influence of soil moisture on termination of diapause (dormant stage of pupae) and survivorship of this immature stage will benefit the development of integrated insect pest management programs for this region. Studies in the USA to better define the economic threshold of fall armyworm and sorghum midge on sorghum will assist farmers in decision-making regarding the application of insecticides to control these pests.

In INTSORMIL's project on agroecology and biotechnology of stalk rot pathogens of sorghum and millet (KSU-210A), collaborating investigators have collected important new populations of *Fusarium*, and new species have been identified. Some of these species are now being used in field tests on sorghum to determine their relative pathogenicity, primarily for stalk rot. Plans for cooperative work on grain mold of both millet and sorghum are being developed. Molecular diagnostic tools have been developed and should speed diagnoses. Studies of mycotoxin production at a relatively gross level have been completed, but details of the genetics, physiology and environmental parameters that control their synthesis under field conditions need further attention. Present results indicate that species identification may be critical in estimating the risks posed by mycotoxins, and that many of the *Fusarium* species common on sorghum do not make high levels of many of the common mycotoxins. The development of the Scientific Writing and *Fusarium* Laboratory workshops were not a part of the original planned activities, but have been very successful outreach efforts that will be continued. The Scientific Writing and *Fusarium* Laboratory workshops serve as interdisciplinary venues for scientists in developed and developing countries that work on various crops to exchange information and to interact with one another in an informal setting.

Investigators of project KSU-210A have also been carrying out systematic strain collection and strain identification; their development of AFLPs as a means to distinguish species should accelerate this process. This research team plans to purchase equipment to automate much of this process during the coming year. The Principal Investigator will be on sabbatical from January – August 2002, and work while he is gone will focus on the continuing characterization of existing collections. He will attempt to add larger collections from pearl millet from West Africa during September 2001, to augment the rather meager existing collections in this area and to provide enough material for mycotoxin analyses of grain-mold contaminated pearl millet.

Toxicology work now requires a collaborator who can test the effects of toxins in commercial animal feeds and who can model their effects in laboratory systems, using human and animal cell lines as models. Screening of grain for these toxins needs to be done to determine relative levels of these toxins in animal and human food supplies.

The INTSORMIL project on insect pest management strategies for sustainable sorghum production (TAM-225) was completed, and two graduate students who had begun their graduate studies with the Principal Investigator continue to be supported after his retirement and until they graduate. Both are doing research on aspects of the biology of greenbug, an economically important insect pest of sorghum. One of the students is studying genetic diversity in natural populations of greenbug for her dissertation research. She has been conducting phylogenetic analyses of three mitochondrial (mtDNA) gene fragments to determine evolutionary relationships among biotypes and greenbug individuals collected from the field. Other techniques were used to assess genetic diversity in natural populations of greenbugs from the field. This study helps confirm the belief that greenbug biotypes have not shared maternal lineage within the past 0.3-0.6 million years. The other graduate student who is completing his studies with support from this project is studying, for his dissertation research, evolution of greenbug (Homoptera: Aphididae) biotype fitness and virulence on sorghum and wild grasses. He has been conducting research with four genotypes of sorghum and nine greenbug biotypes to determine fitness of adult females and fitness of colonies, based on intrinsic rates of increase calculated from nymphs and colony growth rates. In addition, he is determining virulence of greenbug biotypes on different genotypes of sorghum and some grass species. He is determining effects of temperature and humidity on virulence of selected greenbug biotypes and is using cDNA subtraction to determine genetic difference in sorghum genotypes that correlate with virulence and fitness differences in greenbug biotypes.

Crop Utilization and Marketing

This was a sad year with the death of Dr. John Axtell. Apart from being a close collaborator on INTSORMIL's sorghum digestibility work, John was a friend and leader in sorghum research. It is the hope of the Principal Investigator of INTSORMIL's project on chemical and physical aspects of food and nutritional quality of sorghum and millet (PRF-213) that this food-science research team will be able to continue and complete the work the team had ongoing on improving nutritional quality of sorghum grain. Although in many respects this was a year of transition including students graduating and new ones beginning projects, this food science research team made progress in a few important areas. In nutritional quality research, notable progress was made using John Axtell's recent crosses of high protein digestibility material with the very hard "rice-type" sorghums. Some progeny were identified at the F_4, containing kernels with vitreous endosperm which appears nearly normal and contains the abnormally-shaped protein bodies typical of the high digestibility mutant. This was good news, as it shows that this combination is possible. In other related work done with Murty and Chandrashekar in India, early data look similarly good with the possibility for a stable, improved, grain with highly digestible protein. However, it is still too early to say this definitively. In their research on starch digestibility, they showed that the high protein digestibility mutant gives a higher rate of starch digestion in a cooked porridge system. If this bears out *in vivo*, improved weaning foods and other foods with increased availability of energy could be developed from grain that has higher levels of protein digestibility.

In Niger, the couscous/high quality flour project continues to progress, though always at a seemingly slower pace than is initially planned. The first phase of the market study has been completed, that being an in-home consumer test. The results were very positive with respondents rating the sorghum NAD-1 couscous highly in all sensory categories and overwhelmingly indicating that it should be commercialized. The actual market test in Niamey stores and public market is taking place in the summer of 2001. Two expositions on the processed sorghum products and the hybrids held in the Fall 2000 went very well. Adam Aboubacar traveled to Niamey in August 2000 and assisted in these activities. There continues to be a high level of enthusiasm for this project at INRAN which is now shared by many government officials and potential entrepreneurs. The barrier to get over is initiating actual commercial units. INTSORMIL scientists have talked with various NGOs in Niamey (Africare, World Vision, AfriqueVert) as well as some individuals. It seems like a critical time to try to make some commercialization effort a realization. In March 2001, INTSORMIL scientists met with a local entrepreneur who is a member of the processor association set up two years ago by the INRAN food processing group. She has proposed that she have some access to the unit and sell product in Niamey to begin to establish a market. Perhaps this will be the way to at least get commercialization started in a small way. The two Nigerian scientists who came to the meeting in Niamey in March from Maiduguri were also interested in using these technologies in Northern Nigeria for millet hybrid products.

In Ethiopia, INTSORMIL is still moving quite slowly in the food utilization area. Plans to buy an entrepreneurial-scale decorticator and mill for the Nazret station were set back due to the Dakar-based company going out of business. Another company (European-based with a Dakar office) that can fill this order has been identified, and it is hoped that those units will be put in place in the coming fiscal year. Regarding Kenya, Betty Bugusu continues in her doctoral studies at Purdue. She is making very good progress and is an excellent student.

With INTSORMIL's project on food and nutritional quality of sorghum and millet (TAM-226) there is also progress on several fronts. New markets for value-enhanced white food sorghums are being promoted by the U.S. Grains Council from INTSORMIL's research on food sorghum processing and prototype products. In Japan, value-enhanced white food sorghums are processed into four or more commercial snack foods. Initial sales are promising. Sorghum flour was demonstrated effective in nearly 20 traditional Japanese foods by Japanese chefs and food processors.

Several mills are producing sorghum flour for niche markets. In Central America, white sorghums are used in cookies and other products as a substitute for wheat or maize. Several parental sorghum lines released from INTSORMIL are used in commercial hybrids grown in Mexico and the United States. ATx 635 hybrids have outstanding milling properties.

The antioxidant level in certain bran fractions of special sorghums is higher than that of blueberries, and special sorghums with high levels of phenols and antioxidants produce excellent chips and baked products. Antifungal proteins appear related to grain mold resistance in sorghum. A molecular linkage map for sorghum kernel characteristics, milling properties, and mold resistance is nearing completion.

The activities of TAM-226 in Honduras, El Salvador and Southern Africa are top priority. The new emphasis on food science and technology at EAP in Honduras was encouraging, however, they currently seem disinterested in meaningful collaboration. The opportunity to develop a more comprehensive program in El Salvador and Honduras is challenging.

In Africa, the inability to produce large quantities of N'Tenimissa of good pure quality in Mali followed by meaningful demonstrations of its worth to industry has been disappointing. The overall morale of IER personnel has, however, improved, and production of a concentrated sorghum-based drink and 100% sorghum cookies are encouraging developments. Implementing value-added processing may still occur. Research activities at the University of Pretoria in South Africa continue. The chance to interact with a good cadre of Southern and East African students at University of Pretoria is a unique opportunity. The departure of Dr. Trust Beta from the University of Zimbabwe is a setback.

The uncertainty of funding from year to year inhibits commitments to graduate training. Inflation has eroded away much of our graduate training capabilities. The continued success of our projects is due to our access to Non-INTSORMIL supported projects in breeding (W.L. *Bill* Rooney) and grain mold research (R.D. Waniska). Our ability to attract additional financial support for the work has allowed continued productivity. The funds from INTSORMIL have relatively little buying power since we have about the same number of total dollars we had 20 years ago.

Millet research has been minimized as funds from INTSORMIL decrease in actual buying power. Millet is not a crop in Texas and leveraged funds of INTSORMIL scientists in Texas from other sources are all for sorghum research. Overall, INTSORMIL scientists are quite productive, but cannot do everything that is required because of lack of funds.

Future Directions

Based on its achievements, the INTSORMIL team is well positioned to contribute even more effectively to ending hunger and raise incomes. With its increasing strength of scientific expertise in developing countries, INTSORMIL is now able to more effectively reduce constraints to production and utilization of sorghum and millet to the mutual benefit of developing countries and the United States. Advances in sorghum and millet research over INTSORMIL's first 22 years and the training of sorghum and millet scientists by INTSORMIL in the United States, Africa and Central America now enable scientists from developing countries and the United States to jointly plan and execute mutually beneficial collaborative research. These collaborative relationships are keys to INTSORMIL's success and will continue as fundamental approaches to meeting the INTSORMIL mission. In the future, INTSORMIL will target NARS collaborative ties that reflect regional needs for sorghum and/or millet production. These ties are in the sorghum and millet agroecological zones of western, eastern, and southern Africa, and Central America. By concentrating collaboration in selected sites, INTSORMIL optimizes its resources, builds a finite scientific capability on sorghum and millet, and creates technological and human capital that have a sustainable and global impact.

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 global strategy for 2001-2006 is intended to contribute to the shift of sorghum and pearl millet from subsistence crops to value-added, cash crops, and proposes to produce scientific knowledge and technologies to: contribute to economic growth, improve nutrition, increase yield, and improve institutional capability to meet global, regional and national needs.

Sustainable Plant Protection Systems

Agroecology and Biotechnology of Stalk Rot Pathogens of Sorghum and Millet

Project KSU-210A
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Summary

In collaboration with my South African colleagues, I have described a new *Fusarium* species in section *Liseola* from sorghum in Africa and the United States. This species is distinguished morphologically by the production of unique pseudochlamydospores in carnation leaf pieces on carnation leaf agar, and appears to be most closely related to *F. thapsinum*. The new species also can be distinguished molecularly by means of Amplified Fragment Length Polymorphisms, AFLPs. Strains with both *MAT-1* and *MAT-2* mating types were identified, but no sexual stage was generated in crosses made under laboratory conditions. We also tested ex-holotype strains of 15 new *Fusarium* species for their ability to produce the mycotoxins beauvericin, fumonisins, fusaproliferin, and moniliformin.

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.

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Research Approach and Project Output

Research Methods

Cultures

We examined the ex-holotype strains of the *Fusarium* species described by Nirenberg and O'Donnell and Nirenberg et al. for AFLP polymorphisms to determine if our unusual sorghum strains from southern Africa described in last year's annual report belonged to one of these putative species. The standard strains that we used are kept at the Medical Research Council in Tygerberg, South Africa (MRC numbers), my collection at Kansas State University (KSU numbers) and at the BBA, in Berlin, Germany (BBA numbers). The strains we used were (MRC no., KSU no., BBA no.): *F. acutatum* Nirenberg and O'Donnell (7544, X-10769, 69580), *F. begoniae* Nirenberg and O'Donnell (7542, X-10767, 67781), *F. brevicatenulatum* Nirenberg, O'Donnell, Kroschel and Andrianaivo (7531, X-10756, 69197), *F. bulbicola* Nirenberg and O'Donnell (7534, X-10759, 63628), *F. circinatum* Nirenberg and O'Donnell [teleomorph *Gibberella circinata* Nirenberg and O'Donnell] (7541, X-10766, 69720), *F. concentricum* Nirenberg and O'Donnell (7540, X-10765, 64354), *F. denticulatum* Nirenberg and O'Donnell (7538, X-10763, 67772), *F. guttiforme* Nirenberg and O'Donnell (7539, X-10764, 69661), *F. lactis* (Pirotta and Riboni) Nirenberg and O'Donnell (7532, X-10757, 68590), *F. phyllophilum* Nirenberg and O'Donnell (7543, X-10768, 63625), *F. pseudoanthophilum* Nirenberg, O'Donnell and Mubatanhema (7530, X-10755, 69002), *F. pseudocircinatum* Nirenberg and O'Donnell (7536, X-10761 and 69636), *F. pseudonygamai* Nirenberg and O'Donnell (7537, X-10762, 69552), and *F. ramigenum* O'Donnell and Nirenberg (7535, X-10760, 68592). We also examined one strain each of *F. anthophilum* (8127, X-5007), *F. dlamini* (3023, X-05009), *F. napiforme* (3105, X-05015), and *F. succisae* (8126, X-03862).

We also used these strains of the newly described species *Fusarium andiyazi*: South Africa, Kwazulu-Natal: Greytown, cultures isolated from sorghum plants by S.C. Lamprecht, 1990, MRC 5993 – *MAT-1* (KSU 3860), MRC 5995 - *MAT-1* (KSU 3862); Greytown, cultures isolated from sorghum soil debris by S.C. Lamprecht, 1990, MRC 6122 – *MAT-2* (KSU 4804, BPI 748223, ATCC MAY-1399, IMI 386078), MRC 6123 – *MAT-1* (KSU 10771), and MRC 6126 – *MAT-1* (KSU 4807). USA, Colorado: Walsh, cultures isolated from sorghum grain by W.F.O. Marasas, 1991, all *MAT-1*, MRC 6178 (KSU 11149), MRC 6180 (KSU 11150), MRC 6182 (KSU 11152), MRC 6183 (KSU 11153), MRC 6184 (KSU 11154), MRC 6185 (KSU 11155), and MRC 6186 (KSU 11156). Ethiopia: Dire Dawa, Alemaya, cultures isolated from sorghum grain by T. Hussein, 1990, all *MAT-2*, MRC 8045 (KSU 4645), MRC 8046 (KSU 4647), MRC 8047 (KSU 4648), MRC 8048 (KSU 4649), MRC 8049 (KSU 4650), MRC 8118 (KSU 4646), MRC 8119 (KSU 4651), MRC 8120 (KSU 4652), MRC 8121 (KSU 4653), MRC 8122 (KSU 4654), MRC 8123 (KSU 4655), MRC 8124 (KSU 4656). Nigeria, Kaduna: Rigachukan, cultures isolated from sorghum grain by B. Onyike, 1988 (Onyike and Nelson 1992), MRC 8066 – *MAT-2* (KSU 4636), MRC 8067 *MAT-2* (KSU 4946), MRC 8068 *MAT-1* (KSU 4950), and MRC 8125 *MAT-1* (KSU 4642).

We measured growth rates of strains on Potato-Dextrose Agar (PDA) (Difco, Detroit, MI) at both 25 and 30C and incubated in complete darkness for three days. Measurements were made on three replicate cultures per temperature for each strain.

Amplified Fragment Length Polymorphisms

Cultures were grown and DNA was extracted as previously described (see 2000 annual report. AFLPs were generated essentially as described by Vos et al. as modified by Zeller et al. We digested approximately 100 ng of DNA with 2 units each of *Eco*RI and *Mse*I (New England Biolabs, Beverly, MA) according to manufacturer's instructions, and ligated to *Eco*RI adapters (an equimolar mixture of *Eco*RI oligo-1, CTCGTAGACTGCCTACC and *Eco*RI oligo-2, AATTGGTACGCAGTC, 5 pmole/μl) and *Mse*I adapters (an equimolar mixture of *Mse*I oligo-3, GACGATGAGTCCTGAG and *Mse*I oligo-4, TACTCAGGACTCAT, 50 pmole/μl) with T4 DNA ligase (New England Biolabs). These DNA fragments were pre-amplified and amplified as described by Vos et al. The number of amplified fragments in the final amplification was reduced by adding two additional bases to the *Eco*RI and *Mse*I primers (denoted as EXX or MXX). We analyzed the AFLPs resulting from amplification with two primer pairs (ETT/MAC and EGG/MTG) that yielded a total of 157 resolvable bands between 100 and 800 bp in length for the intraspecific comparisons and 368 bands for the interspecific comparisons. The *Eco*RI primers in the final amplification mixes were end-labeled with ^{33}P and fragments were separated in 6% polyacrylamide gels (Long Ranger, FMC, Rockland, ME). Gels were dried and exposed to autoradiography film (Classic Blue Sensitive, Molecular Technologies, St. Louis, MO) for 2-5 days at room temperature to identify DNA bands.

To analyze AFLP profiles, we manually scored the presence or absence of bands. We assumed that bands of the same molecular size in different individuals were identical. For each individual, we determined the presence or absence of each band. Each band was treated as a single independent locus with two alleles and unresolved bands or missing data were scored as ambiguous. We calculated genetic similarities between strains with the Dice coefficient. UPGMA clustering was carried out with the CLUSTER option of SAS (v 6.12).

Mating Compatibility Testing

We identified the mating type idiomorph (*MAT-1* or *MAT-2*) for all isolates identified as *F. andiyazi* with PCR-based assays we had developed earlier in collaboration with our Hungarian and South African collaborators as described in either Kérenyi et al (1999), or Steenkamp et al (2000). All putative *F. andiyazi* isolates were crossed as males to the mating population tester strains for the known mating populations A-H. In addition, we intercrossed all *F. andiyazi* isolates in all possible *MAT-1* × *MAT-2* combinations to determine whether we could identify a corresponding *Gibberella* teleomorph for this *Fusarium* species. All crosses were attempted at least twice using carrot agar and the standard protocols of Klittich and Leslie. We used the following standard *Gibberella fujikuroi* mating population mating-type tester strains from the KSU collection or from the Fungal Genetics Stock Center, Kansas City, Kansas: FGSC 7600 (*MATA-1*), FGSC 7603 (*MATA-2*), FGSC 7611 (*MATB-1*), FGSC 7610 (*MATB-2*), KSU C-01993 (*MATC-1*), KSU C-01995 (*MATC-2*), FGSC 7615 (*MATD-1*), FGSC 7614 (*MATD-2*), FGSC 7616 (*MATE-1*), FGSC 7617 (*MATE-2*), FGSC 7057 (*MATF-1*), FGSC 7056 (*MATF-2*), KSU G-05111 (*MATG-1*), KSU G-05112 (*MATG-2*), KSU H-10847 (*MATH-1*) and KSU H-10850 (*MATH-2*).

Strains were routinely cultured on carnation leaf agar (CLA), or on modified Czapek's complete medium. Strains are maintained as lyophilized cultures (MRC), or as spore suspensions in 15% glycerol frozen at -70C (KSU). A dried culture of MRC strain 6122, representing *F. andiyazi* from sorghum was deposited with the National Fungus Collection, Beltsville, Maryland, USA as BPI 748223. Ex-holotype cultures were deposited with the American Type Culture Collection (MYA-1399) and the International Mycological Institute (386078).

Mycotoxin Production, Isolation and Extraction

Maize grits were used as culture media for mycotoxin production. Grits were moistened with 40% distilled H_2O, mixed, covered with aluminum foil, and autoclaved at 121 C for 1 hr. After cooling overnight, 20% distilled H_2O was added to the grits and the mixture autoclaved again for 1 hr. The sterile grits were distributed in Petri dishes, inoculated with a spore suspension, and incubated at 25 C for 30 days. The humid moldy grits were first dried in a closed laboratory hood for three days, homogenized with a blender transferred to a plastic box and stored at -20 C.

A method previously described by Thakur and Smith (33) was slightly modified and used to extract and analyze beauvericin. The analyses of fumonisins B_1, B_2 and B_3 were performed according to previously described methods by Thakur and Smith and Ritieni et al. We used a method described by Kostecki et al. (13) for the extraction and analyses of fusaproliferin and moniliformin. The mycotoxins moniliformin and fusaproliferin, if present, are partitioned between the two phases: the aqueous phase, which contains moniliformin, and an organic (CH_2Cl_2) phase, which contains fusaproliferin.

HPLC Analyses of the Extracts

Chromatographic analyses of the extracts were done using a Hewlett-Packard (HP) Model Series II, 1090A HPLC fitted with a Rheodyne 7125 injector with a 50 µl loop. Chromatographic separations were achieved using a double end-capped, metal-free silica C-18 (250 mm × 4.6 mm, 5 µm) Alltech Alltima^{TM} column equilibrated at 40 C. The flow rate used for these analyses was 1 ml/min, except for beauvericin (1.2 ml/min). The detection of the mycotoxins was achieved with a diode array detector or a HP 1064A programmable fluorescence detector.

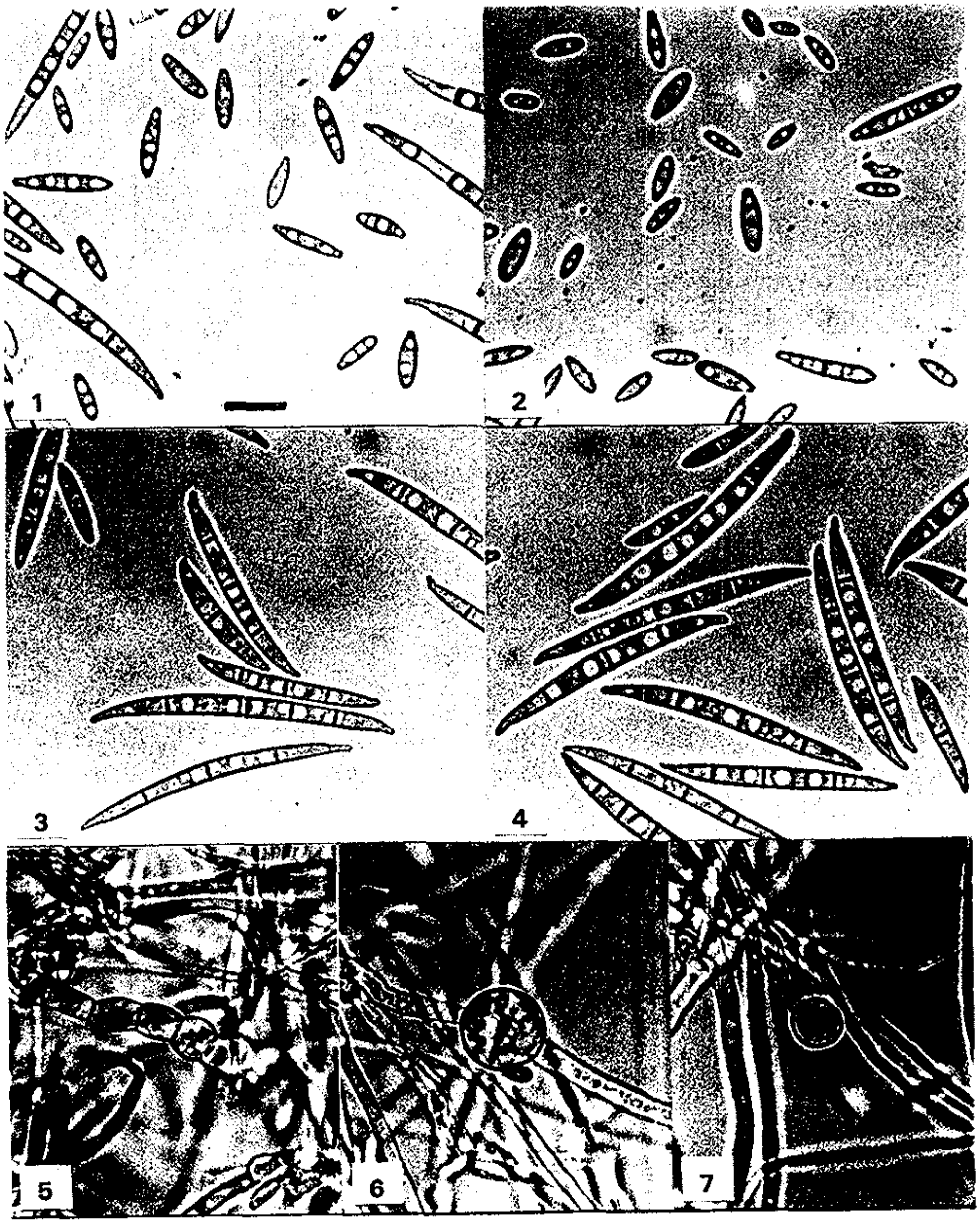
Research Findings

English Version of Formal Species Description

Colony diameter on PDA after dark incubation for 72 hr is 27-33 mm (mean 30 mm) at 25°C and 27-40 mm (mean 32 mm) at 30°C. Colonies floccose to powdery, with both the aerial mycelium and the reverse of the colonies initially white, becoming pale to intense purple. Conidiogenous cells monophialidic, formed laterally on the aerial hyphae or on single and branched conidiophores, hyaline, subulate, 14-42 × 2.0-3.5 µm. Microconidia abundant, borne in chains or false heads, hyaline, clavate to ovoid, with a truncate base, 0-2-septate, 5-23 × 1.5-4.0 µm (Figs. 1-2). Microconidial chains on CLA are initially long (> 15 conidia), later collapsing to short chains (< 15 conidia), particularly in the center of the colony. In some strains the microconidial chains remain intact and do not readily collapse, particularly at the edge of the colony. Sporodochia on CLA, orange, produced when microconidial chains begin to collapse. Macroconidia (Figs. 3-4) produced on monophialides on branched conidiophores in sporodochia, hyaline, thin-walled, straight or slightly curved, falcate, with a pedicellate basal cell and a slightly curved apical cell, 3-6-septate, mostly 3-septate, 18-56 µm × 2.0-4.0 µm. "Pseudochlamydospores" (Figs. 5-7) formed on the carnation leaf pieces or in the aerial mycelium in close proximity to the carnation pieces, never in the submerged hyphae, terminal to intercalary, hyaline, smooth-walled, mostly solitary, also in short chains, 7-16 µm in diameter. The species epithet, "andiyazi" originates from the Xhosa word "andiyazi", which means "I do not know"; in reference to the fact that this pathogen of sorghum remained unknown to science and was difficult to convincingly distinguish until now.

Species Identification and Differentiation

The "pseudochlamydospores" described here as a morphological characteristic are found in all strains of *F. andiyazi* and thus constitute an acceptable taxonomic character. These pseudochlamydospores, although not identical



Figs. 1-7. *Fusarium andiyazi* (MRC 6122). 1-2. Microconidia. 3-4. Pedicellate macroconidia. 5-7. Pseudochlamydospores. All photographs same magnification. The bar in Fig.1 is 10 µm.

to the chlamydospores produced by certain other *Fusarium* species, are distinguishable from "swollen hyphal cells" or thick-walled hyphae described by some other investigators. The morphology of the pseudochlamydospores is variable, but they do not form transverse septa or become transparent as the cultures age. The thickened hyphae of *F. verticillioides* from maize as described by Nyvall and Kommendahl also are not similar to these pseudochlamydospores because the former occur within senescent host tissue or dried-out agar medium, whereas the latter form within or in close proximity to carnation leaf pieces on moist agar medium. Manzo and Claflin reported the presence of "swollen, chlamydospore-like cells" with thin, single-layered cell walls" for strains of "*F. moniliforme*" cultured on sorghum stalk tissue. These chlamydospore-like cells were infrequently seen and were not used as taxonomic or identification tools in their study, even though their strains of "*F. moniliforme*" were derived from various sources.

It is very important that the pseudochlamydospores described in this study were observed under standardized culture procedures as used in *Fusarium* taxonomy. The pseudochlamydospores we observed were not "chlamydospore-like structures" developing in non-chlamydospore producing *Fusarium* species subjected to abnormal treatments. Further study of these pseudochlamydospores is required to elucidate their structure and to compare them with typical chlamydospores found in some other *Fusarium* species, e.g., transmission electron microscopy to determine whether their outer walls are thick and whether they contain lipid bodies as has been shown for *F. nygamai* and *F. napiforme*.

Mating-type Amplification and Mating Compatibility

None of the *F. andiyzai* isolates were interfertile when mated to tester strains from biological species A-H of the *G. fujikuroi* species complex. We determined through the PCR-based assays for mating-type idiomorph that 13 of the isolates were *MAT-1* and that 15 isolates were *MAT-2*. All isolates with the same AFLP haplotype had the same mating-type idiomorph, as would be expected if they were clones. We did not obtain a *Gibberella* stage from any of the intra-specific crosses. This result suggests that female-fertile strains in this species may be relatively rare in field populations, as is known for some of the other mating populations in the *G. fujikuroi* species complex, or that we have not yet determined the proper cultural conditions for producing the sexual stage for this species.

To date, the scientific literature has abounded with reports of "*F. moniliforme*" occurring on grain sorghum as the cause of *Fusarium* grain mold and stalk rot. The description of this new species has wide ranging implications in that all these reports now need to be reevaluated. This problem was solved partially in 1997 with the description of *F. thapsinum* (teleomorph, *G. thapsina*), which previously had also been identified as "*F. moniliforme*." There remain a significant number of sexually "sterile" strains in previous studies of "*F. moniliforme*" that have not been unambiguously identified to species and that could belong to *F. andiyazi*. Sorghum worldwide needs to be re-examined, not only to determine the frequency and distribution of *F. andiyazi*, but also to provide more information on *F. thapsinum* and to ensure that all of the *Fusarium* species common to sorghum have been properly identified and characterized.

AFLP Polymorphism

We compared pairwise AFLP profile similarity both among the *F. andiyazi* isolates, and between the ex-holotype culture (MRC 6122) of this species and representatives of the majority of the described biological and phylogenetic species within the *G. fujikuroi* species complex. All 12 isolates from Ethiopia had the same AFLP banding pattern and were assumed to represent a clone. Three of the strains from Colorado (MRC 6180, MRC 6182 and MRC 6183) also shared one AFLP banding pattern and two others (MRC 6185 and MRC 6186) share a second, presumably representing two additional clones. UPGMA similarity among the 14 unique *F. andiyazi* haplotypes was generally high. The average similarity among distinct isolate haplotypes was 92%, and minimum similarity among the tested isolates was 85%, even though these strains were collected in very different geographic locations. (Table 1)

In comparison, UPGMA similarity between MRC 6122 and representatives of the other tested species was much lower (Table 2), and was comparable to that observed between the other, biological or phylogenetic, species tested. Average similarity among the tested species was 24%, with a maximum similarity of 72% and a minimum of 5.3% (data not shown). The species with highest similarity in AFLP profile to *F. andiyazi* MRC 6122 was an isolate of *F. thapsinum* (KSU 4093, MRC 6537) at 40% UPGMA similarity. These results are the first interspecific comparisons within these fungi that we know of using AFLPs, and are similar in the level of relatedness to those reported by Benyon et al. with RFLP markers for interspecific comparisons in the *Fusarium* and *Roseum* sections of the genus. Thus we interpret these data to support the hypothesis that *F. andiyazi* is not conspecific with any of these previously described species. (Table 2).

Mycotoxin Production

The toxins produced by these species are summarized in Table 3. *F. concentricum* produced the most beauvericin (720 µg/g). *F. begoniae* and *F. phyllophilum* produced the most moniliformin, 1,000 and 1,500 µg/g, respectively. *F. pseudonygamai* produced the most fusaproliferin (131 µg/g), and *F. phyllophilum* produced the most fumonisins B_1 (2.5 µg/g). None of these cultures produced fumonisin B_3, and *F. bulbicola* produced none of the six mycotoxins that we analyzed.

Table 1. Intraspecies UPGMA similarity among *Fusarium andiyazi* isolates using AFLP markers.

Strain†	5993	5995	6122	6126	6123	8066	8045	8067	8068	6178	6180	6184	6185
5993	1.000												
5995	0.920	1.000											
6122	0.897	0.930	1.000										
6126	0.915	0.949	0.962	1.000									
6123	0.897	0.924	0.949	0.949	1.000								
8066	0.897	0.911	0.955	0.949	0.969	1.000							
8045	0.854	0.873	0.904	0.910	0.904	0.917	1.000						
8067	0.859	0.865	0.910	0.903	0.872	0.916	0.852	1.000					
8068	0.859	0.864	0.920	0.901	0.883	0.914	0.877	0.877	1.000				
6178	0.888	0.919	0.963	0.957	0.926	0.944	0.894	0.887	0.934	1.000			
6180	0.872	0.902	0.945	0.939	0.921	0.939	0.890	0.871	0.929	0.982	1.000		
6184	0.897	0.931	0.943	0.955	0.937	0.934	0.892	0.877	0.889	0.932	0.915	1.000	
6185	0.923	0.937	0.977	0.954	0.930	0.946	0.892	0.901	0.934	0.993	0.993	0.937	1.000

† MRC strain number.

Table 2. Pairwise UPGMA similarities based on data from two selective AFLP primer combinations between *F. andiyazi*, and representatives of other described species within the *Gibberella fujikuroi* species complex

Strain[†]	6122	6459	6537	7548	7535	7536
6122 *F. andiyazi*	1.000					
6459 (MP-A) *F. verticillioides*	0.333	1.000				
6537 (MP-F) *F. thapsinum*	0.400	0.391	1.000			
7548 (MP-G) *F. nygamai*	0.263	0.320	0.351	1.000		
7535 *F. ramigenum*	0.368	0.243	0.356	0.238	1.000	
7536 *F. pseudocircinatum*	0.333	0.400	0.294	0.325	0.304	1.000
6512 (MP-E) *F. subglutinans*	0.246	0.254	0.161	0.192	0.110	0.203
6524 (MP-B) *F. sacchari*	0.222	0.229	0.087	0.222	0.200	0.211
C-1993 (MP-C) *F. fujikuroi*	0.130	0.160	0.274	0.256	0.118	0.071
6569 (MP-D) *F. proliferatum*	0.237	0.216	0.247	0.188	0.167	0.175
7541 (MP-H) *F. circinatum*	0.121	0.187	0.159	0.160	0.135	0.114
7539 *F. guttiforme*	0.192	0.169	0.171	0.293	0.222	0.208
7534 *F. bulbicola*	0.141	0.174	0.176	0.175	0.152	0.216
7542 *F. begoniae*	0.232	0.179	0.273	0.308	0.260	0.222
X-3832 *F. succisae*	0.200	0.103	0.208	0.202	0.136	0.145
X-5007 *F. anthophilum*	0.200	0.103	0.156	0.202	0.182	0.238
7540 *F. concentricum*	0.205	0.237	0.187	0.161	0.233	0.173
7544 *F. acutatum*	0.211	0.243	0.192	0.259	0.190	0.300
7543 *F. phyllophilum*	0.237	0.270	0.219	0.259	0.262	0.250
7532 *F. lactis*	0.310	0.294	0.388	0.359	0.278	0.493
7538 *F. denticulatum*	0.286	0.333	0.328	0.222	0.366	0.294
7531 *F. brevicatenulatum*	0.226	0.300	0.271	0.254	0.363	0.369
7530 *F. pseudoanthophilum*	0.254	0.261	0.353	0.250	0.354	0.270
7537 *F. pseudonygamai*	0.231	0.289	0.347	0.311	0.372	0.247
X-5009 *F. dlamini*	0.247	0.111	0.225	0.217	0.099	0.128
X-5015 *F. napiforme*	0.222	0.219	0.222	0.347	0.270	0.261

[†] MRC strain number unless beginning with a letter, then from KSU collection.

Table 3. Production of the mycotoxins beauvericin (BEA), moniliformin (MON), fusaproliferin (FP), and fumonisins B_1, B_2 and B_3 (FB_1, FB_2 FB_3) by 15 new *Fusarium* species.

Fusarium species	Strain Number[†]	Mycotoxins				
		BEA (µg/g)	(µg/g)	FP (µg/g)	FB_1 (µg/kg)	FB_2 (µg/kg)
F. acutatum	7544	6 ± 1	ND[‡]	ND	147 ± 10	360± 23
F. begoniae	7542	ND	1000 ± 64	ND	66 ± 3	ND
F. brevicatenulatum	7531		ND	ND	150 ± 7	ND
F. bulbicola	7534	ND	ND	ND	ND	ND
F. circinatum	7541	57 ± 2	ND	ND	ND	ND
F. concentricum	7540	721 ± 48	ND	ND	ND	ND
F. denticulatum	7538	ND	180 ± 7	ND	ND	ND
F. guttiforme	7539	72 ± 6	ND	85 ± 5	ND	ND
F. lactis	7532	ND	51 ± 3	ND	ND	ND
F. nisikadoi	7533	ND	0.6 ± 0.1	ND	ND	ND
F. phyllophilum	7543	ND	1500 ± 73	ND	2500 ± 100	T[§]
F. pseudoanthophilum	7530	2.2 ± 0.2	ND[b]	ND	ND	ND
F. pseudocircinatum	7536	ND	100 ± 16	12 ± 0.3	280 ± 3	360±30
F. pseudonygamai	7537	ND	53 ± 2	130 ± 2	ND	ND
F. ramigenum	7535	ND	46 ± 9	ND	ND	ND

MON ND
[†]MRC: Medical Research Council strain collection.
[‡]ND - Not Detected.
[§]T-Trace.

The levels of beauvericin found in our study are significantly below the highest beauvericin production (3,200 µg/g) ever reported (18), but do fall within the range previously reported in similar studies. Beauvericin was first identified for its antibiotic and insecticidal activities, but also is toxic to brine shrimp (*Artemia salina*), and to human ematopoietic, epithelial, and fibroblastoid cells.

The three species - *F. pseudocircinatum* (12 µg/g), *F. pseudonygamai* (130 µg/g), and *F. guttiforme* (85 µg/g) - that produce fusaproliferin fall at the low end of the previously reported range (trace to 2,600 µg/g). Fusaproliferin is toxic to brine shrimp and human B-lymphocytes cell line IARC/LCL 171, and can induce teratogenic effects, *e.g.* cephalic dichotomy, macrocephaly and limb asymmetry, in chicken embryos.

Moniliformin is the mycotoxin produced by the largest number of species examined (8 of 15), and now has been reported to be produced by more than 30 *Fusarium* species. *F. begoniae* (1,000 µg/g), *F. phyllophilum* (1,500 µg/g), *F.*

denticulatum (180 μg/g), and *F. pseudocircinatum* (104 μg/g) all produce significant levels of this toxin. Moniliformin is extremely toxic to animals such as ducklings, rats, mice, chickens, and swine, and has been correlated with hepatitis in vervet monkeys and with a human heart condition, Keshan Disease, in China.

Fumonisins B_1, B_2 and B_3 are a group of non-genotoxic carcinogens primarily produced by *Fusarium verticillioides*. Consumption of fumonisin-contaminated grain is correlated with esophageal cancer in humans, and can cause leukoencephalomalacia in horses, pulmonary edema in swine, and liver and kidney damage in rats. The levels of fumonisins B_1 and B_2 found in this study appear to be low, with only *F. phyllophilum* producing sufficient fumonisins to be above the possible level for regulatory action in the United States, and even that level (2.5 μg/g) is at least three orders of magnitude less than the amount of this toxin that can be produced by other species already described in *Fusarium* section *Liseola*.

The production of several mycotoxins by the same *Fusarium* strain is not unusual, and six of the species we examined can produce more than one of the toxins we tested for *F. pseudocircinatum*, for example produces four mycotoxins, but of greater concern are the relatively high levels of both moniliformin and fumonisins that are produced by *F. phyllophilum*. Synergistic interactions of these mycotoxins have not been studied in details and probably deserve more attention. That other toxic compounds produced by these fungi probably still await description only amplifies the significance of this problem.

Networking Activities

Editorial and Committee Service (2000)

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 (2000):

Egypt – April 27 - May 8, October 14-23
Uganda – October 9-14
Australia – November 4-11
Malaysia – November 12-18
Hungary – November 29 – December 3
South Africa – December 4-16
The Netherlands – December 17-19.

Seminar, Workshop and Invited Meeting Presentations (2000)

Organized *Fusarium* Laboratory Workshop in Manhattan from June 11-16; 34 participants and six instructors from nine countries

Editor for Proceedings of Sorghum/Millet pathology conference in Guanjuato, Mexico

Department of Plant Pathology and Microbiology, Texas A&M University, College Station, Texas – 4/00

Egyptian National Agricultural Library, Dokki, Egypt – 5/00.

Department of Plant Pathology, University of Florida, Gainesville, Florida – 5/00.

International Workshop on Sorghum and Millets Pathology, Guanjuato, Mexico – 9/00.

Faculty of Agriculture and Forestry, Makerere University, Kampala, Uganda – 10/00.

Egyptian National Agricultural Library, Dokki, Egypt – 10/00.

School of Biology, Universiti Sains Malaysia, Penang, Malaysia – 11/00.

Agricultural Biotechnology Center, Godollo, Hungary – 11/00.

PROMEC, Medical Research Council, Tygerberg, South Africa – 12/00.

During 2000 Fusarium Cultures were Provided to

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Other Collaborating Scientists

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Dr. Sandra Lamprecht, Plant Protection Institute, Agricultural Research Council, Stellenbosch, South Africa

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Drs. Michael and Brenda Wingfield, FABI, University of Pretoria, Pretoria, South Africa

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Dr. Maya Piñeiro, Mycotoxins Unit, Laboratorio Tecnologia del Uruguay, Montevideo, Uruguay

Dr. Brett Summerell, Royal Botanic Gardens, Sydney, Australia

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

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

Dr. K. K. Klein, Department of Biological Sciences, Mankato State University, Mankato, Minnesota

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

Publications and Presentations

Journal Articles and Book Chapters

Chulze, S. N., A. Torres, M. L. Ramirez and J. F. Leslie. 2000. Genetic variation in *Fusarium* section *Liseola* from no-till maize in Argentina. Applied and Environmental Microbiology 66: 5312-5315.

Leslie, J. F. 2000. *Fusarium* species associated with sorghum. In: Compendium of Sorghum Diseases (R. A. Frederiksen and G. N. Odvody, eds.), pp. 30-31. APS Press, St. Paul, Minnesota. 78 pp.

Leslie, J. F. 2000. Storage molds and mycotoxicoses. In: Compendium of Sorghum Diseases (R. A. Frederiksen and G. N. Odvody, eds.), pp. 42-43. APS Press, St. Paul, Minnesota. 78 pp.

Steenkamp, E. T., B. D. Wingfield, T. A. Coutinho, K. A. Zeller, M. J. Wingfield, W. F. O. Marasas and J. F. Leslie. 2000. PCR-based identification of *MAT-1* and *MAT-2* in the *Gibberella fujikuroi* species complex. Applied and Environmental Microbiology 66: 4378-4382.

Zeller, K. A., J. E. Jurgenson, E. M. El-Assiuty and J. F. Leslie. 2000. Isozyme and amplified fragment length polymorphisms (AFLPs) from *Cephalosporium maydis* in Egypt. Phytoparasitica 28: 121-130.

Abstracts

Jurgenson, J. E., R. L. Bowden, K. A. Zeller and J. F. Leslie. 2000. AFLP Linkage map of *Gibberella zeae*. Phytopathology 90: s40.

Leslie, J. F. and K. A. Zeller. 2000. AFLPs for distinguishing populations and species of *Fusarium*. Phytopathology 90: s46.

Saleh, A. A., K. A. Zeller, E. M. El-Assiuty and J. F. Leslie. 2000. AFLP diversity of *Cephalosporium maydis* in Egypt. Phytopathology 60: s68.

Zeller, K. A., R. L. Bowden and J. F. Leslie. 2000. AFLP diversity of *Fusarium graminearum* (*Gibberella zeae*) in two wheat-scab epidemic populations. Inoculum 51(3): 69.

Zeller, K. A., E. M. El-Assiuty and J. F. Leslie. 2000. Relative colonization ability of maize by four lineages of *Cephalosporium maydis* from Egypt. Inoculum 51(3): 69.

Book Reviews

Leslie, J. F. *Structure and Dynamics of Fungal Populations*; ed. J. J. Worrall; Kluwer Academic Publishers, Norwell, Massachusetts, 348 pp. Reviewed in Mycopathologia 147(2000): 169-170.

Agroecology and Biotechnology of Fungal Pathogens of Sorghum and Millet

Project KSU-210B
Larry E. Claflin
Kansas State University

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Summary

If physiological resistance is shown to be the mechanism for tolerance to ergot in sorghum, it would provide a unique opportunity in breeding programs worldwide to incorporate resistance in acceptable cultivars/hybrids. It is imperative that the mode of inheritance be determined before additional breeding endeavors are attempted. Seemingly, germplasm accessions from Ethiopia were reported as resistant whereas they were fully susceptible in the winter nursery in Puerto Rico. It remains unclear whether they were deemed resistant under a different environment, escapes or from pollen management.

Objectives, Production and Utilization Constraints

Objectives

- U.S./Mexico/Nicaragua/El Salvador: Determine the prokaryotic plant pathogenic organisms responsible for unique and unusual diseases of sorghum that may pose yield constraints. These causal agents are primarily insect disseminated and a joint collaborative project has been implemented with project MSU-205.

- U.S./Kenya: Continue to screen for genetic variability of sorghum germplasm to covered kernel smut and ergot diseases that continually occur and affect the nutrition of people and animals.

- U.S./Mexico/Nicaragua/El Salvador: Ascertain the prevalence of diseases through surveys and use of the ADIN nursery from Texas A & M University.

- U.S./Mexico: Collaborate with Mr. Jesus Narro on a bacterial disease project of sorghum in the Bahel region of Mexico.

- Determine if physiological resistance rather than pollen management is the mechanism for tolerance to *Claviceps africana*.

- Continue to evaluate screening protocols for determining genetic variability of grain sorghum to sooty stripe disease (*Ramulispora sorghi*). Determination of various environmental parameters to maximize incidence and severity of disease will also be included.

- Monitor movement of *Claviceps africana* conidia and incorporate the data into a predictive model for recommending control protocols and possibly eliminate the need for chemicals.

- Develop a unique genomic fingerprint pattern using the polymerase chain reaction (PCR) for the identification of *Burkholderia andropogonis* and utilize the fingerprint pattern for identifying this bacterial pathogen in plant tissue and seeds.

Constraints

Ergot (sugary disease) of sorghum (*Sorghum bicolor* [L.] Moench), caused by *Claviceps africana* was only a problem in grain sorghum in Africa and Asia prior to 1996 when the disease was first detected in Brazil and Argentina. In 1997, the disease spread to Colombia, Honduras, Nicaragua, El Salvador, Mexico, numerous islands in the Caribbean, and in the U.S. (Kansas, Nebraska, and Texas). Ergot is a disease of unfertilized sorghum ovaries. The sudden, widespread appearances of ergot in recent years demonstrate the potential impact of *C. africana* on the sorghum industry worldwide.

The stigma is the principal site of the infection. Susceptibility to infection is from floral gaping, just before or at anthesis. Infected spikelets exude sweet, sticky drops of fluid honeydew containing three types of conidia: macroconidia, secondary conidia, and microconidia. Although insect transmission of *C. purpurea* conidia is known, insects are probably insignificant in disseminating conidia in an ergot epiphytotic in sorghum.

Wind dissemination of secondary conidia is the most important mode of dispersal for local and long distance spread of *C. africana* and may explain the rapid, long-distance disease spread in Australia and the Americas. Concentrations of secondary conidia in the air show a diurnal pattern, with the greatest occurrence at nightfall with an increase in HR and lower temperatures. Dispersal of secondary conidia from a very small initial infection focus results in a wide spread epiphytotic. Secondary conidia is also produced by honeydew that drips and falls onto soil. Such soilborne secondary conidia can infect plants in the field and may be very important for in-field ergot incidence. Dissemination of the pathogen from field to field may be also due to the dispersal of honeydew containing conidia during farming and postharvest operations, personnel, equipment or seed. However, the epidemiological significance of seed contaminated with honeydew is unclear.

Germplasm resistant to ergot have been identified in numerous studies, but these lines are mostly photoperiod-sensitive, tall and agronomically undesirable. Environmental interactions have also limited the use of these accessions in breeding because germplasm reported as resistant in one environment was susceptible in a different geographical location or environment. We evaluated various accessions of *Sorghum* spp. and potential grass hosts for their reaction to ergot under greenhouse conditions at Manhattan, KS. Inflorescences were inoculated by spraying a suspension of 2.0 X 10^5 macroconidia/ml at anthesis, panicles were covered with clear plastic bags, and inoculation was repeated after five days.

Wild and cultivated sorghum representing *Sorghum bicolor* and *S. halepense* were generally susceptible to *C. africana*. However, ergot symptoms were not observed on several accessions from *S. bicolor* ssp. *arundinaceum*, and *S. bicolor* ssp. *drummondii*. Within *S. bicolor* ssp. *arundinaceum*, IS 14257 and IS 14357 representing race *verticilliflorum* and IS 14301 and PI 185574 representing race *arundinaceum* were free of ergot infection. *S. bicolor* spp. d*rummondii* (IS 14131) expressed high levels of resistance to ergot.

IS 14131 and IS 14357 were crossed to A3TX430 to produce male-sterile testcross hybrids to evaluate the physiological basis of resistance in these accessions. Parent lines, male-sterile hybrids, and susceptible lines were evaluated for genetic variability to *C. africana* at the winter nursery in Guayanilla, Puerto Rico and under greenhouse conditions at Manhattan, KS.

Susceptible checks were heavily infected with ergot. The male-sterile crosses were nearly as resistant as the parent lines. Since resistance was expressed in male sterile genetic backgrounds, the mechanism of resistance appears to be physiological in nature. ATX623 had 90% of the florets infected whereas the accessions described as resistant above were nearly free of ergot.

Previously, IS 8525 was the only known accession in a male-sterile cross that exhibited tolerance to *C. africana*. Differences were observed in ergot incidence between environments in College Station and Lubbock, TX. In addition, A-lines were the most susceptible group followed by hybrids, R-lines and B-lines. Significant differences occurred between A-lines for ergot severity under seven environments and between B-lines for six environments. Ergot susceptibility of the A-line does not necessarily infer susceptibility in the B-line. The more recently released A-lines were more susceptible than older releases. Improved stigma receptivity of the newer lines appeared to account for the difference. Tx2737 (R-line) was more susceptible than other R-lines tested. In this line, the stigmas had emerged from glumes one-two days prior to pollen shed allowing for the colonization of the stigma by conidia. These results suggest that stigmas and ovules are hosts for ergot conidia when they are no longer receptive to pollen.

During the growing seasons of 1999 and 2000 spore traps were placed at Crosbyton and Corpus Christi, TX; Lahoma, OK; Garden City, Hays, Hesston, and Manhattan, KS; and Clay Center, NE. Detection of ergot spores from the drums were reported to the stations where the information was gathered. Various private seed companies utilized the data to determine if controls were necessary. In addition, the data will be incorporated in a model known as "SORKAM" that is based on growth and development of sorghum plants.

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).

Burkholderia andropogonis (formerly *Pseudomonas andropogonis*) is the casual agent of bacterial leaf diseases in a wide host range of monocot and dicot plants. This bacterial pathogen has been implicated in foliar and stalk rot diseases from over 100 crops and include sweet and yellow dent corn, blueberry, sorghum, carnation, coffee, statice, rye, and clover. In grain sorghum, *B. andropogonis* is the casual agent of bacterial leaf stripe, a disease characterized by linear purple, tan, red or yellow lesions. *B. andropogonis* is a quarantine pathogen of sorghum and over 50 countries in the world require phytosanitary certificates for import of sorghum feed grain and seed. As a consequence, a need exists for a rapid, inexpensive and reliable detection protocol. There are numerous methods to identify *B. andropogonis* including biochemical and physiological characteristics, fatty acid analysis, cellular protein and dot-immunobinding assay. However, each procedure may be costly, labor intense and time consuming. polymerase chain reaction (PCR), we examined twenty-seven isolates of *B. andropogonis* from ten different hosts for a unique fingerprint pattern that could be used as a rapid identification tool. Included were controls consisting of other common plant pathogens. Once the unique pattern was established, the ultimate goal was to develop a PCR protocol to identify *B. andropogonis* directly from diseased leaf and seed tissue.

Research Approach and Project Output

Ergot

Air samples to measure spore concentrations of *C. africana* were collected with Kramer-Collins seven-day spore samplers situated on metal racks 1.80 m above ground. The sampler and vacuum pump are fastened to a metal rack. An airtight bearing allows the sampler to rotate; thereby keeping the intake orifice facing into the wind at all times. The vacuum pump is situated on the rack just below the sampler.

After seven days, the exposed drum of each sampler is removed from the clock mechanism used to rotate the drum, and an unused drum is immediately inserted in the clock mechanism. A drum is prepared by placing double-coated adhesive cellophane tape around the drum and applying a light coat of silicone on the tape, and then mailed to the sampling stations. After one week, the cooperator returns the exposed drum to our laboratory for processing.

The tape from an exposed drum is removed and transferred to one-mm-thick plexiglas strips (4 x 45 cm). Depositions are examined directly from exposed tapes by using a microscope. The exposed tape is divided in 7 equal segments representing a single 24 hour segment. Those segments are read by fixing them on a glass slide. Spores are counted by examining one continuous microscope-field across the 24 h segment under a 20X objective and converting those counts to average numbers per cubic meter of air for the 24 h period for each location

Modeling System

Spore traps known as the Kramer-Collins trap were utilized in an attempt to detect wind movement of ergot spores from southern sorghum growing locations to the northern latitudes. The trap consist of a vacuum pump, timer, and a rotating drum with a double sided adhesive tape where spores are fixed. The timer is on a seven -day cycle. A quantity of air is forced through the container and particulate materials including pollen and fungi are trapped in the adhesive tape. Drums are sent to the laboratory by cooperators from the various locations at weekly intervals.

Spore viability was measured on collections that arrived in the laboratory within 24 h of removal from the sampler. Germination was measured only in the last 24 h segment of the weekly deposit. At least three spores have to be deposited in the 24 h sample for a germination test to be completed. Exposed tapes were incubated for six hours in a moist chamber at 19 to 20°C, optimum temperatures for germination growth of the pathogen to ascertain spore viability. A spore was considered viable if the germ tube length was equal to the spore diameter. Visual surveys were conducted in surrounding sorghum fields to evaluate the presence and severity of ergot in the area throughout the sampling period. Meteorological data including wind trajectory forecast maps was obtained from the National Weather Service Office, Topeka, KS 66601. Wind trajectory forecast maps for the 850-mb level were used to show probable movement of air over a 24 h period.

To prove physiological resistance is the mechanism in our tolerant hosts, a tedious protocol is being proposed. That entails inoculating sorghum inflorescences at flowering with conidia of *C. africana*. Florets are removed at various time intervals, dissected, stained and then examined with a compound microscope to determine if infection resulted. Lack of colonization of the style or ovary by the conidial germ tube would infer physiological resistance.

Bacterial Streak

Bacterial Strains and Media

Source, plant host and geographical location of strains utilized in developing a DNA fingerprint are listed in Table 1. Stock cultures were maintained on yeast dextrose calcium carbonate agar (YDCA) at 4° C. Prior to use, strains were restreaked on fresh YDCA and incubated for 24 to 48 h at 28° C. For long term storage, cultures were lyophilized and also stored at –70°C in a glycerol/nutrient broth solution.

Table 1. Location, designations, and host of strains used to develop a DNA fingerprint for *Burkholderia andropogonis*.

Strain †	Host	Location
Burkholderia andropogonis		
931 HAYWARD	Carnation	Australia
0700A HAYWARD	Chick pea	Australia
O468C HAYWARD	Clover	Australia
ICPB PS 280	Clover	Hawaii
PDDCC 6780	Coffee	Brazil
ATCC 23061	Sorghum	USA
CUCPB 1115	Sorghum	Unknown
945 HAYWARD	Sorghum	Australia
3310 PA	Sorghum	Kansas
3390 PA	Sorghum	Kansas
3392 PA	Sorghum	Kansas
3394 PA	Sorghum	Kansas
3395 PA	Sorghum	Kansas
3399 PA	Sorghum	Kansas
3407 PA	Millet	Texas
3543 PA	Sorghum	Argentina
3544 PA	Sorghum	Argentina
3545 PA	Sorghum	Argentina
3549 PA	Sugarcane	Louisiana
3558 PA	Sorghum	Kansas
3561 PA	Sorghum	Kansas
3576 PA	Unknown	Egypt
3588 PA	Sorghum	Kansas
3590 PA	Sorghum	Kansas
3547 PA	Sorghum	Argentina
3585 PA	Statice	Kansas
3586 PA	Sorghum	Kansas
3587 PA	Sorghum	Kansas
0929A HAYWARD	Statice	Australia
ATTCC 19309	Velvet bean	Zimbabwe
Acidovorax avenae pv avenae		
NCPPB 3029	Corn	Brazil
PDDCC 3106	Maize	India
PDDCC 1656	Sweetcorn	Florida
Acidovorax avenae sub cattleyae		
PDDCC 3168	Teosinte	India
Pseudomonas rubrisubalbicans		
PDDCC 2850	Sweet corn	Florida
Pseudomonas syringae pv atrofaciens		
ATCC 9004	Wheat	Uknown
Pseudomonas syringae pv coronafaciens		
C-86	Rye	Georgia
Pseudomonas syringae pv syringae		
82 GF	Pinto beans	Nebraska
NCPPB 1242	Proso millet	Australia
Pantoea stewartii		
2225 ES	Corn	South Africa
Xanthomonas campestris pv vasculorum		
4627 XCV	Sugarcane	South Africa

†ATCC, American Type Culture Collection, Rockville, MD, USA; NCPPB, National Collection of Plant Pathogenic Bacteria, Harpenden, Hertfordshire,UK; PDDCC, Plant Disease Division Culture Collection, Auckland, New Zealand; ICPB, N. Schaad, International Collection of Plant Pathogenic Bacteria, USDA, Beltsville, MD, USA; HAYWARD, A.C. Hayward, University of Queensland, Queensland, Australia; 85-02, 82 GF,A.K. Vidaver, University of Nebraska, Lincoln, NE, USA; C-86, B. Cunfer, Georgia Experimental Station, GA, USA; SW 2, SW 104, C. Block , USDA, Iowa State University, Ames, IA, USA; all other strains from the collection of L.E. Claflin, Kansas State University, Manhattan , KS, USA.

DNA Isolation and PCR Assay

Single colonies were grown overnight in 5 mls of nutrient broth yeast extract (NBY) on a shaker. Genomic DNA was isolated by a modification of Leach and White (1990). Cells were pelleted by centrifugation; resuspended in 380 µl of TE (0.1 M EDTA, 10mM Tris Base pH 8.0). Twenty microliters of 25% SDS, 50 µl of pronase was added to each sample and incubated for one hour at 37° C. Following incubation, 50 µl of 5M NaCl was added and the solution then incubated at 65° C for 30 minutes. Tubes were cooled and the solution was extracted with equal volumes of phenol; phenol:chloroform; phenol:chloroform:isoamyl alcohol. DNA was precipitated with 95% ethanol dried in a speed vac and resuspended in 200 ml of TE.

Concentration was determined using a spectrofluorimeter and adjusted to 50ng/µl. BOX element (BOX1A) oligonucleotide primer was synthezied by Oligo's Etc. (Wilsonville, OR). The primer sequence is

5'-CTACGGCAAGGCGACGCTGACG-3'. PCR conditions and amplification procedure were as described previously.

Sooty Stripe

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

Research Findings

A unique genomic pattern of nine bands was generated for *B. andropogonis* (Figure 1) using the primer BOX. Six of the twenty-nine strains of *B. andropogonis* did not have band eight. This group of six consisted of four isolates from Australia and one each from Hawaii and Zimbabwe and

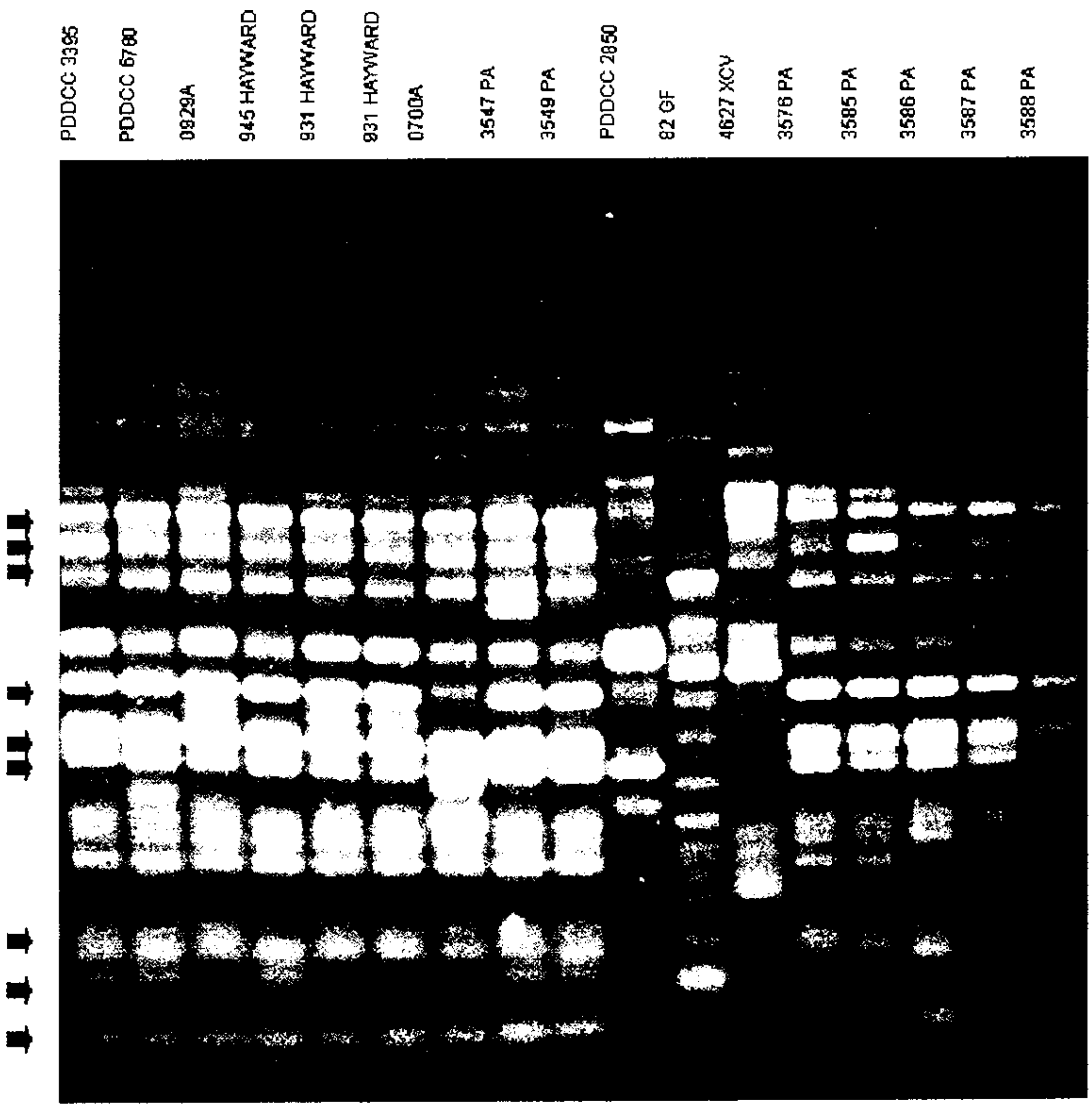

Figure 1. BOX-PCR patterns from genomic DNA of *B. andropogonis* and other bacterial pathogens. Arrows mark the unique nine band pattern of *B. andropogonis*. Using this unique nine band genomic fingerprint work is currently focused on developing a procedure to identify *B. andropogonis* directly from seed and plant tissue samples.

may constitute a second genotype. The genomic banding patterns of all the controls were distinctly different compared to *B. andropogonis* group.

Spore traps failed to detect an ergot outbreak in six counties in Central Kansas in November 1999 although a spore trap and trap crops were approximately 40 KM from the site. The greatest spore concentrations were recovered from Corpus Christi (310 micro- and 38 macroconidia) during week of June 24, and Manhattan (17 micro- and 29 macroconidia) during the week of September 22, 1999. This coincided with ergot infections at those locations. Ergot incidence was dependent on favorable weather and optimal growth stage development of sorghum plants.

Research to determine the potential source of resistance to ergot in sorghum was only initiated within the past two months and no data has been gathered due to a hail storm that seriously damaged the greenhouse complex at Kansas State.

Networking Activities

Workshops

Assisted in organizing and implementing Global 2000: Sorghum and Pearl Millet Diseases III; Guanajuato, Mexico; September 23-30, 2000.

Research Investigator Exchanges

Reina Guzman from El Salvador and Sergio Pichardo from Nicaragua visited Kansas State University from August 15 until September 7, 2001 on a collaborative research update and training session.

L. E. Claflin surveyed sorghum fields and discussed mutual research in El Salvador and Nicaragua in December, 2000.

Various equipment and supplies provided to Reina Guzman in CENTA and Sergio Pichardo in UNA through passthrough funds of KSU 211.

Defective microscopes from CENTA and UNA were carried to the US, cleaned and repaired and then returned to Nicaragua and El Salvador. Repair of the microscopes and replacement of the objectives resulted in a potential savings of $20,000.

Research Information Exchange

Antisera specific to *Xanthomonas campestris* pv. *holcicola* (causal agent of bacterial streak disease of sorghum) was provided to Ranijit Bandyopadhay (ICRISAT) and Jesus Narro (Mexico)

The All Disease and Insect Nursery (ADIN) that was graciously provided by Dr. D. T. Rosenow was planted in two locations in both El Salvador and Nicaragua to determine disease incidence and severity.

Numerous extension publications, compendia, and textbooks were furnished to Reina Guzman and Ing. Sergio Pichardo.

Publications and Presentations

Abstracts

B.A. Ramundo, L.E. Claflin., and D.F. Narvaez. 2000. Identification of *Burkholderia andropogonis* Using PCR Generated Genomic Fingerprints. Global 2000: Sorghum and Pearl Millet Diseases III. Guanajuato, Mexico.

Journal Articles

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

Claflin, L. E. 2000. Ergot: A new disease of grain sorghum in the Western Hemisphere. Revista Mexicana de Fitopathologia. 17:46-48.

Claflin, L. E. 2000. Procaryotic diseases and stalk rots of grain sorghum diseases. *In*, R. A. Fredericksen and G. N. Odvody, eds., Sorghum Disease Compendium, 2nd ed. pp. 5-7, 28-30. American Phytopathological Soc., St. Paul, MN.

Presentations

Claflin, L. E. 2000. Stalk rots of sorghum. Global 2000: Diseases of sorghum and millets. Guanajuato, Mexico, Sept. 25.

Claflin, L. E. 2000. Update on ergot disease of sorghum. University of Nicaragua, Managua. Nov 28.

Claflin, L. E. 2000. Update on ergot disease of sorghum. Ministry of Agriculture. San Salvador, El Salvador, Dec 1.

Claflin, L. E. 2000. Ergot Disease of Grain Sorghum - KSU Research. American Seed Trade Association. Chicago, IL, Dec 7.

Miscellaneous Publications

Claflin, L. E. 2000. Agroecology and biotechnology of fungal pathogens of sorghum and millet from the Greater Horn of Africa. Pp. 11-18 in INTSORMIL Ann. Repts., A Technical Res. Rept. of the Grain Sorghum/Pearl Millet Collaborative Res. Support Prog. (CRISP), University of Nebraska, Lincoln.

Low Input Ecologically Defined Management Strategies for Insect Pests on Sorghum

Project MSU-205
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Rene Clará Valencia, Sorghum Breeder, CENTA, San Salvador, El Salvador
Mario Ernesto Parada Jaco, Entomologist, CENTA, San Salvador, El Salvador
Larry Claflin, Plant Pathologist, Kansas State University, Manhattan, KS

Summary

MSU-205 expanded entomological research activities with INTA, UNA and UNAN in Nicaragua, initiated collaboration with CENTA in El Salvador, and deemphasized research and graduate student participation with EAP in Honduras in 2000. Validation and comparative studies including insect pest management strategies in hillside and coastal plain intercropped sorghum and maize production systems were completed in Honduras. Results of these studies revealed that maize yields were significantly greater in crop management systems with an improved maize variety than in systems with a traditional maize variety, suggesting that crop variety was mainly responsible for differences in yield within cropping systems. Although sorghum yields were not obtained due to crop destruction (wind damage in late season), insect pest infestations were about equal in crop management systems that were compared. In observing aspects of diapause (dormancy) in *Metaponpneumata rogenhoferi*, soil moisture was identified as the stimulus for eclosion of moths, but it appeared to have acted only as a secondary factor in diapause termination. The time spent in the diapause condition may be more important in stimulating termination of the dormant period in this species. This information and that on the biology, ecology and behavior of related species in the lepidopterous caterpillar complex that is devastating to sorghum and maize in this region of Central America will assist in the application of integrated insect pest management programs on these crops.

Travel by the MSU-205 PI in 2000 was successful in the direction of graduate student research in Honduras and resulted in the development of collaborative research plans with scientists at INTA, UNA and UNAN in Nicaragua, and CENTA in El Salvador. Collaborative research activities with a sorghum breeder, agronomist and plant pathologist are planned for 2001 in Nicaragua and El Salvador. Seminars on "Insect Pests on Sorghum and Related Crop Management Practices" were presented at UNA in Nicaragua and CENTA in El Salvador. A Master of Science (M.S.) research program was completed at Mississippi State University with collaboration in Nicaragua and manuscripts were prepared for publication as popular articles and in scientific journals. A second M.S. research program was completed in Honduras and a thesis is in preparation. Plans are for the MSU-205 PI to travel to Nicaragua and El Salvador in 2001.

Objectives, Production and Utilization Constraints

Honduras

- Compare effectiveness of insect pest management systems in traditional and improved intercropped sorghum production systems in hillside and coastal plain fields.
- Determine the influence(s) of insect biological and environmental parameters on diapause (dormant state) of a species in the caterpillar complex that is the principal constraint to sorghum and maize production.
- Complete graduate student research and academic program for Master of Science degree in entomology at Mississippi State University. Prepare manuscripts for publication in scientific journals.

Nicaragua

- Complete graduate student research and academic program for Master of Science degree in entomology at Mississippi State University. Prepare manuscripts for publication in scientific journals and popular article for distribution into farm communities.

- Meet with collaborator scientist in INTA, UNA and UNAN to develop collaborative research plans for 2001.

- Develop research and academic programs for MSU-205 Ph.D. student.

El Salvador

- Meet with collaborator scientist in CENTA to develop collaborative research plans for 2001.

United States

- Plan experiments to evaluate the effectiveness and economical benefit of insecticide spray programs and refine the economic thresholds for fall armyworm and sorghum midge on sorghum.

Research Approach and Project Output

Honduras

The INTSORMIL MSU-205 project has participated in collaborative entomological research and student training in Honduras for the past 22 years. Research emphasis has been on the principal insect pest constraints to production of intercropped sorghum and maize on subsistence farms. Information on the biology, ecology behavior, population dynamics and pest control tactics for soil insects, foliage feeders and stem borers have been obtained and incorporated into insect pest management programs. The results of collaborative research with scientists at the Panamerican School of Agriculture has been published in 1999 by Zamorano Academic Press in a popular article, "La Langosta del Sorgo y el Maiz". This publication was distributed into farm communities to provide recommendations to farmers for management of the complex of insects that is devastating to these crops annually. Cultural, chemical and biological control practices have been identified for use in integrated insect pest management programs for the principal pests on these grain crops. The benefits of this information have been reported in previous INTSORMIL annual reports. For example, an economic evaluation of integrated insect pest management tactics in intercropped sorghum and maize production systems in southern Honduras indicated that sorghum production was increased by 20% and maize by 35% at the farm level. These increases could return $2.9 million a year to production of these crops in this area when market prices are high.

With most studies conducted on hillsides in southern Honduras, research in 1999 and 2000 concentrated on comparing insect pest management strategies in traditional and improved intercropped sorghum and maize production systems in fields in the foothills and on the coastal plain. The two systems compared included sorghum and maize under farmers production practices (traditional system) and improved crop production technology (improved system). Biological information and influence of crop production methods on pest diversity and density, and yield were determined in these contrasting systems. The fall armyworm was the principal pest species encountered in both years. No significant differences were found among the four crop management systems in density of this species or damage to maize. Sorghum was either infested at extremely low density levels or crop stands were destroyed at both locations because of harsh environmental conditions during the late growing season. Insecticide applied to the seed protected maize plants in early developmental stages from damaging corn rootworms. The neotropical corn stalk borer was present in maize but no significant differences were found among crop management systems. The indian meal moth, as the other species mentioned, infested maize over sorghum. No significant differences in yield of sorghum or maize were found among crop management systems in 1999; whereas, in 2000, maize yields were significantly greater in crop management systems with the improved variety than in systems with the traditional maize variety, suggesting that crop variety was mainly responsible for differences in yield.

Information was obtained on field survivorship of one the lepidopterous caterpillars that contributes to sorghum and maize destruction in some years, but is the principal pest on the crops in other years. Information on this insect was lacking prior to MSU-205 investigations. The effect of soil moisture (irrigations at intervals overtime) on diapause termination of *Metaponpneumata rogenhoferi* pupae was observed in areas heavily infested with sicklepod, a very common weed and preferred host for this insect in the foothills and on the coastal plain in southern Honduras. Irrigated soil and soil with no irrigation were treatments established in screen cages placed over sites heavily infested with sicklepod in 1999. Greater numbers of *M. rogenhoferi* were collected in cages in the foothills than in cages on the coastal plain. Soil moisture was the stimulus for eclosion of the moths but it appeared to have acted only as a secondary factor in diapause termination. The time spent in the diapause condition may be more important in stimulating termination of this dormant period in this species. Soil samples taken during the period that *M. rogenhoferi* was in diapause suggested that this species experiences high larval and pupal mortality even though larvae feed on a preferral host, sicklepod.

These studies concluded MSU-205 collaborative research in Honduras. The PI will visit Honduras within the next two years to conduct a follow-up survey to determine the extent of farmer utilization of entomological/pest management information and practices in their farming operations.

Nicaragua

MSU-205 expanded research activities into Nicaragua in 1999, after initially developing collaborative relationships with scientists at INTA in Managua in 1998. Entomological constraints to sorghum production on the Pacific coastal plain are recognized to be sorghum midge, fall armyworm and chinch bug, the midge being most destructive. Research was conducted to determine seasonal occurrence of sorghum midge on host plants and oviposition behavior on specific hosts. Tactics for management of the midge were evaluated and included planting date, crop variety and insecticide efficacy. A Master of Science thesis and degree program was completed and two manuscripts representing this research were prepared for publication in the international journal, "Tropical Agriculture". A popular article, "La Mosquita De La Panoja Del Sorgo", published by INTA, was prepared for distribution into farm communities. The information in this publication will assist farmers in sorghum midge pest management.

The student that successfully completed the Master of Science degree will continue entomological studies for the Ph.D. degree. Research will emphasize economic evaluations of fall armyworm and sorghum midge management practices in monoculture sorghum.

El Salvador

Entomological research with scientists in CENTA was planned and coordinated for the 2001 sorghum growing season in El Salvador. This was accomplished when the MSU-205 PI visited CENTA in El Salvador in November, 2000. Insects of greatest interest and thought to be the most damaging to sorghum crops in El Salvador include the complex of soil inhabiting insects, and defoliators (eg., fall armyworm). The objectives of research for 2001 involve identification of the complex of soil insect pests and determining the extent of damage and economic significance of these insects on sorghum. This objective includes elucidation of the occurrence and aspects of population dynamics of these pest. Plans were made to obtain this information from sampling programs in different crop agroecosystems. A second planned objective will involve the principal insect defoliator, the fall armyworm. Observations on populations of this caterpillar on and damage to sorghums in the All Disease and Insect Nursery (ADIN) will be made during the crop growing season. This will be coordinated with collaborating sorghum breeder and plant pathologists in El Salvador and Kansas State University (KS-210B), respectively. A study will be conducted to identify economic threshold levels for fall armyworm on sorghum, and a study is planned to determine the efficacy of selected insecticides on defoliator caterpillars.

United States

The economic threshold for caterpillar pests on whorl stage sorghum and sorghum midge on panicles is not clearly identified for sorghum in different growth stages. Studies were conducted in 2001 and will be conducted in 2002 to refine these levels using two strategies, one involving number of insects per plant and the other percentage of plants infested. Yield data will be recorded for treatments. This research will be duplicated in Nicaragua with collaboration at INTA and UNA. These findings can improve the application of pest management practices for the specific insects.

Networking Activities

Collaborator scientists and administrators at INTA in Nicaragua expressed interest in supporting a workshop on pest management in Nicaragua. This workshop would include entomology and plant pathology. The MSU-205 and KS-210B PIs would be principal INTSORMIL coordinators, with coordination from INTA. This workshop may be conducted in 2002.

Research investigator exchanges generally have involved shipment of supplies and small equipment for research purposes.

The popular article on sorghum midge in Nicaragua, prepared by INTSORMIL MSU-205 and INTA provides information for farmers in managing this insect pest on sorghum and improving yield.

Publications and Presentations

Journal Articles

Cordero, R.J., R.L. Brown, and H.N. Pitre. 2000. Description of life stages and distribution of *Metaponpneumata rogenhoferi* (Lepidoptera: Noctuidae). Tropical Lepidoperta. 10: 59-67.

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

Lopez, J.I., H.N. Pitre and D.H. Meckenstock. ____. Influence of nitrogen fertilzer on resistance to fall armyworm (Lepidoptera: Noctuidae) in tropical Honduran landrace sorghum. Ceiba. 40: 2 ____. (accepted)

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

Vergara, O.R. and H.N. Pitre. ____. Planting data, weed management and insecticide application practices for control of lepidopterous pests in intercropped sorghum and maize in southern Honduras. Tropical Agriculture. (accepted)

Dissertations and Theses

Zeledon, J.J. 2000. Occurrence, host plant relationships and management of sorghum midge, *Stenodiplosis sorghicola* (Coq.) (Diptera: Cecidomyiidae), on sorghum in Nicaragua. MS thesis. Mississippi State University, Mississippi State, MS.

Miscellaneous Publications

Zeledon, J., H. Pitre, J. Vanegas and H. Obregon. 2000. La mosquita de la panaja del. sorgo. Centro Nacional de Investigaciones Agropecuarias. 6 pp.

Presentations

Pitre, H.N. 2000. Insect pests on sorghum and related crop management practices. Seminar presented at UNA in Managua, Nicaragua.

Pitre, H.N. 2000. Insect pests on sorghum and related crop management practices. Seminar presented at CENTA in San Salvador, El Salvador.

Striga Biotechnology Development and Technology Transfer

Project PRF-213
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Dr. Dale Hess, *Striga* Specialist, ICRISAT, Mali
Dr. Joel Ransom, *Striga* Agronomist, CIMMYT, Kenya
Dr. Robert Eplee, *Striga* Specialist, USDA/ARS/APHIS, USA
Dr. James Riopel, University of Virginia, USA
Dr. H. Geiger, Univ. of Hohenheim, Germany

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 22, we report on characterization of mechanisms of *Striga* resistance in sorghum. We developed new laboratory assays that target the disruption of a particular signal exchange or that detect a precise defense response at a given point in the life cycle of the parasite to define and characterize mechanisms of resistance. In this report, we describe the physiology and genetics of two mechanisms of *Striga* resistance, a hypersensitive response (HR) and an incompatible response (IR) to *Striga* as defense responses in the early stages of the infection process. Field *Striga* resistance is quantitatively inherited and is influenced by confounding environmental factors. On the other hand, individual interactions between host and parasite in the early stages of the infection process appear to be simply inherited. Characterization of these more qualitative interactions between host and parasite, allows us to dissect the complex trait of *Striga* resistance into more manageable components based on the nature or action of signals exchanged between the parasite and its hosts. As a result, selection efforts directed to pooling these variations of signal exchanges between host and parasite may lead to a more durable *Striga* resistance.

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 objective of our collaborative research project are as follows:

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

Research Approach and Project Output

Research Methods

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

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

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

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

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

Research Findings

Hypersensitive Resistance to *Striga* in Sorghum (Ref: Proc. 7th Int. Parasitic Weed Symposium. Fer et al. (eds) Nantes, France, pp. 204-207.)

Striga spp. is an obligate parasitic weed that presents a considerable biological constraint to food crop production in much of Africa and Asia. Despite various approaches to control the devastating effects of *Striga* on sorghum, successful use of these technologies has been hindered by low economic and educational levels of farmers in these communities. Control of *Striga* is also complicated by its enormous seed inoculum that can be triggered to germinate and damage crops even before the *Striga* plant emerges above ground. Much of the *Striga* endemic regions of Africa and Southeast Asia are inhabited by poor subsistence farmers who are unable to adopt expensive chemical control or use of modern cultural practices. Hence, development of high yielding *Striga* resistant crop cultivars is perhaps the most feasible control means for reducing crop losses. Field resistance to the parasitic weed, *Striga* (*Striga* spp.), is a complex agronomic trait controlled by a number of genes. The quantitative nature of its inheritance and the influence of several confounding environmental factors, have made breeding for field resistance a difficult task.

Significant progress has been made in breeding for *Striga* resistance in several crops. However, there has been limited understanding of the basic mechanisms associated with resistance to *Striga*. However, a better understanding of the biology of host-parasite interaction has allowed us to dissect the complex trait of *Striga* resistance into more manageable components based on the nature or action of signals exchanged between the parasite and its hosts. We have developed laboratory assays that target the disruption of a particular signal exchange or that detect a precise defense response at a given point in the life cycle of the parasite to define and characterize mechanisms of resistance. Several hypotheses on possible host resistance mechanisms have been proposed. Most are based on cytological studies and observation of production of exudates in vitro. Nevertheless, there appears to be a parallel between host-pathogen interactions in plant diseases and defense responses triggered during *Striga* invasion. The major limitation to making these observations during the development of the parasite appears to be the lack of appropriate bioassays that reveal early interactions between the host and parasite. In this report, we describe the physiology and genetics of hypersensitive response (HR) to *Striga* as a defense response in the early stages of the infection process.

The hypersensitive response (HR), has been extensively studied in several plant pathogens. HR generally refers to the appearance of a necrotic region around the site of attempted infection, followed closely by death of the affected host cells within hours of the attack. HR responses can be phenotypically diverse ranging HR in a single cell to spreading necrotic areas accompanying limited parasite colonization. Necrosis of the affected tissue has been shown to be directly related to the accumulation, oxidation and polymerization of phenolic compounds. Our work is aimed at studying this host defense mechanism in sorghum using an in vitro system, the Extended Agar Gel Assay, which is a modification of a procedure we had described earlier.

A collection of cultivated sorghum lines with known field reaction to *Striga* infection, a set of wild sorghum accessions, and backcross derived progenies from a wild sorghum introgression project were observed for hypersensitive response to *Striga* invasion. An inheritance study was conducted from a cross between a sorghum line with HR and two susceptible sorghum lines.

Striga seeds were obtained from the USDA/APHIS, Whiteville, Methods Development Center, Whiteville, NC, courtesy of Dr. Robert Eplee and Mrs. Rebecca Norris. *Striga* seeds were stored and handled under quarantine restrictions in an approved quarantine laboratory on the campus of Purdue University. All experiments involving *Striga* seeds and seedlings were performed in this facility. *Striga* seeds were conditioned following a procedure described by Mohamed et al (1998).

Around 1000 conditioned (8-22 days) *Striga* seeds (3 drops of settled seeds) were pipetted into a sterile 150 mm Petri dish. Large Petri dishes with thick agar layer were used for longer incubation. A 0.7% agar solution was autoclaved for 15 min, then cooled to 50°C for one hour. The 50°C agar was poured into the Petri dish (65 mL), containing *Striga*, which produced an even distribution of seeds. Four pre-germinated sorghum seeds were placed at even intervals around the edges of each Petri dish so that the radicles just penetrated the gel. The dishes were covered and placed in an incubator at 28°C. Three days following infection, each dish is treated with ethylene to pre-germinate *Striga* seeds and incubated at 28°C. Two days later (5 days following infection), the dishes were placed under grow light for 24 hours. The dishes were observed for *Striga* attachment and number of attachment sites was recorded. Sites of attached *Striga* were circled for future observation of necrosis and parasitic discouragement. Data were collected on total number of *Striga* attached, penetrated, necrotic, and those discouraged from further development. The percent of *Striga* with necrosis and discouraged relative to total attachments in each of four roots was subjected to statistical analysis.

All known susceptible sorghum cultivars and several of the *Striga* resistant lines had what appeared to be a normal association when observed under the conditions described above. However, in some *Striga* resistant sorghum cultivars and some of the wild sorghum accessions, a key host-defense response was observed. In these genotypes, necrotic areas appeared at *Striga* attachment sites on the sorghum root. These necrotic lesions most often start as red spots and turn brownish with time. The lesions are often large and may spread up to 2mm from the center of attachment but most remain localized. Attached *Striga* most often are discouraged, not developing and eventually dying on the host.

Among sorghum cultivars tested, Framida, Dobbs, and Serena, showed necrosis in about 70% of attached *Striga* and almost 50% of the attached *Striga* were discouraged from penetration. No necrosis was observed on some *Striga* resistant sorghum cultivars including, SRN39, IS9830, 555, as well as on all susceptible sorghum cultivars. Among wild sorghum accessions, P47121 (Sorghum verticilliflorum) showed necrotic lesions on 90% of the *Striga* seedlings attached. In this genotype, 80% of the total attachment points were discouraged from penetration and further development. Cultivars and accessions screened in this study were clearly and consistently classified into two categories, those exhibiting HR response and those with no necrosis.

HR reactions of genotypes appear to be graded and variable in intensity. A single infected root may show reddening in most but not necessarily all attachment sites. Some attachment sites may appear necrotic early and fade with *Striga* growing normally. Overall, however, lines possessing HR reaction to *Striga* show greatly reduced percentages of *Striga* attachments and reduced parasitic association relative to susceptible genotypes. The wild sorghum accession, P47121 showed the strongest necrotic reaction among all genotypes tested. The reaction in P47121 is almost two times the intensity of the reaction of the best cultivated sorghum line (Framida) we tested to date. Almost 83% of *Striga* attached on to P47121 were discouraged compared to 49% for Framida.

In genotypes that exhibited HR, necrosis was observed at attachment sites as early as three days after infection. Discouragement of parasitic development was also evident seven days following infection reaching a maximum in 12 days after infection. Invariably, sorghum genotypes that showed necrosis at attachment sites also showed parasitic discouragement. While parasitic discouragement can be noted, observation made on necrotic tissue is more apparent and reliable since this symptom appears early when the health of the host tissue is not of concern.

Inheritance of the HR reaction was studied in several populations. Initially, backcross progenies derived from an introgression of P47121 into two random mating sorghum populations, but unselected for necrotic lesions, were evaluated for HR reaction. Several BC_2F_3 progenies were identified with HR reaction of intensity similar to that observed in parental P47121. The best progeny, KP33, was selected as a source of cultivated sorghum line with HR and was crossed on to two susceptible sorghum lines. F_1, F_2, and BC_1 progenies were screened for HR reaction using the Extended Agar Gel Assay. Roots of seedlings from these progenies were examined for *Striga* attachment, necrosis, and parasitic discouragement at 5,10 and 15 days post infection. All seedlings of KP33 and its F_1 progenies showed necrosis and about 80% of attached *Striga* were discouraged, suggesting dominance gene action. The F_2 segregation showed a 15:1 (necrosis:no necrosis) distribution suggesting a two dominant gene model for its inheritance. Segregation in the BC generation fit a 3:1 ratio, further supporting the two dominant gene model. The trait is nuclearly inherited with no maternal gene effect.

The physiologic basis of HR, though sufficiently studied, is not yet clear in plant pathogens because some parasites can obtain nutrients from dead plant cells. However, cellular decomposition may lead to a release of toxic substances that are stored in a vacuole. Alternatively, the levels of induced phytoalexins, which usually are rapidly turned over, in plant cells may accumulate in inhibitory concentrations. Hypersensitive response to *Striga* invasion is a readily observable trait with the Extended Agar Gel or the Paper Roll assays, which can be employed for germplasm screening. Since HR expression is always associated with discouraged attachment of the parasite, it is a powerful *Striga* resistance mechanism. For better biological understanding, further investigation into the basic physiological mechanism associated with HR reaction will be pursued. Meanwhile, we are exploiting the simple inheritance of HR for effective pyramiding of genes for *Striga* resistance with multiple mechanisms.

Independent Inheritance of lgs and IR Genes in Sorghum (Ref. Proc. 7th Int. Parasitic Weed Symposium. Fer et al. (eds), Nantes, France, pp. 220-223.)

Our *Striga* research program at Purdue University has focused on studies of host plant resistance based on disrupting parasitic association at specific points in the life cycle of *Striga*. Recent work on physiological and genetic characterization have led to the identification of several resistant mechanisms to parasite attachment. Certain sorghum genotypes with resistance to *Striga* express an incompatible response (IR) to parasitic invasion where attached *Striga* seedlings appear withered or stunted. One of our most widely recognized resistant sorghum genotypes, SRN39, possesses both the low germination stimulant (lgs) production and an incompatible response (IR) mechanisms as its basis for resistance. In vitro assays were used to characterize germination stimulant production and incompatible response reactions expressed in SRN39 and its progenies in a recombinant inbred (RI) population generated from a cross with a susceptible genotype, Shan Qui Red. In this report, we describe an incompatible response (IR) to parasitic invasion as a mechanism of *Striga* resistance post-attachment. This response is similar to that expressed in a non-host and is characterized by either purpling or withering of attached *Striga* seedlings. Such a host apparently produces essential signals for germination and haustorial formation leading to attachment but perhaps possesses certain metabolic inhibitors that discourage the parasite from further growth and development. Thus most attached *Striga* appear either withered or stunted without apparent host cell necrosis around the attachment site. One of our most widely recognized resistant sorghum genotypes, SRN39, possesses both the low germination stimulant (lgs) production and incompatible response (IR) mechanisms as its basis for resistance. The purpose of this study is to provide a preliminary report on the independent inheritance of these two mechanisms using a population of recombinant inbred (RI) lines of sorghum [Sorghum bicolor (L.) Moench].

A population of RI lines of sorghum developed from a cross between a *Striga* resistant cultivar, SRN39 and a susceptible check, Shan Qui Red (SQR), with random F2 individuals selfed to the F_7 generation via the single seed decent (SSD) method of plant breeding. Two hundred RI lines were sampled from our large mapping population for this study.

Two laboratory assays developed in our laboratory were used to characterize the population for lgs and IR reactions. Agar Gel Assay was used to characterize the two parents and RI lines derived from them for their capacity to produce *Striga* germination stimulants. We used the Paper Roll Assay to characterize the same population for incompatible response to *Striga* infection. This assay involves growing sorghum seedlings with their roots between rolled layers of germination paper to which filter paper strips containing artificially germinated *Striga* asiatica seeds were added to evaluate RI lines for IR. This procedure allows timely observation of progressive invasion or lack thereof of the parasite on host roots. For each genotype, three sorghum seedlings were screened. To overcome unwanted genotypic variation for production of germination stimulant in this population, *Striga* seeds were germinated with exposure to ethylene prior to host exposure. *Striga* attachment and penetration were observed on healthy, fully developed host roots. Assuming that pre-germinated *Striga* had equal opportunity to attach to host-roots, reduced development of attached *Striga* was considered a defense response. The different stages of *Striga* development were recorded fitting into three categories: attached *Striga*, attached *Striga* with emerged leaf primordia, and attached *Striga* with multiple developed leaves. The attached *Striga* were also graded on physical appearance. *Striga* seedlings with no discoloration were rated to be growing normally as different from those with purple or withered appearance noted to be discouraged from normal growth and development.

Previous report from our laboratory, assessed the parental genotypes for their capacity to stimulate *Striga* seed germination, and showed that the germination distance recorded between the host root and the furthest germinated *Striga* seed was up to 100 times higher for SQR than for SRN39. The *Striga* resistant line, SRN39 was thus established as a low germination stimulant producer.

In this study, we evaluated parental lines, SQR and SRN39, using in vitro assays, and observed that in addition to being a low germination stimulant producer, SRN39 has an IR reaction to *Striga* attachment and SQR does not. In our Paper Roll Assay, attached *Striga* that did not break from the seed coat by four weeks after infection, were considered to have arrested development. When leaf primordia emerged, *Striga* were considered to have penetrated the host vasculature, but perhaps not achieved normal development for successful parasitic establishment. A normal parasitic relationship was considered to have been established when *Striga* shoots continue to develop and show multiple leaf primordia.

Over a total of five assays per genotype, each consisting of three seedlings, and discarding the cases where sorghum seedlings are poorly developed, more *Striga* seedlings were attached to SQR than to SRN39 with 76 and 59 attached *Striga*, respectively following treatment with ethylene (Table 1). Also, distribution into the three categories of reaction used to describe pattern of *Striga* development is shown. Among *Striga* seedlings attached to SRN39, 78% did not show further development and only 5% initiated multiple leaf primordia (Table 1). However, in contrast, 20% of attached *Striga* showed development of multiple leaves on our susceptible parent, SQR. The limited number of *Striga* that developed on SRN39, as compared to what is found on SQR, led us to conclude that SRN39 possessed a defense response (IR) that appeared to retard development of attached *Striga*.

A second level of observations was made for incompatible response of host genotypes to parasitic invasion as expressed by attached *Striga* becoming either purpled or withered. As shown in Table 1, most of the *Striga* attached to SQR looked normal (86%), but such was the case for only half the *Striga* that attached to SRN39 (47%). The two geno-

Table 1. Characterization of IR to *Striga* infection in resistant (SRN39) and susceptible (SQR) sorghum lines.

	SQR	SRN39	†
Normal Attachment and Penetration			
№ of attached Striga	42	24	NS
№ with leaf primordia	16	3	*
№ *with multiple leaf primordia*	15	3	*
Reactions Following Attachment and Penetration			
№ of attached Striga	3	22	**
№ with leaf primordia	0	7	
№ with multiple leaf primordia	0	0	
Total attachment (№)	76	59	

† Significance of the Chi-2 test comparing distribution between the two genotypes
ns: no significant difference at p<0.05 probability level
*, **: significant difference at p<0.05 and p<0.01 probability level, respectively

types also differed drastically in that much fewer withered *Striga* were found on SQR (4%) than on SRN39, (49%). These observations likely resulted from adverse host-reactions leading to death of attached *Striga*, also considered part of the incompatible response. Chi-square test on these frequencies showed significant differences in host-reactions between SRN39 and SQR (Table 1). The differences observed in the number of purpled or withered *Striga* put forward the existence of IR as a mechanism of resistance specific to SRN39.

Screening of the RI population with the Agar Gel Assay (data not shown) reaffirmed the presence of lgs as a mechanism of *Striga* resistance in SRN39. Segregation of the lgs trait in the RI population confirmed previous reports of a single gene control for low germination stimulant production in SRN39. The RI lines were also screened for IR to *Striga* infection (Table 2). The results showed that attached *Striga* for which seedling did not further develop were found in 83% of the progenies. Attached *Striga* seedling with emerged leaf primordia and attached *Striga* that developed multiple leaf primordia were observed in 41% and 42% of the RI lines, respectively. Purpling or withering parasites were considered for any developmental stage reached by the attached *Striga* and 61% of the progenies showed cases with *Striga* either purpled or withered. These results suggest that the incompatible response is heritable and possibly conditioned by one major and some minor genes. Individuals in the population with purple or withered *Striga* also showed attached parasites but with reduced development. A positive and highly significant correlation between these two expressions was found (Pearson $r=0.45$ at $p<0.001$). Conversely, for some genotypes, attached *Striga* that looked normal could develop until a one leaf stage (Pearson $r=0.47$ at $p<0.001$).

A sorghum linkage map previously generated in our laboratory identified five Quantitative Trait Loci (QTL) as governing field *Striga* resistance in sorghum. The low germination stimulant (lgs) production locus was mapped on a linkage group (Q) next to one of these QTL. We just completed preliminary mapping of IR and this locus appears to map independently of lgs reaffirming the independent inheritance of these two important *Striga* resistance traits.

In conclusion, this preliminary study indicates that, the Paper Roll Assay allows screening of sorghum breeding lines for IR reaction as a *Striga* resistance mechanism. Our results showed that IR is heritable, and based on the molecular marker analysis and the bioassay screening of a large number of RI lines derived from SRN39, it appears to be segregating independently from lgs.

International Testing of Integrated *Striga* Management Practices

In Ethiopia, two of our *Striga* resistant sorghum varieties were officially released in 1999 for commercial cultivation in *Striga* endemic areas of the country. Following this release, we have embarked on a collaborative project involving INTSORMIL, Global 2000, and EARO to test an integrated *Striga* management control measure in Tigre Province. Technologies being tested include resistant varieties, nitrogen fertilizers, and tied ridging as a water conservation measure. This technology package is expected to provide synergism of improved seed and two soil management practices to overcome limitations covered by *Striga*, infertile soil, and lack of water. Moisture conservation by tied ridges allows for better response to fertilization in ways which contribute to better *Striga* control and increased productivity gains of the sorghum crop. An economic impact analysis of the individual technologies as well as the package of technologies is planned.

Networking Activities

Workshop and Program Reviews

Organize and lead a workshop on Regional Collaboration for Sorghum and Millet Research in Eastern Africa among INTSORMIL-ICRISAT-NARS scientists, 10-12 December 2000.

Collaborate with INRAN in development of seed industry in Niger, West Africa.

Member of review team for System Wide Review of Plant Breeding Methodologies in the CGIAR at ICRISAT Centre.

Member of organizing committee and chaired sessions for Global 2000 Sorghum and Millet Diseases Conference, September 2000.

Attend workshop on Raising Agricultural Productivity in the Tropics: Biophysical Challenges for Technology and Policy. Center for International Development at Harvard University, Cambridge, Massachusetts, 17-18 October 2000.

Attend meeting of Board of Directors of Rockefeller Foundation/Cornell University Initiative on the Essential Electronic Agricultural Library, February 2-4, 2001.

Attend Sorghum Improvement Conference for North America. Nashville, TN. 18-20 Feb 2001.

Attend 7th International Parasitic Weed Symposium, Nastes, France. 5-8 June 2001.

Table 2. Results of screening 90 RI genotypes for incompatible response (IR) to *Striga* infection.

	Attached *Striga*	Leaf primordia	Multiple leaf primordia	Normal	Reaction	Total attached *Striga*
№ genotypes	75	37	38	65	55	76
Mean	7.44	1.47	1.80	6.74	3.97	10.71
Range	0-43	0-11	0-17	0-43	0-26	0-47
SD	8.66	2.54	3.75	9.19	5.84	11.24

Research Investigator Exchange

Host a Seed Delegation from Malawi (Dr. Jeffrey Luhanga, Mr. Francis Maideni, Mr. Maxford Jehe, and Ms. Rebecca Weber) through the Purdue Center for Agricultural Business, 22-26 August.

Host Dr. Aberra Debelo, Deputy Director of Research, EARO, Ethiopia

Host Dr. Aberra Deressa (Ethiopia) and Dr. Saddan Hassien (Tanzania)

Host Dr. Paula Bramel, ICRISAT

Host Dr. Admasu M. Berhan, IITA

Germplasm Exchange

Collaborate with Sasakawa Global 2000 and the Ethiopian Agricultural Research Organization in demonstration and diffusion of *Striga* resistant sorghum varieties in Ethiopia. As a result, two of our *Striga* resistant sorghum varieties were officially released for wide cultivation in Ethiopia in 2000.

Total of 25 international trials and seed request sent to 7 African countries during the last year.

Publications

Refereed Papers

Mohammed, A., G. Ejeta, and T. Housley. 2001. *Striga* asiatica seed conditioning and 1-aminoacylopropane-1-carboxylate oxidase activity. Weed Research 41:165-176.

Conference Proceedings

Ejeta, G. 2000. Genetic approaches to the control of *Striga* in sorghum and millets. In: Leslie and Frederiksen (eds.) Global 2000 Sorghum and Pearl Millet Diseases Conference. 23-30 September, Guanajuato, Mexico.

Ejeta, G. 2000. *Striga*: Noxious Parasitic Weeds of Tropical Cereals and Legumes. p. 53-57. In: R.A. Frederiksen and G.N. Odvody (eds.) Compendium of Sorghum Diseases. APS Press.

Ejeta, G., A. Babiker, K. Belete, P. Bramel, A. Ellicott, C. Grenier, T. Housley, I. Kapran, A. Mohamed, P. Rich, C. Shaner, and T. Toure. 2001. Breeding for Durable Resistance to *Striga* in Sorghum. p. 166. In:Fer et al. (eds) Proceedings of the 7th International Parasitic Weed Symposium. 5-8 June, Nantes, France.

Grenier, C., P.J. Rich, A. Mohammed, A. Ellicott, C. Shaner and G. Ejeta. 2001. Independent Inheritance of lgs and IR Genes in Sorghum. In:Fer et al. (eds) Proceedings of the 7th International Parasitic Weed Symposium. 5-8 June, Nantes, France.

Mohamed, A., A. Ellicott, C. Grenier, P.J. Rich, C. Shaner, and G. Ejeta. 2001. Hypersensitive Resistance to *Striga* in Sorghum. p. 204-206. In:Fer et al. (eds) Proceedings of the 7th International Parasitic Weed Symposium. 5-8 June, Nantes, France.

Mohamed, A.H., G. Ejeta, and T.L. Housley. 2001. Control of *Striga* Seed Germination. p. 125. In:Fer et al. (eds) Proceedings of the 7th International Parasitic Weed Symposium. 5-8 June, Nantes, France.

Abstracts

Mohamed, A.H., P.J. Rich, T.L. Housley, and G. Ejeta. 2000. Mechanisms of *Striga* resistance in sorghum. Agron. Abs. p. 111.

Insect Pest Management Strategies For Sustainable Sorghum Production

Project TAM-225
George L. Teetes
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Principal Investigator

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Summary

The principal investigator for project TAM-225 retired from his position as Professor of Entomology, Texas A&M University 31 August 2000. At the time of retirement, two graduate students associated with the project had not completed their degrees. A much-reduced level of funding was received only to continue support of the students' degree programs. This report deals exclusively with the progress and research results of the two graduate students.

Research Results

Andrea Jensen

Dissertation title:
Genetic Diversity in Natural Populations of Greenbug, *Schizaphis graminum* (Rondani)

Objectives

- Using sequence data from PCR-amplified greenbug mtDNA from conserved DNA primers to a) determine if greenbug biotypes are derived from one or several maternal lineages and b) determine the degree of divergence among greenbug biotypes.

- Using random, anonymous greenbug nuclear DNA probes for RFLP analysis to a) determine the extent of genetic variability in natural populations of greenbugs collected in a hierarchical sampling scheme and b) determine natural population structure including estimates of levels of gene flow, sexual reproduction, and effective population size.

Results

Insects often develop new virulent biotypes. It is estimated that 50% of recognized insect biotypes on agricultural crops are of the family Aphididae. Development of biotypes in greenbug, *Schizaphis graminum* (Rondani), is well documented. Characterizing the genetic variability in natural populations of greenbug will enhance management practices. Phylogenetic analyses of 3 mitochondrial (mtDNA) gene fragments were used to determine evolutionary relationships among biotypes and greenbug individuals collected from the field. From these analyses, no clear evolutionary relationship was determined among biotypes or individuals collected from the field. MtDNA haplotype diversity was greater among biotypes (h=0.9) than among greenbugs collected from the field (h=0.78). Microsatellite loci were used to assess genetic diversity in natural populations of greenbugs from the field. There was no population subdivision between greenbugs from 3 regions of Texas. Fixed heterozygosity was observed at 80% of the microsatellite loci. A common clonal type was observed in 55.7% of the greenbug individuals. Forty-four percent of alleles observed were private alleles. The pattern of heterozygoisty observed, the lack of regional population subdivision, and gene flow estimates from private alleles indicate significant migration and that greenbugs in Texas are from parthenogenetic (anholocyclic) lineages. This study helps confirm the belief that greenbug biotypes have not shared an ancestral maternal lineage within the past 0.3-0.6 million years.

Roberto Gorena

Dissertation title:
Evolution of Greenbug (Homoptera: Aphididae) Biotype Fitness and Virulence on Sorghum and Wild Grasses

Objectives

- Determine fitness of individual apterous adult females of greenbug biotypes based on intrinsic rates of increase calculated from nymphs produced per female per day.

- Determine fitness of colonies of greenbugs based on intrinsic rates of increase calculated from colony growth rates.

- Determine virulence of greenbug biotypes on differential genotypes of sorghum and some grass species based on subjective and objective assessments of damage to plants.

- Determine effects of temperature and humidity changes on fitness and virulence of selected greenbug biotypes, and

- Use cDNA subtraction to determine genetic difference in sorghum genotypes that correlate with virulence and fitness differences in greenbug biotypes.

Results

Data collection for this project, entitled "Evolution of fitness and virulence in greenbug (Homoptera: Aphididae) biotypes in sorghum and wild grasses", began in June 1999. Two environmental chambers were rented from the Institute for Plant Genomics and Biotechnology (Texas A&M, College Station) to conduct virulence and fitness experiments. Seed for the experiments were obtained from Dr. Gary Peterson in April 1999. Greenbug biotypes were obtained in winter 1998 from Dr. John Burd, USDA entomologist, Stillwater, OK. Nine biotypes have been continually cultured since 1999at Texas A&M University, from the original material obtained from Dr. Burd. Currently experiments are being conducted using four plant genotypes (Tx7000, Tx2737, Tx2783, PI550607) and the nine greenbug biotypes (A, B, C, E, F, G, I, K, S. Carolina) maintained at Texas A&M University. Virulence experiments, initiated during the fall semester 1999, involve planting several seeds of one plant genotype in 10" plastic pots. These are allowed to grow to approximately 15 cm (3-leaf stage), at which time they are thinned to one plant per pot, measured for height, and infested with about 35 greenbugs of one biotype. This represents one replication for the biotype/genotype combination. The plants are then placed in the environmental chamber, maintained at 28° C; 60% R.H.; and 13:11 L:D cycle. Numbers of greenbugs in colonies are counted at 3 day intervals until the susceptible plant genotype, Tx7000, is rated at a 7 or higher on a standard 9 point damage scale. Colony growth rates are used as a measure of colony fitness that will be compared to fitness of individual greenbugs to determine if there is a benefit/cost to living in colonies. Overall plant damage (virulence) is estimated using the 9-point damage scale, plant growth, and plant weight. Individual fitness experiments were initiated in summer 1999, and experiments with two biotypes (Canada Wild Rye, C) were completed before postponing these experiments to undertake the virulence experiments. Experiments are similar to the virulence tests except that one apterous adult female is placed on the seedlings at the time of infestation. This female is allowed to produce progeny, then all but one nymph are removed from the plant. The nymph is maintained on the plant until its death. Nymphs are counted and removed each day once the female has reached maturity. Average nymphs produced per day, time to first reproduction, and life span are to be used as estimates of individual fitness. Additionally, sorghum plants will be exposed to greenbug damage, mechanical damage, and jasmonic acid (induces plant senescence) and plant tissues will be subjected to DNA microarray analysis to determine genes that are up or down regulated in either situation. This technique will allow a better understanding of how the sorghum plant reacts to greenbug damage as opposed to general injury, allowing plant breeders to better target genes to be introgressed into new cultivars or varieties. Virulence experiments should be completed by December 2001. Individual fitness experiments and DNA microarray analysis should be completed by the end of summer 2002. Some preliminary results have been reported to annual meetings of the Entomological Society of America (2000, 2001), National Grain Sorghum Producers (2001), and the Southwestern Branch of ESA (2001).

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

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Summary

Survival of *C. africana* conidia in honeydew and sphacelia was very poor under several natural and storage environments in southern Zimbabwe with most viability lost before 20 weeks after experiment initiation. Sclerotial formation of *C. africana* occurred only in the latest of three dates of planting in Southern Zimbabwe. Sclerotia were produced in 60-70% of panicles of two sorghum varieties but only 4 and 8 % of the sphacelia developed into sclerotia. Hyperparasitism was associated with sphacelia that had curtailed development of sclerotia. Preliminary data show that at 60-80% RH, germination of secondary conidia of *C. africana* is optimal at 15°C and iterative. Germination can occur at as low as 11°C and as high as 34°C, although in the upper range it is by germ tube only. Flexibility of *C. africana* was indicated when conidia producing only germ tubes at 34°C resumed iterative germination within a few hours when returned to 20°C. Germination was nil at 37°C. During the time of natural ergot infection/epiphytotics in southern Zimbabwe, secondary conidia of *C. africana* were vulnerable to the higher ultraviolet irradiation (UVB) of the rainy season and did not survive more than 6 hours of exposure during daylight hours. Higher survival rates were noted

after 8-8.5 hours of exposure to the lowered UVB irradiation and temperature present during mid-May and June. Propiconazole applied to blooming florets of a male-sterile sorghum at 125 and 250 ppm provided significant protection against sorghum ergot when inoculum application was delayed at any time from 0 through 36 hours. The triazoles have no direct effect on conidial germination so must be within plant tissues to prevent sorghum ergot. These results indicated that uptake of the fungicide was sufficiently rapid to stop any progression of infection by *C. africana* even at 0 time. Where fungicide application was delayed after inoculation at 12 hour intervals from 0 to 48 hours, initial ergot severity (5 days) was near zero at all rates (63, 125, and 250 ppm) at the 0 time delay for propiconazole but at both the 0 and 12 hour delay for triadimefon. Ergot severity was rate dependent for both fungicides at each application delay time but triadimefon provided better initial and longer lasting (9 days) control at each rate and application delay time. In analyses of weather conditions at Rio Bravo, Mexico, maximum and minimum temperatures around 10 to 12 days before half bloom (boot stage) showed the highest significant negative correlation with incidence of sorghum ergot. Minimum relative humidity gave a significant and positive relationship with ergot when present at high values immediately after half bloom. Production of *C. africana* sclerotia in the western hemisphere was confirmed in 1997 sorghum ergot specimens from Celaya, Mexico and the northern (high plains) of Texas. In early 2000, sclerotia were also identified in the Lower Rio Grande Valley near Weslaco, Texas and at Rio Bravo, Tamaulipas, Mexico. No sclerotia formation has been observed in some areas like Corpus Christi where high humidity promotes saprophytic degradation of sphacelia before sclerotial formation can occur.

Objectives, Production and Utilization Constraints

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

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

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

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

- Evaluate biology of *C. africana* including survival, production of sclerotia, sources of initial inoculum, alternate hosts, and characterization of populations in the Americas and Africa. (Mexico, United States, Southern Africa)

Research Approach and Project Output

Sorghum Nurseries to Evaluate Adaptation, Desirability, and Response to Disease, Drought and Sugarcane Aphid

Delays in seed arrival prevented many nurseries from being planted at several Southern Africa locations and late plantings produced good agronomic and disease evaluation data only at the Cedara station in South Africa. Sorghum nurseries distributed for the 2000-2001 season included the TAES All Disease and Insect Nursery (ADIN, 70 entries, 2 reps), the Anthracnose Resistant Germplasm Nursery (ARGN, 43 entries, 2 reps), the International Sorghum Virus Nursery (ISVN, 20 entries, 3 reps), and the Southern Africa Breeding Nursery (SABN, 140 entries, 2 reps). The ARGN nursery is utilized primarily to identify regionally-adapted sorghums with resistance to one or more of the primary foliar diseases, anthracnose, sooty stripe, and leaf blight. The SABN includes some sorghums with foliar disease resistance and/or sugarcane aphid resistance but most have good drought tolerance, especially pre-flowering drought tolerance. The goal of the SABN is to identify cultivars that have broad adaptation to the SADC region and resistance to multiple biological and environmental stresses of the region. Information and cultivars from other disease and insect nurseries were used to identify characteristics needed at different locations and to identify sorghums with the greatest potential for the region. As the best cultivars are identified, the 140 entry SABN will be reduced to a more manageable size for multilocational testing and another nursery, the SADC Regional All Disease and Insect Nursery may also be developed. This regional nursery (probably 50 entries, 2 replicates) would be similar to the U.S.-derived ADIN nursery mentioned earlier but would include sorghums previously identified as having good adaptation to the SADC region and with resistance to one or more major biological and environmental constraints in the region. Grown over several years at multiple locations this nursery of genetically diverse sorghums would identify cultivars adapted to individual locations, determine relative importance of specific pest constraints, determine needed types of pest resistance, and identify potential cultivars with adequate individual and multiple pest resistance. Broad adaptation to the SADC region is a key component in cultivars selected for this nursery because little can be determined about disease and other responses when a non-adapted sorghum dies or grows poorly across multiple locations.

Data was provided by N. McLaren from the Cedara Research station nursery in South Africa where leaf blight (*Exserohilum turcicum*) was the primary foliar disease and ergot (*Claviceps africana*) occurred under the cool temperatures late in the season. Leaf blight incidence and severity was rated on a 0-5 scale where low numbers indicate resistance and high numbers indicate susceptibility. Those sorghums with a low rating for leaf blight are listed in Table 1 along with their agronomic desirability rating. The rating scale for desirability was 0-5 with higher numbers indicating higher or better agronomic desirability. Ergot data are not shown here but some entries from the SABN had sufficient "escape" type resistance under the cool temperatures at Cedara that N. McLaren felt they warrant further investigation.

Sorghum Ergot

Zimbabwe

Work in Zimbabwe is being conducted by Dr. D. Frederickson who is the consulting scientist for the INTSORMIL Ergot project at the SADC/ICRISAT center at the Matopos station near Bulawayo.

Inoculum Survival and Sclerotial Formation

Survival of conidia in honeydew and sphacelia was very poor under several natural and storage environments in southern Zimbabwe with most viability lost before 20 weeks after experiment initiation. These data suggest that conidia are a less likely source of initial inoculum in Zimbabwe than previously believed. Other experiments were established to investigate sclerotial formation on different genotypes utilizing different planting dates to provide different environments influencing sclerotial production. Sclerotial formation from the dates of planting were significantly different as expected since sclerotia only formed in date 3. Varieties were significantly different and date and variety had a significant interaction. Sclerotia were produced in 60-70% of panicles of two varieties but only a small proportion of the sphacelia developed into sclerotia (4 and 8 %). Hyperparasitism was associated with sphacelia that had curtailed development of sclerotia..

Table 1. Leaf blight and agronomic desirability ratings of entries from the Southern Africa Breeding Nursery (SABN)[1].

Entry	Designation	Average Leaf blight 0-5	Average Desirability 0
31	Sima./WSV187	0.5	1.0
64	(86EO361*Macia)-HD14	0.5	2.8
40	ICSV1089BF	0.5	2.0
84	(Macia*Dorado)-LL6.	0.8	1.5
97	(Macia*Sureno)-HF19-GWO193	0.8	2.0
107	(R8505*(R5646*SC326-6)-HF52(BE7414))	0.8	3.5
67	(86EO361*Macia)-HF52	1.0	2.5
73	(R2241*(R5646*SC326-6)-HD25)	1.0	2.0
65	(86EO361*Macia)-HD15	1.0	2.0
79	(Macia*Dorado)-HD4. . CA2	1.3	1.0
26	86EO361	1.3	3.0
66	(86EO361*Macia)-HF41	1.3	3.0
69	(86EO366*WSV387)-HD25	1.3	1.3
35	ZSV 15/Zambia	1.3	2.0
20	(BBon34*B9502)-LD6 Homowaxy	1.5	2.5
1	Segaolane	1.5	2.0
99	(CE151*MP531)-LD42	1.5	3.0
128	(86EO361*Macia)-HD19	1.5	2.5
48	(SRN39*90EO328)-HF5	1.5	2.5
93	(ICSV1089BF*Macia)-HF28. ..	1.8	2.0
96	(ICSV1089BF*Macia)-HF26	1.8	2.0
37	90 EON 328/(Sureno*BDM499)-HD5	1.8	2.8
36	82BDM499/ SC173*SC414	1.8	2.8
32	Tegemeo	2.0	2.5
63	(86EO366*WSV387)-HF14	2.0	3.0
25	Sureno	2.0	1.8
62	(86EO366*WSV387)-HD27. . .	2.0	2.5
68	(86EO361*Macia)-HF25	2.0	2.5
92	(ICSV1089BF*Macia)-HF11. ..	2.0	2.0
95	(Macia*Sureno)-HF19	2.0	2.5
90	(Macia*TAM428)-LL1. .	2.0	2.0
5	(B1*Segaolane)HF1-BE3-C101	2.0	1.3
39	Dorado	2.0	2.0
91	(ICSV1089BF*Macia)-HF9. ..	2.0	2.5

[1] The SABN has two replicates of 140 entries. Leaf blight (caused by *Exserohilum turcicum*) was rated on a 0-5 scale of disease incidence and severity where low numbers indicate resistance and high numbers indicate susceptibility. Only entries having a rating of 2.0 or less are shown. Desirability was rated on a 0-5 scale where higher numbers indicate higher agronomic desirability.

Sclerotial Germination

Germination of sclerotia was evaluated under Zimbabwe environments but excessively dry early season conditions followed by incessant rain tended to rot the sclerotia rather than promoting germination.

Alternate Hosts and Genetic Characterization of C. Africana.

Ergot was collected from many grasses in southern Zimbabwe and identified with up to three potentially being alternate grass hosts of *C. Africana*. Genetic characterization is being conducted by S. Pazoutova and D. Frederickson is conducting Koch's postulates to confirm alternate host status. Grass and sorghum ergot collections were also made in several areas of South Africa during a collection trip with N. McLaren. These collections are also being sent to S. Pazoutova and from her site the sorghum isolates are being shared with P. Tooley in Ft Detrick..

Effect of Environment on Production, Function, and Longevity of Secondary Conidia.

Studies were also initiated on production of secondary conidia and their germination as affected by relative humidity, temperature, and their interaction. Preliminary data show that at 60-80% RH, germination of secondary conidia is optimal at 15°C, and iterative. Germination can occur at as low as 11°C and as high as 34°C, although in the upper range it is by germ tube only. Flexibility of the pathogen was indicated by the observation that iterative germination resumed within a few hours when returned to 20°C from germ tube growth at 34°C. Germination was nil at 37°C but the minimum temperature allowing germination has not yet been determined.

In studies of the cumulative effect of natural irradiance on viability of secondary conidia Dr. Frederickson determined that during the time of natural ergot infection/epiphytotics, secondary conidia were vulnerable to the high temperatures and ultraviolet irradiation of the rainy season and did not survive more than 6 hours of exposure during daylight hours. Similar experiments conducted later under lower maximum and minimum temperatures of mid-May and during June under a cloudy morning but clear, bright afternoon showed higher survival rates after 8-8.5 hours of exposure.

Work being conducted by N. Mclaren on the regional sorghum ergot project is reported in the Southern Africa regional report.

United States and Mexico

Noe Montes continued work on sorghum ergot at Corpus Christi and locations in Mexico as a visiting scientist from INIFAP through December, 2000.

Inoculum Delay

A test was conducted to determine the amount of time needed after application of the triazole fungicide, propiconazole (Tilt 3.6E), before it had efficacy against *C. africana* in plant tissues. When the fungicide makes contact with the inflorescence tissue systemic uptake may require some time before levels within tissues (probably at the base of the ovary) become sufficient to prevent infection. This process may also be influenced or delayed by factors such as relative humidity, temperature and solar radiation. Sorghum heads of male-sterile ATX 623 were bagged at bloom initiation until they had completed bloom. At this time all ovaries on each head were synchronously susceptible to *C. africana* if they still retained receptivity and were not yet fertilized. Heads were hand sprayed with propiconazole at one of two rates (125 and 250 ppm) and all sorghum heads were re-bagged one more time. At 6 hour intervals over 36 hours, ten sorghum heads of each treatment rate and a control were inoculated and then left unbagged. Ergot severity as percent of the florets per head with visible honeydew was evaluated at 5 days after inoculation. The results showed that compared to the control heads (60-80% ergot severity) the fungicide provided significant protection at both rates beginning at 0 time and throughout the 36 hours of this test. Propiconazole at the higher 250 ppm rate provided near complete control of ergot.

Fungicide Delay

The initiation of fungicide application is a major decision because it establishes the onset of ergot control and determines time of subsequent applications done at specific intervals. Commonly the first fungicide application is made following head emergence, either prior to bloom or at bloom initiation. An additional two to three applications are made at 5-7 day intervals. This application methodology is based on the knowledge that any ovary in blooming male-sterile flowers is vulnerable to infection by *Claviceps africana* if inoculum is present. It also considers the 36-48 hours required for infection to be established and for the approximate 24 hr time lag between application of triazole fungicides and the uptake and accumulation into tissues at levels able to prevent infection.

In seed production fields there are likely to be problems with timing of fungicide application. If fungicide application is somehow delayed or the sorghum plants begin blooming earlier than expected the sorghum heads may be vulnerable to ergot. An experiment was conducted to determine the risk of ergot infection on blooming heads of male-sterile sorghum when inoculum is present and fungicide application is delayed. Fungicides used in this test were propiconazole (Tilt 3.6E) and triadimefon (Bayleton 50DF) at rates of 63, 125, and 250 ppm. Sorghum heads of male-sterile ATX623 were bagged at bloom initiation until they had completed bloom. All heads were then inoculated until runoff with a conidial suspension of *Claviceps africana* (1.6 x 10^6 spores/ml) and the heads were re-bagged. At 0 time and every 12 hours for 48 hours, 10 heads for each rate of each fungicide and a control were hand sprayed and re-bagged.

Ergot severity ratings (Table 2) were done at 5 and 9 days after inoculation. At 5 days both propiconazole and triadimefon at all rates and application delay times significantly reduced infection by *C. africana* compared to the controls (90-96%). Propiconazole provided near complete control of ergot at all three rates at 0 time but only at 125 and 250 ppm with a 12 hour application delay. Triadimefon provided near complete control of ergot at all rates at 0 and 12 hour application delays but only at 250 ppm with a 24 hour application delay. At application delays from 24 through 48 hours ergot severity progressively increased for each fungicide and rate. Ergot severity was also rate dependent at each application delay time but especially apparent beginning at the 12 and 24 hour application delay times for propiconazole and triadimefon, respectively.

At 9 days after inoculation only triadimefon at 250 ppm applied at 0 time still provided near complete control of ergot. Other rates of both fungicides still provided significant control but propiconazole was rapidly losing efficacy against *C. africana* at all rates and application delay times. Triadimefon still had high efficacy at all rates at 0 time and at 250 ppm through the 48 hour application delay time.

This information showed that ergot control can be maximized if we apply the most effective fungicide to the crop at an appropriate rate at the proper development stage. The data agree with our previously reported results showing that contact and coverage are important factors in control of sorghum ergot and that, of the triazoles evaluated, triadimefon was the most effective. This experiment also demonstrated that *C. africana* can be very aggressive if conditions are conducive for infection and no protection is provided.

Weather Variables and Incidence of Ergot

N. Montes periodically planted a group of sorghum hybrids over several months to evaluate the effect of cold degree units on natural development of sorghum ergot in northern Mexico. Daily minimum temperatures below 13°C had a highly significant effect on the incidence of ergot, especially if they occurred 9 to 11 days before half bloom. Cooler temperatures near bloom (approximately boot stage) are more important in increasing the potential for sorghum ergot because they probably cause some male-sterility in the developing sorghum florets enclosed by the flag leaf sheath.

An experimental trial of 33 sorghum hybrids with four replications was planted over several dates spaced from early April to mid September of 1997 at Rio Bravo, Tamaulipas, Mexico. The flowering dates ranged from May to mid-December. At soft dough stage, sorghum ergot was recorded as number of infected heads within plots. Weather data were obtained from *INIFAP* Rio Bravo Experimental Weather Station (daily maximum and minimum temperatures, and relative humidity). Triad values (average of 3 consecutive days) of maximum and minimum temperature were recorded up to 30 days before half bloom and 6 days after half bloom. Triad values of maximum and minimum

Table 2. Effect of application delay and rate of triazole fungicide on average severity of sorghum ergot on fully bloomed heads of a male-sterile sorghum at Corpus Christi in 2000[1]

Fungicide (ppm)	Ergot severity with fungicide application delay in hours after inoculation[2]									
	0		12		24		36		48	
	Five days after inoculation									
Propiconazole										
0 (control)	94	a	90	s	95	a	92	a	93	a
62	0.6	b	7	b	30	b	60	b	64	b
125	0.2	b	0.6	bc	14	c	38	c	44	bc
250	0.1	b	0.1	c	3	d	15	d	28	c
Triadimefon										
0 (control)	95	a	95	a	94	a	94	a	96	a
62	0.1	b	0.5	b	26	b	31	b	53	b
125	0.02	b	0.2	b	5	c	14	c	19	c
250	0	b	0.01	b	0.4	c	0.4	d	4	d
	Nine days after inoculation									
Propiconazole										
0 (control)	99	a	100	a	100	a	100	a	100	a
62	55	b	73	b	82	b	97	a	91	ab
125	20	c	46	c	72	bc	91	b	89	b
250	6	d	22	d	60	c	77	c	84	b
Triadimefon										
0 (control)	99	a	100	a	100	a	100	a	100	a
62	6	b	52	b	81	b	92	b	92	ab
125	2	bc	34	c	80	b	84	b	822	b
250	0.8	c	13	d	24	c	13	c	41	c

[1] Fully bloomed heads of male-sterile ATX623 sorghum were inoculated with *C. africana* at zero (0) time and fungicide application was delayed until after the time periods indicated. propiconazole=Tilt 3.6E (Syngenta), triadimefon = Bayleton 50DF (Bayer).

[2] Average ergot severity (percent infected florets/head) was determined from ten sorghum heads/plot at 5 and 9 days after the test initiation (inoculation with *C. Africana*). Values in the same column for each fungicide followed by the same letter are statistically similar according to Tukey P<0.05

relative humidity were recorded up to 10 days before and after half bloom. Correlation analyses were conducted to determine the relationship between weather triad values and natural incidence of ergot. Regression analysis was also used to determine which variables contributed significantly to variation in ergot potential. Ergot was present only from September. Triad values of maximum and minimum temperatures around 10 to 12 days before half bloom (boot stage) showed the highest significant negative correlation with the disease. Minimum relative humidity gave a significant and positive relationship with the ergot when present at high values immediately after half bloom.

Sclerotial Production in the Western Hemisphere.

Production of *C. africana* sclerotia in the western hemisphere was confirmed in 1997 sorghum ergot specimens from Celaya, Mexico and the northern (high plains) of Texas. In early 2000 sclerotia were identified in the Lower Rio Grande Valley near Weslaco, Texas and at Rio Bravo, Tamaulipas, Mexico. Formation of sclerotial tissue appears to be favored by low relative humidity and cool temperatures after infection. These conditions favor survival of intact structures of *C. africana* and allows more time for the formation of sclerotial tissue because low relative humidity reduces colonization of fungal tissue by saprophytic fungi and parasitic *Cerebella spp.* There are locations like Corpus Christi and some in Mexico, where sclerotia have never been observed because high relative humidity favors saprophytic degradation of sphacelia before sclerotia formation can occur.

Head Smut

A collaborative experiment with L. Prom, USDA/ARS plant pathologist, College Station, TX was conducted on depth of planting and control of head smut. R.Frederiksen, TAM224, had long theorized that low incidence of head smut sometimes noted in years when dry conditions existed at planting may be due to deep planting into soil layers below those containing the higher populations of the head smut pathogen (*Sporisorium reilianum*). Preliminary data indicate that plants from sorghum seed planted at the deepest depth (9-12 in, 23-30 cm) had the least amount of head smut compared to those planted at 2-4 in (5-13 cm) and 6-8 in (15-20 cm). Soil samples were taken at all three depths in the soil profile prior to planting. After planting, single samples were taken which included soil from the surface to the depth of seed placement in the soil. Numbers of teliospores of *S. reilianum* will be determined from these soil samples using an isolation technique developed several years ago by TAM-228 and plant pathologist G. Kaula of Zambia.

Charcoal Stalk Rot

Charcoal stalk rot caused by *Macrophomina phaseolina* can be a major disease constraint in several growing regions during extended periods of drought, especially when the drought occurs after flowering. Hybrids with poor post-flowering drought tolerance can have reduced yields and high levels of stalk lodging.

Collections of Naturally-Occurring Charcoal Stalk Rot in South Texas

In the 2001 growing season, drought stress was widespread in many regions of South Texas with charcoal stalk rot being most severe in areas where sorghum with moderate to high yield potential came under heavy stress after flowering during the early to mid grain filling periods.

In Texas, charcoal stalk rot can also be devastating to corn (maize) but lodging is typically less due to a stronger stalk. Charcoal stalk rot is actually more common on maize in South Texas but is often overlooked because stalks remain standing and the disease may sometimes develop late in crop maturity. The pathogen also occurs in soybeans in this region and on pearl millet, although, in this region, there are only a few fields of pearl millet grown primarily for cattle grazing. Due to the widespread occurrence of charcoal rot in the South Texas region this year, several systematic collections of charcoal rot-affected plant tissue and associated soil samples were made across the region from several crop hosts representing diverse soils, climates, and cropping systems. The collections will be used to characterize and compare the soilborne populations of *M. phaseolina* with those occurring within plant tissues.

Previous research by C. Pearson at Kansas State determined that host preference differences existed between *M. phaseolina* isolates infecting corn and those infecting soybean and that those differences could be detected in culture. We will determine what host preference differences may exist in South Texas populations using several research approaches to distinguish among isolates and determine how these might relate to populations elsewhere in the world.

Charcoal Stalk Rot/ Drought Stress Evaluation of Sorghum Hybrids

A charcoal stalk rot/ drought stress test of forty seven sorghum hybrids was established at Corpus Christi in 2001. Several commercial companies provided their best drought tolerant hybrids which were evaluated along with the best, new drought tolerant hybrids being developed by TAM-222, TAM-223, and B. Rooney. The hybrids were grown in a randomized block design using six single row replicates (20 ft long) of each hybrid in a drought-prone sandy clay loam soil. Soilborne populations of *M. phaseolina* were high and natural charcoal stalk rot was common in both sorghum and corn grown on the plot the previous year. An initial 1-2 wk later-than-normal planting date was followed by two additional planting dates about 1.5 wk apart to maximize potential for drought and different types of drought stress. Only the first planting date has been harvested but there were distinct differences between hybrids despite the lack of actual charcoal stalk rot development. Pre-flowering drought stress became severe near flowering but charcoal stalk rot was prevented when post-flowering stress was relieved at the early soft dough stage of most hybrids. Planting dates two and three had only early season drought stress with near normal yields expected in date 2 but plants in date 3 may be adversely affected if current high temperatures and rapidly decreasing soil moisture continue.

Considering the high levels of pre-flowering drought stress, several commercial hybrids and new TAES hybrids produced moderate to high yields with low to high test weight grain. The ten highest yielding hybrids produced average yields of 3754-4085 lb/ac (4208-4579 kg/ha) but test weights varied from 50.7 to 59.8 lb/bu. Most lower-yielding hybrids had test weights below 56 lb/bu. For planting date 1, the standard commercial hybrids ATX399 ×TX430 and ATX2752 × TX430 were among the poorer performing hybrids and ATX2752 × TX2783 was among the best hybrids. Most hybrids with the A-line A35 performed well, but those with the A-line A1 or R-line 88BE2668 were variable in their performance.

Networking Activities

TAM-228 was involved in collaborative ergot research projects with L.E. Claflin (KSU-210B) and C.R. Rush (TAES, Amarillo).

Noe Montes is now a Ph.D. graduate student in the Department of Plant Pathology and Microbiology, Texas A&M University with Gary Odvody and Tom Isakeit as his co-major professors.

An interactive CD-ROM called Images of Southern Africa, 1999 was created and distributed globally to a wide number of INTSORMIL and other sorghum researchers and individuals in the sorghum industry. The CD-ROM was produced both in an HTML format for web browser viewing and another self-running software program (Flipalbum) for direct viewing in Windows 95 and higher for those without a web browser. The approximately 180 images were from slides taken during a trip to the Southern Africa region in 1999. Images are primarily of insects and diseases occurring on sorghum and pearl millet and of people in sorghum research nurseries and fields at various Southern Africa locations.

TAM-228 P.I. was a member of the organizing committee for Global 2000, Sorghum and Pearl Millet Diseases III conference held in Guanajuato, MX September 23-30, 2000. TAM-228 was heavily involved in many phases of the conference including chairing several sessions and making presentations and displaying posters. Noe Montes did a lot of the local planning and other preparation for the conference, and at the conference he made presentations, displayed posters, and led several discussions or acted as interpreter during the conference field day tours.

TAM-228 provided funding to support D. Frederickson in her INTSORMIL sorghum ergot research project at the Matopos station in Zimbabwe. TAM-228 also provided essential research supplies difficult to obtain in Zimbabwe and also worked collaboratively with her on several aspects of her project.

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

Member of USDA-ARS Sorghum Germplasm Committee, 1997-2001.

Co-editor along with R. Frederiksen, TAM-224, in revision of the Compendium of Sorghum Diseases which was published September 2000. by the American Phytopathological Society

International Travel

Guanajuato, Mexico, September 23-30, 2000 to participate in Global 2000, Sorghum and Pearl Millet Diseases III conference.

Germplasm Exchange

Several sorghum nurseries were sent to South Africa, Zimbabwe, Zambia, and Botswana. These nurseries contain genetically diverse sorghums including those with broad adaptation to the SADC region, drought tolerance, sugarcane aphid resistance, and resistance to one or more pathogens of importance in the SADC region.

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Sustainable Production Systems

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

Project PRF-205
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Summary

The Mali analysis of new sorghum technology introduction emphasized the importance of combining demand expansion and liquidity increase with technology diffusion. Basic food commodity prices collapse in good and even normal rainfall conditions. The introduction of new processed products with traditional cereals is now occurring in urban Senegal and Mali. These products, such as couscous of millet and the use of high- quality sorghum flour in cookies in Mali, are a response in the food industry to the requirements for high-quality food products for processing (the white sorghums) and for reducing the labor requirements for women to process and prepare the traditional cereals. The availability of these new products made from traditional cereals changes the labor demands associated with their food preparation. In the longer run, the rapid growth of a poultry industry will enable substantial increases in food grain demand benefitting the traditional cereals.

With regard to liquidity for paying for increased input use, we show how capital can be generated internally within the household for these technology increases but farmers will have to recognize the potential returns. Combining new technology with demand expansion and liquidity can result in increases of 19% (average farmers) to 24% (better farmers). An aggregate analysis of the effects on sorghum showed increased sorghum consumption of 14% and a price increase of 25% from the price collapse level of 59 Fcfa/kg. This price collapse level resulted from technology introduction without the demand expansion in good rainfall years.

Since the collapse of West African peanut exports in the 1970s, the Senegalese Government has been concerned with the economic decline of the Peanut Basin. Previously credit, animal traction, and inorganic fertilizers were made available to peanut producers at subsidized prices. After removal of subsidies in the '80s and the devaluation of 1994, purchased input use has been sharply curtailed. Devaluation after a lag often encourages intensification by raising the domestic agricultural prices relative to imports. In the Senegalese case increases of farmers' incomes by 31 to 51% in the two zones of the Peanut Basin can result from moderate levels of inorganic and organic fertilizers on millet and peanuts. The liquidity constraint has been overrated in the literature and can be overcome with livestock sales or other sources of farmer incomes.

The most important constraint to intensification appears to be farmers seeing the technology in the field. Input markets also need to evolve especially for improved seeds and inorganic fertilizers. The removal of protection on the domestic fertilizer market would result in increased fertilization of peanuts rather than millet, indicating the importance of the fixed peanut prices. For millet it will continue to be important to expand demand through increasing sales of locally available processed food products from millet and some substitution for maize in the Senegalese chicken ration production.

It is early to evaluate diffusion of the Striga-resistant cultivars in Ethiopia since the three new cultivars were released only in 1999 and 2000 though they were available from informal farmer diffusion since 1998. Only 8% of the farmers were utilizing the new cultivars, according to estimates made in farmer meetings. The cultivars are earlier than the locals so that farmer preference is to use them 38%

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of the time (farmers' estimates) when early rains fail. Their earliness makes them more subject to bird attack and to molds in normal and good rainfall years. Farmers also prefer to use inorganic fertilizers with the locals rather than the new cultivars thereby taking advantage of the longer time in the field of the locals. Presently joint activity is planned between one INTSORMIL scientist (Purdue) and Tigray scientists to incorporate Striga resistance into local materials.

In the report to IGAD on developing technologies for the drylands of six countries of the Horn, the substantial potential of the drylands was emphasized when more water and higher soil fertility are made available. Once there is an improved agronomic environment, the return to new cultivars will be substantially increased. A cultivar-alone strategy is not sustainable; it either would not increase yields (if nutrients are already inadequate) or would lead to nutrient depletion. With the combined inputs (water retention technique, inorganic fertilizer and new cultivars), the lower disease incidence and longer sunlight hours can give dryland regions a comparative advantage over higher rainfall regions. The evolution of input markets (especially seed and inorganic fertilizer) will be crucial for the intensification process. Demand expansion needs to be a fundamental component of strategies to introduce new technologies for the traditional cereals. Fortunately there is substantial potential for this market expansion. The final point is the need for better integration of extension services and NGOs into the regional testing of new technologies. Given the critical importance of adaptation and demonstration trials and the large numbers required, it will be very important to get the extension service and NGOs involved in this process and to upgrade their scientific training.

Objectives, Production, and Utilization Constraints

The general objectives of this research are to estimate the potential effects of new technologies, to identify constraints to their introduction, and to recommend complementary policies to accelerate the introduction process. In this period there were four primary areas of research:

- The Mali part of the three Sahelian country studies of new technology introduction and policy changes for the traditional cereals (sorghum and millet).
- The Senegal part of this same study.
- A diffusion study in Tigray to estimate the extent and effects of the adoption of Striga-resistant sorghums and associated technologies).
- Fieldwork on the introduction of new technology, performance of institutions, evolution of input and product markets in the drylands of six countries of the Horn.

Research Approach and Project Output

Technological Change for Sorghum in Mali

Sorghum and millet are the predominant cereals in semiarid and dry sub-humid regions of West Africa. Both cereals are tolerant of low and irregular rainfall and low soil fertility. To introduce new technologies, the first prerequisite is to understand the farmers' decision-making process. Farmers have cash requirements at the harvest period for a number of urgent expenditures. Most farmers have subsistence food requirements for which they want to store their cereals during the year. These two objectives for income at harvest time and for subsistence food requirements are farmers' responses to risk. Farmers attempt first to obtain these objectives, not always successfully. Then they maximize their incomes. These responses to risk are then incorporated into our models of their decisions about new technologies and their reactions to policy changes.

The average and better farmers can increase their incomes approximately 12% with introduction of the improved sorghum cultivar. For the average farmer, this includes moderate levels of inorganic fertilizer (50 kg/ha of compound fertilizer). Both types of farmers already practice a water-retention technique with the predominant ridging done with animal traction. The better farmers are already utilizing this moderate level of inorganic fertilizer. This includes moderate increases in capital availability to pay for increased fertilization and seeds (Vitale, 2001, Ch. 7).

The impact of new technologies can be considerably increased with market expansion to moderate the price collapses resulting from good weather or the introduction of new technologies.[1] The combined effects of increased human food consumption of the traditional cereals, aided by commencement in use of these cereals as an animal feed, could result in approximately a 20% increase in cereal prices in good rainfall years.[2] This type of demand expansion would further augment best-farmers' incomes by another 5% and average farmers by another 8%. If the farmer can moderately increase his liquidity, as by selling animals to finance the increased inputs, then with the three combined changes, the better farmer can increase his income by 24% and the average farmer by 19% (Vitale, 2001, pp. 173, 188). These are the total effects on income increase from the new technology introduction, demand expansion, and higher liquidity. With these three changes combined, both the better and the average farmers would use higher levels of

[1] Traditional food crops have a very low elasticity of demand. There are few substitutes for the basic food commodities and consumers can only eat so much of them. Shortages result in large price increases and large production increases due to favorable weather and/or technology introduction lead to price collapses. These price collapses plus the tendency of governments to avoid price increasesin deficit years with imports tend to discourage those wanting to use the higher input levels associated with technological change.

[2] A smaller price increase of 8% in normal rainfall years and no increase in adverse rainfall years were included here.

inorganic fertilizer on 1.5 ha and put a small area (0.8 ha.) into tied ridges.

Demand expansion and increased liquidity make the new technology adoption more profitable. Note that farmers do not have to depend upon outside credit sources but can increase their cash available to purchase inputs from several income sources, such as animal sales, off-farm work, and remittances from relatives. Gradual adoption of technology over time can also lead to increased savings between years.

A sector model was employed to evaluate the economy wide effects of new technologies, demand expansion, and liquidity increases. In good rainfall years, the introduction of technology alone has minimal effects on the aggregate consumption of sorghum, hence a falling price. In the absence of demand expansion prices fell from 66 to 59 Fcfa/kg (Fig. 1). With short-run demand expansion,[3] sorghum prices increase to 90 and then fall to 74 with liquidity increases, enabling further output increases. The increased consumption is 14%. Further demand expansion as the poultry revolution continues could result in a price increase to 99 Fcfa/kg with a consumption increase of 20%.[4] In 1995

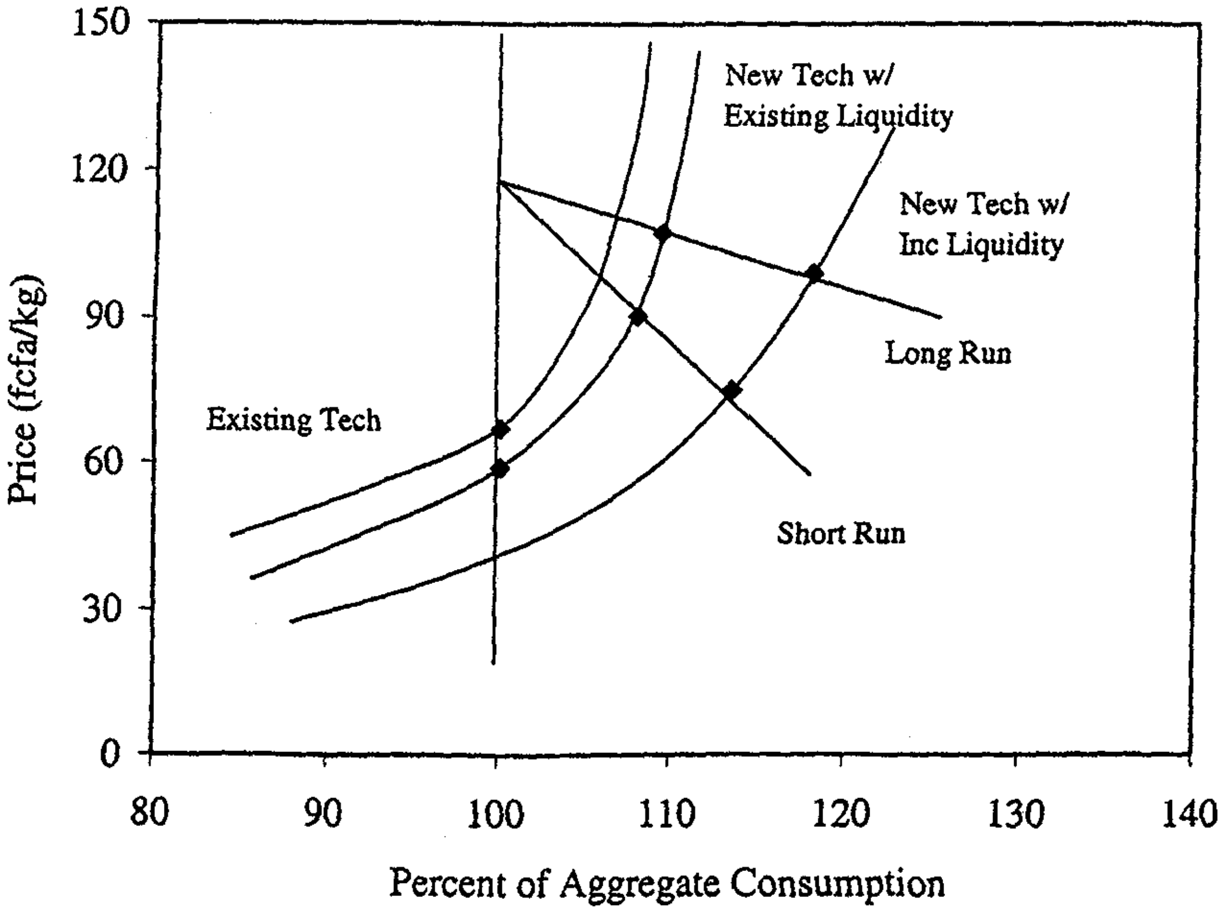

Figure 1. Combined effects of new technology, demand expansion, and liquidity increases on sorghum prices and quantity consumed

Source: Vitale, 2001, p. 296

[3] If urban consumers shift 10% of their cereal diet from rice to the new processed traditional cereal products being introduced, another 25 kg/year/urban consumer would be utilized. Another 10 kg/year/urban consumer could come from the start of the poultry revolution or the use of sorghum in bread or beer.

[4] The short-run price elasticity of demand is -0.25 and the long run -0.91 (Vitale and Sanders, 2001, p. 7.

and 1997, good rainfall years, the sorghum price increased to 120 Fcfa with increased sorghum exports to neighboring countries. These price increases resulting from demand expansion seem to be very reasonable estimates (Vitale and Sanders, 2001).

In the above cases, the benefits to consumers with new technologies are not as large as in many cases of technological change because a fundamental component of the process is to also shift demand outward and thereby increase prices. This maintains the incentive for farmers to introduce new technologies as the higher prices lead to higher profits for farmers.

Technological Change in the Peanut Basin of Senegal

. In Senegal the two basic cereals consumed are rice and millet with the shares ranging from 40 to 50% for each over the period, 1984-1996. Wheat and maize are minor contributors with shares of 6 to 8% (Sidibe, 2000, pp. 14, 15). Over the same period Senegal was a major food importer, with 39% of its food imported. Food aid was very important in 1984 and 1985 but was essentially phased out in 1996.

Purchased inputs have been principally used on cotton and peanuts. In 1996-97, 22 thousand metric tons of inorganic fertilizer were used on peanuts as compared with 7 thousand on the cereals (Sidibe, 2000, p.13). The initial effect of the devaluation of 1994 was to sharply depress the prices of crops relative to the imported fertilizer. However, by the late '90s the relative product prices had increased as domestic production became more profitable relative to imports. Millet recovered its pre-devaluation levels of relative profitability for intensification. For peanuts fertilization became substantially more profitable in the late '90s (Figures 2 and 3; Sidibe, 2000, pp. 17,19).

As in Mali, the farmers first have minimum harvest income and subsistence requirement goals and then they maximize their incomes. Cereal prices tend to collapse at harvest and those forced to sell cereals pay a high price by selling then. In Senegal the fixed peanut price enables the attainment of the income goals without losses from the lower prices received. The costs are higher for achieving these income goals in Mali. The subsistence cereal goal results in a larger production of cereals than would be the case in its absence.

The introduction of moderate levels of inorganic fertilizer on millet and peanuts results in 34 to 51% increases in incomes for the Southeastern and Central Peanut Basin (Sidibe, 2000, p. 82). The shadow prices of the essential inputs (fertilizers and seeds) have a ratio of 4:1 with the market prices indicating the high potential returns to increased input use. The principal constraint is the liquidity to purchase the inputs. Capital for input purchases can be ob-

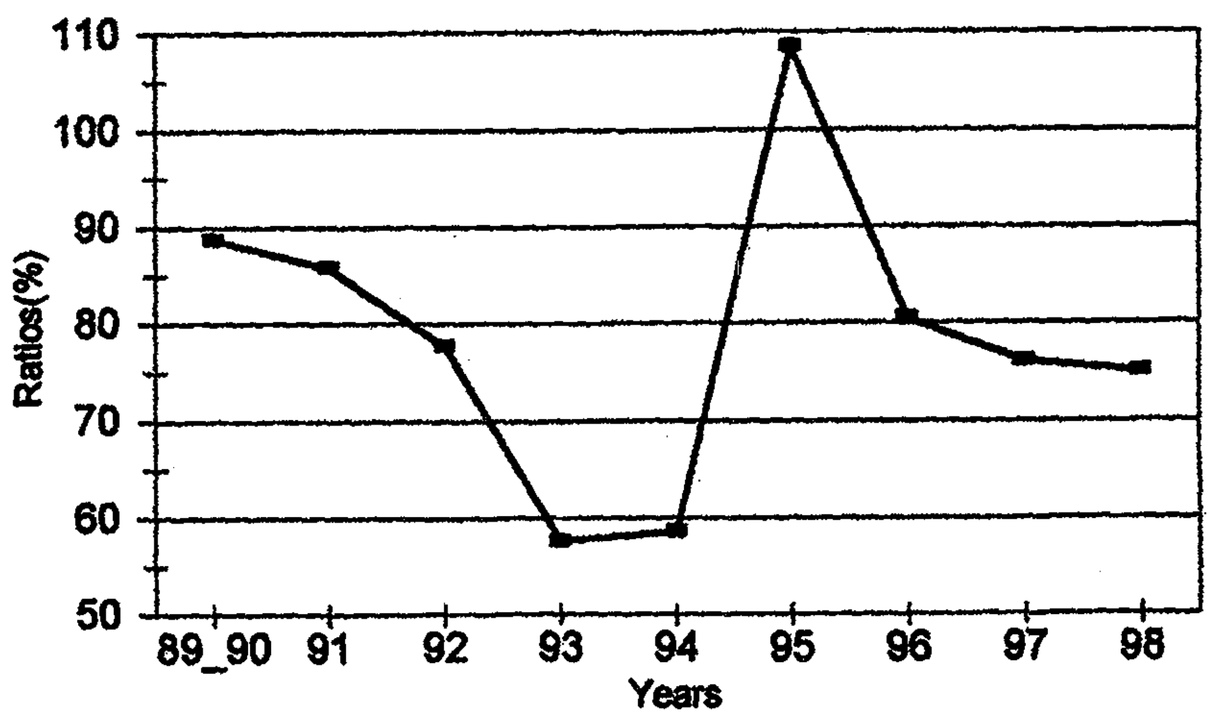

Figure 2. The farm-gate millet/fertilizer price ratio before and after the 1994 devaluation

Source: Sidibe, 2000, p. 17

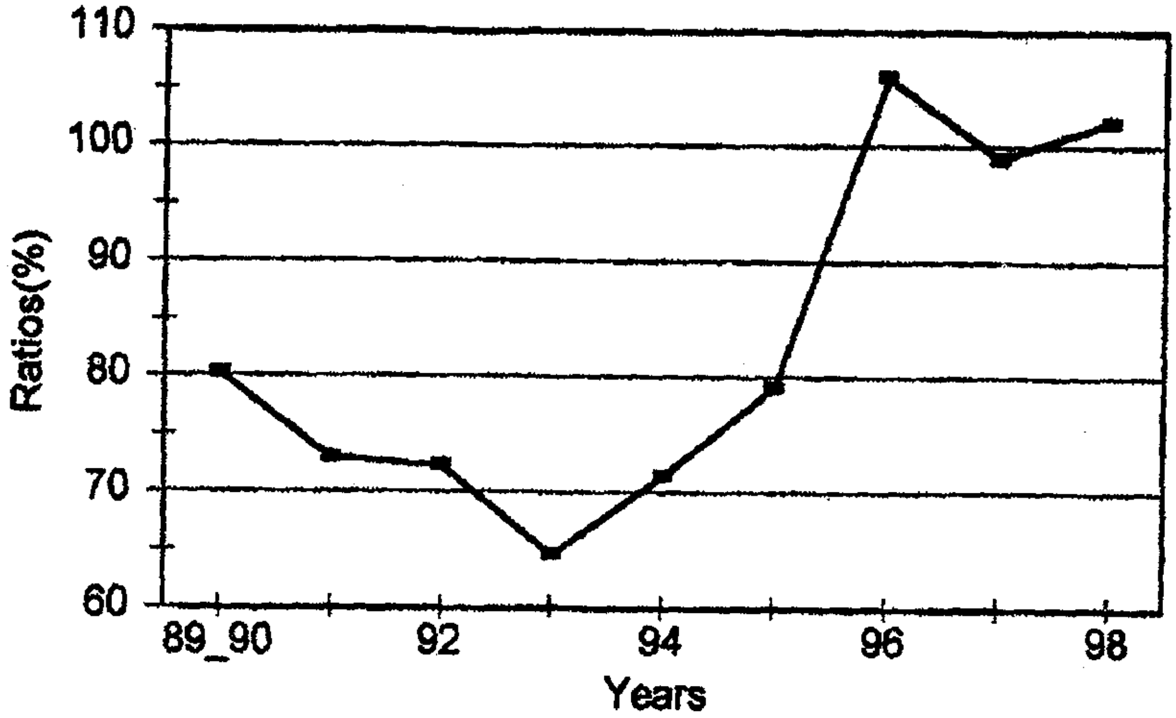

Figure 3. The farm-gate peanut/fertilizer price ration before and after the 1994 devaluation
Source: Sidibe, 2000, p. 19

tained from sales of livestock, off-farm work, and remittances. There are formal credit sources for peanuts; Informal credit is also available but at very high interest rates.

Farmers have their savings in animals, which they periodically cash in for emergencies, ceremonies, and other reasons. Farmers need to be convinced that inorganic fertilizers are high-return activities. Then many farmers will be able to internally generate the cash for input purchases. With increases of liquidity from 10 to 40%, farm incomes are increased another 11 to 30% in the Southeastern Peanut Basin and by 5 to 19% in the Central Peanut Basin (Sidibe, 2000, pp. 69-73, 82). This increased cash availability could result from selling one to three sheep in the Southeastern Peanut Basin and six poultry for 10% and one sheep for 40% increases in the poorer Central Peanut Basin.

The problem is not one of lack of liquidity for intensifying production but of convincing farmers that input purchases are high productivity investments for which they should internally generate their own funds. The principal constraint to the increased use of inputs is hypothesized to be the lack of awareness by farmers of the potential returns to fertilizer as well as the availability of fertilizer and seeds. The availability of the high quality seeds and fertilizers at the appropriate time then become important factors for future research.

Demand increases for millet for both increased processed food and in the local poultry feeding industry were also evaluated for their farm-level effects. Price increases of 20 to 100% were considered feasible. These price increases further augmented farm incomes but without another shift in technology beyond the moderate levels of organic and inorganic fertilizers already utilized at the lower price level.

Senegal has a protected domestic fertilizer industry for the production of phosphorus. Eliminating the protection and allowing international fertilizer prices results in increased fertilizer use on peanuts with 12 to 14% income increases for the two regions of the peanut zone (Sidibe, 2000, pp. 100-14). The fixed price of peanuts apparently makes it more profitable to put the fertilizer here than on the millet.

Introduction of Striga-Resistant Sorghum Cultivars and Associated Technologies in Ethiopia (Tigray)

The state of Tigray is formed by smallholders, approximately 616,000, producing cereals, grain legumes and oilseeds. Twenty-eight percent of the crop area is planted in sorghum. Farm size is small (1.2 ha), purchased input use is minimal, yields are low (<1mt/ha for cereals), poverty and food insecurity are pervasive and severe (Wubeneh and Sanders, 2001, pp. 1,2). Two-thirds of the farmers do not fallow due to land shortages, with approximately 60% of the farmers using manure and crop residues to maintain fertility.

After several years of demonstrations in the Global 2000-Government of Ethiopia program in Tigray, three Striga-resistant sorghum cultivars were officially released in 1999 and 2000 and distributed in the site of the interviews.[5] The initial technology package included the cultivars, a tied ridger, and inorganic fertilizer. Farmers found the ridger too heavy and awkward (Sanders and McMillan, 2001). In the experiment station in Nazret, the agricultural engineer modified it and a new simpler modification of the traditional plow was released in 2000 to a private company. The field trials were a useful feedback device to the experiment station.

Ninety farmers were interviewed in the main region in which the demonstration trials took place and the new cultivar seed was made available. Farmers did not like the ridger but they did appreciate the concept of retaining more of the water available. Farmers in Tigray have adopted a number of manual practices to retain water. So far in 2001, 72% of the farmers used stone bunds, 33% dirt bunds, and 16% used trenches to retain water (similar to the zaï in Burkina Faso) (Wubeneh and Sanders, 2000, p. 5). The bunds slow runoff and the trenches hold water in a similar manner to the tied ridges. Once farmers used the trenches their use of inorganic fertilizer increased and was higher than in the overall sample. One-third of those doing the trenches used manure alone, 7% used inorganic fertilizer alone, and 33% the combination of inorganic and organic fertilizers.

Estimates were made of the extent of adoption of the new cultivar based upon community meetings. About 40% of the non-adopting farmers had not heard about the new cultivars (Wubeneh and Sanders, 2000, p. 4). So it is still early in the diffusion process. Only 8% of the farmers used the new cultivars.

The farm sample of 90 farmers was stratified between adopters and non-adopters. Eighty-five of the 90 farmers planted the local sorghums with an average area of 1.3 ha. Of the 25 farmers utilizing the new cultivars, the average area was 0.3 ha. Farmers appreciated the Striga resistance and in adverse rainfall years the earliness of the new cultivars. In 38% of the years (according to farmers' estimates), early rains fail. When this happens, farmers who know about the new cultivars use them. With the early cultivars farmers can follow an insurance strategy of reducing risk, especially in years with the failure of the early rains or in years where there is still land available later in the season after the local cultivars have been planted. However, early planting of these short-season cultivars in normal or good rainfall years resulted in serious bird and grain quality problems. Another farmer compliant about the Striga-resistant cultivars was an inadequate stalk strength to withstand strong winds.

Since the local cultivar is in the field longer, there is more potential for it to respond to inputs and to produce higher yields. Seventy-nine percent of the farmers producing the local cultivar used manure and 72% of those used the new cultivars. Farmers rejected the inorganic fertilizer for the new cultivars but used it on the local cultivars. Nineteen percent of the producers of the local cultivar used inorganic fertilizers. Table 1 shows the yields on the farms using inputs, but note that these are aggregate yields and not all fields would be fertilized. (Wubeneh and Sanders, 2001, p. 5).

Table 1. Average sorghum yields in the Tagtay Adiabo Woreda of Tigray region for farmers using different fertilization techniques (Yields in kg ha^{-1})

Variety	No manure & no fertilizer	*Manure* only	Fertil-izer only	Manure plus fertilizer
Local	461 (14)	521 (49)	577 (3)	838 (16)
Striga resistant	305 (7)	635 (18)	-	-

Note: Figures in parentheses are number of observations. These are not response function yields but aggregate *yields for the* farms. Plots nearest to the household normally would be fertilized and thos farther away unfertilized.

Source: Wubeneh and Sanders, 2001, p. 7

It is still early in the diffusion process so planting the new cultivars later in the season in good and normal rainfall years may become a portfolio strategy to respond to Striga. A longer-season Striga-resistant material appears to be an important research item for the region. Collaborative work supported by Rockefeller is ongoing between a Purdue breeder and Tigray scientists on incorporating Striga resistance into local cultivars.

New Technologies for the Semiarid Zones of the Horn. For an IGAD project, a team of five undertook an analysis of technology introduction into the drylands of six countries in the African Horn. The recommended technology development strategy was to concentrate on the combined inputs for increasing water availability and soil fertility. The approach to water retention varies with soil type. On the sandy soils rapid infiltration is the principal constraint. Here almost

[5] The farm trials in this site were initiated in 1997-98. Since then the new sorghum cultivars have been informally distributed between farmers.

anything done to increase plant density or soil fertility will also increase water retention. Unfortunately, organic matter also burns up very rapidly in these soils so a water-retention technique needs to be an annual process.

On heavier soils with some clay, crusting is a frequent problem especially after cultivation has reduced the nutrient and organic matter levels. On these soils it is first necessary to reduce runoff and thereby make more water available for the soil-fertility amendment. The increased water reduces the risk and increases the returns from inorganic fertilizers. On very heavy soils, such as vertisols, the water-retention device needs to be knocked down in higher rainfall years.

A large number of traditional and new water-retention devices are being diffused now in Sub-Saharan Africa. Facilitating the introduction of more effective measures for different soil types and economic environments has been shown to have a high economic return (Shapiro and Sanders, 2001).

Once the agronomic environment is improved, the return is substantially increased for new cultivars with biotic resistances, improved yield characteristics, and higher food quality. Before the introduction of improved agronomy (increased water availability, higher soil fertility) there may be short-term gains from new cultivars alone but they will mine the soils of basic nutrients. Hence, this is not a sustainable strategy. In most regions of the production of traditional cereals, the soil-mining process is ongoing so there are already deficiencies in nitrogen and/or phosphorus.

The reports emphasized the importance of improving input markets and expanding product markets for the drylands. The seed sector has been especially adversely affected by the last two decades of structural adjustment. Governmental failure has been replaced by market failure since the private sector has not shown interest in the dryland crop activities except in irrigated zones. Most NGOs do not have the competence or the inclination to pave the way for future private-sector activity. Special incentives for scientists to engage in the private sector and subsidies for short-term seed production by the state sector for orphan crops are advocated.

Traditional food crops, including sorghum and millet, suffer from very inelastic demand resulting in price collapses with good weather and technological change. Since the new technologies involve increased input expenditures, farmers are more at risk from collapsing prices. Hence, programs to introduce new technologies need to simultaneously engage in demand expansion programs. One objective of the demand expansion is to moderate these price collapses and thereby encourage more rapid diffusion of new technologies.

Fortunately, there is substantial potential for demand expansion of the traditional cereals through new processed foods and for feed use. As economies grow, the demand for poultry increases especially rapidly. Developing countries have not been able to respond to this without rapidly rising imports. Horn countries need to begin anticipating these demand increases.

The success of Global 2000 in Sub-Saharan Africa is indicating the importance of demonstration trials of new technologies (plus the evolution of input markets) to accelerate the diffusion process. The altitude, soil, and rainfall variation in most of the Horn countries require substantial region-specific screening of new technologies. National agricultural research systems do not have the funds or the manpower for all of this. These adaptation trials are as critical as the demonstration trials and need to precede them in many cases. Another strategic recommendation of the Horn report was for a better integration of national extension services and NGOs into the network of the national agricultural research organization with the objective of delegating to them more adaptation and demonstration trials. These adaptation and demonstration trials will require increased training for and better reporting by both the national extension services and the NGOs.

Networking Activities

Fieldwork Collaborating with African Agencies

A principal field activity of the last one and one-half years has been leading a team of five scientists to respond to a research request to INTSORMIL from IGAD funded by USAID-REDSO. The request was for (1) a review of technologies introduced into the drylands of the Horn countries; (2) an analysis of the performance of the research, extension and NGO activities; (3) a description of the functioning of the input and product markets; (4) identification of the role of women and policy in technology introduction and income increasing activities; and (5) recommendations for future projects to accelerate technology introduction. The two- volume report on six countries in the Horn was published at the end of this INTSORMIL budget year (see Publications and Presentations). A workshop will be held in September 2001. The reports are being widely distributed. The five-person team included an economist from Purdue, an anthropologist from Florida, a plant breeder from Kenya, a pathologist from Uganda, and an agronomist from Ethiopia.

We have also been collaborating with the sorghum and the millet networks in West Africa, ICRISAT, INSAH (the regional organization for the Sahel), and various national research programs. This collaboration involves attending their workshops and planning meetings, writing technical articles, and presenting papers at their functions.

Direct Interchange and Services

As part of our collaboration with the Tigray state research station, we provided them with a portable computer. Nega Wubeneh was also in regular contact with them, traveling to Tigray at the end of his time in the field to present his preliminary results.

In Ethiopia, Sanders has been collaborating intensively on the IGAD report with Kidane Georgis, the agronomist in charge of the drylands center for EARO, the national agricultural research organization in Ethiopia. They plan further journal article writing together.

Sanders has been collaborating on journal articles for several years with economists in ICRISAT and ILRI. His principal ICRISAT collaborator is presently the Director of their Natural Resources Program. Our main networking activity is with our present and past students.

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

Project UNL-213
Stephen C. Mason
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Summary

Growing season harvest of pearl millet tillers in the Maiwa production system in southern Niger can produce approximately 700 kg ha^{-1} forage without adversely effecting grain or stover yields at harvest.

Pearl millet planting date studies in Nebraska indicate that air heat unit accumulation after April 1 is better for making planting date recommendations than calendar dates. In eastern Nebraska, the highest pearl millet grain yield is produced by planting approximately 400 heat units after April 1 for a silty clay loam soil and 600 heat units for a sandy soil. In western Nebraska, the highest pearl millet yields occur when planted 100 to 200 heat units after April 1, but the yield decline for delayed planting was less than in eastern Nebraska, indicating that it has potential as an emergency replant crop in this region. Pearl millet grain yields are optimized by planting in narrow row spacing (i.e., 38 cm).

Pearl millet and grain sorghum increased grain yield either linearly or quadratically with increasing nitrogen fertilizer application rate in Nebraska and Central America, with the highest yield being produced with the highest nitrogen rate except for one grain sorghum experiment in Santa Cruz Porrillo, El Salvador.

Water supply studies in Nebraska showed that grain sorghum produces higher grain yield and grain water use efficiency (WUE) than pearl millet, and had a greater response to irrigation. Pearl millet and grain sorghum used similar

amounts of water and produced similar plant biomass at harvest.

INTSORMIL Project UNL-213 developed a five-year strategic plan to help focus and coordinate agronomy research efforts in West Africa. This plan focuses on providing adequate quantities of nutrients for high yield production, combining station and farm research, and institutional capacity building through short-term training and graduate education.

Objectives, Production and Utilization Constraints

Objectives

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

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

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

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

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

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

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

- Conduct N rate and N use efficiency studies for grain sorghum production in El Salvador and Nicaragua.

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

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

- Develop a strategic plan for agronomy research in West Africa.

Constraints

This project has focused primarily on crop production systems which increase the probability of obtaining higher pearl millet and sorghum 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 management, 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 and grain sorghum are usually grown in stressful environments with high temperatures, lack of predictable water supply, fragile soils with low nutrient status, and limited growing season length. Lack of water is usually considered to be the most critical environmental factor controlling growth and limiting yield in Africa, but a source of nitrogen and/or phosphorus often is more critical. This is especially true for intensive cropping systems using improved cultivars on degraded land. Nutrient use and water use efficiencies are closely interwoven with higher yields possible with improved cropping systems utilizing improved cultivars. Since human capital for research and extension activities are very limited for pearl millet producing areas in West Africa, project activities are generally conducted as 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). Studies have been initiated with new collaborators in Central America on nitrogen fertilizer management for grain sorghum production which is also a critical issue in the region. In the U.S. Great Plains, production practice recommendations for high yielding, dwarf hybrids, and development of markets are important to adoption as a grain crop. This complex interaction of water, nitrogen, phosphorus, cultivars and yield enhancing production practices is the focus of Project UNL-213's research efforts.

Domestic (Nebraska)

Water Supply Effect on Pearl Millet
Grain and Stover Yield
(Nouri Maman, Ph.D. Thesis)

Research Methods

The experiment is being conducted on a Keith silt loam under a linear move irrigation system with drop nozzles at the High Plains Agricultural Laboratory located at Sidney, NE (west) in 2000 and 2001. The experiment is being conducted using a randomized complete block design with a factorial (2 x 4) treatment arrangement and three replications. Factor 1 was the pearl millet hybrid (68Ax 086R) and one grain sorghum hybrid (DK 28E). Factor 2 was composed of 4 different water regimes. The water regimes consisted of; (i) Control, dryland; (ii) Full water supply at all growth stages (apply water to bring soil moisture level to 80% field capacity any time it falls to 70% field capacity); (iii) Water supply at boot stage, and (iv) water supply at grain filling stage. Soil water was measured using neutron probes. Grain and stover yields were collected at harvest, and seasonal grain and biomass water use efficiencies (WUE) were calculated. A similar study was conducted at Mead, NE (east) using a furrow irrigation system. Data were analyzed using analysis of variance procedures.

Research Results

At Sidney no rainfall occurred during the growing season, thus extremely low grain and stover yields of both pearl millet and grain sorghum were produced (Table 1). The crops used similar amounts of water, but the grain sorghum yield was greater than for pearl millet. Pearl millet biomass yields were greater under dryland conditions than for grain sorghum, and biomass yields increased little in response to full irrigation. Grain sorghum had better WUEs than pearl millet except for biomass WUE under dryland conditions. Grain and stover yields were much higher for both crops at Mead which had timely rainfall from mid-vegetative growth until mid-grain fill growth stages. Grain sorghum produced higher grain yield than pearl millet, but biomass yields were similar. Grain yields were unaffected by the water regime, but sorghum grain yields tended to increase more with irrigation, especially irrigation at the boot growth stage, than pearl millet. This study is being continued during the 2001 growing season.

Nitrogen Response of Pearl Millet
(Nouri Maman, Ph.D. Thesis)

Research Methods

The pearl millet hybrids 68Ax086R and 293x086R were planted in randomized complete block experiments with side-dress nitrogen fertilizer rates of zero, 40, 80 and 120 kg ha^{-1} and four replications. The study was conducted in Sidney, NE (west) on a Keith silt loam soil with kg ha^{-1} residual nitrate-nitrogen and in Mead, NE on a Sharpsburg silty clay loam soil with kg ha^{-1} residual nitrate-nitrogen. Leaf nitrogen concentration, leaf chlorophyll concentration, grain and stover yield, and plant nitrogen uptake were collected. Data were analyzed using analysis of variance, and nitrogen response using single-degree orthogonal contrasts.

Research Results

Pearl millet grain yields were quite low at Sidney due to the lack of rainfall during the growing season, while grain yields were more than twice as high at Mead due to timely rains during critical growth stages (Table 2). Nitrogen fertilizer application increased grain yield linearly at both locations, indicating that more than 120 kg ha^{-1} was required to maximize pearl millet grain yield in these two contrasting environments. This study is being continued.

Table 1. Water regime influence on grain and stover yield, and water use efficiency of pearl millet and grain sorghum.

Crop	Water Regime	Sidney: Yield Grain	Sidney: Yield Biomass	Sidney: Water use	Sidney: Water use efficiency Grain	Sidney: Water use efficiency Biomass	Mead: Yield Grain	Mead: Yield Biomass
		--- ---		mm	Kg grain/ha/mm		--- Mg ha^{-1} ---	
Pearl Millet	Dryland	0.8	12.4	230	3.3	54.5	4.9	11.0
	Boot Irrigation	1.2	8.4	323	3.6	26.2	4.8	11.5
	Grain Fill Irrigation	1.8	10.2	327	5.5	31.4	4.9	11.5
	Full Irrigation	3.7	13.1	462	8.0	28.4	5.2	13.0
	Mean	1.9	11.0	336	5.1	35.1	5.0	11.7
Sorghum	Dryland	2.0	7.3	224	8.9	32.3	6.7	10.6
	Boot Irrigation	4.2	12.1	296	14.5	42.6	7.5	12.2
	Grain Fill Irrigation	4.0	12.3	312	15.1	39.3	7.1	12.1
	Full Irrigation	7.1	19.1	490	13.1	39.1	7.7	13.2
	Mean	4.3	12.7	331	12.9	38.3	7.2	12.0
F-test Probabilities				Pr>F				
Crop (C)		<0.01	0.35	0.58	<0.01	0.68	<0.01	0.53
Water Regime (WR)		<0.01	0.07	<0.01	0.05	0.79	0.12	0.02
C * WR		0.04	0.16	0.21	0.34	0.31	0.28	0.79
C.V. (%)		21	35	7	32	51	8	11

Table 2. Grain yield responses of pearl millet and grain sorghum to nitrogen fertilizer application.

Nebraska - Pearl Millet†			El Salvador - Grain Sorghum‡			Nicaragua - Grain Sorghum¶			
N rate	Sidney	Mead	N rate	Izalco	Santa Cruz Porrillo	N rate	Segovias	Chinandega	Tisma
kg ha^{-1}	Mg ha^{-1}		kg ha^{-1}	Mg ha^{-1}		kg ha^{-1}	Mg ha^{-1}		
0	1.17	2.5	0	0.8	1.6	0	1.5	1.6	3.9
40	1.45	3.3	26	1.3	2.0	30	2.7	2.2	4.5
80	1.51	3.7	52	1.5	2.3	60	3.6	2.6	5.3
120	1.54	4.0	78	1.8	2.1	90	4.0	3.0	6.9
Contrast	N Linear	N Linear		N Quad	N Quad		N Quad	N Linear	N Quad

† Average of two hybrids
‡ Average of six varieties
¶ Average of four varieties

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

Research Methods

An ongoing study to determine recommended planting date and row spacing for pearl millet hybrids was conducted on a silty clay loam and sandy soil site in Mead, NE (east), a loam soil in Sidney, NE (west), and a sandy soil site in Ogallala, NE (west-central). Sidney has low rainfall, short growing season. and efforts are being made to intensify wheat-fallow production systems by incorporating pearl millet as a summer annual crop in this region. The pearl millet hybrids 68A X 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 in studies between 1995 and 2001.

Research Results

Recommended planting date for pearl millet and grain sorghum to optimize grain yield was not clearly indicated by comparing yield to calendar date as this did not take into consideration grain yield differences across years nor soil and air temperatures (Fig. 1). For the Mead silty clay loam site, relative yields for heat unit accumulation after April 1 increased slightly until approximately 400 heat unit accumulation at planting, then yields declined greatly for both crops with later planting dates. Similar trends were found for the Mead sandy soil type, except yields did not start to decline until approximately 600 heat units had accumulated at planting. Data from the Ogallala sandy and Sidney loam sites suggest that the greatest pearl millet yields occurred with 100 to 200 heat unit accumulation at planting, but that the yield decline for late planting was much less than for the Mead sites. Grain sorghum yields across planting dates at the Ogallala sandy sites were quite variable, and declined rapidly after the earliest planting date at approximately 500 heat unit accumulation. In all sites, early planting resulted in only slightly lower grain yield than for the optimal planting dates, but also led to significant bird feeding problems for pearl millet. In western and west-central Nebraska, pearl millet had a longer planting date "window" than grain sorghum, and results suggest that it might have potential as a late-season replant emergency crop to replace early summer annual crops lost to hail or pests. Narrowing row spacing from 76 cm to 38 cm increased interception of solar radiation and grain yield of both pearl millet and grain sorghum by 13 to 15%. These data suggest that narrow row spacing and that planting date recommendations based upon heat unit accumulation after April 1 should be used by producers.

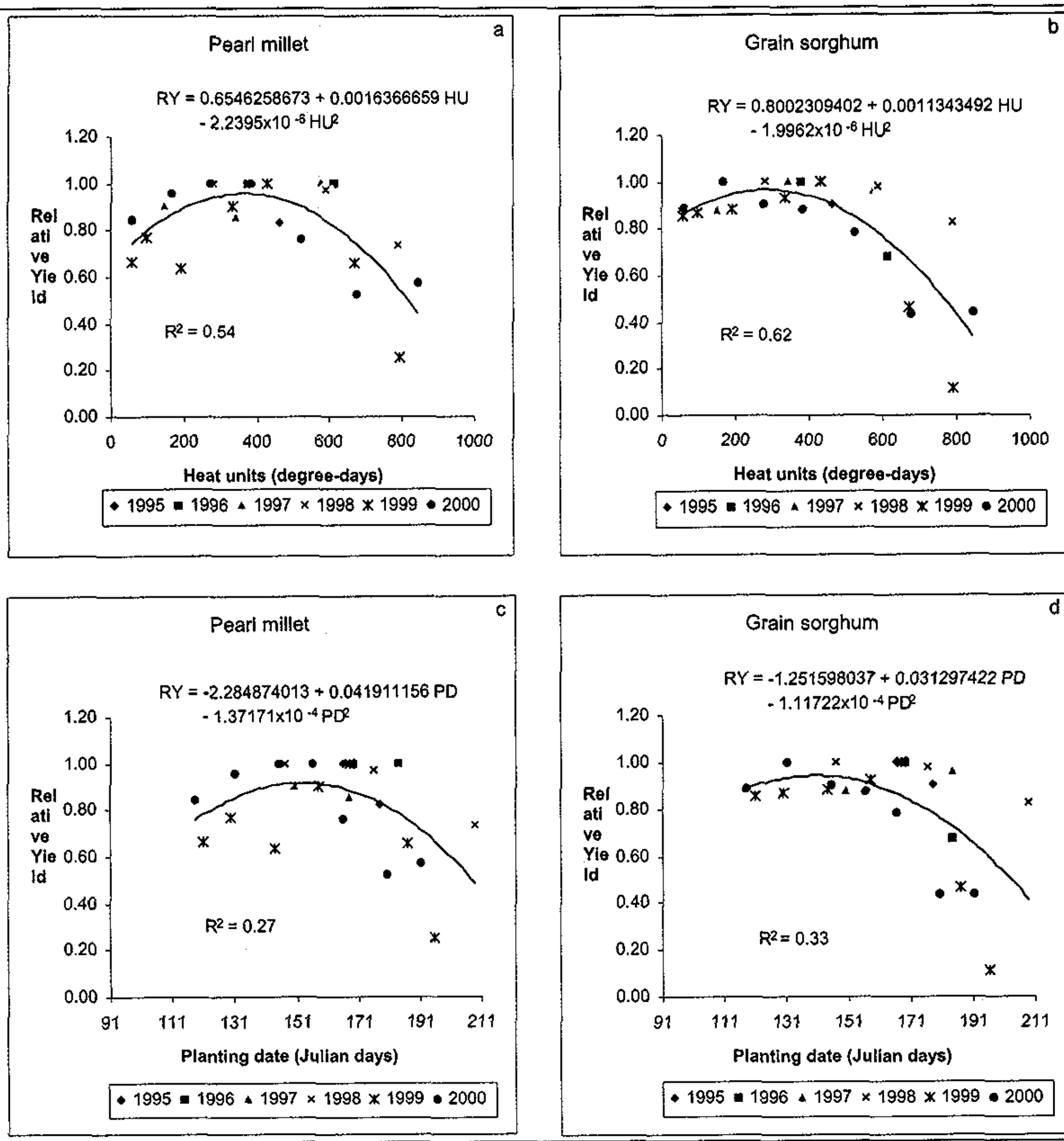
Grain Sorghum - Maize Hybrid Comparisons
in Dryland and Irrigated Environments
(Delon Kathol, M.S. Thesis)

Research Methods

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

Research Results

The seasonal rainfall was good in 1999 and 2000, and led to high yields of both grain sorghum and pearl millet. Maize out yielded grain sorghum under both dryland and irrigated conditions, and row spacing had little effect on grain yield of both crops. Averaged over years, irrigated, dryland and row spacings, grain sorghum yield increased at a rate of 0.05 Mg ha^{-1}/decade since the 1950s. Maize yield increase rate from 1970 to 1990 was similar to grain sorghum, but between 1950 and 1970 yield increased 1.1 Mg ha^{-1} /decade This study is being repeated in 2001 to help provide adequate variation in environments to better understand the basis for producers shifting from dryland grain sorghum to maize.



RY = Relative yield
HU = Heat unit
PD = Planting date

Figure 1. Relative yield of pearl millet and grain sorghum for planting dates based on Julian days and heat unit accumulation after April 1 (base temperature = 10 ° C) for the Sharpsburg silty clay loam soil at Mead, Nebraska.

International

Burkina Faso, Mali, and Niger:Population Hybrid by Production Environment Study (Cooperative with INTSORMIL Project ARS-213)

Research Methods

A randomized complete block designed study to evaluate a pearl millet population hybrid produced by INTSORMIL project ARS-213 with the best local variety under low and high yield environments was conducted in Cinzana (Mali), SARIA (Burkina Faso) and Maradi (Niger). The low yield environment consisted of no fertilizer with pearl millet planted in hills with 0.8m x 0.8m spacing. The high yield environment consisted of 23 kg ha^{-1} nitrogen, 20 kg ha^{-1} phosphorus and planting in hills with 0.8m x 0.4m spacing, except in Maradi where the hill spacing remained constant. Data were analyzed using analysis of variance procedures.

Research Results

The local pearl millet variety produced higher grain yield in all three locations. Observations in Mali and Burkina

Faso indicated that the population hybrid was shorter maturity and more susceptible to stalk borer than the local variety. The high management level increased increased grain yield from 476 to 772 kg ha^{-1} (62%) in Mali and Burkina Faso, while fertilizer application reduced grain yield in Niger, likely due to the dry growing season. This study is being continued in 2001.

Mali Weed Control Study

Research Methods

A randomized complete block designed experiment to evaluate the interactive effects of planting date, pearl millet genotype and hand weeding method on pearl millet grain and stover yield was initiated at Cinzana, Mali. Planting dates were 12 June and 28 June, varieties were India na 05 and Sanioba and six hand weed control methods (weed free, in-row weeding, between row weeding, in-row with soil ridging, in-row with mulching, and weedy check). Data were analyzed using analysis of variance procedures.

Research Results

Neither date of planting nor variety had a significant effect on pearl millet grain yield, although the later planting date tended to produce slightly more grain. Weeding method significantly affected both grain and stover yield with complete weeding or weeding in-row resulting in 1055 kg ha^{-1} grain, between row and in-row with ridging or mulching resulting in 911 to 965 kg ha^{-1}, and the weedy check producing 722 kg ha^{-1}.

Niger Maiwa Study

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 treatments: plots thinned to 2 plants/hill at 14 days after planting (B_1), B_1 plus tillers harvested 65 days after planting, and B_1 plus tillers harvested 85 days after planting. Tillers were harvested, dried, weighed and analyzed for neutral detergent fiber (NDF), acid detergent fiber (ADF), digestible dry matter (DDM), crude protein (CP) and phosphorus. Grain and stover were harvested at the end of the growing season and the stover analyzed for forage quality.

Research Results

Forage is needed for ruminant livestock in West Africa during the growing season when grazing is restricted by presence of crop fields. Late-maturing, photoperiod sensitive pearl millet varieties produce many tillers without panicles which could potentially be used as feed. This study evaluated the potential of growing season harvest of pearl millet tillers for forage in Niger. Tiller harvest timing and hill spacing had no effect on grain (1500 kg ha^{-1}), stover (10,500 kg ha^{-1}) or pre-harvest tiller yield. Tiller harvest resulted in approximately 230 kg ha^{-1} leaf and 200 kg ha^{-1} stem biomass at both 65 and 85 days after planting (DAP) (Table 3). Tillers harvested at 65 days DAP had 2% higher leaf acid-detergent fiber (ADF), 4.4% lower stem neutral-detergent fiber (NDF), 1.5% lower leaf digestible dry matter DDM), 5% higher leaf and stem crude protein (CP), and 0.6% higher leaf and stem P concentration than at 85 DAP. Tiller NDF and DDM were higher, and ADF, CP and P were lower in 1999 than in 1998 due to larger tiller biomass harvested and longer storage time before laboratory analysis. Hill spacing and tiller harvest had little influence on the ruminant nutritional value of the stover. Pre-harvest of pearl millet tillers is a potential feed source for ruminant animals without reducing grain or stover production, and has higher feed quality than stover harvested at maturity.

Central America Nitrogen Rate Studies

Research Methods

A two-year study was initiated at two locations in El Salvador and three locations in Nicaragua with the objective to determine recommended nitrogen fertilizer rates for grain sorghum production, and to identify high nitrogen use efficient varieties. At each location a factorial combination of four (Nicaragua) or six (El Salvador) grain sorghum varieties were grown with four nitrogen fertilizer rates in a randomized complete block design with four replications. Grain and stover yield, and N concentration of grain and stover were collected to allow determination of nitrogen use efficiency. Data analysis was done using analysis of variance procedures, and orthogonal contrasts determined.

Research Results

Nitrogen fertilizer application increased grain yield either linearly or quadratically at each location (Table 2). At all locations, except Santa Cruz Porrillo, El Salvador, the highest grain yield was produced at the highest nitrogen fertilizer rate of 78 or 90 kg ha^{-1}. These studies are being continued.

Networking Activities

Workshops

ROCAFREMI (West and Central Africa Pearl Millet Research Network) Strategic Planning Meeting, 11 - 15 December 2000, Cotonou, Benin.

ROCAFREMI (West and Central Africa Pearl Millet Research Network) and ROCARS (West and Central Africa Sorghum Research Network) Annual Meeting, 23 28 April, Bamako, Mali.

Table 3. Maiwa pearl millet growing season tiller biomass and feed quality for as affected by hill spacing in 1998 and 1999 in Bengou (Niger).

Treatments	Tillers biomass		NDF		ADF		DDM		Crude Protein		Phosphorus	
	Leaf	Stem	Leaf	Stem	Leaf	Stem	Leaf	Stem	Leaf	Stem	Leaf	Stem
	— kg ha^{-1} —		% Dry Matter									
Year (Y)												
1998	124	30	64.9	64.5	33.5	36.8	62.8	60.2	13.6	8.9	0.22	0.17
1999	335	377	72.7	72.8	10.2	1.2	81.0	80.2	7.7	5.8	0.07	0.06
Hill Spacing (HS)												
1.0 m x 1.0 m	230	214	67.8	68.6	21.8	24.4	72.0	69.9	11.2	6.7	0.14	0.10
1.5 m x 1.0 m	229	193	69.8	68.8	2.0	23.6	71.8	70.5	10.1	8.0	0.16	0.13
Tiller Harvest (TH)												
65 DAP	221	203	70.1	66.5	22.8	23.5	71.1	70.6	13.6	10.2	0.18	0.15
85 DAP	238	204	67.5	70.9	20.9	24.5	72.6	69.8	7.7	4.5	0.11	0.09
Probability F-test			Pr > F									
Y	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
HS	.95	0.61	.23	0.89	0.70	0.17	0.70	0.17	0.11	0.12	0.09	0.01
TH	.36	0.99	.11	0.03	<0.01	0.09	<0.01	0.09	<0.01	<0.01	<0.01	<0.01
Y*HS	23	0.70	0.31	0.44	.25	0.54	0.25	0.54	0.01	0.70	0.05	0.03
Y*TH	.18	0.99	0.40	0.14	.98	0.90	0.98	0.90	<0.01	<0.01	0.02	0.11
HS*TH	.42	0.53	0.40	0.98	.60	0.57	0.60	0.57	0.69	0.75	0.98	0.36
Y*HS*TH	0 .07	0.48	0.68	0.46	.81	0.21	0.81	0.21	0.859	0.11	0.07	0.80
C.V. (%)	21.3	54.8	6.3	7.5	6.9	6.2	1.6	1.7	18.4	30.0	19.7	26.0

NDF = Neutral Detergent Fiber; ADF = Acid Detergent Fiber; DDM = Digetible Dry Matter

Research Investigator Exchange

Visited research collaborators from Burkina Faso, Mali, and Niger during Dec. and April trips to West Africa. This time was used to develop a five-year strategic plan for INTSORMIL Project UNL-213 with central studies both on-station and on-farm related to microdose fertilizer management for pearl millet. Additionally, each West African scientist will conduct research on a topic of personal interest and related to national research priorities.

Pale Siebou (Burkina Faso) and Nouri Maman (Niger) continued graduate degree studies. Delon Kathol (U.S.A.) started a M.S. degree in Jan 2001.

Research Information Exchange

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

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

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

Publications and Presentations

Abstracts

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Extension Bulletins

Coulibaly, A., S. Traoré, M. Bagayoko and S.C. Mason. 2000. Soil fertility management in millet cropping system. In J. Slaats and O. Niangado (eds.). Technology leaflets: Agricultural Research Station Cinzana. IER - Syngenta Foundation.

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Nutrient Use Efficiency in Sorghum and Pearl Millet

Project UNL-214
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Summary

Continuation of on-farm trials in Niger to demonstrate the beneficial effects of soil preparation, sorghum hybrids and additional fertilizer were conducted in three rainfall zones. Results showed that use of tied ridges plus 5T manure and supplemental urea resulted in 1920 kg ha^{-1} versus 190 kg ha^{-1} for the traditional practice for the driest zone. Farmers in this region are now converting to the newer practices and would be expected to see significant average yield increases in a short time span. Trials in Ghana comparing response of cowpea and sorghum to P fertilizer showed that sorghum response was greater than cowpea. The average net benefit (profit) increased in both crops by using P although at a different rate (less for cowpea). Another study on grain sorghum response to N fertilizer when in rotation with various crops (sorghum, peanut, cowpea, soybean) showed that overall grain biomass and grain yield of the sorghum increased with added N averaged over all rotations. Nitrogen applied at 120 kg ha^{-1} resulted in a 49% increase in biomass and a 70% increase in grain yield over the control. The effects of the rotation could not be measured this year since the rotation has just been initiated. Field experiments conducted at Nebraska to determine N, moisture and genotype interaction effects indicated that moisture stress increased N use efficiency values (biomass unit plant N^{-1}), and it was highest for San Chi San, the known high N use efficiency genotype. Nitrogen use efficiency decreased with added N over genotype and moisture stress level. Determining the extent of this three way interaction will be important in arriving at the best management decisions when producing grain sorghum.

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 Research Output

International Research

Results of 2000 Niger trials - Seyni Sirfi

On farm trials were continued in 2000 to show sorghum grain producers the effect of improved soil preparation on plant establishment and yield. Use of tied ridges also improves soil structure and texture, and use of manure combined with inorganic fertilizers increases crop nutrient and water use efficiencies and maintains soil fertility. The three soil preparation treatments were tied ridge (T_1), simple ridge (T_2) and conventional/traditional (T_3). The first two treatments were applied preplant. Fertility treatments consisted of 5 T manure incorporated preplant and 50 kg ha^{-1} sidedressed during vegetative growth. Hybrid NAD-1 was planted in three different rainfall zones: Tillakaïna (330 mm), Konni (400-520 mm) and Bengou (600+ mm). At Tillakaïna (Table 1), there was a significant difference between treatments for all variables, except for threshing index. However at Konni (Table 2), there was no significant difference between treatments for any variable. No results were reported from Bengou this year.

In the Tillakaïna arid zone (Table 1) for plant emergence, plants standing and yield, the treatments with ridges gave the best results. The best grain yields were obtained with treatments T_1 (tied-ridge + 5 t of manure + 50 kg of urea ha^{-1}) and T_2 (simple ridge + 5 t of manure + 50 kg of urea ha^{-1}). Grain yield obtained from these treatments are respectively 1920 and 1116 kg ha^{-1}. The lowest grain yield, 190 kg ha^{-1} was obtained with T_3, the farmer traditional practice. From these results one can see that the tied-ridge treatment gave twice the grain yield obtained with the simple ridge treatment, and almost 10 times the local management practice. The same trends were observed with the other variables. There were also differences in harvest index between treatments. However, there was no difference for threshing index between treatments.

In the Konni intermediate zone, as mentioned above, there was no difference between treatments (Table 2) for any variable measured. It was also noted that the yields were lower than those of the arid zone Tillakïana. The average grain yield was around 500 kg ha^{-1} at Konni and 2000 kg ha^{-1} at Tillakaïna. The principal reason was that in the Konni zone, the sorghum was infested by the insect *cecydomie* before maturity. However, it was noted that total biomass production was higher in the Konni zone. For the tied-ridge treatment, the total biomass yield was around 9000 kg ha^{-1} for Konni and 6,000 kg ha^{-1} for Tillakaïna.

The results obtained show better performance of tied-ridge treatments compared to the other treatments.

Table 1. Effect of different cultural practices on grain sorghum (hybrid NAD-1) production at Tillakaïna (Niger) (INRAN/INTSORMIL, on-farm study, 6 farmers).

Treatment		Yield (kg ha^{-1})		Threshing	Harvest
	Panicles	Grain	Biomass	index	index
T_1 = tied-ridge	3358	1920	6584	0.59	0.19
T_2 = simple ridge	1911	1116	4079	0.56	0.17
T_3 = control	275	190	1073	0.55	0.10
LSD (5%)	1041	665	679	0.14	0.08
F-test Probability		Pr > F			
Rep (farms)	0.031*	0.021*	<0.01**	0.535 ns	0.028*
Treatments	<0.01**	<0.01**	<0.01**	0.780 ns	0.074
C.V. (%)	35	39	12	18	33

Threshing index = grain weight/panicle weight
Harvest index = grain weight/biomass weight

Table 2. Effect of different cultural practices on grain sorghum (hybrid NAD-1) production at Konni (Niger) (INRAN/INTSORMIL, on-farm study with 3 farmers).

Treatment		Yield (kg ha^{-1})		Threshing	Harvest
	Panicles	Grain	Biomass	index	index
T_1 = tied-ridge	1030	490	8950	0.422	0.04
T_2 = simple ridge	1120	420	9200	0.433	0.04
T_3 = control	1120	400	7500	0.329	0.04
LSD (5%)	793	501	3887	0.202	0.03
F-test Probability		Pr > F			
Rep (farms)	0.089	0.164	0.165	0.088	0.218
Treatments	0.944	0.901	0.547	0.438	0.887
C.V. (%)	43	66	26	30	54

Threshing index = grain weight/panicle weight
Harvest index = grain weight/biomass weight

These results showed that tied-ridges and simple ridges are good cultural practices for the enhancement of sorghum grain and total biomass yields. These cultural practices are to be recommended for areas with low rainfall. It is very necessary to continue this study in other areas with similar rainfall trends as Tillakaïna so that more sorghum producers will receive the benefit from these cultural practices.

Results of 2000 Ghana trials - Samual Buah

Comparative Response of Cowpea and Sorghum to Phosphorus Fertilizer on a Savannah Soil

Permanent plots were established in 1999 for rotating grain sorghum and cowpea through a 2-year growing cycle. Sorghum (cv. *Kapaala*) and cowpea (cv. *IT87D-1951*) were planted on adjacent plots. Main plot treatments were 3 phases or frequencies of P applications: (i) direct (applied to sorghum), (ii) residual (applied to preceding cowpea), and (iii) cumulative (applied to both sorghum and cowpea). Subplots were 0, 30, 60, and 90 kg P/ha. Sorghum plots received a uniform application of 40 kg N/ha each year. Responses to the frequency of P application were measured. Frequency of P application did not interact significantly with P levels hence the main effects are reported.

Sorghum responded similarly to frequencies of P application (Table 3). However, there was a trend towards greater grain yields with direct application of P to sorghum. Sorghum grain yield responded positively to P fertilizer level in a linear manner, but the relationship was not very strong ($r^2 = 0.11$). Furthermore yield components such as 100-kernel weight (seed size) and kernels/m^2 (kernel number) also increased with increasing P level. Compared with unfertilized sorghum, the addition of 60 kg P/ha resulted in the largest grain yield increase of 40% (1042 kg ha^{-1} more). Grain yield was more correlated with kernel number (r=0.96) than seed size (r=0.82). On average, net benefits (per ha) for frequency of P application increased from ¢2,239,939 (cumulative P) to ¢2,464,349 with direct P fertilization (exchange rate: ¢6,700/US$, December 2000). Average net benefits for P rates increased from ¢2,102,233 (90 kg P/ha) to ¢2,724,037 with added P at the rate of 60 kg ha^{-1}.

Frequency of P application did not markedly influence cowpea grain yield and yield components (Table 4). However, there was a trend towards lower grain yields with P application to preceding sorghum. Among the parameters measured or calculated, added P only influenced seed number and grain yields at physiological maturity. Cowpea grain yield responded positively to P fertilizer level in a qua-

Table 3. Sorghum grain yield and yield components as affected by added P, 2000.

Frequency of P application	Dry matter yield at V8-V10	Days to 50% flowering	100-kernel weight	kernels/m^2	Grain yield
	kg ha^{-1}	days	g	no	kg ha^{-1}
Cumulative (C)	952	69	2.54	10558	3162
Direct (D)	962	68	2.62	11033	3412
Residual (R)	713	71	2.47	9133	2627
C vs. R	NS	NS	NS	NS	NS
C vs. D	NS	NS	NS	NS	NS
P rate (kg/ha)					
0	700	70	2.35	9414	2586
30	810	70	2.51	9572	2840
60	944	69	2.69	11570	3627
90	1062	69	2.62	10383	3215
P-linear	**	**	*	*	*
P-quadratic	NS	NS	NS	NS	NS

*,**, and NS = significant at 1 and 5% probability levels and are not significant, respectively.

Table 4. Cowpea grain yield and yield components as affected by P fertilizer, 2000.

Frequency of P application	Pods/m^2	Seed/m^2	100-seed weight	Grain yield
	no	no		kg/ha
Cumulative (C)	163	1080	13.0	1542
Direct (D)	159	1063	13.1	1539
Residual (R)	138	944	13.0	1350
C vs. R	NS	NS	NS	NS
C vs. D	NS	NS	NS	NS
P rate (kg/ha)				
0	137	865	12.9	1232
30	164	1116	13.0	1591
60	154	1075	13.1	1554
90	159	1060	13.1	1530
P-linear	NS	NS	NS	*
P-quadratic	NS	*	NS	*

*,**, and NS = significant at 1 and 5% probability levels and are not significant, respectively.

dratic manner (Y = 1251.94 + 12.46P-0.11P2, r^2=0.21). Moreover seed number and grain yield were greatest at 30 kg P/ha and declined with further increase in the level of added P. In general, seed number exerted a greater influence on grain yield (r=0.99) than seed size (r=0.41). Additionally, grain yield was correlated with pods/m^2 (r=0.68) and average pod weight (r=0.90). Net benefits for frequency of P application increased from ¢1,278,673 (cumulative P) to ¢1,694,972 with residual P applied to the preceding sorghum crops. Net benefits for P rates increased from ¢1,135,107 (90 kg P/ha) to ¢1,716,816 with added P at the rate of 30 kg/ha.

Previous Crop Effects on Grain Sorghum Response to Nitrogen Fertilizer

The study was initiated in 2000 to evaluate the combined effects of previous crop (sorghum, groundnut, cowpea, and soybean) and different N rates on sorghum production in the savanna zone of Ghana. Permanent sorghum, cowpea, groundnut, and soybean plots were established under dryland conditions. Additionally, sorghum was established on an adjacent plot. Thereafter, sorghum and the rotation crops will be alternated on the two sets of plots, establishing a 2-year rotation between sorghum and each legume, along with continuous sorghum. Thus, sorghum will be planted following the previous crops at 4 N levels: 0, 40, 80 and 120 kg N/ha each year. All plots received a uniform application of 30 kg P/ha.

Data are for sorghum and the set-up year (Table 5) only because the previous crops treatment was not imposed during the set-up year. Days to 50% flowering, panicle weight, kernel number, biomass and grain yields were influenced by fertilizer N in 2000. Biomass production increased linearly with increasing N levels. However, there was a quadratic relationship between N levels and grain yield ($Y=2700+31.7N-0.13N^2$, r^2=0.63). Further increase in N level beyond 80 kg did not result in any significant yield increase. On average, the addition of N fertilizer resulted in 39 and 58% increases in biomass and grain production, respectively. Fertilizer N evidently affected grain formation more strongly than biomass production. At physiological maturity, kernel size was not influenced markedly by added N. However, unfertilized sorghum produced numerically, fewer kernels (58% less), when compared with fertilized treatments.

Consequently, the unfertilized plots had the lowest grain yield. Grain yield was more correlated with kernel number (r=0.97) than seed size (r=0.45).

Domestic Research

Results of 2000 domestic trials - Teshoma Regassa

A field experiment was conducted in 2000 to see the effects of moisture and N on the responses of sorghum cultivars San Chi San and CK60. Different moisture conditions for the moisture treatments were created by covering parts of the main plots with white plastic in order to drain away any rainwater falling on the plots during the crop season. The crop gradually exhausted moisture from the soil profile leading in the development of moisture stress as the crop season advanced. In addition to rainfall, the non-stressed plots received additional moisture applied as irrigation during the grain filling period. For those plots where plastic was applied, soil moisture was determined by Sentry 200-Ap moisture probe (Troxler International Inc.).

Table 6 shows the main effects of the three treatment factors on measured crop parameters at two growth stages. A significant effect of moisture was observed for chlorophyll determined by a Minolta SPAD meter and percentage leaf N at both growth stages. Nitrogen use efficiency was greater for moisture stress plots but the stressed plots had lower percentage of N in plant parts as compared to the non-stressed plots. Statistically significant difference was observed between the two cultivars for most of the parameters measured. Chlorophyll was higher for CK-60 at both growth stages. This is in agreement to leaf N content of CK-60 which was significantly higher for this cultivar at both growth stages. Head N was lower for CK-60 at heading while grain N was higher. Dry matter and grain yield was significantly higher for San Chi San, which may be a reflection of its high N use efficiency. This is consistent with the observation obtained the previous year for similar parameters where San Chi San had the highest N use efficiency both in terms of biomass or grain. Higher N concentration was consistently observed for CK-60 in leaf stem and head or grain at both growth stages. This high tissue percent nitrogen was not reflected on grain yield leading to low N use efficiency. The low N use efficiency of this cultivar may be attributed to such high proportion of N in non-economical organs that may hoard the nitrogen that could have been mo-

Table 5. Sorghum grain yield and yield components as affected by fertilizer N, 2000.

N rate	Days to 50% flowering	Biomass yield at maturity	100-kernel weight	Kernels/m^2	Grain yield
kg ha^{-1}	days	kg ha^{-1}	g	no	kg ha^{-1}
0	67	4131	2.7	8868	2749
40	66	5191	2.5	12384	3625
80	65	5808	2.7	14739	4597
120	65	6108	2.7	14942	4686
N-linear	**	**	NS	**	**
N-quadratic	NS	NS	NS	**	*

*,**, and NS = significant at 1 and 5% probability levels and are not significant, respectively.

Table 6. Chlorophyll, dry matter, grain yield, plant part nitrogen content and nitrogen use efficiencies of two sorghum cultivars at two growth stages.

Moisture	Heading						Maturity							
	Chlor.	Total DM (g/plant)	Nitrogen (%)			NUE 1	Chlor.	Total DM (g/ plant)	Grain Yield (g/ plant)	Nitrogen (%)			NUE 1	NUE 2
			Leaf	Stem	Head					Leaf	Stem	Grain		
No stress (NPL)	50	50	2.60	0.82	1.96	66.68	46	74	30.58	1.99	0.50	1.67	78.78	31.51
Stress (PL)	48	52	2.47	0.78	1.88	69.27	40	75	32.08	1.65	0.41	1.46	91.03	38.94
	*	ns	*	ns	ns		*	ns	ns	*	ns	ns		
Cultivar														
CK-60	51	42	2.85	.91	.91	61.29	50	60	23.88	2.03	0.53	1.82	74.06	29.48
San Chi San	48	60	2.22	0.68	1.93	75.81	36	88	38.78	1.60	0.38	1.31	98.09	43.23
	*	**	**	**	ns		**	**	**	**	**	**		
Nitrogen (kg/ha)														
0	42	44	2.05	0.62	1.77	83.26	35	59	25.01	1.52	0.44	1.53	94.39	40.01
40	49	50	2.59	0.77	1.92	66.84	41	71	29.47	1.80	0.44	1.61	85.27	35.39
80	53	55	2.72	0.87	1.96	64.04	46	84	35.61	1.88	0.44	1.48	85.41	36.21
120	53	55	2.78	0.93	2.03	61.78	50	85	35.22	2.07	0.49	1.63	78.01	32.32
	***	**	**	**	**		**	**	**	**	*ns*	*ns*		

**Significant at $P \leq 0.01$
* Significant at $P \leq 0.05$
ns Statistically non significant at $P \leq 0.05$.

bilized to the grain. San Chi San has, however, lower percent N in all plant parts as compared to that of CK-60, but significantly greater dry matter and grain production. Nitrogen use efficiency was higher for San Chi San both at heading and maturity. All measured parameters increased in response to added N. Observed increase in response to added N leveled off for some parameters such as dry matter and grain yield at the highest rates. Nitrogen use efficiency was seen to drop for each increase in applied N indicating a declining return to N in terms of unit of dry matter and/or grain yield obtainable due to additional unit increase of N. Thus, in general, increased N reduced N use efficiency. This was also consistent with the observations made the previous year for these parameters.

Networking Activities

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

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

Collaboration with World Vision International is still in progress in 2000. The UNL-214 PI helped expedite the roles of the collaborating NARS scientists in Niger, Mali and Ghana with WVI personnel in the field in these countries.

Publications

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Germplasm Enhancement and Conservation

Breeding Pearl Millet with Improved Performance and Stability

ARS-204
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Summary

This project was initiated in January 2000. Population hybrids among West African land races and crosses among new cytoplasmic-nuclear male steriles and land races, improved cultivars and breeding lines were made in 1999 and in the greenhouse during the 1999-2000 winter. Cooperators were identified in Niger, Mali, and Nigeria for testing and evaluation of pearl millet population hybrids among land races. One site in each Niger, Burkina Faso, and Mali were identified for a regional study (in cooperation with project UNL-213) to compare a land race and a population hybrid at two fertility levels. Seeds were sent to all cooperator.

Population hybrids among West African land races out yielded the mean yields of their parents. However, the hybrids did not out-yield the local genotypes, indicating a need to produce hybrids among locally adapted types. The potential for producing male sterile parents and pollinator from various West African genotypes was determined on two commercial cytoplasms and seven experimental cytoplasms. Although most of the West African germplasm tested had genotypes that tended to maintain sterility, there were various frequencies of fertility restorers in the germplasm.

Objectives, Production and Utilization Constraints

Objectives

West Africa

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

United States

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

Constraints

Constraints in West Africa include moisture, availability of fertilizers, resources to purchase fertilizer and other inputs, pest damage (insects, diseases, weeds and birds), low yields, unstable markets, etc. Plant breeding can help to provide genetic resistance to pest, improve yields, and improve stability of yields. These genetic improvements due to plant breeding can have long-term recurring benefits.

Research Approach and Project Output

Land races, improved cultivars and breeding lines were used to pollinate pearl millet inbreds with two standard cytoplasms(A_1 and A_4) and seven new experimental cytoplasms in cytoplasmic-nuclear male sterility (CMS) systems(Table 1). Data in Table 1 indicated that fertility responses in each cytoplasm/cross was fairly consistent across location. Cytoplasms C74, A_1 and A_4 appeared to be easier to restore to male fertility than the other cytoplasms in the crosses studied. Most of the crosses segregated for both CMS and male fertility restoration indicating that selection is possible within the land races and breeding material studied, to develop both A(CMS)- and R(restorer)- lines to produce hybrids using West African germplasm.

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Table 1. Percent cytoplasmic-genic male sterile plants in Georgia, Niger, and India from crosses among nine cytoplasms crossed with 11 genotypes from West Africa.

	Cytoplasm								
Land race	C67	C68	C74	C81	C84	C88	C92	A_1	A_4
AnKouTess Amelior									
Georgia	90	97	70	99	100	95	97	87	84
Niger	100	100	69	100	100	100	98	65	69
India	95	96	68	98	96	92	94	68	59
Means	95	98	69	99	99	96	96	73	71
SoSat-C88									
Georgia	100	96	100	98	98	100	92	86	100
Niger	100	100	98	100	100	95	100	75	90
India									
Means	100	98	99	99	99	98	96	81	95
HKP-GMS									
Georgia	85	93	76	97	98	91	93	73	83
Niger	100	92	67	100	100	98	100	73	84
India	91	91	70	91	80	75	76	15	80
Means	92	92	71	96	93	88	90	54	82
ICMVIS 89305									
Georgia	92	98	81	94	95	94	93	75	84
Niger	100	98	62	100	100	100	94	76	71
India	89	84	57	95	88	86	83	13	59
Means	94	93	67	96	94	93	90	55	71
Gwagwa									
Georgia	98	90	60	95	93	90	95	83	77
Niger	96	98	68	98	98	100	91	70	74
India	94	91	46	96	94	87	90	44	59
Means	96	93	58	96	95	92	92	66	70
GR-P1									
Georgia	97	93	78	98	97	98	95	82	85
Niger	100	94	84	100	98	94	100	74	76
India	84	77	64	94	89	83	93	32	56
Means	94	88	75	97	95	92	96	63	72
Mansori									
Georgia	90	81	72	92	87	80	83	47	79
Niger	88	78	73	88	90	79	85	56	71
India									
Means	89	80	73	90	89	80	84	52	75
Niger 223-34									
Georgia			100	100	80	60	67	0	
Niger	14	14	100	100	100	74	80	3	0
India									
Means	14	14	100	100	90	67	74	2	0
Niger 415-26									
Georgia			100	100	100	100	100		17
Niger	100	98	100	100	100	100	100	100	100
India									
Means	100	98	100	100	100	100	100	100	59
Niger 391-402									
Georgia			100	100	100	100	92	100	100
Niger	100	100	100	100	100	100	100	96	100
India									
Means	100	100	100	100	100	100	96	98	100
Niger 247-58									
Georgia				100	100	100	100		90
Niger	100	100	100	100	100	100	100	100	100
India									
Means	100	100	100	100	100	100	100	100	95

Land races from West Africa were assembled and grown under quarantine. Land races were intercrossed by collecting pollen from about 300 plants of one land race, bulking the pollen and using the bulked pollen to pollinate 300 plants of another land race. These crosses are cycle 1 and are referred to as population hybrids (Table 2). The same procedure was used to produce cycle 2, except that the pollen collection and crossing were conducted on 300 random plants within each cycle1 population hybrid. These population hybrids were evaluated for grain yield in Niger, Nigeria and Mali in replicated trials. These hybrids were evaluated in forage production trials in Georgia. These crosses were tested for fertility maintenance and restoration in Georgia, Niger and India. In cooperation with Project UNL-213, one of the population hybrids (WA-13 or ExBornu × Mansori) was grown in a replicated test with the best local land race using a low and a recommended fertility level in Niger, Burkina Faso, and Mali.

Grain yields ranged from 15 to 215% greater for the population hybrids than for the midparent (mean yield of two parents) yields in Mali (Table 2). However, only WA-11, 13 and 19 were significantly (P=0.05) different than the midparent grain yield. No population hybrids out-yielded the best local genotypes in either Mali, Nigeria or Niger. The land races used to produce the population hybrids were not used as controls in Nigeria and Niger tests. Cycle 2 (WA9 and WA10) of two of the hybrids tended to yield less than cycle 1 (WA13 and WA14), whereas for one hybrid, cycle 2 (WA8) tended to yield more than cycle 1 (WA12) in Mali and Niger but about the same in Nigeria. The reduction in yield of cycle 2 compared to cycle 1 was expected. However, the yield reduction in these population hybrids should be less than observed for single cross hybrids between two inbreds. The amount of yield reduction will depend on the heterozygosity and heterogeneity of the land races crossed. Theoretically, the more variable the land races used in a cross, the less should be the yield reduction from cycle 1 to cycle 2. Significant differences were observed for rust resistance in the population hybrids, but almost no significant differences were observed for downy mildew resistance. These first year data indicate that the population hybrid concept could make a significant contribution to improving grain yields of pearl millet in West Africa since the hybrids yielded as the parents(when included in the tests in Nigeria and Mali). However, it appears that the crosses need to be made among locally adapted genotypes.

Significant differences were observed for dry matter yields among the population hybrids and for dry matter yields of certain population hybrids over their mid-parent yields (Table 2). Cycle 1 hybrids yielded more dry matter than cycle 2 hybrids (WA12 vs WA8, WA13 vs WA9 and WA14 vs WA10), but the differences were smaller than expected. Reciprocal crosses of six population hybrids were included in the forage yield trial in Georgia. Results in Table 3 indicated no significant reciprocal cross difference for all except the P3Kolo × Iniari cross. This needs further study. Improved fodder production and quality could have a major impact on improving the quality of life for farmers in West Africa.

The grain yields of WA-13 in comparison to the local genotypes in the cooperative project study with UNL-213 was disappointing, especially since this hybrid in early studies in Niger yielded 81% more grain than local land races

Table 2. Characteristics of West African land races and land race hybrids.

Genotype	Cycle No.	Grain yield: Nigeria kg ha^{-1}	Grain yield: Niger g/plot	Grain yield: Mali kg ha^{-1}	Downy mildew (Nigeria) %	Rust resistance (Georgia) %	Dry matter (Georgia) kg ha^{-1}
WA8 Exbornu × Ugandi	2	984	1550	1335	33	1.9	11123
WA9 Exbornu × Mansori	2	856	725	832	33	13.3	11569
WA10 Exbornu × Iniari	2	1177	1050	732	21	12.7	12442
WA11Exbornu × P3Kolo	1	844	1550	1868	27	0.0	12527
WA12 Exbornu × Ugandi	1	1268	1125	932	25	21.1	11785
WA13 Exbornu × Mansori	1	1120	1300	1665	19	21.3	12677
WA14 Exbornu ×Iniari	1	1343	1275	1067	24	7.7	12761
WA15 P3Kolo × Ugandi	1	975	1150	1132	42	30.4	11883
WA16 P3Kolo × Mansori	1	1084	1500	1400	42	5.6	13053
WA17 P3Kolo × Iniari	1	1189	1675	935	37	3.0	12946
WA18 Ugandi × Mansori	1	1234	1175	1400	25	11.2	12195
WA19 Ugandi × Iniari	1	1047	1425	1967	51	20.8	10656
WA20 Ugandi × Mansori	1	1343	1400	665	36	9.5	12999
Exbornu		692		602	55		7653
Ugandi				467	15		9936
Mansori				532	9		9525
Iniari				667	16		9563
P2Kolo				932	33		10159
Toroniou				1800	22		
Boboni				2867	32		
Sosat-C88		1314					
Local Check		1625	1650				
LSD (0.05)		440	550	1037	43	21.7	1600

Table 3. Dry matter yields in reciprocal crosses among West Africa land races in 2000 at Tifton, GA.

	Dry matter yield kg ha^{-1}
Exbornu × P3Kolo	12527
P3Kolo × Exbornu	12668
P3Kolo × Ugandi	11883
Ugandi × P3Kolo	11241
P3Kolo × Mansori	13053
Mansori × P3Kolo	13926
Ugandi × Iniari	10656
Iniari × Ugandi	11189
Iniari × Mansori	12419
Mansori × Iniari	12999
Iniari × P3Kolo	11187
P3Kolo × Iniari	12946
LSD (0.05)	1600

Table 4. Pearl millet population hybrid grain yield compared to best local variety in 2000.

Genotype	Mali	Burkina Faso	Niger
		kg ha^{-1}	
Local variety	815	730	995
Population hybrid	527	424	521

Management level	Mali & Burkina Faso	Fertilizer	Niger†
	kg ha^{-1}		kg ha^{-1}
High	772	With	673
Low	476	Without	853

† Dry growing conditions during the early part of the growing season

(Table 4). It appears that cultivars in West Africa do not have broad adaptation and consequently WA-13 did not do well in these studies. It will probably be necessary to produce population hybrids among local genotypes to take advantage of the hybrid vigor and have hybrids that are locally adapted. This part of the project is discussed further in the UNL-213 report.

Networking Activities

Sent 25 population hybrids to each Mali, Niger, and Nigeria 10 population hybrids to Senegal.

Moussa Sonogo, pearl millet breeder in Mali, spent six weeks in the Tifton, GA program.

Michael Mogorosi from Botswana spent two weeks in the Tifton, GA program.

Other cooperating scientists

Dr. Bruce Hamaker, Purdue University, Department of Agriultural Economics, 1145 Krannert Building, Room 609, West Lafayetter IN 47907-1145

Dr. Ouendeba Botorou, ROCAFREMI Coordinator, ICRISAT Sahelian Center, B.P. 12404, Niamey, Niger

Breeding Sorghum for Increased Nutritional Value

Project PRF-203
John D. Axtell
Purdue University

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Bruce Hamaker, Cereal Chemistry, Food Science, Purdue University, West Lafayette, IN
Adam Aboubacar, Cereal Chemist, Postdoctoral, Food Science, Purdue University, West Lafayette, IN
Ouendeba Botorou, Millet Coordinator, ROCAFREMI, Niamey, Niger
Jeff Bennetzen, Biological Sciences, Purdue University, West Lafayette, IN
Wayne Hanna, Millet Breeder, USDA, Tifton, Georgia

Summary

Since the inception of INTSORMIL, PRF-203 had made significant contributions in advancing sorghum research globally, in training of numerous graduate students from around the world, and in strengthening agricultural research institutions in many developing countries. Purdue has been recognized as the Center of Excellence in sorghum nutritional quality research primarily because of the research conducted in and the global leadership provided by the PI of PRF 203. Several significant observations in the area of nutritional quality research were made by the PI over the years. The discovery of high lysine sorghum, the anti-nutritional properties of sorghum tannins, the development of low lignin brown midrib sorghums through mutagenesis, the development of *in vitro* techniques for evaluating digestibility of sorghum, the development of highly digestible sorghum cultivars were some of the contributions made by PRF 203. The PI had also advanced sorghum genetics research with his involvement in the development of the first sorghum linkage map, the first breakthrough in sorghum transformation, and in the early research on discovery and cloning of the transposable element system in sorghum. However, this report only summarizes the PIs effort in the last few years.

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).

Utilization of sorghum grain has been limited by poor protein digestibility in humans and other monogastric animals. Sorghum germplasm with protein digestibility as high or higher than maize or other staple cereals has been identified through Purdue/INTSORMIL research. Studies on the genetics of this trait indicate that it is a simply inherited trait which can be transferred to other genotypes for utilization in sorghum producing regions throughout the world. One limitation which has now been substantially overcome is the food grain quality of these highly digestible cultivars. New research demonstrates that vitreous kernels with good food grain and processing properties have been identified and are now available for breeding programs.

Research Approach and Project Output

Sensitivity and Reliability of a High-Throughput Assay for Measuring Protein Digestibility in Sorghum.

Millions of people in the developing world depend on cereals as their primary source of dietary protein. In parts of Africa and Asia where the climate is dry and soils relatively infertile, grain sorghum is the staple food for millions. However, sorghum proteins are relatively poorly digestible compared to other cereals. Human studies conducted in Peru reported in vivo cooked protein digestibilities of approximately 46% in tannin-free sorghum, 81% in wheat and 73% in corn. Since sorghum is the main source of dietary protein for the frequently undernourished poor majority in these developing countries, breeding efforts for new cultivars with improved protein digestibility are urgently needed.

In order to develop new lines rapidly and cost effectively, both phenotypic and marker assisted selection (MAS) are important. In both cases, accurate assessment of the phenotype is crucial. Phenotypic selection for any trait of interest is effective when phenotypic data can be accurately and quickly scored. Mistakes made in the assessment of a phenotype can cause the response to selection to decline and fail to result in the desired outcome. In MAS, the ability to detect a QTL associated with any trait of interest highly depends on the ability to correctly assess the phenotype of individuals. Phenotypic assays that are time consuming limit the ability to assess large populations.

The in vitro pepsin protein digestibility and the pH-stat methods are the currently used standard assays for measuring protein digestibility in sorghum grain. These two assays are time consuming and expensive. The normal digestion time for 20 samples is 2 to 3 days using either of these two assays making them impractical as a routine screening assay in a large-scale breeding program. The recent development of a turbidity assay for rapid protein digestibility assessment increases the ability of the scientist to score large populations. The turbidity assay indirectly measures protein digestibility of a sample by measuring the remaining kafirin protein (storage protein) after pepsin digestion. Compared to the standard digestibility assays, the turbidity assay is quicker and less expensive. Specifically, the one technician, 400 to 500 samples can be analyzed per week using the turbidity assay compared to 50 to 75 samples per week using either pH-stat or pepsin protein digestibility. Use of robotics would increase the capacity of the turbidity assay by an order of magnitude, making it a viable high-throughput technique.

Although the assay is faster and cheaper than other methods, its sensitivity and reliability are unknown. Estimation of the sensitivity and reliability is important in determining overall utility of this new assay. If a sample is declared to be highly digestible in one replicate then it is important that the results can be consistently duplicated.

Six experiments were established to determine the sensitivity and reliability of the turbidity assay. The first experiment was to determine the sensitivity of a newly purchased micro-titer plate reader (VERS Amax ™) in reading data from different wells both within and between plates. A good plate reader must be highly consistent in reading data regardless of the location of the sample on the plate. Consistency in readings that is not dependent on the spatial organization of the samples indicates reliability of the device. The second experiment was to determine if treatment location and samples in adjacent wells on the plate affect absorbance (OD) values. This objective addresses the possibility that samples with extremely high OD values may influence OD values of neighboring wells. If the OD values of a sample are unaffected by the values of neighboring samples then the VERS Amax is a reliable reader of OD values for the turbidity assay. The third experiment was to determine if the amount of time between addition of TCA and plate reading significantly affects OD values of different treatments. Knowing the effect of time after TCA addition is important because the average time spent manually loading a plate is about 5 minutes. If wells receiving TCA in the first minute are comparable to the ones receiving TCA in the fifth minute, then the assay is not sensitive to time indicating that the assay is reliable even when time differences exist. The fourth experiment was to determine whether the three pipetting steps called for by the assay are necessary or whether the assay could be modified to reduce the number of pipetting stages. Reduction in pipetting stages is important in saving time for the technician as well as reducing complexity and eliminating possible source of variation. If the assay is used with a robotic agent the reduction in pipetting steps leads to a saving in time and in programming. Our fifth experiment was to estimate how much volume difference during plate loading affects OD values. Variation in final volume and concentration of sample loaded into each well is common in normal pipetting practices. Therefore the determination of exactly how much volume difference affects the OD values of a given treatment is important to understanding the assay's reliability with respect to variation in volume and concentration. The sixth experiment was to determine the reliability of the turbidity assay for measuring protein digestibility of sorghum. This will determine whether digestibility values are reproducible.

Our results showed that 1) repeated readings within each plate had correlations of about 99% compared to correlations of about 9-12% for readings between plates, 2) a treatment location on the plate did not affect its mean and variance absorbance values, 3) mean and variance absorbance values for a 3-step assay were larger than for a 2-step assay, 4) VERS Amax plate reader was highly sensitive to digested sample concentration, but not sensitive to overall volume differences, and 5) the assay had an intraclass correlation reliability coefficient of over 0.98. In conclusion, the turbidity assay is quick and highly reliable in measuring protein digestibility in sorghum and could be an important tool for plant breeders.

Genetic Analysis of Protein Digestibility and Lysine Concentration in Sorghum Mutant Line P-851171

Both high protein digestibility and high lysine concentration are important attributes of nutritional quality in sorghum [*Sorghum bicolor* (L.) Moench]. Protein digestibility is lower in sorghum grain than in any other major cereal grain. Several studies have shown that sorghum protein digestibility is even lower when products are cooked. Other data collected and analyzed from recovering malnourished Peruvian children fed with porridges prepared from sorghum flour concluded that sorghum was 46% digestible as compared to 81% for wheat (*Triticum aestivum* L. em Thell), 73% for maize (*Zea mays* L.), and 66% for rice (*Oryza sativa* L.).

To increase protein digestibility in grain sorghum, processing methods such as fermentation, heat-extruded decortication and alkali addition have been utilized. Additional development of high digestibility sorghum lines would be beneficial.

The recent identification of a sorghum line, P-851171, with protein digestibility levels surpassing that of maize may provide a source of high protein digestibility. Oria et al. showed that the endosperm of P-851171 has a novel mutation that appears to alter the structure of protein bodies from the normal spherical and smooth shape found in wild-type sorghum genotypes to a folded shape with deep invaginations. The further concluded that the mutation shifts the less digestible γ-kafirins from the surface of the protein bodies to the bottom of the folds. This exposes the more digestible α-kafirins to digestion by proteases making P-851171 more digestible than normal sorghums. Currently, this protein body mutation (*hpd*, for high protein digestibility) is the only reported trait in sorghum that increases the level of protein digestibility to that of other major cereals. P-851171 is derived from P-721Q, a sorghum line developed through chemical mutagenesis, and possesses a unique kernel mutation referred to as "*opaque*". This *opaque* mutation is characterized by seed with high lysine concentration and soft kernel texture. Because of this undesirable soft kernel texture and poor yielding ability of P-721Q, crosses between P-721Q and other elite lines were made and resulted in improved yields and high lysine concentration of lines such as P-851171.

The inheritance of *hpd* mutation has not been studied. The protein digestibility of P-721Q has been shown to be about the same as in P-851171. Oria et al. also showed that P-721Q has the *hpd* mutation. Mohan showed that the *opaque* mutation in P-721Q is inherited as a single gene with partial dominance. Whether this pattern is consistent in P-851171 is an important question. Lewamy showed that high-lysine landraces such as IS-117758 and IS-11167, and other P-721Q-derivative lines vary considerably for protein digestibility and lysine concentration. To date, no studies have examined the association between protein digestibility and lysine concentration in crosses involving P-851171. Additionally, molecular marker studies have not been conducted to map either protein digestibility or lysine concentration in this germplasm and whether *hpd* mutation is distinct from the opaque mutation has not been addressed.

The objectives of this study were to 1) investigate how protein digestibility and lysine concentration are inherited in P-851171; 2) map *hpd* and *opaque* using SSR markers, and 3) determine the genetic relationship between *hpd* and *opaque*.

Random 501 $F_{2:3}$ and 479 $F_{2:4}$ families generated from a cross between P-851171 (mutant, *opaque-*, *hpd-*) and P-721N (wild type, *opaque+*, *hpd+*) were evaluated for protein digestibility using the turbidity assay. Of these a subset of 150 $F_{2:3}$ families were evaluated for lysine concentration using the AOAC standard ion-exchange chromatography procedure. Analysis of these data suggested that high protein digestibility and high lysine concentration are each controlled by a single partially dominant gene in this cross. The subset of 150 $F_{2:3}$ families were also used to map loci controlling the two traits using 23 polymorphic SSR markers. The marker *Txp*113 on linkage group A was found to be associated with the *hpd* locus, and the *opaque* locus. Putative recombinants between *hpd* and *opaque* were identified.

Progress on Diffusion of Sorghum Hybrids in Niger

Since 1995 INTSORMIL has supported INRAN with an initiative to develop a private seed activity using NAD-1 as a vehicle. Lack of a seed production activity has been a constraint to the diffusion of improved varieties in Niger. Following the release of NAD-1 as the first commercial sorghum hybrid in the country, we have had an array of joint efforts with INTSOMRIL to promote the production, distribution, and utilization of improved sorghum varieties and hybrids. In the following paragraphs, we will highlight efforts undertaken in promoting the concept of seed with the private sector, small farmers, as well as in advancing sorghum breeding research with further advances in delivering genetic technology:

Private sector

The government of Niger after pulling out of seed business is now looking for partners in the country to help with this critical issue. A seed trade association (APPSN) was created recently with INRAN and INTSORMIL input. APPSN was rapidly identified for the supply of emergency seeds when the need arose these past two years. APPSN members now contact INRAN regularly for all their needs in foundation seed of sorghum, millet, cowpea, and groundnut. They will need continued support both technically and financially before they will be able to take on seed production for increasing farmer demand.

Small farmers

A project on training small farmers has been a successful effort for farmer coops that eventually will become seed companies or contract growers for larger producers. We work with farmers and other supporting agencies at locations including Gidan Iddar (INRAN/INTSORMIL/IFAD), Tiaguirire INRAN/ INTSORMIL/WINROCK) and Tillabery (INRAN/ INTSORMIL/PSNII). At these three locations farmers are producing NAD-1 seed using parental seeds coming from INRAN stations of Lossa and Tillabery. Farmer ability to comprehend and apply hybrid seed production techniques is being demonstrated times and again at all three locations. Farmers receive hands-on training during crop season but also formal training using a manual initiated by INTSORMIL. A revised edition of the manual was recently translated into Hausa and Zarma languages of Niger with both roman and Arabic script. Local languages are used in training sessions for 10 technicians and 50 farmers from Gidan Iddar and Maizabi. The translated versions should help strengthen the training component by increasing access to seed techniques for a larger number of people. Overall collaboration at the farm level has shown that a low cost, local, high quality seed mechanism is feasible in Niger, but it also underlines the need for startup funds in the form of credit or support.

Research

This activity has focused on production of parental as well as hybrid seed through INRAN seed unit (SU), demonstrations and field days, as well as in further development of new hybrids. The SU is under the leadership of Issoufou Kapran and Boukary Hama (Ph.D. seed technology, Mississippi). It has oversight responsibility to supervise production of all foundation seeds at INRAN, as well as training and field 'inspection' based on requests from private seed producers. Funding for SU initially came from INRAN and INTSORMIL but SU is expected to gradually move towards semi-autonomous status.

Two field days were organized that showcased the value of hybrid cultivars: at the ICRISAT Sahelian Center, and at Lossa/Tillabery where visitors were able to appreciate hybrid productivity in large-scale demonstration plots, and production of female parents and hybrid seed in isolated fields. Field days were attended by farmers, APPSN, NGOs, extension staff, congressmen and advisers of the minister of agriculture, as well as numerous INRAN and ICRISAT staff.

Finally the effort to develop new and better hybrids other than NAD-1 continues, through testing of hybrids received from INTSORMIL collaborators or hybrids synthesized locally using seed parents from Purdue, Nebraska, and Texas A&M. The most promising hybrid is identified as F1-223 and has both high yield and good grain quality as determined by INRAN food technology specialists.

Molecular Characterization of a Mutable Pigmentation Phenotype and Isolation of the First Active Transposable Element from Sorghum bicolor

Transposable elements as causative agents of variegation and genetic ariation were first discovered in maize by Barbara McClintock in the 1940s and since have been found in many organisms. Transposon-induced variegation traits are powerful genetic tools to study gene expression and regulation. Although variegation mutants have been described in at least 35 plant species, active transposable elements have been isolated from only a minority of these plants. Three well characterized maize transposons - *Ac/Ds*, *En/Spm*, and *Mu* (4-6) - have been used in gene-tagging approaches to isolate a large number of plant genes. More recent studies have revealed high levels of microsynteny among grass genomes, suggesting that plants containing small genomes could be used as efficient model systems for gene tagging and isolation. Among the cereal grains, sorghum has one of the smallest genomes, and it is closely related to maize. Thus, the identification of an active transposable element for gene tagging in sorghum could provide a new route to the isolation of the corresponding maize genes. In addition to serving as a model for other cereals, sorghum is a major source of nutrition in developing countries and ranks fourth in economic importance among grain crops, after maize, wheat, and rice.

Accumulation of red phlobaphene pigments in sorghum grain pericarp is under the control of the *Y* gene. A mutable allele of *Y*, designated as *y-cs* (*y-candystripe*), produces a variegated pericarp phenotype. Using probes from the maize *p1* gene that cross-hybridize with the sorghum *Y* gene, we isolated the *y-cs* allele containing a large insertion element. Our results show that the *Y* gene is a member of the *MYB*-transcription factor family. The insertion element, named *Candystripe1* (*Cs1*), is present in the second intron of the *Y* gene and shares features of the CACTA superfamily of transposons. *Cs1* is 23,018 bp in size and is bordered by 20-bp terminal inverted repeat sequences. It generated a 3-bp target site duplication upon insertion with the *Y* gene and excised from *y-cs*, leaving a 2-bp footprint in two cases analyzed. Reinsertion of the excised copy of *Cs1* was identified by Southern hybridization in the genome of each of seven red pericarp revertant lines tested. *Cs1* is the first active transposable element isolated from sorghum. Our analysis suggests that *Cs1*-homologous sequences are present in low copy number in sorghum and other grasses, including sudangrass, maize, rice, teosinte, and sugarcane. The low copy number and high transposition frequency of *Cs1* imply that this transposon could prove to be an efficient gene isolation tool in sorghum.

Education

Education of LDC and U.S. scientists in plant breeding and genetics with special emphasis on exposure of graduate students to the U.S. seed industry 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 is presented by category of employment.

Academic Appointments (6 students)

Dr. Mitch Tuinstra, Sorghum Breeder, Kansas State University
Dr. Gebisa Ejeta, Sorghum Breeding/Genetics, Purdue University
Dr. Bruce Hamaker,Cereal Chemist, Purdue University
Dr. Nora Mason, Popcorn Breeder, University of Nebraska
Mr. Tom Tyler, Urban Gardening, Washington, D.C.
Dr. Robert Bacon, Wheat Breeder, Arkansas State University

National Program Scientists (17 students)

Dr. Osman Ibrahim, Sorghum Breeder, Sudan National Research Program (ARC)
Dr. Joe Mushonga, Sorghum Breeder, Zimbabwe National Crops Research Program
Dr. Carlos Carvalho, Sorghum Molecular Biology, EMBRAPA Corn and Sorghum Research Center, Brazil
Dr. Ouendeba Botorou, Millet Breeder, Niger National Program (INRAN)
Dr. Issoufou Kapran, Sorghum Breeder, Niger National Program (INRAN)
Dr. Yahia Ibrahim, Sorghum Breeder, Sudan National Research Program (ARC)
Dr. John Clark, Sorghum Breeder, Niger National. Program (INRAN, Retired)
Dr. Moussa Adamou, Sorghum Breeder, Niger National Program (INRAN, Retired)
Dr. Lexington Nduulu, Sorghum Breeder, Kenya National Program (KARI)
Mr. Tadesse Mulatu, Sorghum Breeder, Ethiopian National Program (deceased)
Dr. Rameshwar Singh, Sorghum Breeder, Pantnagar University, India
Dr. Robert Schaffert, Sorghum Breeder, EMBRAPA, Brazil
Dr. Chris Nwasike, Millet Breeder, Nigeria (Deceased)
Dr. Lichuan Tu, Sorghum/Sesame Breeder, People's Republic of China
Dr. Adam Aboubacar, Sorghum Biochemist, Niger National Cereal Program (INRAN)
Dr. Laila Monawar, Sorghum Food Chemist, Sudan National Program (ARC)
Mr. Zenon Kabiro, Sorghum Breeder, Burundi National Program

Seed Industry Scientists (13 students)

Dr. Ed Grote, Corn Breeder, Pioneer Hybrid International
Dr. Kay Porter, Sorghum Director, Pioneer Hybrid International
Dr. Yilma Kebede, Sorghum Breeder, Pioneer Hybrid International
Dr. Joe Keaschall, Corn Breeder, Pioneer Hybrid International
Dr. Paul Christensen, International Division, DeKalb
Dr. Tom Prest, Corn Breeder, Northrup King Seed Co. (Navartis)
Dr. D.P. Mohan, Sorghum Breeder, Pioneer Hybrid, Sudan (Retired)
Dr. Gloria Cagampang, Sorghum Biochemist, Kellogg Cereal Company
Dr. Billy Woodruff, Corn Breeder, DeKalb
Ms. Rebecca Hartigan, Corn Breeder, Becks Seed company (Private Business)
Dr. Paul Peter, Owner/Manager, Garden Classics, Landscape Tree Nursery (Private Business)
Dr. Kevin Cavanaugh, Corn Breeder, Becks Seed Company
Mr. Xiaokun Yang, Corn biotechnician, Asgrow Seed Company

International Center Scientists (9students)

Dr. Emmanuel Monyo, Millet Breeder, SADC/ICRISAT Sorghum and Millet Improvement Program
Dr. Sam Mukuru, Sorghum Breeder, ICRISAT (Retired)
Dr. Dallas Oswalt, Chief Training Officer, ICRISAT (Retired)
Dr. Dale Hess, Sorghum/*Striga* Breeder, ICRISAT Mali Program
Dr. Vartan Guiragossian, Sorghum Breeder, ICRISAT (Deceased)
Dr. R. Jambunathan, Sorghum Biochemist, ICRISAT (Retired)

Dr. Bantayehue Gelaw, Corn Breeder, CIMMYT, Maize Program, Zimbabwe
Dr. Ronald Cantrell, Director General, IRRI (International Rice Research Institute)
Dr. Laurie Kitch, Cowpea Breeder, FAO UN Food-Agriculture Organization

Networking Activities

Workshops

A Hybrid Seed Workshop for West 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 West Africa and to assist the development of a private sector seed industry which brings many benefits to farmers in West Africa.

The Workshop consisted of approximately 150 participants from 14 countries including: United States, Niger, Ghana, Mali, Cote d'Ivoire, India, Burkina Faso, Kenya, Chad, Egypt, Senegal, France, Nigeria, Zimbabwe, and Zambia. The following organizations participated:

Winrock International (Senegal/Mali)
PROCELOS- CILSS (Burkina Faso)
World Bank
ONAHA (Niamey)
USAID/Washington
ITRA (Chad)
INTSORMIL
ARC/FCRI (Egypt)
INRAN
CIRAD-CA (France)
IER/Mali
ISRA (Senegal)
WCASNR/ROCARS (Mali)
DDEIA/CUN (Niamey)
IDESSA (Cote d'Ivoire)
Premier Seed Nigeria Ltd. (Nigeria)
Mahyco Seed Ltd. (India)
ICRISAT Sahelian Center/Niger
C.TRA.P.A. (Burkina Faso)
ICRISAT/WCA (Nigeria)
ROCAFREMI (Niger)
Ministry of Food and Agricriculture (Ghana)
Mahindra Hybrid Seed Co. (India)
PASP (Niamey)
IN.E.R.A. (Burkina Faso)
Ministry of Agriculture (Namibia)
Care International (Niamey)
SADC/ICRISAT/SMIP (Bulawayo)
World Vision International (Ghana, Mali)
AGRIMEX (Niamey)
Rockefeller Foundation (Kenya)
USAID/REDSO/ESA (Nairobi)

A second workshop activity during 1999 was a training program conducted at the ICRISAT Sahelian Center in the Spring of 1999 by Lee House and Issoufou Kapran. Training was on elements of hybrid seed production for INRAN and World Bank technicians in Niger. This activity was very useful and productive during the growing season and will definitely be repeated in the Spring of 2000. A practical training manual on hybrid seed production in Niger was prepared in English and French.

Research Investigator Exchanges

A number of sorghum scientists from the U.S. and throughout the world were involved in exchanges during 1996-2000. Dr. Robert Schaffert from the EMBRAPA program in Brazil spent a one-year sabbatical leave as a visiting professor at Purdue University. Support was provided by EMBRAPA, INTSORMIL, IPIA and the Department of Agronomy. Main activities included a conference on the development of sorghum hybrids, which are tolerant to the acid high aluminum savannas in Brazil, which was held during the Spring of 1998. A major topic of discussion was how to transfer the very successful experience in Brazil to many problem soil areas in Africa, including Niger.

Many other scientists participated in the INTSORMIL Plant Breeding Workshop and visited Purdue while in the U.S. One exchange occurred with the new Director General of ICRISAT, Dr. Shawki Barghouti, to discuss West African sorghum research. Dr. M.V. Rao who was, according to Dr. Norman Borlaug, the most influential wheat breeder during the Green Revolution Days in India, spent a week with our faculty and graduate students on the sorghum project in 1997.

Germplasm and Research Information Exchange

Numerous requests for germplasm and information were received and distributed to collaborators in Africa, South Asia, and Latin America. Former students are constantly in contact to receive germplasm which they learned about while they were graduate students in the Purdue/INTSORMIL sorghum project. Cultivars with improved protein quality have been widely distributed throughout the world as lines and populations. The brown midrib mutant genes for improved forage quality have been distributed throughout the world over the past 4 years to researchers interested in improved forage quality. Collaborating scientists have requested basic supplies from the project including pollinating bags, staplers, marking pencils, etc. Many of these researchers work in areas where even the basic supplies are not available and so we provide them until they can identify a domestic source in their own country. A training manual on hybrid seed production in English and French has been widely distributed in West Africa. This manual is used to conduct short term training courses for technicians and scientists, many of whom are with PVOs and NGOs.

Publications and Presentations

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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. Ouendeba Botorou, Millet Breeder, INRAN, Niamey, Niger
Dr. Aberra Debelo, Sorghum Breeder, EARO, Ethiopia
Dr. Ketema Belete, Pearl Millet Breeder, EARO, Ethiopia
Dr. Aberra Deressa, Agronomist, EARO, Ethiopia
Mr. Zenbaba Gutema, Sorghum Breeder, EARO, Ethiopia
Mr. C.K. Kamau, Sorghum Breeder, KARI, Kenya
Dr. Peter Esele, Plant Pathologist, NARO, Uganda
Mr. Tesfamichael Abraha, Agronomist, DARE, Eritrea
Dr. Peter Goldsbrough, Department of Horticulture, Purdue University
Dr. Mitchell Tuinstra, Department of Agronomy, Kansas State University
Dr. Darrell Rosenow, Texas A&M Univ. Agricultural Res. Center, Route 3, Lubbock, TX
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 normal growth and 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 22, we report on two studies conducted under PRF-207. The first study involves assessment of genetic variation and relationships among seedling vigor traits in sorghum. One hundred recombinant inbred lines derived from two contrasting parents were evaluated over two years in field, incubator, and greenhouse experiments for seedling vigor and stand establishment. Significant genetic differences were observed for vigor and establishment under all three conditions. Estimates of heritability and the significant additive genetic variances obtained indicated that selection for vigor and stand establishment would be effective as long as superior sources of the trait are available.

The second study focused on the evaluation of the role of various phenolic compounds in sorghum kernels on early season seedling vigor. We found that high concentration of phenolic compounds were associated with increased seedling vigor, high germination rates, and higher growth rates. Kernel weight was negatively associated with concentrations of pigments and flavonoids. Genetic analysis of phenolic compounds in our germplasm population showed that effective selection for seedling vigor can be done by selecting sorghum kernels with high concentration of certain phenols.

Objectives, Production and Utilization Constraints

Objectives

Research

- To study the inheritance of traits associated with resistance to biotic and abiotic stesses in sorghum and/or millets.
- To elucidate mechanisms of resistance to these stresses in sorghum and/or millets.
- To evaluate and adapt new biotechnological techniques and approaches in addressing sorghum and millet constraints for which conventional approaches have not been successful.

Germplasm Development, Conservation, and Diversity

- To develop sorghum varieties and hybrids with improved yield potential and broader environmental adaptation.
- To develop and enhance sorghum germplasm with increased levels of resistance to drought, cold, diseases, and improved grain quality characteristics.
- To assemble unique sorghum germplasm, and to encourage and facilitate free exchange of germplasm between U.S. and LDC scientists and institutions.
- To assess applicability of various statistical and DNA fingerprinting technologies for evaluating genomic similarity or for discerning genetic diversity of sorghum and millet germplasm pools.

Training, Networking, and Institutional Development

- To provide graduate and non-graduate education of U.S. and LDC scientists in the area of plant breeding and genetics.
- To develop liaison and facilitate effective collaboration between LDC and U.S. sorghum and millet scientists.
- To encourage and facilitate positive institutional changes in research, extension and seed programs of collaborating countries involved in sorghum and millet research and development.

Program Approaches

The research efforts of PRF-207 are entirely interdisciplinary. The on-campus research at Purdue is in close collaboration with colleagues in several departments. We undertake basic research in the areas of biotic and abiotic stresses where a concerted effort is underway in elucidating the biochemical and genetic mechanism of resistance to these constraints. Field and laboratory evaluations of sorghum and millet germplasm are coordinated, the results from one often complimenting the other. In addition, there have been collaborative research efforts with colleagues in Africa where field evaluation of joint experiments are conducted.

Our germplasm development and enhancement program utilizes the wealth of sorghum and millet germplasm we have accumulated in the program. Intercrosses are made in specific combinations and populations generated via conventional hybridization techniques, through mutagenesis, or through tissue culture in vitro. Conventional progenies derived from these populations are evaluated both in the laboratory and in the field at West Lafayette, Indiana for an array of traits, including high yield potential, grain quality, as well as certain chemical constituents that we have found to correlate well with field resistance to pests and diseases. We also evaluate our germplasm for tropical adaptation and disease resistance during the off-season at the USDA Tropical Agricultural Research Center at Isabella, Puerto Rico. Selected progenies from relevant populations are then sampled for evaluation of specific adaptation and usefulness to collaborative programs in Sudan, Niger, and more recently Mali. Evaluation of the drought tolerance of our breeding materials have been conducted at Lubbock, Texas in collaboration with Dr. Darrell Rosenow, in a winter nursery at Puerto Vallarta, Mexico, as well as the University of Arizona Dryland Station at Yuma, Arizona. Over the years, assistance in field evaluation of nurseries has also been provided by industry colleagues particularly at Pioneer HiBred and DeKalb Genetics

The training, networking and institutional development efforts of PRF-207 have been provided through graduate education, organization of special workshops and symposia as well as direct and closer interaction with research scientists and program leaders of NARS and associated programs. Much of the effort in this area has been primarily in Sudan and Ethiopia (East Africa), in Niger and Mali (West Africa), with limited activity Southern Africa and in India.

Project Output

Research Findings

Genetic Variation And Relationships Among Seedling Vigor Traits in Sorghum (Ref: Crop Science, 2001 (In Press)

Seedling vigor in sorghum [*Sorghum bicolor* (L.) Moench] is important for improving stand establishment of the crop, particularly in arid regions and in areas where low soil temperatures prevail at planting time. Early vigor is considered an essential component of crop plant development under most environmental conditions. In arid environments, crop varieties with early seedling vigor and good stand establishment tend to enhance transpiration resulting in increased dry matter accumulation and improved grain yield. In temperate environments, where low soil temperature and high moisture often prevail at time of planting, early planting and use of minimum tillage accentuate germination and seedling growth problems. Poor early vigor has been a handicap for the introduction of maize (*Zea mays L.*) hybrids based on Corn Belt germplasm in the European Atlantic coast, because temperatures are too low in the spring for rapid growth. Seedling tolerance to low temperature is enhanced by rapid germination, high percent germination, and vigorous seedling growth. Plant characteristics that are responsible for differences in early seedling vigor among and within plant species have not been fully characterized. Simple plant characteristics such as kernel weight, percent germination, seedling weight and height have been identified as good indicators of seedling vigor. Seedling vigor in sorghum has been assessed by direct measurement of seedling dry weight, which was highly correlated to leaf area, leaf number, and plant height. Laboratory experiments have been shown to be adequate in estimating germination and in establishing significant positive correlations between germination in the laboratory and emergence, and seedling vigor in the field.

This study was conducted to examine the genetic variation, heritability, and relationships among seedling vigor traits in a recombinant inbred (RI) sorghum population developed from two contrasting inbreds. Our study was prompted by past field observations that certain Chinese kaoliang sorghum lines consistently showed early season seedling vigor that was superior to most sorghum lines and hybrids in our sorghum breeding nurseries. The objectives of this study therefore, were to determine if these differences were genetic and to establish interrelationships among different estimates of seedling vigor in a RI population derived from the cross between 'SRN39', an African caudatum , and 'Shan-Qui Red', a Chinese kaoliang.

One hundred RI lines and their parents, ('SRN39', an African caudatum and 'Shan Qui Red', a Chinese kaoliang), were evaluated for seedling vigor in several experiments conducted in the field, in an incubator, and in a greenhouse. Data on visual seedling vigor scores, percent germination at 12°c and 22°c , percent emergence, seedling height, and shoot dry weight were collected. Genotypic differences were significant for many of these seedling vigor traits. Significant genetic and additive variances were observed for field vigor scores as well as for those traits measured in the more controlled environments. Heritability estimates for visual scores, percent germination, emergence, and seedling height were high, while those for seedling dry weight were low to medium. Genetic correlation coefficients of visual seedling scores with the different estimates of vigor were significant except for 100-seed weight. Significant genetic interrelationships were revealed among traits measured in the greenhouse and incubator germination at 22°c. Visual scores taken in field experiments appeared effective in integrating germination, emergence at high temperatures, and shoot dry weight. The significant additive genetic variances obtained indicate that the superior seedling vigor observed in the Kaoliang parent, 'Shan Qui Red', can be effectively utilized for improving germination in cold temperature, as well as germination, emergence, seedling growth and development at optimum temperature.

Early germination, emergence, and stand establishment, are important traits in sorghum and other field crops. Significant genetic variation for seedling vigor traits exist within the cultivated species of sorghum. Chinese kaoliangs appear to be excellent sources of seedling vigor and stand establishment. In this study, we demonstrated that the vigorous seedling growth observed in the kaoliang line, 'SQR', is a heritable trait. This line may be a good source of both cold tolerance and overall seedling vigor even at higher temperatures. The significant genetic variances and heritability estimates for many of the vigor traits including germination at low temperature indicate that 'SQR' can be used in improving seedling vigor and stand establishment of sorghum in both low and high temperature conditions. If the superior cold tolerance of kaoliangs is further substantiated, sorghum cultivars that withstand early season cold temperatures can readily be developed using Chinese lines as sources.

Effect of Phenolic Compounds in Sorghum Kernels on Seedling Vigor (Ref: In Review)

Sorghum [*Sorghum bicolor* L. Moench.] plants produce large amounts of phenolic compounds which constitute a defense mechanism against fungi , insects and birds, but also have antinutritional effects. Early vigor and good seedling establishment, tend to enhance transpiration at the expense of direct soil evaporation, resulting in high level of dry matter accumulation and improved grain yield in arid environments. In temperate zones early planting and use of minimum tillage accentuate germination and seedling growth problems, because low soil temperature and high moisture often prevail at planting time. Simple plant characteristics are responsible for differences in early vigor among and within plant species. These include kernel weight, percent germination, seedling length and weight.

Sorghum plants produce large amounts and a great diversity of phenolic compounds. Many of these phenols determine plant color, appearance, nutritional quality, and host defenses. Sorghum phenolic compounds can be divided into five basic groups; phenolic acids, lignins, quinones, flavonoids and tannin. Phenolic acids, flavonoids and tannins are the most common groups in sorghum.

It was reported that percent germination in sorghum cultivars with high (3.4 %) and low (0.5%) tannin content was the same. The rates of germination were also the same, but the subsequent rates of root and shoot growth were much lower in high tannin seeds. The interpretation was that starch and protein degradation were inhibited in high tannin seeds during germination, leading to suppressed seedling growth. A marked suppression of seedling root growth was also observed with a low tannin (0.1 %) sorghum cultivar, germinated in the presence 1 %, 2 % and 3 % tannic acid concentrations. The inhibition increased with concentration and time. It was concluded that tannins present in sorghum seeds retard seedling growth due to inhibition of starch degradation by inactivating hydrolytic enzymes during germination.. Phenolic acids affected sorghum germination and seedlings growth on filter paper in petri dish, but no effect was detected when applied in soil. High concentrations of phenolic compounds were shown to reduce radish (*Raphanus sativus* L.) seed germination and corn (*Zea mays L.*) shoot growth. Several researchers have shown the negative effect of phenolic compounds present in different plant residues, on sorghum germination and seedling growth. A preceding sunflower (*Helianthus annuus* L.) crop decreased sorghum germination and seedling growth. Leaf litter of *Prosopis juliflora* (Swartz) DC, significantly reduced sorghum germination and seedling dry matter production.

The role of kernel phenols on seedling vigor and stand establishment are not well understood. Earlier studies on the relationship of phenolic compounds with seedling vigor traits on sorghum have essentially been concerned with their effect when exogenously applied. The objectives of this study were; i) to evaluate the effects of different phenolic compounds, present in sorghum seeds on early vigor; ii) to assess the relationships between different phenolic compounds and to estimate their heritability.

One hundred recombinant inbred (RI) lines derived from two parental lines that differ for an array of phenolic compounds were evaluated. High phenolic compound contents were associated with vigorous seedlings, high percent germination at 22° C, emergence, and taller seedlings. Kernel weight was negatively associated with concentrations of pigments and flavan-4-ols. Only tannin content was negatively correlated with germination at 12° c, indicating that phenolic compounds may not be important for adaptation to low temperature. Lines with a red coleoptile, had significantly higher pigment and total phenol contents, and tended to be more vigorous at seedling stages than green coleoptile lines. Highly significant genotypic and additive components of variance, and high broad-sense heritability estimates were found for pigments, flavan-4-ols, tannin, and total phenols content in this sorghum population. Our study demonstrates that selection for low or high concentrations of phenol in sorghum kernels is feasible.

Networking Activities

Workshop and Program Reviews

Organize and lead a workshop on Regional Collaboration for Sorghum and Millet Research in Eastern Africa among INTSORMIL-ICRISAT-NARS scientists, 10-12 December 2000.

Collaborate with INRAN in development of seed industry in Niger, West Africa.

Member of review team for System wide Review of Plant Breeding Methodologies in the CGIAR at ICRISAT Centre.

Member of organizing committee and chaired sessions for Global 2000 Sorghum and Millet Diseases Conference, September 2000.

Attend workshop on Raising Agricultural Productivity in the Tropics: Biophysical Challenges for Technology and Policy. Center for International Development at Harvard University, Cambridge, Massachusetts, 17-18 October 2000.

Attend meeting of Board of Directors of Rockefeller Foundation/Cornell University Initiative on the Essential Electronic Agricultural Library, February 2-4, 2001.

Attend Sorghum Improvement Conference for North America. Nashville, TN. 18-20 Feb 2001.

Attend 7th International Parasitic Weed Symposium, Nastes, France. 5-8 June 2001.

Research Investigator Exchange

Host a Seed Delegation from Malawi (Dr. Jeffrey Luhanga, Mr. Francis Maideni, Mr. Maxford Jehe, and Ms. Rebecca Weber) through the Purdue Center for Agricultural Business, 22-26 August.

Host Dr. Aberra Debelo, Deputy Director of Research, EARO, Ethiopia

Host Dr. Aberra Deressa (Ethiopia) and Dr. Saddan Hassien (Tanzania)

Host Dr. Paula Bramel, ICRISAT

Host Dr. Admasu M. Berhan, IITA

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 seven countries in 2000-01.

Publications

Journal Articles

King, D., M.Z. Fan, G. Ejeta, A. Asem, and O. Odeola. 2000. The effects of tannins on nutrient utilization in the White Pekin duck. British Poultry Science 41:630-639.

Cisse, N., and G. Ejeta. 2001. Genetic variation and relationships among seedling vigor traits in sorghum. Crop Sci. (In Press).

Conference Proceedings

Tuinstra, M.R., T. Teferra, L.E. Claflin, R.G. Henzell, A. Borrell, N. Seetharama, G. Ejeta, and D.T. Rosenow. 2000. Breeding for resistance to root and stalk rots in sorghum. In: Leslie and Frederiksen (eds.) Global 2000 Sorghum and Millet Diseases Conference. 23-30 September, Guanajuato, Mexico.

Tuinstra, M.R., T. Teferra, L.E. Claflin, R.G. Henzell, A. Borrell, N. Seetharama, G. Ejeta, and D.T. Rosenow. 2001. Breeding for resistance to root and stalk rots in sorghum. In: 22nd Biennial Grain Sorghum Research and Utilization Conference. 18-20 February 2001, Nashville, TN.

Workshop on Raising Agricultural Productivity in the Tropics: Biophysical Challenges for Technology and Policy. Center for International Development at Harvard University, Cambridge, Massachusetts, 17-18 October 2000.

Abstracts

Gunaratna, N. and G. Ejeta. 2000. Inheritance of seedling cold tolerance in sorghum. Agronomy Abs. p. 111.

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

Project TAM-222
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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 U.S. and host countries. Forty-eight new fully converted exotic lines and 70 partially converted lines from the cooperative TAMU-TAES/USDA-ARS Sorghum Conversion Program were identified for release.

Approximately 1,300 items from the Mali Sorghum Collection of indigenous sorghum varieties was grown out under quarantine for seed increase, evaluation, and characterization in St. Croix, U.S.V.I. Several very unique and promising new Durra and Durra-Dochna type cultivars from the dry northern part of Mali were identified in the Collection, and hold promise in sorghum improvement in the drought prone areas of Africa and the U.S..

Breeding progeny developed in TAM-222 showed excellent potential in the Southern Africa Region and in Nicaragua and El Salvador combining high yield, drought resistance, and grain quality. They offer good potential for use as varieties directly where appropriate and also as parental lines for use in hybrids. Macia (an improved cultivar from Mozambique) derivative lines looked especially promising and also offer potential to develop some improved white-seeded, tan-plant parental lines for U.S. use.

Sterilization and evaluation continued on a large number of new B-line breeding genotypes to assist decisions on

which one to release. These lines contain various combinations of stay green drought resistance, lodging resistance, improved grain quality, and head smut resistance. Also, several are white-seeded, tan-plant A-B pairs that could be useful in food-type hybrids.

Flour made from the IER/INTSORMIL developed tan plant guinea cultivar, N'Tenimissa, was successfully used in Mali by a private bakery to produce and market a new cookie, deli'ken, made with some sorghum flour being substituted for wheat flour. This demonstrates that new cultivars with improved grain quality traits can stimulate the development and commercialization of new sorghum-based products. Some of the new N'Tenimissa breeding progenies show good promise to be even superior to N'Tenimissa for production and grain quality.

Collaborative INTSORMIL activities were initiated in Senegal and Ghana in the areas of sorghum breeding, disease resistance, and *Striga*, as well as some entomology and agronomy research. A MOU was signed with Senegal. The single scientist agronomy collaboration (and MOU) already with Ghana was built upon and the program expanded to other disciplines and scientists.

Objectives, Production and Utilization Constraints

Objectives

U.S.

- 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

- Develop, release, and distribute agronomically acceptable white-seeded, tan-plant Guinea type sorghum cultivars to enhance the commercial value and demand for improved value, high quality sorghum grain.
- Develop high yielding white, tan non-Guinea type improved cultivars with high levels of resistance to head bug and grain mold with adaptation to the drought and soil conditions of Mali, and with acceptable levels of disease resistance.Characterize and describe the indigenous Mali origin Sorghum Collection and evaluate for useful traits and breeding potential, introduce into U.S., and place in storage in U.S., ICRISAT, and ORSTOM.
- Initiate collaboration with breeders and other scientists in Ghana and Senegal to establish INTSORMIL collaboration in those countries.

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 Southern Africa

- 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 semiarid environment ideal for large scale field screening for both pre- and post-flowering drought response and breeding for improved resistance to drought.

Diseases are important worldwide and most internationally important diseases are present and are also serious constraints in Texas, especially downy mildew, charcoal rot, grain mold/weathering, head smut, and head blight. The Texas environment, particularly South Texas, is ideal for screening and breeding sorghums with high levels of resistance to most internationally important diseases.

Poor grain quality is a major problem in Mali and much of West Africa and is primarily due to the head bug/grain mold complex. Head bugs are a major constraint to the use of improved high yielding nonguineense type sorghums in much of West Africa, with head bug damage often compounded by grain mold, resulting in a soft, discolored endosperm, which is unfit for decortication and traditional food products. Early maturity of introduced types also increases the grain deterioration problem. In southern Mali, late maturing, photoperiod sensitive sorghums are needed to assure grain maturity after the rainy season.

Mali and Niger, especially the more northern areas, are both drought prone areas where drought tolerance is important. Foliar diseases such as anthracnose and sooty stripe are important in the central and southern parts of Mali and in certain areas of Southern Africa. In Sudan, and much of East Africa, the major constraint is drought, and related production problems. Moisture-stress related charcoal rot and subsequent lodging are serious problems. *Striga* is a major constraint in Mali, Niger, and Sudan.

In Central America, diseases and grain quality are major constraints, with drought also important in the drier portions of the region. Improvement in the photoperiod sensitive, food-type maicillos criollos grown in association with maize on small, hillside farms is a unique challenge.

There is a constant need in both host countries and the U.S. to conserve genetic diversity and utilize new diverse germplasm sources with resistance to pests, diseases, and environmental stress. Many developing countries are an important source of diverse germplasm in sorghum and millet. The collection, preservation and utilization of genetic diversity in sorghum is important to long-term, sustainable sorghum improvement programs needed to insure sufficient food for increasing populations of the future.

Research Approach and Project Output

Research Methods

Introductions from various countries with drought or disease resistance, or specific desirable grain or plant traits, are crossed in Texas to appropriate elite U.S. lines or elite breeding materials. Seed of the early generations are sent to host countries for selection of appropriate traits and adaptation. Technical assistance is provided, as time and travel permits, in the selection 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 involving sources of drought resistance are selected under field conditions for pre- and/or post flowering drought resistance, yield, and adaptation at several locations in West Texas. Molecular markers for the stay green trait are being used in a marker assisted selection program. Selected advanced materials are incorporated into standard replicated trials for evaluation at several locations in Texas and sent to host countries for evaluation and use.

Converted and partially converted lines from the Sorghum Conversion Program, exotic lines, new introductions, and breeding materials are screened and evaluated in Texas for new sources of resistance to internationally important diseases and resistance to drought.

New sorghum germplasm is assembled or collected as opportunities exist and introduced into the U.S. through the quarantine greenhouse (small number of items) or the USDA Plant Quarantine Station in St. Croix (many items), they are then evaluated in Puerto Rico and Texas for useful traits. Selected photoperiod sensitive cultivars are entered into the cooperative TAES-USDA Sorghum Conversion Program. Cooperative work with NARS assures their country's indigenous sorghum cultivars are preserved in long term permanent storage, as well as evaluated and used in germplasm enhancement programs. Growouts of entire collections (Sudan and Mali) have been grown in their country of origin for characterization, seed increase and evaluation prior to introduction into the U.S. Assistance is provided in developing smaller working or core collections for the NARS to actively maintain and use in their improvement programs.

Research Findings

The Mali Sorghum Collection (including all indigenous cultivars known of Mali origin) was grown in Mali in 1997 for characterization, evaluation and seed increase and seed introduced into the U.S. It was a cooperative effort among IER (Mali), INTSORMIL, ICRISAT, ORSTOM (France), CIRAD (France)and USDA-ARS. The Collection totaled nearly 2,500 plots with possibly 600 duplicates from ICRISAT and ORSTOM. Approximately one-third of the Mali Collection was grown out under quarantine in St. Croix the winter of 1999-2000, and seed increased. The remaining two-thirds was grown out in the winter 2000-2001 in St. Croix , evaluated and characterization completed, and a Working Collection developed. The evaluation and characterization was done by Dr. Aboubacar Toure, Mr. Niaba Teme, Dr. Jeff Dahlberg and Dr. Darrell Rosenow, and they were assisted by Dr. John Erpelding in selecting a tentative Working Collection. The complete set of over 40 descriptors and classification of the entire Mali Collection was compiled by Dr. Dahlberg and sent to USDA-ARS for entry into the Germplasm GRIN system. Some extremely interesting unique high yielding and elite appearing Durra and Durra-Bicolor type sorghum from Northern Mali were identified. They appear to possess excellent yield potential with large seed, grain and glumes with strong Durra like traits, but in a non-durra shaped panicle. These will be evaluated for photoperiod sensitivity, and selected one entered into the Sorghum Conversion Program.

Breeding, selection, and screening for drought resistance continued, using major field screening nurseries at Lubbock, Halfway, Lamesa, Chillicothe, Corpus Christi and Beeville. Extreme stress at Chillicothe and Lubbock resulted in severe pre-flowering stress. Lack of rainfall resulted in loss of the Lamesa nursery. The "stay green" line, B35, continues to be an excellent source of post-flowering drought resistance and lodging resistance in breeding progeny. Breeding derivatives of the parental line, B1, a derivative of B35, showed some good drought resistance, with many showing outstanding lodging resistance especially the pedigrees (B1*(B7904*(SC748*SC630))), (B1*BTx635), and (B2-1*BTx635). Sterilization continued on the above mentioned B lines including several white seeded, tan plant lines.

New disease resistant breeding materials were developed, screened, and selected along with advanced generation breeding materials for improved agronomic types with high levels of, and/or multiple, disease resistance. Screening and selection was done primarily in large disease screening nurseries, mostly in South Texas. Major diseases involved were downy mildew, head smut, anthracnose, grain mold/weathering, and charcoal rot. Resistance to other foliage diseases such as rust, zonate, and gray leaf spot was also selected in some nurseries.

Five advanced generation female parental lines (A-B1, 2-2(B), 35, 803, 807) are in the initial stages of document release preparation. The male steriles (A-lines) have been distributed to private companies through a pre-release Materials Transfer Agreement and the response for release has been positive. A1, A2-2(B) and A35 possess good post-flowering drought tolerance and a moderate level of lodging resistance. Hybrids with A803 and A807 show good pre-flowering drought tolerance, and A807 hybrids an improved level of grain weathering resistance.

Approximately 40 A-B pairs and 8 R lines developed cooperatively with L.E. Clark in the cooperative drought breeding program have been identified for possible release. These lines contain many traits with emphasis on stay green, and lodging resistance. Several are white-seeded tan plant lines and some show enhanced weathering resistance. These will be proposed for release mostly as germplasm stocks. Another set of advanced generation germplasm releases containing 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 was tentatively identified.

Forty-eight new fully converted lines are now ready for final release preparation and distribution. Data was obtained on a set of 27 and the other set of 21 was selected from seed increase and purification plots. These are cooperative TAMU-TAES/USDA-ARS releases from the sorghum conversion program. In addition, 71 partially converted bulks are ready for release writeup and distribution.

Molecular analysis using RFLP markers, collection of field drought data, and manuscript preparation continued on 100 F_8 recombinant inbred lines (RILs) each of (B35*Tx430) and (B35*Tx7000). Of the five QTL's identified for the stay green trait in the cross (B35*Tx7000) two (Sg2 and Sg3) appearing to be the most important. In the cross (B35*Tx430), the same QTL's were identified for stay green along with two others, and five QTL's were identified for yield. Two hundred progenies each from two other populations, B35*Tx7000 and SC56*Tx7000, were also evaluated for drought and lodging. Several QTLs were identified for pre- and post-flowering drought resistance and lodging resistance. Some of the QTLs for stay green in the SC56 population were the same as those previously identified from B35. In a cooperative program with four private seed companies MAS involving identified stay green QTLs was used to backcross the stay green trait into elite parental lines. All the above research is cooperation with Henry Nguyen of Texas Tech/TAES. Near isogenic lines (NILs) were developed (BC6) to do fine mapping of stay green QTLs and to do functional genomics research. In another project, advanced backcross populations and hybrids were generated and evaluated to identify QTLs for yield and heterosis in exotic germplasm.

Several new tan-plant N'Tenimissa derivative guinea type breeding lines looked promising in Mali in 2000, showing less stalk breakage, and better head bug resistant than N'Tenimissa. Also, some new, shorter N'Tenimissa derivative F_3 and F_4 lines showed real promise. Selection also continued among non-guinea type, tan-plant breeding lines with improved levels of head bug tolerance and grain mold resistance. N'Tenimissa grain was increased for use in various food quality and food product trials.

DeliKen, a locally produced cookie, made partially using flour from the recently developed tan plant Guinea-type sorghum variety, N'Tenimissa was marketed successfully in the Bamako, Mali area by GAM, the largest local bakery of bread and cookies in Bamako. It was favorably received and was strongly promoted by the Mali government.

Several breeding progeny from crosses generated for Host Country and the U.S. have looked very good agronomically in Southern Africa. Some showed excellent sooty stripe resistance, especially progeny of Macia, ICSV1089BF, Dorado, and SRN39. Various progenies showed excellent drought resistance, combined with excellent yield potential. The cross, Macia*Dorado, was especially outstanding. Many Macia derivatives look excellent. Other lines giving good progeny included 87EON366, WSV387, TAM428, SRN39, ICSV1089BF, Sureño, Dorado, 86EON361 and 90EON328.

From the evaluation of the ADIN in Nicaragua and El Salvador, several Texas A&M breeding lines looked outstanding with excellent yield potential and adaptation. Eighteen lines which looked excellent at both locations are presented in Table 1. In Nicaragua, the TAMU Drought Line Test was evaluated. Several new B-lines from the TAM 222 breeding program showed excellent adaption and could be very useful in producing hybrids in Nicaragua (Table 2). They all looked considerably better than standard commercially used B-lines.

From a 75-entry Mali Drought Test, 17 lines which showed good drought tolerance and grain yield potential at both Cinzana and Bema (Northern Mali) were identified and given in Table 3. The drought stress was quite severe and was primarily at the pre-flowering stage. The reaction of these is quite consistent with evaluations under pre-flowering stress in the U.S. and with the previous observations of the excellent drought resistance of Caudatums (Feteritas) from Sudan across the dryer sorghum production areas in Africa.

Table 1. Selected sorghums from the ADIN with excellent adaptation and yield in both El Salvador and Nicaragua, 2000.

Designation	Pedigree
Sureño	((SC423*CS3541)*E35-1)-1/M62650
86EON361	(R5646*SC326-6)
90EON328	(Sureño*BDM499)-HD5
96CD635	(SRN39*90EON328)-HF4
96CA5986	(Sureño*87EON366)-CW13
98CD187	(87EON366*90EON328)-HF6
90EON343	((Tx2895*(SC170*R4671))-BH7
99CA2244	86EO361*90EON343)-HD12
94CW5045	(Malisor 84-7*86EON361)-LF25
B.LD6 (wxy)	(B.BON34*B9502)-LD6
99CA2519	(87EON366*(CS3541*SC630))-F5-BE1
R.9618	(8OCC2241*R8504)-B6
98BRON122	(GR127-90M37*GR107-90M18)-LG2
MB108B	MB108B-7-1-23
96GCPOB143	(86EON361*GR107-36-3)-LG7
B8PR1059	(88B885*GB102B)
96GCPOB172	(88CC445*Tx2862)-HG62

Evaluation based on overall desirability and yield ratings made by D.T. Rosenow, December 2000.

Table 2. Nine new B-lines and four restorer lines with excellent adaptation in Nicaragua, 2000.†

Designation	Pedigree	Plant color‡	Grain color§
B807	(BTx623*(BTx625*B35))	P	R
B.DLON357	(B1*B9501)	P	R
B.HF14	(B1*BTx635)-HF14	T	W
B.V26	(B2-1*BTx635)-V26	T	W
B.LD6(non wx)	(B.BON34*B9502)-LD6	T	W
B.LD6(wxy)	B.BON34*B9502)-LD6	T	W
B.V18	(B1*B9501)-V18	P	W
B.PDLT157	(B1*B9501)/PDLT157	P	W
B.V2	(B1*B9501)——V2	P	W
CE151	CE151-262-A1/Senegal	T	W
Macia	Macia/Mozamb.	T	W
Kuyuma	Kuyuma/Zambia	T	W
R.LD17	(CE151*BOM499)-LD17	P	W

† Evaluation based on overall agronomic adaptation and yield expression by D.T. Rosenow, December, 2000.
‡ Purple; T = Tan
§ R = Red; W = White (All are transluscent)

Table 3. Selected sorghum cultivars with excellent pre-flowering drough resistance at Cinzana and Bema, Mali, 2000.

Designation	Type, Country of Origin
Ajabsido	Feterita/Sudan
Koro Kollo	Feterita/Sudan
P898012	Caudatum/Sudan-Purdue
SC414-12E	Caudatum Kafir/Sudan
SC701-14E	Caudatum/Sudan
CE151-262-A1	Zerazera der/Senegal
Macia	Zerazera der/Mozambique
Kuyuma	Zerazera der/Zambia
MP531	Zerazera der/S. Africa Region
WSV387(Tx)	Zerazera der/S. Africa Region
93SU1671	Caudatum/Sudan
93SU1672	Caudatum/Sudan
93SU96	Caudatum/Sudan
98SU577	Caudatum/Sudan
IS9290C	Gadam El Hamam Caudatum/Sudan
82BDM499	(SC173*SC414)
SC1211-11E-3	Cacho de Chivo der/Honduras

Evaluation by D.T. Rosenow, November, 200

Networking Activities

Workshops/Conferences

Participated in the USDA-ARS Crop Germplasm Workshop (substituting for Dr. Bruce Maunder, Sorghum CGC Chair) at Beltsville, Maryland, July 19-20, 2000.

Participated in the Global 2000: Sorghum and Millet Diseases III Workshop, Guanajuato, Mexico, September 25-29, 2000.

Participated in the Fourth Australia Sorghum Conference, February 5-10, 2001, Kooralbyn, QLD, Australia.

Participated in the Mid-Term evaluation of ROCARS (West and Central African Sorghum Network - WCASRN) and the joint meeting with ROCAFREMI (P. Millet Network) to initiate the plan to look at merging the two networks, April 21-28, 2001.

Research Investigator Exchanges

Traveled to Mali November 1-15, 2000 to evaluate and plan INTSORMIL/IER collaborative research. Traveled to Bema in northern Mali to the research station to evaluate the INTSORMIL Drought Test and IER breeding materials.

Arranged and planned the travel of Drs. Ndiaga Cisse (sorghum breeder), Demba M'Baye (pathologist) from Senegal and Drs. S.S. Bauh (agronomist), and Ibrahim Atokple (sorghum breeder) from Ghana to Bamako, Mali, November 5-9 to meet with me, Dr. Aboubacar Toure, and other Malian IER scientists to develop plans to initiate collaborative INTSORMIL research in Ghana and Senegal among U.S. and Malian scientists and those from Ghana and Senegal.

Traveled to Nicaragua on December 3-5, 2000 to evaluate INTSORMIL sorghum trials and plan future research with Rafael Obando, and travel to Esteli in the northern mountains to view sorghum on-farm trials and the agriculture of the area.

Traveled to El Salvador December 6-9, 2000 to evaluate sorghum trials, breeding materials and plan future research with Rene Clara and Gary Peterson. We also traveled to the northeast and west part of the country, and also to the southeast of San Salvador, to evaluate sorghum on-farming plantings and the sorghum production of the area.

Traveled to the Global 2000 Sorghum and Pearl Millet Disease Workshop in Guanajuato, Mexico, September 25-29, 2000. Presented a poster paper and interacted with sorghum pathologists and other scientists throughout the world and discussed future research plans.

Traveled to the USDA-ARS Crop Germplasm Workshop in Washington, D.C. July 19-20, 2000, substituting for Dr. Bruce Maunder representing the Sorghum Crop Germplasm Committee. Discussed germplasm issues with various crop curators, Regional Station scientists, and NSSL and USDA-ARS scientists and administrators.

Traveled to Queensland, Australia, February 5-10, 2001 to participate in and present invited paper at the Fourth Australian Sorghum Conference at Kooralbyn. Also presented a talk at the after-conference producers tour at Moree, New South Wales on February 9.

Traveled to the GSPA Sorghum Industry Conference and SICNA Conference February 18-20, 2001 at Nashville, Tennessee, and presented a poster paper. At the conference, met with many public and private breeders to exchange research information.

Traveled to St. Croix, U.S. Virgin Island May 21-26, 2001 to assist in the characterization and evaluation of the remaining two-thirds of the Mali Sorghum Collection grown out for seed increase under quarantine on St. Croix. Arranged and planned the travel of Dr. Aboubacar Toure from Mali, Mr. Niaba Teme (M.S. Mali graduate student at TTU/TAMU), and Dr. Jeff Dahlberg (former USDA-ARS Sorghum Curator) to travel to St. Croix to evaluate and complete the characterization of the Mali Collection. Along with Dr. John Erpelding, USDA-ARS Sorghum Curator, we selected a tentative Working Collection representing 10-15% of the entire collection.

Traveled to Bamako Mali, April 21-28, 2001 to participate and represent INTSORMIL at the Mid-Term Evaluation of ROCARS and participate in the joint meeting of the sorghum and millet networks (ROCARS and ROCAFREMI) to plan for the future merger of the two networks. I helped negotiate among the Swiss and USAID Donors, and the ROCARS and ROCAFREMI Steering Committees to reach an agreeable future merger strategy. I also interacted with scientists from Mali, Ghana, Senegal, Niger, Nigeria, Burkina Faso, and other countries on INTSORMIL future plans in the Western Africa Region and worked out tentative plans to initiate collaborative research.

Hosted Dr. John Erpelding, the new USDA-ARS Sorghum Curator, Mayaguez, Puerto Rico at Lubbock and visited Chillicothe (Conversion Program), Monsanto sorghum research plots, and the World Collection Growout at the Cargill Research Station, August 16-18, 2000.

Arranged and hosted Dr. David Jordan, Australian Sorghum Breeder, at Lubbock, Texas, October 1-4, 2000 and evaluated sorghum research plots and discussed future research on the stay green drought resistance trait.

Met with Rafael Obando and Sergio Pichardo from Nicaragua and Rene Clara of El Salvador, February 23-24, 2001 at Lubbock to discuss future research plans and sorghum germplasm needs.

Participated in the Sorghum Crop Germplasm Committee (SGC) as Ad Hoc member, February 18, 2001 at the Sorghum Industry Conference in Nashville, Tennessee.

Participated in the USAID Management Review of INTSORMIL at College Station, Texas, March 1-2, 2001.

Arranged and organized the travel for Dr. Aboubacar Toure and Mamourou Diourte to travel to Senegal and Ghana January 2-15, 2001 to interact with the new INTSORMIL collaborators in those countries.

Arranged the travel and hosted Dr. Aboubacar Toure at Lubbock, May 27-30, 2001 to visit Malian researchers in school there, and to discuss and plan future INTSORMIL/IER collaborative research.

Coordinated the training of Mr. Niaba Teme, sorghum technician with IER, Mali, who completed his B.S. and is now working on his M.S. at Texas Tech University/and TAES at Lubbock.

Interacted with several private seed company scientists at various times such as the TSTA Crop Testing Advisory Committee Meeting (October 17, 2000) the TAES sorghum futuring meeting (September 14, 2000), and thru individual scientist visits to the TAES research station at Lubbock.

Germplasm and Research Information Exchange

Germplasm Conservation and Use

Continued the coordination of the work with the Mali Sorghum Collection with the planting in January 2001 of the remaining 1300 items from the Collection under quarantine on the island of St. Croix. The late group of about 460 items was grown there the winter of 1999-2000. The Collection was evaluated, characterization completed, and a tentative working collection identified in cooperation with Drs. Aboubacar Toure, Jeff Dahlberg, and John Erpelding, and Mr. Niaba Teme. After the seed is sent to Experiment, Georgia and processed, seed of the entire collection will be sent to NSSL and will be distributed as appropriate to ICRISAT, ORSTOM, and IER. The complete set of data on the over 40 grain, glume, and plant characterizations was complied by Jeff Dahlberg and sent to the USDA for entry into the GRIN system.

Nineteen new sorghum breeding lines from IER, Mali were introduced into the U.S. These included some Durras from northern Mali and white-seeded, tan-plant, good food quality guinea derivative and non-guinea types. The 35 lines introduced from Mali in 1999 were evaluated (all were photoperiod sensitive) and were increased in 2000-2001 Puerto Rico. Also grown out under quarantine were 12 introductions from China, including two high lysine lines.

Two sets of new fully converted exotic lines (27 and 21 items) from the cooperative TAMU-TAES/USDA-ARS Sorghum Conversion Program were selected for release and are being prepared for release along with 70 partially converted lines.

Seed Production and Distribution

A large number of sorghum breeding and germplasm lines, from early to advanced generation progeny, A, B, and R lines, converted lines, and experimental hybrids were increased and distributed to international and domestic collaborators. These contained sources of desirable traits such as resistance to downy mildew, anthracnose, sooty stripe, leaf blight, rust, and charcoal rot, pre- and post-flowering drought resistance, grain mold and weathering resistance, and lodging resistance. Seed was increased and many sets of standard replicated trials containing elite germplasm and source lines were packaged and distributed in the U.S. and internationally. These include the ADIN (All Disease and Insect Nursery), GWT (Grain Weathering Test), DLT (Drought Line Test), DHT (Drought Hybrid Test), and the UHSN (Uniform Head Smut Nursery). Countries to which large numbers of germplasm items were distributed include Mali, Niger, Zimbabwe, Botswana, Zambia, Ethiopia, Guatemala, Honduras, El Salvador, Nicaragua, and Mexico.

Assistance Given

Joint evaluation of germplasm and nursery and test entry decisions was done collaboratively with national scientists in Mali. Training on disease and drought breeding methodology, as well as information on sources of new useful germplasm and sources of desirable traits, was provided to several visitors. Pollinating bags, coin envelopes, and other breeding supplies were provided to the Mali breeding program. Purchases included computers for Senegal (2), and Mali (1), and a vehicle for Mali, as well as other supplies for Mali.

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, Niamey, Niger.
Dr. Aberra Debello, Ethiopian Country Coordinator, IAR, Addis Ababa, Ethiopia
Dr. Fred Rattunde, Sorghum Breeder, ICRISAT, Bamako, Mali
Dr. Eva Weltzien Rattunde, Sorghum Breeder, ICRISAT, Bamako, Mali
Dr. Inoussa Akintayo, WCASRN Coordinator, WCASRN, ICRISAT, Bamako, Mali
Dr. Chris Manthe, Entomologist, DAR, Gaborone, Botswana.
Dr. John Erpelding, Sorghum Curator, USDA/ARS, Tropical Agriculture Research Station, Mayaguez, Puerto Rico.

Dr. Mitch Tuinstra, Sorghum Breeder, Kansas State University, Manhattan, KS 66506.
Dr. Ken Kofoid, Sorghum Breeder, Ft. Hays Branch Station, Kansas State University, Hays, KS.
Dr. Jeff Dahlberg, Research Director, National Grain Sorghum Producers Association, Lubbock, TX.

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Germplasm Enhancement for Resistance to Insects and Improved Efficiency for Sustainable Agriculture Systems

Project TAM-223
Gary C. Peterson
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Dr. Medson Chisi, Sorghum Breeding, Golden Valley Research Station, Box 54, Fringila, Zambia
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Dr. Lloyd Rooney, Cereal Chemistry, Department of Soil and Crop Sciences, Texas A&M University, College Station, TX 77843 (TAM-226)
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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*), greenbug (*Schizaphis graminum*), and sugarcane aphid (*Melanaphis sacchari*). Breeding and selection activities primarily use conventional methodology. Collaborative molecular biology research has mapped genes for resistance to greenbug biotypes and molecular markers are being used to concurrently select for greenbug resistance and stay-green (post-flowering drought tolerance). Several hundred lines from different populations are in evaluation in several environments to identify superior lines. Superior lines will be resistant to greenbug biotype I, have excellent stay-green, and express wide adaptation.

A primary research objective is to develop sorghum midge resistant lines that are suitable for use as hybrid parents. In addition to pest resistance the lines should produce excellent grain yield under high pest density, acceptable yield with the pest absent, and contain other traits including adaptation, disease resistance, etc. The best lines currently available in the breeding program will in hybrid combination produce grain yield, when sorghum midge are absent at anthesis, 10-15% less than the best susceptible hybrids. When sorghum midge are present at anthesis the resistant hybrids produce significantly more grain than susceptible hybrids.

The greenbug resistance program has lines in advanced yield testing with excellent resistance. Many of the lines possess wide adaptation and resistance to several diseases. Included is an array of plant and grain color combinations including tan plant, white grain and tan plant, red grain. The multiple stress resistance, wide adaptation, diverse plant types will contribute to utilization by private industry after release.

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.
- Develop and release high yielding, agronomically improved sorghums with multiple stress resistance.

Constraints

Sorghum production and yield stability is constrained by many biotic and abiotic stresses including insects, diseases and drought. Insects pose a risk in all areas of sorghum production with damage depending on the insect and local environment. To reduce stress impact sorghum cultivars with enhanced environmental fitness suitable for use in more sustainable production systems are needed. Cultivars experience stress concurrently or sequentially and genetic resistance to multiple stresses will reduce environmental risk and contribute to improved productivity. This is especially important as production ecosystems experience induced change due to technology improvement with the natural balance between cultivars and biotic stresses changing and insect damage becoming increasingly severe.

Genetic resistance may be utilized at no additional producer cost to meet the demands of increased food production in an economically profitable, environmentally sustainable production system. This requires a multi-disciplinary research program to integrate resistant genotypes into the management system. Genotypes 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.

Research Approach and Project Output

Research Methods

Collaborative research is conducted in LDC's on specific problems. LDC research is supported through graduate education, germplasm exchange and evaluation, site visits, and research at nursery locations in Texas. This project is active in three regional programs - West Africa (Mali), Southern Africa, and Central America. Mali research efforts are being reallocated to other sites with current activity directed at support of a Ph.D. student. Research in Southern Africa is incorporating resistance to sugarcane aphid into adapted cultivars. Nicaragua and El Salvador activity provides for additional research on sorghum midge (the most important production constraint in Nicaragua), drought, disease, adaptation, and end-use traits. For the United States, sorghum midge, greenbug and yellow sugarcane aphid resistant sources have been identified and used in developing elite resistant sorghums. Primary emphasis is on biotype I resistance. Through collaborative ties with other projects genetic inheritance, resistance mechanisms, molecular mapping, and marker-assisted selection research conducted. Appropriate selection methodology is used to concurrently select for other biotic or abiotic stress resistance to develop germplasm with wide adaptation, multiple stress resistance, and improved end-use traits.

Germplasm is evaluated for resistance to economically important insects 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 germplasms with superior trait(s). Although the primary selection criteria is for insect resistance, the geographical diversity of Texas nursery locations provides the opportunity to select for wide adaptation, resistance to specific diseases, drought resistance, and weathering resistance. Based on data analysis and phenotypic evaluation, crosses are made among elite lines to produce additional germplasm for subsequent evaluation. The overall objective is to combine as many stress resistance genes as possible into a single high yielding genotype.

For insects important in LDC's but not in the U.S., germplasm is provided to the LDC cooperator. The germplasm is evaluated for resistance to the specific insect under the local production system (fertilizer, tillage, plant population, etc.), and agronomic and yield data collected if possible. The populations are grown in the U.S. and selected for adaptation.

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. A midge line test (MLT), composed of experimental breeding lines and checks (resistant and susceptible), and a midge hybrid test (MHT) composed of experimental hybrids and checks (resistant and susceptible) was evaluated for sorghum midge resistance at three locations in the U.S. under high (Corpus Christi late), moderate (Corpus Christi early), and low (Halfway) population density. The MLT was also grown at the INTA research station near Managua, Nicaragua and at Potchefstroom, South Africa to evaluate for adaptation. Diverse locations to screen for sorghum midge resistance are required to identify lines and hybrids that perform well under moderate/low midge density, and high sorghum midge density. At maturity the replicated trials are visually scored for midge damage (MDR) on a subjective scale of 1 = 0-10% aborted kernels, 2 = 11-21% aborted kernels, up to 9 = 91-100% kernels.

In the MLT, the test average MDR (Corpus Christi early = 1.3; Corpus Christi late = 3.7) led to the conclusion that low to moderate numbers of midges were present at anthesis in both plantings (partial results shown in Table 1). The 68 entry test included 56 experimental entries, three susceptible checks, and 13 resistant checks. All susceptible checks (RTx430, BTx378, and BTx3042) sustained a low MDR in the early planting and high MDR in the late planting. Most resistant checks and experimental lines were significantly less damaged than the susceptible checks in the late planting. Several experimental entries sustained less damage than the most resistant checks. In the early planting (low numbers of midges at anthesis) many experimental entries were significantly less damaged than the susceptible checks although differences were difficult to identify. Two new seed parents (A-/B-lines), designated 8PR1011 and 8PR1013, exhibited high resistance under low midge density and moderate resistance under high midge density.

The primary sorghum midge resistance source is TAM2566 (SC175-9) a partially converted zerazera (IS12666) from Ethiopia. Major research emphasis for several years has been to use other resistance sources to 1) diversity 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. However, the major constraint to use of sorghum midge resistant hybrids is the lack of parental lines which possess excellent resistance and grain yield potential under pest infestation, and excellent grain yield potential in the absence of the pest. Until resistant hybrids are developed that yield equal to susceptible hybrids without midges present sorghum midge resistant technology will not be adopted in the United States.

Grain yield potential was evaluated to identify breeding lines suitable for use as hybrid parents. Grain yield and MDR for entries in the Midge Hybrid Test at Corpus Christi early (CA), Corpus Christi late (CM) and Halfway (H) are shown in Table 2 (partial results). The Halfway location is an environment with few midges present at anthesis but very good expression of grain yield. The standard resistant check is ATx2755*Tx2767 (MDR=4.3 (CM) and 1.0 (CA), grain yield=1673 (CM), 3258 (CA) and 3080 (H) kg/ha). The standard susceptible check is ATx2752*RTx430 (MDR=5.7 (CM) and 1.3 (CA), grain yield=2113 (CM), 4095 (CA), and 3444 (H) kg ha^{-1}). Results of the Midge Hybrid Test showed that grain yield in the early hybrid test was over 800 lbs per acre higher than in the late test (1998 kg ha^{-1} vs 2800 kg ha^{-1}). This resulted from significantly less sorghum midge damage in the early planted (1.2) than in the late planted (3.6) test. Additionally, less damage in the early test would allow the susceptible checks to express their grain yield potential. Several resistant experimental hybrids produced grain yield not significantly different than some susceptible hybrids in the early planting and significantly more in the late planting. At Halfway, grain yield of the experimental resistant entries and susceptible checks was comparable. Differences in seed size between resistant and susceptible entries were identified in each test although the results were not consistent. Results confirm previous observations - most resistant hybrids will not produce grain yield equal to susceptible hybrids in plantings where no or few midges are present but will out yield susceptible hybrids in plantings with moderate to high number of midges. The line designated 8PR1013 has a large open panicle with white grain and possess excellent resistance. It was selected for inclusion in the PROFIT (Productive Rotations On Farms In Texas) hybrid seed project.

Selections were made to develop germplasm resistant to biotype I and K greenbug. The primary sources of resistance to biotype I and K are PI550607 and PI550610. Both sources are used in developing R-lines, and PI550610 is used in B-line development. Screening against the greenbug biotypes identified genotypes that express moderate resistance. Biotype resistance is conditioned by different genes and a moderate resistance level of resistance is emphasized in the selection criteria. Crosses to introgress resistance gene(s) into other germplasm were made.

New R-lines resistant to biotype E and/or I produced excellent hybrids. The lines represent a range of plant types including tan plant, white pericarp and tan plant, red pericarp. New tan plant, red grain biotype E resistant A-lines were evaluated in hybrid combination. The hybrids expressed excellent grain yield potential, wide adaptation and resistance to several diseases. Based on performance one A-line, 8PR1059, and two restorer lines, 5BRON139 (resistant to biotype E) and LG35 (resistant to biotype E/I/K) were selected for inclusion in the PROFIT hybrid program. Hybrid seed will be available in 2002 for wide area testing of tan plant, red grain, greenbug and disease resistant hybrids.

Marker-assisted selection research to combine greenbug resistance and stay-green (post-flowering drought tolerance) into a single genotype continued. This is a collaborative research activity between this project, TAM-222, and the molecular biology laboratory of Dr. Henry Nguyen (Texas Tech University). Mr. Sidi Bekaye Coulibaly (Mali) is conducting this Ph.D. research to compare the efficiency

Table 1. Midge damage rating, height, and days to anthesis for entries in the 2000 Midge Line Test.

Pedigree/Designation	Class†	Midge damage rating‡		† Plant heigh		Days to 50% anthesis	
		CM§	CA	CM	CA	CM	CA
				—CM—			
(Tx2880*SC170-6-17)-SM15-CM1-	E	1.3	1	72	67	97	102
Tx2782	R-CK	1.7	1	75	63	72	77
(MB108B/P.G.*MB110-49-)-BM10-CM1-	E	1.7	1	69	66	102	97
(PM12713*Tx2882)-CM3-CM2-	E	1.7	1	83	75	152	147
B9PR2147	E	1.7	1.7	75	72	105	104
Tx2880	R-CK	2.3	1	73	68	98	101
(MB110-der*Tx623)-	E	2.3	2.3	81	77	114	107
((SC62*Tx2782)-B12-CC1-CC1*Tx2878)-SM18-	E	2.3	1	74	71	116	121
(MR118-3-*Tx2882)-SM15-	E	2.3	2	76	73	111	103
(Tx2767*((SC572-14*SC62-14)-B5-))-SM5-SM1-	E	2.3	1.7	68	64	120	120
(Tx2782*MB108B/P.G.)-CM10-SM1-	E	2.3	1	75	72	99	84
((MB120C-BM5-CS2-)*MB108B/P.G.)-SM5-CM1-CM2-CM1-	E	2.3	1	73	69	120	141
((MB120C-BM5-CS2-)*MB108B/P.G.)-SM5-CM1-CM2-CM2-	E	2.3	1	74	69	129	120
(MR112B-92M2*Tx2880)-SM17-	E	2.3	1.3	65	63	107	115
(MR127-92M5*MR114-90M11)-SM2-CM2-	E	2.3	1	74	70	97	97
(MR112B-92M2*Tx2880)-SM3-SM1-	E	2.3	1	67	68	105	105
(PM12713*Tx2882)-SM8-CM1-	E	2.3	2.7	83	80	149	154
97M1/(PM12713*Tx2766)/7BRON134	E	2.7	1	77	69	94	112
97M16/(MR112-90M5*87EO366)/7BRON156	E	2.7	1	69	68	115	122
(Tx2882*SRN39)-CM3-SM2-SM2-CM1	E	2.7	1.7	77	70	96	91
((MB126E-BM3-BM2-)*MB108B/P.G.)-CM9-	E	2.7	1	77	67	101	112
(B1*MB126E-BM6)-CM4-CM2-	E	2.7	1	80	75	111	120
B8PR1021/MB116C	E	2.7	1	73	68	89	96
B9PR2137	E	2.7	1	78	69	125	140
(PM12713*Tx2882)-CM3-CM2-	E	2.7	1	84	81	146	163
BTx640	R-CK	3	1.3	69	67	98	109
97M13/(Tx2882*6EO374)/7BRON152	E	3	1	74	70	106	106
((SC228*Tx2767)*Tx2876)	E	3	1	74	70	97	95
(Tx2882*SRN39)-CM3-SM2-SM2-SM2	E	3	1.3	76	69	108	117
(BVar*MB102-3)-CM5-SM2	E	3	2.3	76	71	93	91
(BArg34*MB120C-BM5)-SM3-	E	3	1	68	65	98	105
97M9/(Tx2882*7EO366)/7BRON146	E	3.3	1	77	69	107	121
(PM12713*Tx2882)-CM7-CM1-	E	3.3	1	81	72	109	108
(88B885/(Tx623*CS3541)*Tx2782)-BM8-LMBK-	E	3.3	1.7	76	74	125	121
(MR127-92M5*MR114-90M11)-SM17-	E	3.3	1.3	80	71	91	104
B8PR1011/MB120A	E	3.3	1	72	66	118	125
B8PR1013/MB120A	E	3.3	1	71	67	120	126
B8PR1017/MB124B	E	3.3	1	79	71	84	89
B8PR1019/MB131B	E	3.3	1	68	61	105	121
B8PR1041/BArg34*MB120C	E	3.3	1	66	67	111	105
(MR112B-92M2*Tx2880)-SM17-	E	3.3	1	75	70	99	121
97M17/(PR12713*Tx2880)/7BRON156	E	3.7	1	71	68	103	119
BTx641	R-CK	4	1	69	65	114	105
(Tx631*MB126E-BM6-)-SM4-CM1-	E	4	1.3	83	75	83	107
(MB120C-BM5-*MB108B/P.G.)-SM10-CM1-	E	4	1	74	69	119	120
(MB126E-BM3-*MB108B/P.G.)-SM5-CM2-	E	4	1	75	69	104	116
(PM12713*Tx2880)-CM5-CM3-	E	4	0.7	78	75	109	119
(Tx430*MR112B-92M2)-SM29-	E	4	0.7	65	69	99	96
B9PR2145	E	4.3	1.3	79	72	111	116
TAM2566	R-CK	4.7	1	64	67	92	89
(MR127-92M5*MR114-90M11)-SM2-SM1-	E	4.7	1	77	70	101	107
(BVar*MB102-3)-CM5-SM2	E	4.7	1.3	74	69	129	129
(MB120C-BM5-*MB108B/P.G.)-SM10-CM1-	E	4.7	1.3	73	70	121	144
MB108B/P.G.	R-CK	5.3	1.3	81	73	137	119
BTx2755	R-CK	6	1	72	67	89	101
Tx2767	R-CK	6	1.7	84	74	114	116
Tx2882	R-CK	6	1.3	80	72	97	97
RTx430	S-CK	6.7	2.7	77	69	111	105
BTx378	S-CK	8.3	2.3	70	65	116	115
BTx3042	S-CK	9	3	60	61	95	103
MEAN		3.7	1.3	75	70	107	112

† E = Experimental Entry; R = Resistant Check; S = Susceptible check.
‡ Rated on a scale of 1 = 0-10% damaged kernels, 2 = 11-20% damaged kernels, up to 9 = 81-100% damaged kernels.
§ CM = Corpus Christi late; CA = Corpus Christi early; H = Halfway.

Table 2. Grain yield, midge damage rating, and 100 seed weight for selected entries in the 2000 Midge Hybrid Test.

	Class[†]	Grain yield			Midge damage rating[‡]		100 Kernel weight		
		CM[§]	CA	H	CM	CA	CM	CA	H
A8PR1011*Tx2880	E	3720	3682	3152	1	1.7	3.2	2.5	2.71
A8PR1015*Tx2880	E	3538	3959	3265	1	1	3.8	3.2	2.6
A8PR1013*Tx2882	E	3381	3393	3122	1.7	1	3.3	2.3	2.51
A8PR1019*Tx2880	E	3328	2947	2673	1	1	2.5	2.5	2.85
A8PR1019*Tx2882	E	3305	2970	2603	1.7	1	2	2.5	2.76
ATx2755*97M17	E	3274	2741	3590	2.7	1	3.7	2.5	2.8
A8PR1013*Tx2880	E	3008	3267	2372	1	1	2.7	2.5	2.67
ATx2755*97M14	E	2624	2579	3431	2	1	2.8	2.8	2.98
ATx2755*97M16	E	2617	3514	3548	3	1	2.5	3	2.91
A8PR1021*Tx2880	E	2480	2457	2202	1.3	1	1.7	2.2	2.53
A8PR1017*Tx2880	E	2268	2981	2426	1.7	1	3.3	2.2	2.46
A8PR1011*Tx2882	E	2195	3240	2897	2.3	1	2.3	2.3	2.89
A8PR1017*Tx2882	E	2167	2339	2077	2.3	1.3	2.8	2.2	2.43
ATx2755*97M13	E	2145	3273	3308	3.3	1.3	3.3	2.2	3.08
A9PR2145*Tx2882	E	2128	2901	2681	1.3	1.3	2.7	2.5	2.51
ATx2752*RTx430	S-CK	2113	4095	3445	5.7	1.3	2.3	3	2.68
ATx2755*Tx2882	R-CK	2042	2540	3089	2.7	1.3	3.7	2.7	2.91
ATx2755*97M9	E	2008	2333	2421	3	1	2.7	2.2	2.63
ATx2755*Tx2880	R-CK	1705	1655	2397	4	1	3.8	2.5	2.9
ATx2755*Tx2767	R-CK	1673	3258	3080	4.3	1	3	2.5	2.84
ATx3197*Tx7078	S-CK	1461	1863	1226	6.7	1.3	2.8	2.8	2.84
ATx2752*Tx2783	S-CK	1328	4110	3180	7	1.3	2.3	3.5	2.39
ATx2752*Tx2862	S-CK	1168	2104	3140	7	2	2.3	3.7	2.53
A807*Tx2783	S-CK	1092	3265	3794	8	2.3	2	3.2	2.72
A1*Tx2783	S-CK	969	4305	3634	7.7	2	2	3	2.84
A1*Tx2862	S-CK	830	3111	2770	9	2.7	2	3	2.78
A807*Tx2862	S-CK	714	4695	3347	8.7	1.3	2	3	2.82
A35*Tx2862	S-CK	686	4767	1747	8.7	1.3	2.3	3	2.79
A35*Tx2783	S-CK	468	3988	3727	8.3	1.3	1.3	3.7	2.76
Mean		1998	2800	2605	3.6	1.2	2.7	2.6	2.6
LSD .05		846	994	736	2.3	0.8	0.9	0.1	0.3

of marker-assisted selection versus traditional selection methodology. Three greenbug resistance sources are used: Capbam through Tx2783, PI550607, and PI550610. The source of post-flowering drought tolerance is the cross B35*Tx7000. Backcrossing was continued to introgress the resistance genes into elite genetic backgrounds. The research project is focusing on the evaluation of BC2 to BC4 backcross progeny for post-flowering drought resistance. Molecular markers were used to identify stay-green (post-flowering drought resistance trait) QTLs that were introgressed into greenbug resistant and other sorghum elite lines. DNA analysis will be performed to provide a stay-green and greenbug resistance QTL profile of the backcross progeny (mainly the BC2) to correlate molecular data with phenotypic data. In addition to phenotypic stay-green scoring in the field tests, lines (stay-green introgressed into greenbug resistant lines) will also be evaluated in greenhouse seedling stage tests to determine the level of greenbug resistance.

The program to develop resistance to sugarcane aphid completed the second year. The program now involves TAM-223 and Southern Africa collaborators. 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, and backcrosses of selected F_1's to adapted cultivars made to introduce additional favorable traits including foliar disease resistance. The breeding populations were planted at Corpus Christi and Lubbock, Texas for U.S. selection.

A 100-entry test for sugarcane aphid resistance was developed and sent to Southern Africa. The test was evaluated for resistance to sugarcane aphid in a greenhouse screening at the ARC, Potchefstroom, South Africa (Table 3). Thirty-eight experimental entries sustained damage less than or equal to several resistant checks (WM#322, Ent. 62/SADC, FGYQ353, TAM428). The sugarcane aphid resistant breeding materials are mostly in the F_4 or F_5 generation. The breeding lines will undergo additional selection in Texas, and screening and agronomic evaluation in Southern Africa. The lines should contain wide adaptation, sugarcane aphid resistance, disease resistance (primarily sooty stripe and anthracnose), and other favorable traits. Traits needed to enhance use include tan plant, white pericarp, and appro-

Table 3. Mean damage score and aphid abundance in the 2001 Sugarcane Aphid Test, Potchefstroom, South Africa.

Source	Designation	Damage[†]	Abundance[‡]
97LI726	Sima (IS23250)	1.0	1.0
97LI727	CE151	1.0	2.0
97LI728	WM#177	1.0	1.0
97LI729	WM#322	1.0	2.0
00CC110-BK	PRGC/E#222878	1.0	1.0
00CC111-BK	PRGC/E#222879	1.0	1.5
00CC112-BK	PRGC/E#69414	1.0	1.5
00CC113-BK	SDSL89426	1.0	1.5
00CC201-BK	(Macia*TAM428)-HD1-	1.0	1.0
00CC119-BK	(Macia*TAM428)-LL2	1.0	2.0
00CC120-BK	(CE151*BDM499)-LD17-BE2	1.0	3.0
00CC125-BK	(87EO366*TAM428)-HF2	1.0	1.5
98LI303	GR128-92M12	1.0	1.0
00CC134,228-BK	(Tx436*GR108-90M24)-LG8	1.0	1.0
00CC150-BK	(6OB128/(Tx2862*6EO361)*CE151)-LG19-	1.0	2.0
00BG13433-BK	(SDSL89426*6OB124/GR134B-LG56-)-LG5-CG1	1.0	1.0
00BG13499-BK	(SV1*Sima/IS23250)-LG6	1.0	1.5
00BG13552-BK	(6BRON126/(87BH8606-14*GR107-90M46)*EPSON2-40/E#15/SADC)-LG2-LG1	1.0	3.0
00BG13567-BK	(CE151*TAM428)-CG1	1.0	1.0
00BG13575-BK	(CE151*TAM428)-LG1	1.0	2.0
00BG13612-BK	(Segaolane*WM#322)-LG2-LG2	1.0	1.0
00BG13615-BK	(Segaolane*WM#322)-CG1	1.0	1.5
00BG13629-BK	(Segaolane*FGYQ336)-CG5	1.0	2.0
00BG13655-BK	(Town*EPSON2-40/E#15/SADC)-CG3	1.0	2.5
00BG13737-BK	(6OB124/(GR134B-LG56)*EPSON2-40/E#15/SADC)-CG2	1.0	2.0
00BG13748-BK	(6OB128/(Tx2862*6EO361)*CE151)-LG3-LG1	1.0	1.0
00BG13749-BK	(6OB128/(Tx2862*6EO361)*CE151)-LG4-CG1	1.0	1.5
00BG13775-BK	(6OB128/(Tx2862*6EO361)*CE151)-LG25-CG1	1.0	1.5
00BG13778-BK	(6OB128/(Tx2862*6EO361)*CE151)-LG27-LG1	1.0	1.0
00BG13835-BK	(CE151*A964)-CG1	1.0	1.5
00BG13891-BK	(EPSON2-40/E#15/SADC*TAM428)-CG1	1.0	2.0
00BG13982-BK	(5BRON139/((6EO361*GR107der)-LG7)*CE151)-LG2	1.0	2.0
00BG14014-BK	(6BRON161/((7EO366*Tx2783)-HG54)*CE151)-CG3	1.0	2.5
00CC108-BK	Ent.62/SADC	1.5	2.0
00CC119-BK	(Macia*TAM428)-LL7	1.5	2.0
00CC240-BK	(Tx2883*(Tx2880*(GR108-90M24*(Tx2862*(Tx430*(Tx2862*PI550607))))))-PR2-	1.5	3.5
00CC142-BK	(SDSL89426*6OB124/GR134B-)-LG5-	1.5	2.0
00CC147-BK	(Tx430*Sima/IS23250)-LG5-	1.5	1.5
00BG13477-BK	(EPSON2-40/E#15/SADC*A964)-CG3	1.5	2.0
00BG13551-BK	(6BRON126/(87BH8606-14*GR107-90M46)*EPSON2-40/E#15/SADC)-LG1-LG1	1.5	2.5
00BG13553-BK	(6BRON126/(87BH8606-14*GR107-90M46)*EPSON2-40/E#15/SADC)-LG3-CG1	1.5	2.5
00BG13607-BK	(Segaolane*CE151)-LG2	1.5	2.0
00BG13668-BK	(Macia*TAM428)-CG2	1.5	2.5
00BG13679-BK	(A964*FGYQ336)-LG4-LG2	1.5	2.0
00BG13954-BK	(5BRON131/((80C2241*GR108-90M30)-HG46)*WM#177)-LG1	1.5	1.5
00BG14038-BK	(6BRON161/((7EO366*Tx2783)-HG54)*CE151)-LG1	1.5	1.5
97LI730	FGYQ336	2.0	2.5
00CC109-BK	FGYQ353	2.0	2.0
97LI725	TAM428	2.0	1.5
00CC117-BK	(CE151*BDM499)-LD17-BE1	2.0	2.0
00CC121-BK	(Macia*TAM428)-LL9	2.0	2.0
98LI308	6OB124	2.0	2.0
00CC131,226-BK	(Tx2783*VG15/M50009)-LG9-	2.0	3.0
00BG13471-BK	(EPSON2-40/E#15/SADC*A964)-LG2-CG1	2.0	2.5
00BG13494-BK	(EPSON2-40/E#15/SADC*5BRON131/(80C2241*GR108-30)-HG46-)-CG5	2.0	2.0
00BG13583-BK	(EPSON2-40/E#15/SADC*TAM428)-LG3-CG1	2.0	2.5
00BG13643-BK	(Town*EPSON2-40/E#15/SADC)-LG1-CG2	2.0	3.0
00BG13652-BK	(Town*EPSON2-40/E#15/SADC)-LG12-CG3	2.0	3.0
00BG13654-BK	(Town*EPSON2-40/E#15/SADC)-CG2	2.0	3.0
00BG13665-BK	(Macia*TAM428)-LG8-LG1	2.0	3.0

Table 3. (Continued)

Source	Designation	Damage†	Abundance‡
00BG13714-BK	(6OB124/(GR134B-LG56)*WM#177)-LG2	2.0	3.0
00BG13744-BK	(6OB128/(Tx2862*6EO361)*CE151)-LG1-CG1	2.0	2.5
00BG13751-BK	(6OB128/(Tx2862*6EO361)*CE151)-LG5-CG1	2.0	1.5
00BG13752-BK	(6OB128/(Tx2862*6EO361)*CE151)-LG5-LG1	2.0	3.0
00BG13848-BK	(6OB128/((Tx2862*6EO361)-LG30)*EPSON2-40/E#15/SADC)	2.0	2.5
00BG13869-BK	(6BRON126/((87BH8606-14*GR107-90M46)-HG10)*CE151)-CG1	2.0	2.0
98LI269	MB108B	2.5	4.0
00BG13512-BK	(6OB124/(GR134B-LG56)*WM#177)-CG1	2.5	2.0
00BG13558-BK	(CE151*TAM428)-LG2-CG1	2.5	2.0
00BG13664-BK	(Macia*TAM428)-LG4-LG1	2.5	3.0
00BG13683-BK	(A964*FGYQ336)-LG13-LG1	2.5	3.0
00BG13705-BK	(6OB124/(GR134B-LG56)*WM#177)-LG7-CG2	2.5	2.5
00BG13739-BK	(6OB124/(GR134B-LG56)*EPSON2-40/E#15/SADC)-CG4	2.5	2.0
00BG13759-BK	(6OB128/(Tx2862*6EO361)*CE151)-LG10-CG1	2.5	3.0
00BG13796-BK	(6BRON161/(7EO366*Tx2783)*CE151)-LG5-CG2	2.5	3.5
00BG13871-BK	(6BRON126/((87BH8606-14*GR107-90M46)-HG10)*CE151)-CG2	2.5	2.5
00BG13874-BK	(6BRON126/((87BH8606-14*GR107-90M46)-HG10)*CE151)-CG5	2.5	2.0
00BG13913-BK	(Town*EPSON2-40/E#15/SADC)-LG1	2.5	2.5
00BG13931-BK	(6OB128/((Tx2862*6EO361)-LG30)*CE151)-CG5	2.5	4.0
00CC114-BK	Kuyuma	3.0	3.0
97LI732	Segaolane	3.5	3.5
97LI734	Macia	4.0	3.5
	MEAN	2.0	2.4
	LSD	1.5	1.3

† Rated on a scale of 1 = no aphids or damage, 2 = light damage (few small bottom leaves significantly damaged), 3 = medium damage (few leaves with large damage), 4 = many leaves with damage and dying, 5 = plants dead or dying.

‡ Rated on scale of 1 = no aphids, 2 = light infestation (few aphids on few leaves), 3 = medium infestation (small colonies on many leaves), 4 = heavy infestation (many aphids on many leaves).

priate height and maturity. The midge line test was also evaluated for resistance to sugarcane aphid. Several experimental entries were identified with good levels of resistance and will be included in the 2002 sugarcane aphid test.

Networking Activities

Workshops

Global 2000: Sorghum and Pearl Millet Diseases III, 23-30 September 2000, Guanajuato, Mexico. Presented invited paper titled "PROFIT - A New Paradigm for Sorghum Research and Information Delivery.

INTSORMIL/ICRISAT strategic research planning session. Represent INTSORMIL as Technical Committee chair, 30 September 2000, Guanajuato, Mexico.

Southern Africa Sorghum and Millet Improvement Network Steering Committee meeting. Represent INTSORMIL as Southern Africa Regional Coordinator. 4-5 October 2000. Bulawayo, Zimbabwe.

SADC Regional Workshop on Sorghum and Millet Crop Improvement. Represent INTSORMIL as Southern Africa Regional Coordinator. 16-18 October 2000. Bulawayo, Zimbabwe.

Research Investigator Exchanges

Zimbabwe, Mozambique, Namibia, and Zambia - 1 to 20 October 2000. Discuss INTSORMIL research and collaborative activities with officials and/or scientists in each country. In Zimbabwe, met with ICRISAT representatives to discuss collaborative activities with SMINET, and with Department of Research and Special Services scientists in breeding, plant pathology, and cereal quality to discuss research. In Mozambique, met with the Instituto Nacional de investigação Agronómica Director General and scientists, USAID, and World Vision to discuss initiation of INTSORMIL activity in-country and the Inter-CRSP training program. In Namibia, met with representatives of the Ministry of Agriculture, Water and Rural Development, and USAID to discuss INTSORMIL activity and plans for the next five years. In Zambia, met with Ministry of Agriculture, Department of Agricultural Research scientists and USAID to discuss INTSORMIL/Zambia activity and five-year plans.

Nicaragua and El Salvador - 3 to 9 December 2000. In Nicaragua, evaluated sorghum research plots at Managua and sorghum production in the Estelí region. In El Salvador, evaluated sorghum research plots near San Salvador and Izalco, and sorghum production and plots in the Texistepeque region.

South Africa, Botswana, and Zambia - 2 to 14 April, 2001. In South Africa, met with collaborators at the ARC, Potchefstroom, to evaluate collaborative activity and plan future research. Discussed ARC/INTSORMIL collaboration with ARC administrators. In Botswana met with Department of Agricultural Research scientists to plan future research activity. In Zambia met with Ministry of Agriculture, Department of Agricultural Research scientists to discuss sorghum and pearl millet research. Evaluated pearl millet research in the Kaoma region. Attended the Mt. Mukulu Station field day.

Germplasm and Research Information Exchange

Germplasm Conservation and Use

- Germplasm was distributed to private companies as requested and to the following countries, including but not limited to: Mali, Senegal, Nicaragua, El Salvador, South Africa, Botswana, Zimbabwe, Zambia, and Mozambique. Entries in the All Disease and Insect Nursery (ADIN) were evaluated at many locations domestically and internationally.

- The following TAM-223 developed experimental lines were increased in Lubbock (2000 summer) or Puerto Rico (2001 winter nursery) for use as hybrid seed parents in the summer of 2001: sorghum midge resistant: Tx2880 and A8PR1013; biotype E greenbug resistant: 5BRON139, A8PR1059, biotype E/I greenbug resistant: LG35. Seed was provided to a private seed company to produce hybrids for wide area testing in 2002 as part of the PROFIT initiative.

- Germplasm previously developed and released by this project is used widely used by commercial seed companies in hybrid production.

- Participated in short- or long-term training of collaborators from Mali, Nicaragua and El Salvador.

Other Cooperators

Collaboration with the following scientists was important in the activities of TAM-223:

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

Dr. Y. Doumbia, Entomology, IER, Sotuba, B.P. 438, Bamako, Mali

Publications and Presentations

Abstracts

Rosenow, D.T., N. Teme, C.A. Woodfin, G.N. Odvody, and G.C. Peterson. 2000. Relationship of stay-green with charcoal rot and lodging in sorghum. *In* Proc. of Global 2000: Sorghum and Pearl Millet Diseases III. Guanajuato, Mexico, Sep. 23-30, 2000. (In Press).

Presentations

Peterson, G.C., B.B. Pendleton, and G.L. Teetes. 2000. PROFIT - Productive Rotations On Farms In Texas: A New Paradigm for Sorghum Research and Information Delivery. *In* Proc. of Global 2000: Sorghum and Pearl Millet Diseases III. Guanajuato, Mexico, Sep. 23-30, 2000. (In Press).

Books, Book Chapters and Proceedings

Machado, S., E.D. Bynum, Jr., T.L. Archer, R.J. Lascano, J. Bordovsky, K. Bronson, D.M. Nesmith, E. Segarra, D.T. Rosenow, and G.C. Peterson. 2000. Spatial and temporal variability of sorghum and corn yield: interactions of biotic and abiotic factors. *In* Proc. of the 5th Int. Conv. on Precision Agriculture, Minneapolis, MN, July 16-19, 2000.

Miscellaneous Publications

Rosenow, D.T., J.A. Dahlberg, G.C. Peterson, L.E. Clark, J.W. Sij, A.J. Hamburger, P. Madera-Torres, and C.A. Woodfin. 1999. Release of 27 converted sorghum lines. International Sorghum and Millets Newsletter 40: 29-31.

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

Principal Investigator

Dr. Bruce R. Hamaker, Department of Food Science, Purdue University, West Lafayette, IN 47907-1160

Collaborating Scientists

Mr. Kaka Saley, Cereal Scientist; Dr. Adam Aboubacar, Cereal Technologist; Ms. Ramatou Seydou, Chemist; Moustapha Moussa, Cereal Technologist; Mr. Moussa Oumarou, Chemist; INRAN B.P. 429, Niamey, Niger

Ms. Senayit Yetneberk, Food Technologist, IAR, Nazret Research Station, P.O. Box 436, Nazret, Ethiopia

Ms. Betty Bugusu, Food Technologist, KARI, Katumani National Dryland Farming Research Center, P.O. Box 340, Machakos, Kenya

Dr. Arun Chandrashekar, Cereal Chemist, CFTRI, Department of Food Microbiology, Mysore 570013, India; Dr. D.S. Murty, Mahyco Research Foundation, Hyderabad, India

Dr. John Axtell (deceased), Sorghum Breeder; Dr. Gebisa Ejeta, Sorghum Breeder; Dr. Robert Elkin, Poultry Nutritionist; Ms. Chia-Ping Huang, Cereal Chemist; Ms. Debra Sherman, Microscopist; Lexingtons Nduulu, Sorghum Breeder, Purdue University, West Lafayette, IN 47907

Dr. Brian Larkins, Plant Molecular Biologist, University of Arizona, Tucson, AZ

Summary

In the past year, we have continued work on nutritional quality of sorghum grain, including protein digestibility and starch digestibility (availability) in cooked products and raw grain, and on processing grains to couscous and high quality flours in West Africa and factors related to product quality. We sadly saw the passing in December 2000 of John Axtell who was our partner and collaborator. He is greatly missed. Following the identification in the mid-1990's of a high protein digestibility trait in sorghum and subsequent development of a turbidity-based rapid screening assay, recent efforts have focused on improvement of grain quality. The mutation results in deeply folded, rapidly digestible protein bodies and was found in modified high-lysine lines derived from the soft, floury kernel mutant, P721Q. This year we identified highly digestible grain that had a normal appearing grain type with vitreous (hard) endosperm (see Figure 2). However, problems are still evident in stability of this phenotype, as variability in grain quality was noticed both within panicles and due to growing environment and location. Yet, this was promising as it shows the potential for combining the high protein digestibility mutation with a hard, normal kernel type. We are also completing a three year collaboration with Indian scientists funded through the Mahyco Research Foundation to incorporate the high protein digestibility trait into elite Indian sorghum germplasm. Results look promising regarding the combining of the trait into improved quality kernels, and both India and Purdue laboratories are involved in definitive testing of the trait. Biochemical studies performed at CFTRI, India have further characterized the mutation and its effect in the seed, and suggest a single gene mutation that results in abnormal protein body development and concurrent over expression of lysine-containing proteins. Animal studies are planned for assessment of the improved material *in vivo*.

We have focused again in our laboratory on the fundamentals causing the somewhat low starch digestibility found in sorghum grain used in livestock feed and more pronounced reduction in digestibility in cooked porridges consumed by humans. High protein digestibility mutant sorghum flour cooked to a paste was found to have a significantly higher *in vitro* starch digestion rate than normal sorghum when pretreated with a protease (pepsin) prior to α-amylase digestion (see Figure 3). This strengthens a general thought that protein and starch digestibilities are linked, and that a rapidly digesting protein would result in rapidly digesting starch. This may be useful in creating a more nutrient available weaning foods from sorghum. Further studies will give attention to the mechanism involved and the possibility of manipulating starch digestion rates both ways for potential health benefits of slowly digesting starches as well as those that are rapidly digesting.

Processing of agglomerated products (principally couscous) and high quality flours in Niger continues with the current objective to test high quality products in the home and marketplace. Our overall objective of the INTSORMIL/INRAN (Niger) project is to facilitate and stimulate commercial processing of high quality sorghum

and millet products in Niamey and other urban areas in Niger. This is a cross-disciplinary project done in concert with sorghum breeders and economists, and involves the cereal processing unit put together at INRAN over the past five years. The sorghum hybrid, NAD-1, grown in the first planting following the rainy season, is used as a pure high quality grain source for the processing unit. Processing of hybrid sorghum agglomerated products or high quality flours for commercial markets would create an outlet for the increased production of hybrids, and could encourage their adoption. Equally important, cereal processors require a consistent supply of good quality grain, with preference given to a single grain sources, such that a hybrid would provide. I. Kapran and J. Axtell developed hybrid technology in Niger with the release of NAD-1. New, improved tan plant sorghum hybrids are now in test plots. In the past year, an in-home consumer study was conducted in Niamey by INRAN food technologists and economists to assess quality and marketability of the couscous. Early results indicate that the couscous has sensory properties very much liked by consumers. Overall average ratings for color, particle size, firmness, stickiness, flavor, swelling power, taste were good to very good, and, compared to imported couscous, consumers found NAD-1 couscous to be as acceptable. A large scale market test in Niamey is being conducted in the Summer 2001. In-home and market test studies were designed collaboratively with economists C. Nelson (INTSORMIL) and J. Ndjeunga (ICRISAT).

Objectives, Production and Utilization Constraints

Objectives

- 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.
- Optimize processes and improve quality of commercializable sorghum and millet processed foods, and facilitate transfer of technologies.

Constraints

Research on food and nutritional quality of sorghum and millet grains is necessary to improve grain quality characteristics and stimulate commercial processing 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

Couscous and High Quality Flour Processing

Couscous Processing Unit in Niger

Over the past five years PRF-212 and INRAN/Niger Food Technology Laboratory have worked together to set up in Niamey an entrepreneurial-scale couscous and flour processing unit. Much time and effort was put into optimizing the process. The project's goal is to develop agglomerated and flour products of consistently high quality that can be successful in the commercial marketplace, and to demonstrate and extend these technologies to interested entrepreneurs. In 1995, the core of the sorghum/millet processing unit was installed at INRAN; consisting of a central mechanized agglomerator designed and fabricated at CIRAD, France by J. Faure, a mixer for flour wetting, a couscousierre (steamer), a small solar drier with through ventilation powered by a solar cell (fabricated in Niamey by ONERSOL), and a sealer for packaging. The initial unit was funded through the then functioning Niger InterCRSP project. Since that time, a much larger passive solar drying unit was built at INRAN to dry approximately 200 kg couscous every 2 days. As high quality flours are essential to make quality couscous, a small-scale commercial grain decorticator (dehuller) and hammer mill (Urpata Sahel, Dakar) were procured through PRF-212 to compete the unit. This last addition has also permitting INRAN cereal technologists to begin work on production of high quality sorghum and millet flours and other products made from them. A similar decortication and hammer mill unit is in the process of being obtained for the sorghum utilization group at EARO/Ethiopia (delays in procurement have been experienced with the fabricator).

Central to this effort has been a continued working relationship with the sorghum breeding program of Kapran-INRAN/Axtell-Purdue. Their hybrid, NAD-1, is being used to produce processed products, and in the last year was used both to produce large quantities of couscous for an in-home consumer test conducted Fall 2000 and for a three-level market test conducted Summer 2001. This effort was assisted by economists C. Nelson (INTSORMIL) and J.

Ndjeunga (ICRISAT/Mali). An added objective of the project is to stimulate demand for sorghum hybrids through processed products sold in the marketplace. The advantage of the hybrid to a processor is a ready supply of pure source grain, which is a prerequisite to processing high quality commercial products. Current products that are produced by the group are the agglomerated products – fine couscous (or *dambou*), medium couscous, and the coarse particle-size product *degue* – and high quality decorticated flour. All agglomerated products are precooked and dried. Figure 1 shows the packaged couscous product as used in the test trials. In an effort to move extend these process technologies to interested entrepreneurs, the INRAN Cereal Technology group has formed an association with local food processors. Through joint meetings they have sought advice from entrepreneurs in terms of product quality, marketing, and packaging.

Over the course of the project, fundamental studies have been conduced at Purdue to describe grain properties necessary to produce a high quality commercial couscous and to elucidate the basis of couscous stickiness, an undesirable property in sorghum and millet-based agglomerated products. Studies of note include determination of the relationship between decortication rate and couscous color, and elucidation of the origin of stickiness in cooked couscous. Substantial improvement in couscous color was achieved through appropriate decortication, with the poorest colored grain requiring decortication to 30-40% to achieve a light colored processed product. Decortication rate also affected couscous granule size distribution. For all the cultivars, highest proportion of fine (< 1mm) couscous granules was obtained at 10 % kernel removal. As percent kernel removed increased, the proportion of fine (< 1mm) granules decreased and that of intermediate (1-2 mm) and coarse (> 2mm) granules increased gradually. The best couscous

Sorghum Couscous —— INRAN/Niger

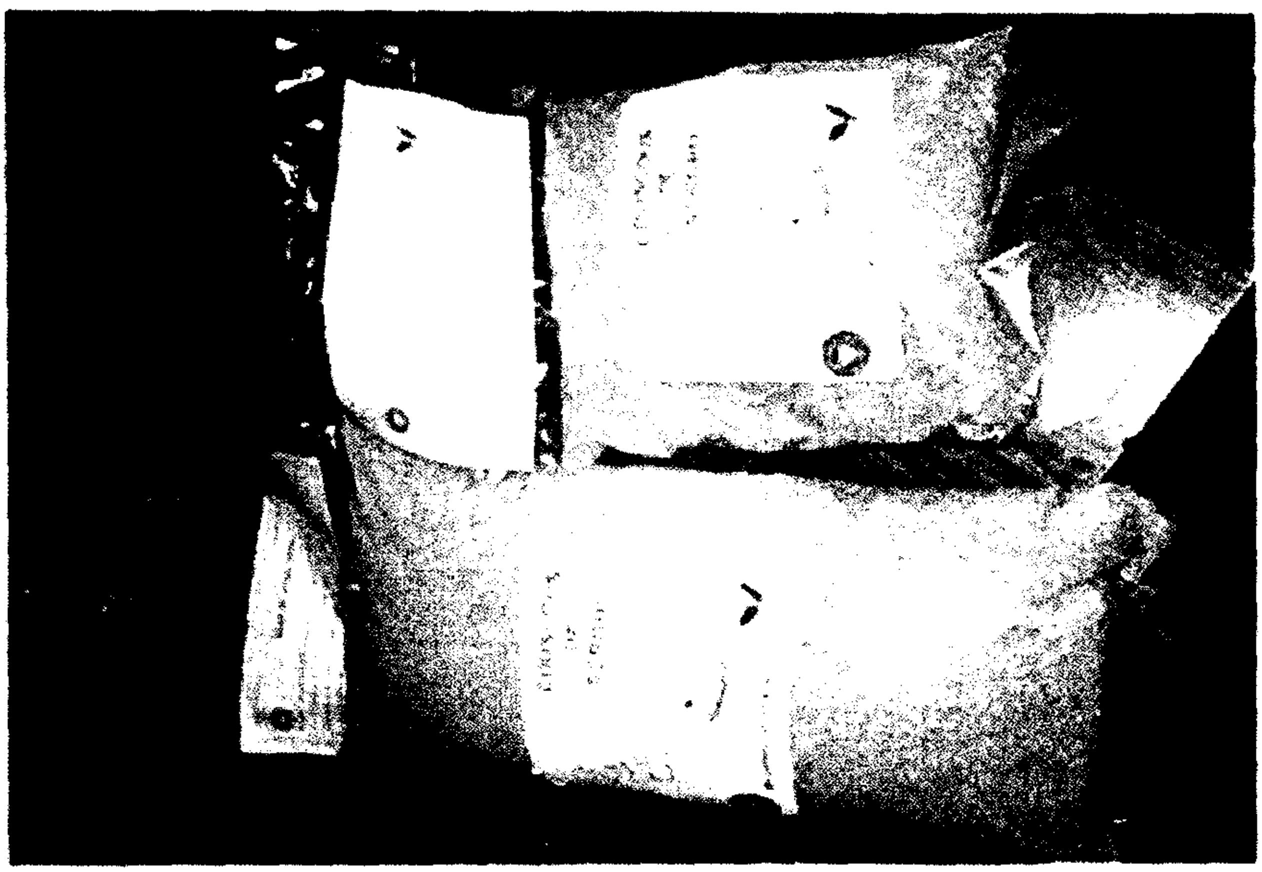

Figure 1. Hybrid sorghum NAD-1 couscous product prepared for testing in the Niamey, Niger market and expositions put on by food technologists at INRAN. 144 bags of 500 g each were sold for 500 CFA at the August 2000 exposition.

granule distribution was obtained when flours from 20 to 30% kernel decorticated were used. Stickiness, one of the critical textural characteristics of couscous, is viewed as an undesirable factor. Good quality cooked couscous is a soft, fluffy product that easily falls apart on the plate. In studies of the sticky factor in couscous, we found that a branched, water-soluble fraction of cooked couscous was highly and significantly correlated to the product's stickiness. Because structural features of this branched glucan were similar to that of the large branched starch molecule, amylopectin, it was concluded to be fragmented amylopectin. Further studies showed that molecular fragmentation takes place at the milling step and that harder kernel-type sorghum varieties were more prone to breakage. When added to starch gels, isolates of the fragmented fraction created stickier gels, thus confirming its function in the cooked couscous product. Other than control by milling and selection of kernel type, addition of 2% oil was found to substantially reduce couscous stickiness, particularly in those varieties with higher stickiness values.

In-Home Consumer Test of Couscous Product

An in-home consumer test was undertaken to determine the market potential of couscous made from NAD-1. The study was designed in two phases and carried out by the INRAN cereal technology and economics groups. C. Nelson and J. Ndjeunga assisted in study design, and A. Aboubacar from Purdue traveled to Niamey in August 2000 to assist in study planning and implementation, as well as to participate in a public exposition of the processing unit. The objective of phase I was to determine factors affecting consumer acceptability of a commercial sorghum couscous in different sectors of the market. This phase yielded information on the potential marketability of couscous or improvement in processing to meet consumer demand. The study was conducted with 72 families and 24 restaurants in the capital city of Niamey. All families selected were of the medium income category and in which couscous is consumed regularly. For each family and restaurant, three kilograms of couscous were provided. Couscous was cooked on the day of data collection. The manner of couscous cooking was left to the discretion of each family and restaurant. The questionnaire included terms ranging from sensory to price acceptability. Sensory terms were rated on a scale ranging from 1 to 5 (1 = very bad, 2 = bad, 3 = acceptable, 4 = good, 5 = very good). Consumers were also asked to give general comments on the couscous. Preliminary results indicated that the couscous had sensory properties very much liked by consumers. For example, overall average rating for color, particle size, firmness, stickiness, flavor, swelling power, taste were 4.1, 3.9, 4.2, 4.6, 4.0, 4.5, 4.2, respectively. Compared to imported couscous, consumers found NAD-1 couscous to be as acceptable. Even more encouraging was that consumers rated imported couscous as expensive. On a scale from 1 = very expensive, 2 = expensive to 3 = realistic, the overall average rating for imported couscous was 1.8. On the question of whether NAD-1 couscous can be readily marketed, 93% of people asked responded positively. Consumers were also asked what price they were willing to pay for bags of 0.5, 1, 2, and 5 Kg of NAD-1 couscous. The answers varied widely depending on family income. For example, consumers priced a 500 g bag of NAD-1 couscous from 165 to 300 CFA. The higher the income group corresponded to the more money consumers were willing to pay. Encouragingly, 144 bags of 500 g NAD-1 couscous were sold at a price of 500 CFA a bag on the exposition day.

The objective of the exposition day was to show to local authorities, food processors, entrepreneurs, and to the general public the results of research work conducted by the Food Technology Laboratory on processing of locally grown agricultural products. On August 12, 2000, the exposition day was held as planned. It was well attended by the public, government representatives (three ministers and one member of parliament), research institutions representatives, NGOs, private entrepreneurs, and mass media. The program began with three welcoming speeches followed by a narrated visit and demonstration of the food processing equipments, a display of 33 different processed products from millet, sorghum, cowpea, and cassava, each with its processing diagram. A booth was also set up for sales of NAD-1 products (*dambou*, couscous, *dégué*). Invitees were then served different meals based on NAD-1 products (particularly couscous). The event was so successful that the Minister of Rural Development, in a closing statement at the end of the day, requested that the organizers plan a second exposition day for a larger number of the public, government officials, and mass media to attend. He assured them of funding from the ministry and the second event took place in October 2000 and was televised throughout the country.

A Three-way Complex Involving Starch, Free Fatty Acids, and Protein – Fundamental Studies on Paste (Porridge) Properties

We have conducted some studies on a unique three-component complex we identified that was found in sorghum porridge. The high molecular weight complex (in the range of 1 million Daltons) consists of starch amylose, soluble protein, and free fatty acids was found to have a functional effect of markedly increasing the viscosity of warm (about 50°C) pastes. When whole grain sorghum was ground to flour and stored under ambient conditions, results showed 2-3 fold increases in Rapid ViscoAnalyzer cooling stage viscosity that was caused by release of free fatty acids. This occurred after about one month storage. The soluble complex was subsequently detected using high performance size exclusion chromatography (HPSEC) in a model system consisting of sorghum starch, soluble whey protein, and pure and mixed free fatty acid combinations. In a recent follow-up study, optimum ratios of these ingredients were determined through HPSEC monitoring and a fairly pure three-component complex preparation was obtained. Rheological (viscosity) characteristics are being studied to provide information on porridge quality changes that occur due to flour type and storage temperature.

Sorghum with High Protein Digestibility

Grain Quality

Work has continued on the high protein digestibility sorghum mutant that we reported on first in the mid-1990's. This genotype contains protein bodies with altered morphology consisting of a deeply folded structure that results in a high rate of digestion of the kafirin storage proteins. It was previously shown that the hard-to-digest γ-kafirin protein at the periphery of normal protein bodies, is found at the base of the folds of the mutant protein bodies, thus allowing the α-kafirin major storage protein to be quickly digested. Because of the soft, floury kernel background in which the high digestibility material was found (high-lysine P721Q-derived material), much of recent work, including this last year's, has focused on trying to improve grain quality. These studies were conducted in collaboration with J. Axtell's breeding program.

Studies reported in previous INTSORMIL Annual Reports showed that some degree of endosperm modification had been achieved through crossing the soft kernel P721Q–derived lines (high-lysine, high protein digestibility mutant) with hard, food grade genotypes. Modified endosperm, however, was atypical with the vitreous (hard) sector appearing internal and surrounded by opaque-looking sectors on the outside and inside of the kernel. Moreover, stability and uniformity of the modified endosperm was not apparent. Grain quality seemed to vary within a panicle, and growing location and year affected degree of modification. Recent efforts at Purdue have focused on a new generation of crosses of modified materials with very hard (rice-like) genotypes. At the F_4 generation, some progeny appeared improved with greater endosperm fill of vitreous sectors. In a few cases, kernels were identified that appear to be normal in the vitreous endosperm pattern (present at the periphery) and contained the mutant protein bodies with high digestibility (Figure 2). This shows importantly that the potential exists for normal kernel types combined with the high protein digestibility mutation. However, stability and uniformity of the modified kernel type still appears to be an issue.

A methodology development in the past year has been a modification in the preparing of samples for transmission electron microscopy, so that mature, dry seeds can be used opposed to developing material. Results of embedding and viewing dry grain can be seen in Figure 2. This allows us to view kernel endosperm characteristics and test protein body structure without having to grow out the seeds again to get developing tissue. This procedure was worked out by C.P. Huang and D. Sherman at Purdue. Although we consider reliable the turbidity assay that we developed for screening for the high protein digestibility trait (method available on request), viewing protein body structure is, unfortunately, still the definitive test available to determine whether the mutation is present.

Over the past three years, we have been involved in a collaborative study supported by the Mahyco Research Foundation (India) designed to incorporate the high protein digestibility mutation into elite high quality Indian sorghum genotypes. Collaborators in India have been Dr. A. Chandrashekar of the Central Food Technology Research Institute in Mysore and Dr. V.S. Murty associated with the Foundation. Progeny from crosses are currently being evaluated for improved grain type with the accompanying altered protein body structure. Other studies from this collaboration to be reported elsewhere show a number of biochemical changes in the mutant that suggest a single mutation is responsible for the high protein digestibility and high-lysine traits.

Protein Body Structure in Developing Sorghum High Protein Digestibility Mutant Seeds

A seed developmental study was conducted on the high protein digestibility sorghum mutant to examine how abnormal protein bodies develop and mature. Two questions were posed: 1) were protein body structures in early phases of development lobed and deeply folded? – earlier micrographs had suggested that an internal spherical structure exists that may have been synthesized prior to the accumulation outside of α-kafirin in the lobed, folded structure, and 2) are α-kafirin proteins continuous in mature seed among protein bodies of the mutant– if so, this would suggest that proteins may have improved functional properties in food systems as they would be able to freely interact with one another.

Transmission electron micrographs of developing mutant seed showed that early developmental peripheral endosperm cells had highly folded protein bodies similar to those in cells that had undergone complete development. Thus, altered protein body structure appears immediately in the earliest stages of protein body synthesis. Of note also in these micrographs was the appearance in few, small peripheral endosperm cells of normal-appearing spherical protein bodies. This curious observation was verified in different developmental stages of different mutant endosperms, and could be the observance that two different types of protein bodies exist in an endosperm.

In mature seeds, micrographs showed that α-kafirin of protein bodies from the high protein digestibility mutant melds in places to form a type of protein matrix, instead of the individual and distinct protein bodies of normal genotypes. Previous work in our laboratory (reported in the 1999 and 2000 INTSORMIL Annual Reports) demonstrated that the α-zein maize protein (analogous to α-kafirin) forms viscoelastic fibrils in a bread dough system if the dough is mixed at 35°C (above the glass transition temperature of wetted zein). Bread loaf volume was consequently improved with zein addition. Free α-kafirin, that appears to exist in the high protein digestibility mutant sorghum kernels, may, thus, be able to contribute functionally to a food product by participating in viscoelastic fibril formation during

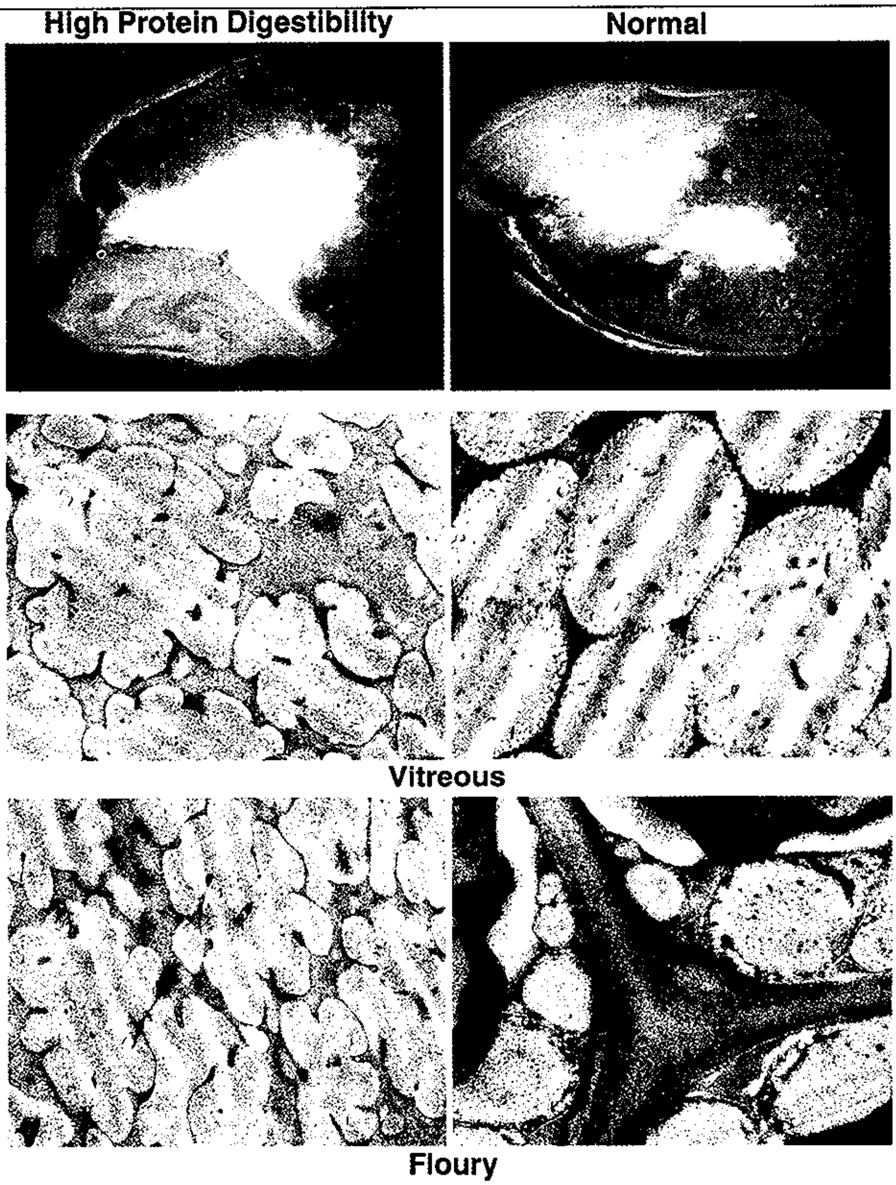

Figure 2. Longitudinal cross-sections of high protein digestibility (left) and normal (right) sorghum grains showing normal-appearing, hard kernel character of each. Transmission electron micrographs below of mature kernel endosperms of same show the altered protein body structure of the high digestibility mutant opposed to the typical spherical shape of normal protein bodies. Though not typical of high protein digestibility grain, this phenotype shows the potential of combining both nutritional and grain quality traits together.

processing. In other related work in our laboratory, we found that added zein protein to a starch-based model system produced extrudates that were more brittle (or more crisp) at intermediate moisture contents around 14% than sole starch extrudates. Further work needs to be done to determine whether available kafirin can be used to improve sorghum flour utilization characteristics.

Sorghum Starch Digestibility

Sorghum starch is somewhat less digestible than starches from other cereals. This is true both in animal feed, where processed sorghum has on average about 5% less nutritional value compared to maize, and is probably more pronounced in human food, where studies on children showed 21% of energy consumed from a sorghum diet was excreted in the feces; this compared to 13% for maize and 7% for rice. For human food, although there is a clear need to improve starch (energy) digestibility for certain segments of the population, i.e., weaned infants and those who have marginal caloric intake; in other segments there is a potential benefit in consuming slow digesting or resistant starch - for health reasons, or for slow energy release for extended work or sports. Better understanding of the mechanisms involved in lower starch digestion rates in raw and cooked sorghum products will provide strategies to increase starch digestibility or perhaps, if desirable, to also reduce digestibility.

Previously reported *in vitro* experiments from our laboratory using α-amylase as the digestive enzyme showed that starch from cooked sorghum flour pastes was about 20% less digestible than starch from a maize flour paste. Isolated starches, however, were about equal in digestibility, with sorghum starch even slightly more digestible than maize. Results from experiments using protein disrupting agents support a view that sorghum protein reduces starch digestibility in cooked flours. However, other extrinsic factors may also be part of the cause for the lower digestion rate of the cooked sorghum flour system, such as anti-nutritional factors (e.g., amylase inhibitor, phenolic compounds), dietary fiber content, resistant starch, and complexation of starch with lipid.

In vitro Starch Digestibility of Cooked Cereal Flours and Effect of Protease Pretreatment

An initial study was designed to determine how rate of protein digestibility affects rate of starch digestibility; the specific objective was to determine whether cooked high protein digestibility sorghum lines have corresponding high starch digestibility in cooked flour systems. Our hypothesis was that the mutant lines with rapid initial digestion rates of protein would concurrently make starch more available for digestion by α-amylase.

In an initial study, two sorghum cultivars (normal MR732 and a high protein digestibility mutant P851171), a normal maize inbred line (B73), and a rice cultivar (MILLS) were selected and analyzed for moisture, protein, and total starch contents. Protein digestibility was determined using the turbidity assay (as described in previous INTSORMIL Annual Reports) and starch digestibility was measured based on an α-amylase hydrolysis method. Cooked pastes were used as is or pretreated with the protease pepsin for 1 hour.

Cooked sorghum flours, both normal and mutant, showed significantly ($p<0.001$) lower starch digestibility than maize and rice flours (Figure 3). Starch digestibility of sorghum flour was 80-82% that of maize and 72% that of rice. These results are consistent with previous *in vitro* and *in vivo* studies that have shown sorghum starch (energy) to be less digestible than other cereals. Following 1 hour pepsin pretreatment, an increase in starch digestibility was observed in all the cooked cereal flours, though minimally in the normal sorghum flour. Notably, the highest increase of 21% was observed in the high protein digestibility sorghum mutant (P851171), followed by rice, 6.7%, and maize, 6.3%. Normal sorghum (MR732) flour had the lowest increase of 5.3%. In order to verify these results, starch digestibility studies were conducted on a different set of cultivars containing 2 normal and 2 high protein digestibility mutant sorghums. The results (data not shown) showed a similar trend of lower starch digestibility in normal sorghums after 1 h of pepsin pretreatment as opposed to the high protein digestibility genotypes.

The major difference observed between normal and high protein digestibility sorghum lines was attributed to differences in protein digestibility. As the protein is broken down by pepsin digestion, starch apparently becomes more accessible to starch hydrolysis enzymes resulting in higher starch digestibility. This phenomenon reflects the sequence of digestion of food in the human gastrointestinal tract, such that protein is first digested in the stomach by action of pepsin enzyme and later starch is digested in the small intestines by action of amylase enzymes.

The finding that high protein digestibility translates into high starch digestibility suggests that high protein digestibility sorghum genotypes have a improved potential as highly digestible energy sources for weaned infants and other nutritionally marginalized groups compared to normal sorghum cultivars. Further work is planned to better understand the fundamental basis of higher starch digestibility.

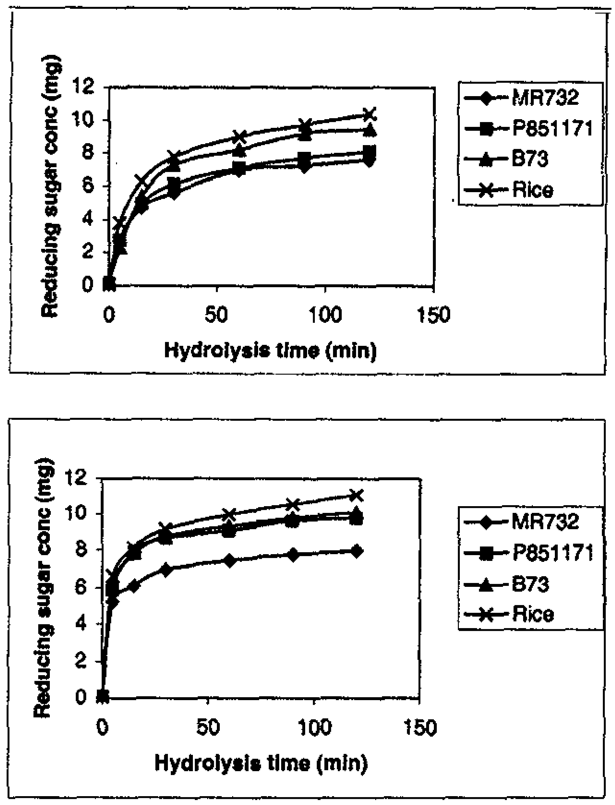

Figure 3. Time-course α-amylase starch digestion patterns using of normal (MR732) and high protein digestibility (P851171) sorghum, maize (B73), and rice flours. Upper graph shows digestion patterns using a-amylase alone and lower graph shows patterns after a 1 hr pepsin predigestion. High protein digestibility sorghum showed the largest increase in starch digestion rate following pepsin pretreatment.

Networking Activities

Aboubacar traveled to Niamey, Niger in August 2000 to assist with planning and implementation of the in-home consumer and market test of sorghum couscous. He also participated in arranging and putting on an exposition held at INRAN Food Technology Laboratory for government officials, entrepreneurs, and the media.

Hamaker attended the annual Sorghum Grain Conference held in Nashville, TN on February 2001 and presented a poster on the turbidity-based rapid screening assay for identification of the high protein digestibility trait.

Hamaker traveled to Niamey, Niger in March 2001 to work with collaborating food technologists on the couscous/flour marketing project, and, as newly assigned coordinator of the West Africa/Eastern Region project, to meet with INTSORMIL collaborating scientists from Niger and prospective new collaborators from Nigeria. A two day workshop was held in Niamey consisting of project reports, planning discussions, and a field trip.

Hamaker traveled to Mysore and Hyderabad, India in June 2001 to meet and discuss results of a three-year project on incorporating high protein digestibility material into Indian elite food quality lines. The project was funded by the Mahyco Research Foundation (India).

Publications and Presentations

Abstracts

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Aboubacar, A. and Hamaker, B.R. 2000. A new turbidity assay rapidly and efficiently identifies highly digestible sorghum cultivars. American Association of Cereal Chemists annual meeting, Kansas City, November, p. 271.

Mix, N.C., Aboubacar, A., and Hamaker, B.R. 2000. Origin of a water-soluble carbohydrate fraction related to couscous stickiness. American Association of Cereal Chemists annual meeting, Kansas City, November, p. 282.

Zhang, G. and Hamaker, B.R. 2000. Detection of a three-component complex among starch, protein, and free fatty acid. American Association of Cereal Chemists annual meeting, Kansas City, November, p. 314.

Bugusu, B.A. and Hamaker, B.R. 2000. Effect of added zein on properties and microstructure of sorghum-wheat composite flour dough and bread. American Association of Cereal Chemists annual meeting, Kansas City, November, p. 325.

Journal Articles

Bugusu, B.A., Campanella, O., Hamaker, B.R. 2001. Improvement of sorghum-wheat composite dough rheological properties and breadmaking quality through zein addition. Cereal Chem. 78:31-35.

Aboubacar, A., Axtell, J.D., Huang, C.P., Hamaker, B.R. 2001. A rapid protein digestibility assay for identifying highly digestible sorghum lines. Cereal Chem. 78:160-165.

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Weaver, C.M., Mason, A.C., Hamaker, B.R. 2000. Food uses, *In* Designing Crops for Added Value, American Society of Agronomy, Madison, WI.

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Mix, N.C. 2000. Origin and role of fragmented starch in couscous and porridge stickiness. M.S. thesis. Purdue University, West Lafayette, IN.

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Han, X.Z. 2001. Influence of starch structure and starch granule-associated proteins on rheological properties of starch pastes. Purdue University, West Lafayette, IN.

Food and Nutritional Quality of Sorghum and Millet

Project TAM-226

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Summary

New markets for value-enhanced white food sorghums developed in part by this project were promoted by the US Grains Council. Value-enhanced white food sorghums have been used by the Japanese food industry to market four snacks and several other products. More than 20 containers of identity preserved (IP) white sorghum were purchased.

In Central America, white food sorghums are used in pan dulce, breads, cookies and other products as a substitute for wheat or maize.

Several mills are producing sorghum flour for niche markets.

Special sorghums with high levels of phenols and antioxidants produce excellent chips and baked products. The antioxidant level in brown sorghum bran is higher than that of blueberries.

New commercial sorghum hybrids with tan plant white pericarp color were released from commercial hybrid seed companies. Several parental sorghum lines released from our program are used in commercial food hybrids. ATx 635 hybrids have outstanding milling properties.

Sorghum milling yields must be calculated on the basis of flour or grit yields adjusted to a common color value, i.e., an L of 70 for grits and 85 for flour where color attributes are important.

In Mali, 20% flour from N'Tenimissa, a white food sorghum, was used successfully in biscuits by a large industrial processor. The bland flavor and light color of white food type sorghums were superior to maize in composite baked products. However, IP grains of consistent quality are not available in sufficient quantity.

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

Near infra red equipment was calibrated and used for whole grain analysis of sorghums successfully. More work on calibrations for starch and physical tests is required.

A single kernel hardness tester was used successfully for hardness, kernel size and kernel weight. They are highly efficient methods for evaluation of grain quality.

Two M.S. students completed their studies. One joined the food industry and another continues studies for a Ph.D..

Objectives, Production, and Utilization Constraints

Objectives

- Develop new food products from sorghum and millet using technology appropriate for use in less developed areas.
- Determine physical, chemical and structural factors that affect the food and nutritional quality of sorghum; seek ways of modifying its properties or improving methods of processing.
- Develop simple, practical laboratory methods for use in breeding programs to assess important grain quality characteristics.
- Determine the factors that affect resistance to grain molds and field deterioration in sorghum and devise laboratory procedures to detect genotypes with resistance.

Constraints

Factors affecting food quality, processing properties, and nutritional value of sorghum and millet are critically important. If the grain cannot be processed and consumed for food or feed, then the agronomic and breeding research has been wasted. This project relates quality to measurable characteristics that can be used to select for sorghum and millet with acceptable traditional and industrial utilization attributes. It defines quality attributes and collaborates with breeders to incorporate desirable properties into new cultivars at early stages in the breeding and improvement programs. The project also seeks to find more efficient ways of processing sorghums and millets into new foods with better acceptability that can generate income for farmers and entrepreneurs.

The major constraint to development of profitable sorghum and millet foods is the lack of a consistent supply of good quality grain. Until a source of IP, good quality grain can be produced, sorghum and millet products will continue to be inferior. Systems for marketing IP grains as value-added products for urban consumers are critically important.

Grain molds 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.

Significant Accomplishment - New Markets for Food Sorghums

Several extruded salty snacks and milled products are advertised and sold by Japanese food companies (Figure 1). A Japanese company has invested in a dry milling operation to supply ingredients from white food sorghum. They are marketing flour, meal, grits and decorticated sorghum sold as a rice like product. More than 20 containers of US IP white food sorghum were imported with more in the pipeline if these products and other new ones to be launched soon are successful. Utilization of sorghum in a highly developed country will greatly help our efforts to convince food companies in other less developed areas that sorghum is a good food ingredient.

Our long-term efforts to improve sorghum and demonstrate its use in prototype food products have finally accomplished something tangible. This could be the spark that ignites a large firestorm toward use of IP sorghum for food.

Applications in Honduras and El Salvador

Our research on sorghum has been applied in Honduras and El Salvador. The variety Sureño, and others with white tan plant color, are used in Central America for tortillas, rosquillos, and rosquettes. In El Salvador, sorghum flours from white tan plant varieties are used in small bakeries to produce pan dulce, muffins, bread, rosquettes, rosquillos and other variations of these products. There is significant interest in use of sorghum flour in blends and alone for baked products. There is a lack of milling equipment to secure flour although there appears to be sufficient production of food type sorghums. The ability to IP food sorghums for processing must be developed for consistent success.

Applications of Technology in Mali

Work in Mali continues to demonstrate the value of new, white, tan plant sorghum varieties in food systems. The major problem continues to be lack of an effective IP production scheme to produce sorghum of good quality for processing into value-added flour and meal. The General Foods Company of Mali has found that 20% white sorghum flour can be substituted for wheat flour for production of biscuits. The key is to secure adequate production of the tan plant white sorghum varieties that can be IP and delivered to users at a profit. Much remains to be done. In addition, new higher yielding improved tan plant photo-sensitive white sorghum cultivars are needed to improve production levels. Farmers growing the white tans prefer the porridge made from the tan plant grains. This is similar to farmers in Honduras and El Salvador who prefer tortillas made from white tan plant sorghum varieties instead of the native Criollos which have purple glumes and are often stained.

Figure 1. Commercial snacks from white food sorghum sold in Japan.

Sorghum Phenols and Catechins as Antioxidants

Brown and black sorghums were processed into bran and other milling fractions for analysis of their potential for use in food antioxidants and nutraceutical products. The brown and black sorghum brans have ORAC (oxygen radical absorbance capacity) values that ranged from 23 – 410 (U mol Trolox equivalent, TE/g), compared to blueberries with values of 63-282 on a dry matter basis. Additional sorghum samples evaluated confirmed that brown high tannin sorghums have outstanding antioxidant activities. Moreover, the bran is high in dietary fiber, phytates and natural brown or black pigments that impart attractive color to baked products such as cookies and multigrain breads. A healthy bread that contains modest levels of high tannin sorghums as a source of antioxidants is currently being sold as a result of these findings.

Additional studies to produce highly nutritious multigrain breads and cookies are nearing completion along with a bread mix for bread machines. Black sorghum bran gave breads with appearance, texture, color and specific volume (cm3/g) similar to commercial specialty or dark rye breads. Studies to determine the absorption of these components by humans are beginning: one at ITESM in Mexico, and the other by Dr. Prior, Human Nutritionist at the University of Arkansas Children's Nutrition Center. We are expanding efforts on characterization of the phenols via HPLC and other techniques. Mr. J. Awika from Kenya completed his M.S. on antioxidants from sorghum and continues on toward a Ph.D..

The Effect of Grain Color and pH on Sorghum Tortilla Chips

Brown and black sorghums produced intensely dark tortillas and tortilla chips with color and tastes similar to blue corn tortilla chips. The black sorghum produced bright blue almost black chips that were better than those obtained from blue corn varieties. The details were used by Ms. N. Zelaya from Honduras to complete her M.S. degree.

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 several students conducting research in this area presently. New food type sorghum hybrids are being grown in Mexico where sorghum is the second leading cereal crop.

Four different sorghum genotypes, white normal (WNO), white waxy (WWX), white heterowaxy (WHWX) and brown normal (BNO), were decorticated in a PRL mill and then roller-milled into brewing grits. Grain hardness values determined with the TADD mill indicated that the BNO sorghum had the softest endosperm and yielded the lowest amount of decorticated kernels. Decorticated kernels had lower protein, crude fiber, ash, and color scores and higher starch contents than their respective whole kernels. The yield of brewing adjuncts from decorticated WNO, WWX, WHWX and BNO were 87.4, 89.9, 90.0 and 81%, respectively. Worts produced from WWX brewing adjuncts filtered faster than the heterowaxy and normal counterparts. All sorghum worts had in practical terms similar pH, viscosity, alpha amino nitrogen and color scores. The fermentable carbohydrate content of the BNO sorghum wort was slightly lower compared with the white sorghum worts. White sorghums with hard, waxy endosperms were the most suitable for use as brewing adjuncts. These new hybrids should be successfully utilized by the brewing industry.

Sorghum Flour in Biscuits and Cookies in Central America and Mexico

Sorghum flour (SF) can be substituted for wheat flour in a variety of cookies. 50:50 blends can be used with little reduction in cookie quality. It is possible to produce cookies without wheat flour, but a binder is needed to strengthen the crumb. The addition of 5% pregelatinized corn starch to 95% SF made the dough easier to handle, held the cookie structure together, and improved the handling properties of the cookies. However, over time, cookies from this treatment tended to be more fragile than those of 100% wheat flour. The bland flavor and light color of sorghum flour makes it advantageous to use in flour substitution, but the grittiness of the particles must be controlled.

Special cookies for consumers suffering from Celiac (gluten intolerance) are made by homemakers and small commercial companies. Sorghum flour produces acceptable baked products with additives to substitute for its lack of gluten.

Ms. Herrera working with CENTA in El Salvador has conducted many trials in local bakeries showing that sorghum can be used effectively in baking of rosquetes, sweet breads and many other products as well. We initiated a program to work with her to assist in sorghum flour production from the improved white, tan plant food sorghums that are available in Salvador. She spent one month working in our laboratory to evaluate several different methods of processing sorghum into flour and how the flour quality affected the properties of traditional products made in Salvador. She has extension programs to work with small bakers. This work along with the breeding program in El Salvador and Nicaragua will continue to improve sorghum quality for use in foods.

The lack of commercial production of sorghum flour by small operators is a major constraint to more widespread use of sorghum by small holders in the region. The need for IP food sorghum production and processing is critical. Bland flavor sorghum flour has an advantage over corn flour as a substitute for wheat flour. This affords an opportunity to utilize sorghum in popular food items where it has an advantage over maize. As we work to enhance utilization at the entrepreneur level, the combination of cereals and legumes to produce value-added foods is critically important. Acquisition of good quality raw grains and legumes is the limiting economic factor in many cases.

The price of rice is such that locally grown sorghums could compete for markets in certain snacks, ready to eat breakfast cereals and composite flours for baking. In rural non-rice producing areas, a decorticated sorghum could serve as cost effective substitute or diluent for rice in many households.

Tan Plant Food Type Hybrid Performance and Quality Trials

Several new tan plant food hybrids were entered into the nurseries which were grown in 5 locations in Texas, two in Kansas and one in Nebraska. The tan plant hybrids were competitive with maturity comparable to traditional purple plant hybrids. The availability of short season tan plant hybrids is limited. More of them are required to food sorghum production into drier, shorter season environments. Grain weathering and molds are limiting factors affecting food sorghum production.

The objective to evaluate commercial food type hybrids was achieved. These trials originated by Bill Rooney, Sorghum Breeder, TAES, and sponsored by the Grain Sorghum Producers Association and a special TAES fund called PROFIT provide information required to develop markets for value-enhanced food sorghums. IP white food sorghums are now available to service these markets. They are the direct results of the significant long term research done in this project and others within INTSORMIL in conjunction with other funding sources

Grain samples from international food quality nurseries and hybrid trials are evaluated to monitor new materials in the pipeline and to encourage private seed companies to develop new improved value-enhanced hybrids. The grain industry in the US is rapidly changing to a value-enhanced IP marketing system which fits into our long-term goal of improving sorghum quality for food and feeds. Sufficient quantities of value-enhanced sorghums exist to service the developing markets in Japan and elsewhere. This must occur in our target countries if we are to have success in value-added processing of sorghum and millets elsewhere.

Yield, Agronomics and Quality Attributes of Commercial White Tan Food Sorghum Hybrids

Commercial sorghums and value-enhanced white food sorghum grown on farmers' fields and in local grain elevators were analyzed for composition, physical and milling properties. The milling properties of value-enhanced food-type sorghum hybrids grown under commercial production were compared with commercial samples of sorghums. The white food grains had higher test weight, true density, reduced floaters and slightly higher yields of decorticated grain than the red sorghum. However, the major difference was in color, which was significantly lighter and brighter for the food-type sorghums (Figure 2). The red pericarp contributes significant color to the flour which would have been worse if the grain had been weathered slightly. This information was used in the US Grain Councils value-enhanced grains - 2001 summary of quality for grain importers.

Improved Methods of Analysis

Near infra red equipment to analyze for proximate analysis and starch in whole grains were calibrated for whole and ground sorghum samples. This allows rapid analysis of sorghum for many of its components. More work is required to improve the calibrations especially that for starch. Currently the calibration set for protein and moisture contains 185 samples, with starch and other data available for only 29.

A single kernel hardness characterization system used for wheat kernel hardness was modified slightly to work more efficiently for sorghum kernel hardness measurement. Preliminary information looks promising with a high correlation between hardness scores, milling properties and other characteristics.

Funds to improve these methods were received from a special research program on sorghum from the Texas Legislature called PROFIT.

Role of AFP in Minimizing Grain Molding of Sorghum

Grain deterioration caused by molding is a major problem that significantly affects grain quality for sorghum utilization in most regions of the world. Grain molds and weathering reduce processing quality significantly and can totally destroy the value of the grain for humans. This often happens in the kharife sorghum crop in India and is common in the gulf coast areas of the US and Mexico. In Mali, photo insensitive sorghum varieties are totally destroyed by the combination of head bugs followed by molds, which render the kernels soft, floury and easily pulverized. The grain cannot be decorticated to mill into a flour. Thus, farmers grow photosensitive types.

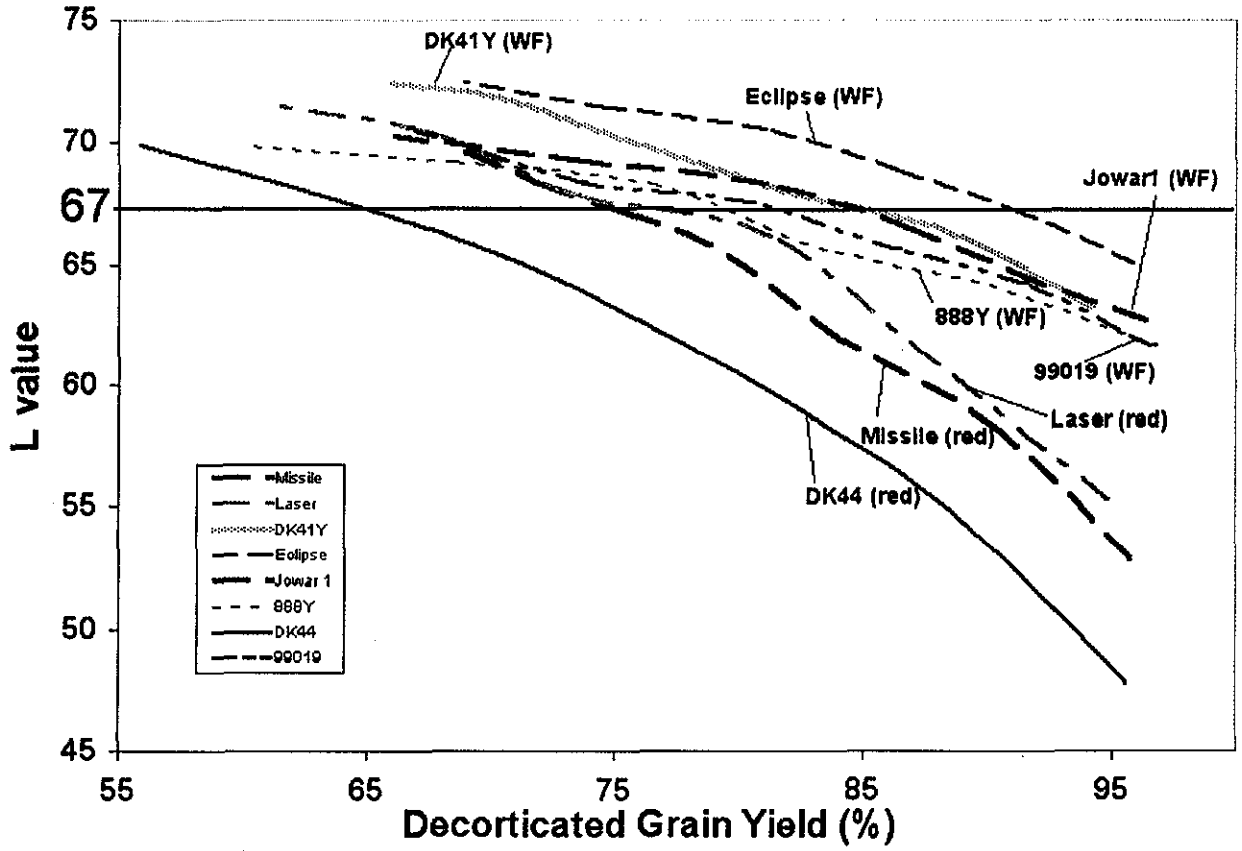

Figure 2. The relationship between color and milling yields of sorghums adjusted to comparable lightness (L) values for red, white-purple and white food type sorghums

Many factors affect the molding of sorghum and none of them in themselves account for tolerance. The kernel structure, especially endosperm hardness, pericarp surface wax covering, presence of a pigmented testa, phenolic compounds, plant height, glume characteristics, antifungal proteins and many unknown factors affect grain mold tolerance. Our research over the years has identified some of them but with the exclusion of the high-tannin sorghums no factor appears dominant.

Several AFPs (sormatin, chitinases, b-1, 3-glucanase, and ribosomal inactivating proteins (RIP)) are present in pericarp, germ and endosperm; these AFPs inhibit grain mold fungal species. Some sorghum lines and hybrids have improved tolerance to grain molding and weathering; but no commercial hybrid is resistant in hot, humid environments. Fungal colonization discolors the pericarp surface initially and then fungi break down the endosperm composition and structure. This adversely affects sorghum grain yield and quality, such as physical properties, processing, nutritional and market value. Hence, grain mold resistance is necessary in food-type sorghums grown in hot, humid environments.

Commercial hybrids (15) and public breeders elite lines (50) were grown at College Station during of 2000 and 2001. Samples of grain were collected at physiological maturity (black layer) and combine harvest maturity (21 days after black layer). A poster entitled "Antifungal Proteins in Commercial Hybrids and Elite Sorghums" was presented at the Nashville Sorghum Research and Utilization Conference (2001). Several elite lines and a few commercial hybrids consistently exhibited higher levels of AFPs while more sorghums had higher levels inconsistently.

Dr. Waniska collaborates with Dr. Bill Rooney, Mr. David Wooton (a Ph.D. student of Dr. Bill Rooney), Mr. Cleve Franks and Dr. Robert Klein (USDA). Mr. John Wooton, plant breeding graduate student, has collected samples and Mr. Cleve Franks are quantifying antifungal proteins in Raul Rodriguez' (former Ph.D. student) F2:5 materials. The goal is to create a map of the sorghum genome for antifungal proteins which will provide a method to select sorghums in the leaf stage instead of waiting until the grain has matured. The need to understand sorghum molding and weathering is critical. If markers can be found that identify factors affecting mold resistance, we should make better progress since field screening is difficult or impossible.

Networking Activities

Southern Africa

Several graduate students are conducting research on aspects of sorghum utilization with Professor Taylor, Food Science Dept., University of Pretoria. Ms. Leda Hugo, Mozambique, is a Ph.D. student at University of Pretoria working on the effect of malting sorghum on its use in composite breads. She is a professor at University of Eduardo Mondlane University and completed her M.S. at Texas A&M University. Lloyd Rooney serves on her Ph.D. committee.

Ms. S. Yetneberk from Ethiopia has started her Ph.D program and L. Rooney is a co-director of her committee. Her project is related to determination of factors affecting the quality of injera from sorghum cultivars present in Ethiopia.

Dr. Trust Beta completed her Ph.D on processing sorghum with high levels of polyphenols into foods. She has published several manuscripts related to dry milling, malting and brewing applications of local Zimbabwean sorghum cultivars. Her work has been cooperative with the Matopos grain quality lab in Zimbabwe. Unfortunately, she resigned from the University of Zimbabwe and is now a researcher at Iowa State University in the USA.

Graduate students in the Food Science Department at University of Pretoria are from many other African countries. Many participate in the Regional Master of Science program which consists of joint programs between CSIR and University of Pretoria. Thus, INTSORMIL interactions with this program at University of Pretoria informs many future African food industry leaders of the potential role of sorghum and millets as food and industrial ingredients. INTSORMIL can provide assistance to the region by involvement in these programs where possible.

Mr. J. Awika from Kenya completed his M.S. degree and is continuing on a Ph.D. in food science and technology on nutraceuticals from sorghum. He has received several scholarships from national and local sources due to his outstanding academic performance. He is partially supported by INTSORMIL.

Honduras, Salvador, Mexico and South America

Ms Herrera, food technologist, Rene Clara, Sorghum Breeder and others from Nicaragua spent time in the cereal quality lab. Ms. Herrera completed a one month short course on sorghum food processing and related activities. Dr. L. Rooney, traveled to San Salvador to present a seminar on food use of sorghum and to develop collaborative research and development plans. A major Salvadoran food manufacturer is interested in using sorghum for snack and ready-to-eat breakfast foods. Unfortunately, we did not have time to follow up so we will do that this next year with some sorghum increases. The information obtained in Japan applies quite well to the situation in Salvador and elsewhere in Central America. A small food company has initiated use of modest amounts of sorghum in their extruded snacks as the result of participation in our snack foods short course..

Mr. Javier Bueso traveled to EAP to assist in conducting research on processing quality of sorghum. He is working on a Ph.D. in our lab. Ms. Nolvia Zelaya, M.S. student from Honduras, completed her M.S. thesis on sorghum tortillas in our laboratory. She joined the research and development program in Frito-Lay, Inc. in Plano, TX. Her husband is completing a Ph.D. in sorghum breeding.

L.W. Rooney has long term cooperative projects 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 new improved food sorghum hybrids in wet and dry milling and as adjuncts in brewing. His Ph.D. and subsequent experience in our laboratory was partially funded from INTSORMIL.

We currently have three graduate students from Mexico partially funded on TAM-226.

Mali

N'Tenimissa (a new white, tan plant, locally adapted photosensitive sorghum cultivar specifically designed for value-added processing in Mali) is liked by farmers for its improved porridge quality. 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 and bland flavor provided it is not contaminated with off types.

Sustained production of IP grain in sufficient quantities for value-added processing has proven difficult to achieve. Ms. Berthe and others in the IER Food Technology laboratory have demonstrated the improved value of N'Tenimissa in commercial food products, i.e., biscuits made by General Foods of Mali. The real challenge is to produce large enough quantities of IP grain for value-added processing on an economically sound basis and to convince industry to pay more for added value. This is a very elusive problem that limits adaptation of technology for processed food products from sorghum and millet in Mali and elsewhere.

North America

Several papers were presented at the annual American Association of Cereal Chemists conference in Kansas City, MO. L.W. Rooney presented sorghum quality/ utilization discussions to Texas Sorghum Producers Board Members and panels, US Grains Council sponsored visitors and in value-added conferences in Mexico and Japan. L.W. Rooney was awarded funds (100K+) from the Texas Advanced Technology Research program for a two-year effort to evaluate special sorghums for antioxidant potential and use in nutraceuticals. Sorghum bran fractions contained from 20-400+ ORAC units compared to 80-200+ ORAC units for blueberries which are considered excellent sources of antioxidants.

Presentations were made to sorghum production conferences in Texas, to US Grain Council market development teams from Japan, Mexico, Central America, Taiwan and to visitors from Australia, Mali, Niger, Botswana, Honduras, Guatemala, El Salvador and China. L.W. Rooney summarized progress in developing value-added sorghums for utilization in the 4th Australian Sorghum Conference.

Our laboratory conducts an annual short course on practical snack foods production for private industry in which sorghum utilization was part of the program. A book on Snack Food Processing was co-edited by Lloyd Rooney and published in June 01. It contains information on food sorghum. Participants from all over the world enrolled in the short course including several from Central America and Mexico.

Sorghum Market Development Activities

The Grain Sorghum Producers Association has market development activities to capitalize on value-enhanced sorghums for use in value-added products in Japan, Taiwan, Mexico, Central and South America. Our research activities on development of food type sorghums, milling properties, composite flours, tortillas, snacks and other prototype food products from sorghum was presented at US Grain Council sponsored value-enhanced market development workshops in the United States, Japan, Mexico (3 times) and trade teams from several countries.

The concept of IP production and marketing of grains is expanding significantly. Our development of white food-type, waxy, heterowaxy and nonwaxy sorghums fits into these marketing schemes.

Training, Education and Human Resource Development

Monterrey Institute of Technology: our collaboration with Dr. Serna-Saldivar, Head, Food Science Dept., ITESM, Monterey, Mexico has lead to completion of six Master of Science degrees. These young scientists have positions in the Mexican food industry which transfers the technology directly to industry.

Dr. Rooney presented an invited lecture to a student symposia at Instituto Tecnologico y de Estudios Superiores de Monterrey where several former students were on the program (figure 3). Another invited lecture on chemistry of nixtamalization of sorghum/maize was presented to 100 plus science students at the University of Coahuilla in Saltillo Mexico. These seminars provide information to students interested in the food chemistry/science areas eventually leading to graduate students interested in these areas.

Two EAP BS students were provided partial scholarships from INTSORMIL to complete their senior thesis research on baking and extrusion of sorghum. Three graduate students currently work on INTSORMIL related research in our laboratory, with partial financial support while several others are supported from other funds. Inflation has significantly reduced the number of graduate students that can be supported.

Figure 3. Former TAM-226 Mexican Graduate Students participating in the Monterrey Institute of Technology Student Symposium: Dr. Rodrigo Lobeira, Research and Development, MASECA - Gruma Corporation; Ms. Sara Guajardo, Instructor, ITESM Departamento de Tecnologia de Alimentos; Dr. Ximena Quintero, Principal Scientist, Frito-Lay, Inc., Plano, TX; Dr. Lloyd W. Rooney, Professor and Faculty Fellow, TAMU; Dr. Sergio Serna-Saldivar, Head, Food Science Department, ITESM

Honors: Lloyd W. Rooney was inducted into the Mexican National Academy of Sciences in may 2001 for his long term commitment to research and development efforts in the area of nixtamalization and tortilla quality (Figure 4). He was cited for his extensive training of graduate students from Mexico. He has served as chair or co-chair for more than 30 M.S. and Ph.D. degrees awarded to Mexican students. The election to membership in the Mexican Academy of Science is limited to one international scientist per year. Many of the students were at least partially funded or conducted research funded by INTSORMIL.

Publications and Presentations

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Figure 4. Induction of Dr. Lloyd W. Rooney, Professor and Faculty Fellow, Texas A&M University into the Mexican National Academy of Science. Left to Right: Dr. L.W. Rooney, Professor and Faculty Fellow; Dr. R. Druker-Colin, President of Mexican National Academy of Sciences, Dr. Octavio Paredes-Lopez, Director, IPN Unidad, Irapuato, Mexican National Academy of Sciences; Dr. Serna-Saldivar, Professor and Head, Food Science Dept., ITESM

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Strategic Marketing of Sorghum and Pearl Millet Food Products in Western and Southern Africa

Project UIUC-205
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Summary

Results and analysis from a study on valuing the attributes of millet in the preparation of tuo and couscous in Niger were drafted for journal submission. Results show a strong preference for the local land race, Hainikire, with one modern variety, MTDO92, coming close in overall consumer preference. Given consumer preference for the local land race, adoption of modern varieties is likely to be slow or non-existent if the improved varieties do not exhibit some of the consumption attributes preferred by households.

The first PI research trip since April, 1999 resulted in the initiation of two research projects on marketing chains, identity preservation, and value added in Mali. One project will work at building a sustainable identity preserved marketing chain for sorghum varieties capable of being processed into white flour. There is a significant gap between commercial demand for such flour and grain production. So, it will be necessary to build profitability, commitment, and trust over a period of several years by building on success and correcting mistakes. The formal and informal economic mechanisms for encouraging and enforcing commitment will be studied in a survey of grain processing in Bamako. The survey will seek to uncover the extent of market integration by processors, and constraints to fuller market participation.

Objectives, Production and Utilization Constraints

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 processor. The research in West Africa is working in understanding the current economic structure of grain marketing, and to discover marketing arrangements that promote identity preservation for commercialization. The research in Botswana is directed at identifying how to sustain the growth of sorghum processing. The most immanent threat to sustained growth is supply interruption. So the research plan is constructed to identify the full range of feasible supply alternatives and their economic welfare implications.

Research Approach and Project Output

The principal investigator was finally able to travel in April, 2001. A trip to Mali resulted in the initiation of two significant research projects on the processing of sorghum in Bamako.

Marketing Chain for White Sorghum Flour in Mali

Research was initiated to build a marketing chain for white sorghum flour for the production of déli'ken biscuits in Bamako, Mali. During the last few years a tan plant variety of sorghum, N'Tenimissa, has begun to be produced by a small number of farmers in Mali. Working with scientists from the Institut d'Economie Rurale (IER), some grain from this production has been used to initiate production of a commercial sweet biscuit, déli'ken, which is produced with twenty percent sorghum flour. Déli'ken production, at the General Alimentaire Malienne (GAM) factory in Bamako, started in May 2000, with flour provided by a processor, working with IER. For the first four to five months of production there was a good flour supply that was certified by IER to be from the variety N'Tenimissa.

The launch of Déli'ken was given strong publicity from the media. The national Ministers of Agriculture and Industry hailed the introduction as a significant achievement for Mali. Initial demand for Déli'ken was strong and encouraging. Around October, 2000, GAM began to experience a shortage of white flour from N'TENIMISSA. They slowed production while they searched for a supply of white flour. Déli'ken was sold out of inventories, which can be held up to six months. When Déli'ken inventories started running low, GAM contracted with a local grain processor for ten tonnes of sorghum flour. In January, 2001 the processor produced the flour from grain purchased in the local market. GAM found that the flour from the processor was of poor quality with many off-color specks in the flour. Some batches of Déli'ken were produced with the flour from local varieties and demand began to decline.

The biscuits produced with this flour had inferior color and taste attributes. This experience is evidence of the central importance of a regular supply of N'TENIMISSA flour for production of Déli'ken. GAM would like to increase production of Déli'ken to a rate that uses 1-1.3 mt. per week, or 55-70 mt per year of flour. This would require 82-140 mt per year of N'TENIMISSA grain. Current commercial production does not exceed 5 mt. of grain.

This year, N'Tenimissa was planted on 36 ha of land by farmers who have contracted with IER and a local grain merchant to produce an identify-preserved supply for the production of white flour. These farmers have used fertilizer for N'TENIMISSA production, so there is a potential for over 30 mt. of N'TENIMISSA production this year. The grain merchant has contracted to purchase N'TENIMISSA at CFA 10 over the going sorghum price. The supply chain is being monitored closely in order to build confidence in all the participants, with the aim of expanding production and marketing in future crop years.

Grain Processing in Bamako, Mali and Constraints to Its Growth

A survey of grain processing in Bamako, Mali was initiated. The survey will attempt to characterize the key economic characteristics of grain processors. Little is currently known about the extent of commercial processing of sorghum and millet in urban Mali. There is the impression of significant processing for the urban market. But, there is no solid evidence about the extent or nature of this processing. Claims about the status of processing and its future need the support of evidence. This applies to grain processing in general, not just the processing of sorghum and millet.

Therefore the first objective of this research is to conduct a comprehensive survey of grain processors in urban Bamako. The survey will be constructed to obtain fundamental baseline facts about the nature of processing, such as the amount and type of capital, like dehullers and mills, the number of man-hours used in annual production, the quantity and type of storage, transportation methods, and the number of laborers employed during the production year. The survey will collect information about the product mix that the processor produces, including the product types and their quantities. Information about the supply of raw grain will also be collected, including the annual quantity of each grain type purchased and where it was purchased. This survey information should provide a basic understanding of the size distribution of grain processors in urban Bamako, the type and quantity of products they produce, and the annual quantity of grain that they process.

The second objective of the analysis is to determine the extent of formal commercialization of the grain processors and the constraints to their growth. Processors will be asked for a response to a list of the most significant expected constraints on current and future production. This data will be supplemented with detailed questions about the commercial transactions of the producers in order to determine the extent of integration into the formal commercial economy. In order to analyze integration into the formal economy, data will be collected on the dependence on personal relationships for exchange. The role of trust, commitment, and relationship in ensuring timely delivery of quality inputs, distribution of products, and timely payment for products will be analyzed. In addition, data will be collected on the processor's participation in credit markets. This data will be analyzed in order to determine the commercial relationships of the processors that provide opportunities for expansion and growth.

Constraints on Sorghum Supply for Food Processors in Botswana

The research question concerns the incentives necessary to cause small farmers in Botswana to view sorghum production as a commercial enterprise tied to the value added processing carried out by small-scale millers. A region of Botswana – Baralong – has been chosen for a survey because it contains commercial and subsistence farmers. The research method employs agricultural household models to identify the key components of resource allocation decisions that influence willingness to engage in commercial contracting. The economic model of agricultural households emphasizes the interrelation between production, marketing, consumption, savings, and investment decisions. When households live in risky environments, as in Botswana, risk balancing of the components of the household portfolio is central.

Thus, the survey is being constructed to collect information about key components of the household portfolio and the decisions that are made to manage risky contingencies. Commercial and subsistence households will be sampled in order to learn the significant differences in the constraints and incentives facing these households.

Networking Activities

Two significant networking activities took place during the April, 2001 trip to Bamako. First, collaborative research was set up with the ICRISAT IFAD project on natural resource use and seed systems. Dr. Ousmane Youm, director of the IFAD project, agreed to collaboration between IFAD's N'TENIMISSA seed distribution, and INTSORMIL's work on developing marketing channels to convert the N'TENIMISSA grain into white flour. Second, I made contact with Dr. Marcel Galiba, the director of the Sasakawa Global 2000 grain commercialization project. He expressed interest in the grain processing survey and requested information about findings. These findings could serve to stimulate collaboration with Sasakawa Global 2000 on strategies for overcoming constraints to the processing of sorghum and millet.

Publications and Presentations

Professional Presentation

Ndjunga, J. and C.H. Nelson. "Toward Understanding Household Preference for Millet Varieties in the West African Semi-Arid Tropics", selected paper, annual meeting of American Agricultural Economics Association, Tampa, FL. July, 2000.

Degree and Non-Degree Programs

Tshepo Makepe, B.S. Botswana College of Agriculture, began the M.S. program in Agricultural and Consumer Economics in January, 2001. He is expected to complete his degree by August, 2002.

Host Country Program Enhancement

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Central America Regional Program

Stephen C. Mason
University of Nebraska

Coordinators

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Rodolfo R. Valdivia Lorente, Regional Scientist, INTA, Nicaragua
Ing. Rolando Ventura Elías, Agronomist, CENTA, El Salvador
Ms. Caroline Villadares, Food Scientist, CITESGRAN, EAP, Honduras

Collaborative Program

Institutions

Active INTSORMIL collaboration in Central America is occuring primarily among the following institutions: Centro Nacional de Technología de Agricopecuaria y Forestal (CENTA), El Salvador; Instituto Nicaragüense de Tecnología (INTA) ,Nicaragua; Universidad Nacional Agraria (UNA), Nicaragua; Universidad Autónoma de Nicaragua (UNAN), Nicaragua;Escuela Agrícola Panamerican (EAP), Honduras; Kansas State University, Mississippi State University, Texas A & M University; and the University of Nebraska.

Organization and Management

In 1999, a major change in program occurred due to increasing opportunities for grain sorghum research in El Salvador and Nicaragua and a reordering of priorities at EAP,

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which had been INTSORMIL's principal institutional partner in Central America for a number of years. As a result, INTSORMIL has recently shifted the emphasis of its program in Central America from Honduras to El Salvador and Nicaragua. In October 1999, scientists from collaborating institutions met and developed a two-year research plan with collaborative projects in plant breeding, utilization, plant protection (entomology and plant pathology), and agronomy. This two-year program will be completed during the coming year, and a research reporting and planning meeting will be scheduled for early 2002 to make collaborative research plans for the period 2002 - 2006.

Financial Inputs

Primary financial support for the program is from the INTSORMIL Central America Regional Program budget, which was $90,000 during the past year. The four collaborative research projects (plant breeding, utilization, plant protection, and agronomy) were budgeted $16,000, with the balance maintained at the INTSORMIL Management Entity to cover regional expenses. These regional expenses included a trip by Central American institutional leaders to the United States to attend the annual meeting of the National Grain Sorghum Producers and to meet with INTSORMIL university collaborators, equipment purchases and administrative travel.

Collaboration

INTSORMIL's Central America program has supported informal collaboration with many non-governmental organizations, and formal collaboration with national extension services, and it has served as a catalyst for Central American grain sorghum research and technology transfer. In addition, René Clará Valencia coordinated the regional grain sorghum yield trials conducted by the PCCMCA, and plans were made to share improved grain sorghum germplasm with watershed projects of the Centro Internacional de Agricultura Tropical (CIAT) at Yorito, Honduras and San Dionisio, Nicaragua.

Sorghum/Millet Constraints Researched

Production and Utilization Constraints and Research Findings

Introduction

Grain sorghum is the third most important crop in Central America (El Salvador, Guatemala, Honduras, and Nicaragua) after maize and beans. The area devoted to grain sorghum in 2000 was 252,544 ha^{-1} with an average grain yield of 1.5 Mg ha^{-1} (FAO, 2001). 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 dependence on one crop. The dominant cropping system is maize intercropped with *maicillos criollos* (called millón in Nicaragua). These tropical grain sorghums are three to four meters tall, drought tolerant, and photoperiod sensitive. The grain is used as human food and a feed grain for livestock, and the stover is used for livestock forage. Although maicillo criollos produce low yields, they are planted on approximately 67%, of the grain sorghum area in Central America. As the need to boost grain sorghum productivity in Central America increases, maicillos are slowly being replaced by higher yielding, uniform cultivars.

The limited grain yield response of traditional maicillo criollo varieties to management practices is a primary constraint to increased production. Soil and water conservation, improved production practices and soil fertility management, and increased genetic potential of cultivars is essential to obtain economical yield increases. To date increased grain sorghum yield and area are due primarily to utilization of improved cultivars (hybrids and varieties), which are increasing Central American grain sorghum production.

Alternative uses for sorghum grain need to be developed to encourage sustainable economic growth in semi-arid areas in Central America. White grain, tan-plant colored grain sorghum cultivars are well adapted to Central American human food and livestock feed systems. Innovative processing systems, like extrusion and flaking, are needed to increase starch digestibility and maximize net energy intake for livestock feed. A lack of milling equipment for production of grain sorghum flour limits adoption of the use of grain sorghum flour for baked products. Human consumption needs to be promoted, especially in tortilla related products, extruded snacks and flour substitution through use of superior grain-quality sorghum cultivars. Use of grain sorghum cultivars for forage, or dual use for both grain and forage are important to small producers.

Plant Breeding

Research Methods

The plant breeding programs in both El Salvador and Nicaragua are striving to identify adapted grain sorghum lines with good agronomic and utilization characteristics for development either as photoperiod-sensitive or insensitive varieties for grain production or dual use as grain and forage. Photoperiod-sensitive lines may also serve as parents for hybrids. Once potentially superior lines are identified, then preliminary yield trials are conducted followed by on-farm verification trials and ultimate release. The breeding programs are constantly evaluating new sources of germplasm identified in the region, from INTSORMIL breeding programs in the United States, and from ICRISAT. Each year, grain sorghum hybrid tests have been conducted in three to seven countries in Central America. In 2000, these studies were conducted in El Salvador, Guatemala, and Nicaragua with hybrids from private company Christani Burhard (Guatemala) and varieties from CENTA (El Salvador) being evaluated.

Research Results

Grain sorghum nurseries for photoperiod-sensitive and insensitive germplasm were utilized in both El Salvador and Nicaragua. In El Salvador, 72 photoperiod-insensitive, uniform lines and 28 photoperiod-sensitive families were identified with desirable agronomic characteristics. The All Disease and Insect Nursery (ADIN) from Texas A & M University was also evaluated. In addition, yield trials on 15 insensitive varieties were conducted, and verification trials were carried out to evaluate the performance of the dual-use sorghum variety CENTA S-3. In the latter, CENTA S-3 was compared to the presently used CENTA S-2 on 99 farms, and CENTA S-3 was found to have 10 day earlier maturity, be 24 cm shorter, produce 19% more biomass, and similar grain yield. A forage pearl millet trial was conducted with millet genotypes producing similar yield to dual use grain sorghum varieties, while the forage had 4 to 9% greater protein concentration.

Research in Nicaragua focused on conducting yield trials of white grain sorghums, red grain varieties, midge-resistant varieties and drought-tolerant varieties. On-farm trials of the variety LP-99 was conducted at 17 locations, and it was found to have similar or slightly higher yields than Pinolero-1 or local checks. Germplasm from Texas A & M University in the All Disease and Insect Nursery (ADIN), the Drought Line Test (81 Advanced Lines) Midge Line Test (70 Advanced Lines), and Grain Weathering (Mold) Test (40 Advanced Lines) were evaluated, and useful material will be incorporated into the Nicaraguan breeding program.

Dr. Darrell Rosenow identified 18 Texas A & M University breeding lines from the ADIN with excellent yield potential in El Salvador and Nicaragua. He also identified 13 B-lines form the Drought Line Test in Nicaragua with excellent adaptation and superior characteristics to those presently used to produce hybrids, which should prove useful in hybrid production.

Entomology and Plant Pathology

Research Methods

The research focus was to identify the pests more commonly occurring in grain sorghum fields to help guide future research. In El Salvador, 93 grain sorghum producers were surveyed in four regions within the country, and plant samples were collected from 112 farmers fields for identification of diseases and insects present. In Nicaragua, the All Disease and Insect Nursery was planted to identify diseases present, but disease pressure was very low thus useful results were not obtained.

Validation and comparative studies including insect pest management strategies in hillside and coastal plain intercropped grain sorghum and maize production systems were completed in Honduras. M.S. thesis research on sorghum midge was conducted in Nicaragua.

Research Results

In the surveys producers reported that the principal grain sorghum insect pests were "la gallina ciega" (Col: *Scarabaeidae*) [50%], armyworm (*Spodoptera* species) [23%], and the principal disease was head mold (*Sporisorium* species) [14%]. Plant samples indicated the major foliage insect to be fall armyworm (*Spodoptera frugiperda*) [4%], panicle insects to be "gusano rosado or telarañero" (*Sathrobrota rileyi*) [31%] and sorghum midge (*Stenodipolosis sorghicola*) [20%], and stalk insects to be the stalk borer (*Diatraea saccharalis*) [21%]. The most important leaf diseases were rust (*Puccinia* species) [51%], Cercospora leaf spot (*Cercospora* species) [47%], tizon (*Helminthosporium* species) [38%], zonal spot (*Gloeocercospora* species [27%] *Colletotricum* spot [17%], and mildew (*Peronosclerospora* species). Fungi found in grain sorghum heads included *Cladosporium* [50%], *Cercospora* [17%], *Fusarium* [15%], *Sporisorium* 10% and *Curvularia* species [17%], while the major disease in stalks was *Fusarium moniliforme* [83%].

The cropping systems research in Honduras revealed that maize yields were greater in crop management systems with improved maize varieties, suggesting that crop variety was mainly responsible for yield differences among cropping systems. Grain sorghum yields were not obtained to crop damage from wind, but insect infestations were about equal for all cropping systems. Soil moisture was identified as the stimulus for eclosion of *Metaponpneumata rogenhoferi* moths, which appeared to act as a secondary factor in diapause termination. This information along with previously gathered information on biology, ecology and insect behavior of related species in the lepidopterous caterpillar complex will assist in the application of integrated management of this devastating insect problem.

Grain Utilization (Quality)

Research Methods

The Central America program has historically concentrated on improving the grain yield and processing characteristics of sorghum for use in tortillas and related products with research conducted at the Escuela Agricultura Panamericana (EAP) in Honduras. In recent years the research has broadened to include grain sorghum flour substitution in yeast and sweet breads in El Salvador, and on brewing and starch problems in Mexico. This research includes market surveys, and research on specific grain quality/food utilization issues usually with undergraduate students at EAP, or graduate students at Texas A & M University or the Instituto Tecnologico y de Estudios Superiores de Monterrey, Mexico.

Research Results

In El Salvador, a market survey was conducted with bakers in the San Salvador metropolitan area. This survey found 39 bread bakers interested in using grain sorghum flour as a substitute for wheat flour, and 7 bread bakers presently substituting 25% grain sorghum flour for wheat flour in break baking. Training was provided to 9 bakers about substituting grain sorghum flour for wheat flour in French and sweet breads. The private company "Bocadeli" has interest in using grain sorghum flour in elaboration of rapid snack food products.

Brewing research was conducted on grain sorghum genotypes with different color and starch characteristics. The yield of brewing adjuncts was greater for white than the red genotypes used, and worts from waxy starched genotypes filtered faster than from the other genotypes. White grain sorghums with hard, waxy endosperms were the most suitable for use as brewing adjuncts.

Grain sorghum flour can be substituted up to 50% for wheat flour with little reduction in cookie quality. It is possible to produce cookies from 100% grain sorghum flour, but a binder is required to increase crumb strength. The addition of 5% pregelatinized corn starch with 95% grain sorghum flour makes the dough easier to handle, improves cookie structure, and gives better handling properties. The bland flavor and light color of grain sorghum flour makes it a good substitute for wheat flour, but particle grittiness has to be carefully controlled.

Studies on the effect of grain color on tortilla chip quality were conducted by Honduran graduate student Nolvia Zelaya. These studies found that brown and black grain sorghums produced intensely dark tortillas and tortilla chips with similar taste to tortilla chips made from blue corn genotypes. The black grain sorghum produced bright blue, almost black, tortilla chips of better quality than those produced from blue corn.

Agronomy

Research Methods

Agronomic research was initiated to evaluate nitrogen use efficiency of grain sorghum genotypes and to determine optimal nitrogen fertilizer rate recommendations. Four grain sorghum varieties were grown at two sites in El Salvador and in Nicaragua with four nitrogen fertilizer rates. Flowering date, plant height, grain and stover yield, and grain and stover nitrogen concentration data were collected. In addition, nitrogen rate studies were conducted with tall photoperiod-sensitive grain sorghums (maicillos criollos or millón) intercropped with dry beans in Nicaragua and intercropped with maize in El Salvador. Plans are being made to conduct an economic evaluation of intercropping and sole cropping systems in 2002.

Research Results

Nitrogen fertilizer application increased grain yield either linearly or quadratically at each location (UNL-213, Table 2). At all locations, except Santa Cruz Porrillo, El Salvador, the highest grain yield was produced at the highest nitrogen fertilizer rate of 78 or 90 kg/ha. Genotype yield level and response to nitrogen fertilizer rate varied greatly across locations making it difficult to draw nitrogen use efficiency conclusions without further research. The photoperiod-sensitive genotypes intercropped with beans or maize in general had lower yields and responded less to nitrogen application than sole-cropped varieties.

Mutual Research Benefits

Many production constraints are similar between Central America and the U. S. including drought, diseases, and insects. 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 grain sorghum and can potentially contribute useful food quality traits to U.S. germplasm, and several lines are presently in the Texas A & M University /USDA-ARS Sorghum Conversion Program. Germplasm exchange will contribute to development of novel genetic combinations with multiple stress resistance, wide adaptation, and improved food quality. Entomology and plant pathology research includes pests that affect grain sorghum both in Central America and in the U.S., such as sorghum midge and ergot.

Institution Building

Equipment and Other Support

INTSORMIL assisted with maintenance of a Jeep Grand Cherokee in Nicaragua, and a Ford pickup, John Deere tractor and planter in El Salvador. Two computers and pollinating bags were provided along with assorted laboratory materials. In addition, microscopes were repaired for UNA and CENTA laboratories.

Training and Education

One half-tuition scholarship was awarded to an EAP student to conduct research on grain sorghum utilization in Honduras. Mr. Javier Bueso (Honduras), Assistant Professor, EAP , is pursuing a Ph.D. degree in the Grain Quality Lab at Texas A & M University with part of the dissertation research conducted in the EAP CITESGRAN laboratory in Honduras. Novia Zelaya (Honduras) completed a M.S. degree at Texas A & M University with thesis research on the effect of grain color on tortilla chip quality. Johnson Zeledon (Nicaragua) completed a M.S. degree at Mississippi State University. His thesis research focused on the biology and management of sorghum midge on grain sorghum in Nicaragua. He will continue studies for a Ph.D. degree with dissertation research on grain sorghum insect pest management in Nicaragua. Short-term training for grain sorghum plant pathologists Reina Flor Guzman de Serrano (CENTA, El Salvador) and Sergio Pichardo Guido (UNA, Nicaragua) was provided at Kansas State University, and for food scientist Fidelia Herrara de Paz (CENTA, El Salvador) at Texas A & M University. Institutional leaders in grain sorghum research (René Clará Valencia, CENTA, El Salvador; Rafael Obando Solis, CNIA/INTA, Nicaragua; Sergio Pichardo Guido, UNA, Nicaragua) visited research programs at Kansas State University, Mississippi State University, Texas A & M University and the University of Nebraska, and participated in the National Grain Sorghum Producers Conference held in Nashville, TN.

Networking

INTSORMIL sponsored the Global 2000: Sorghum and Millet Diseases III Workshop, Guanajuato, Mexico 25 - 29 Sept. 2000. Many INTSORMIL collaborators from Central America and the U.S. participated and presented papers.

Dr. Henry Pitre traveled to Honduras and Nicaragua to direct graduate student research, and to El Salvador to establish new collaborative research for 2001.

René Clará represented INTSORMIL at the PCCMCA meeting in Costa Rica in April, 2001.

Drs. Larry Claflin and Stephen Mason visited INTSORMIL scientists conducting collaborative research in El Salvador and Nicaragua in June 2000. Dr. Claflin visited again in December 2000 to assist with research.

Mr. Rafael Mateo, Honduras/Texas A & M University traveled to El Salvador in August 2000 to provide training on use of the plot planter transferred from Honduras.

Dr. Lloyd Rooney visited El Salvador in August 2000 to initiate research work with CENTA and present a seminar on food uses of grain sorghum.

Drs. Gary Peterson and Darrell Rosenow visited El Salvador and Nicaragua in December 2000 to evaluate grain sorghum plant breeding materials.

Mr. Javier Bueso, graduate student at Texas A & M University, traveled to Honduras in June 2000 to assist with research use of grain sorghum flour in making cookies.

Strong collaboration has developed between the INTSORMIL sorghum program and other organizations in Honduras to implement programs to improve the sustainability of steepland agricultural production. A partial list of collaborators during the life of the project was listed previously in the report. Collaboration has been established with NARS/ICRISAT/CIAT to evaluate sorghum and millet for tolerance to acid soils in Honduras, and collaboration is being established with the CIAT Hillside project reference sites in Yorito (Honduras) and San Dionisio (Nicaragua). Increased collaboration with programs located in El Salvador and Nicaragua are expected as the INTSORMIL program expands in these two countries.

Research Accomplishments

Successfully implemented the two-year collaborative research plan developed in October 1999. This includes transition of program emphasis from Honduras to El Salvador and Nicaragua, completion of the first-year research objectives, and professional reporting of research results and financial expenditures.

Program implementation has leveraged new or increased research on grain sorghum by more than 25 scientists in national programs in the region.

Identified 18 Texas A & M University breeding lines from the ADIN with excellent yield potential and yield potential in El Salvador and Nicaragua. He also identified 13 B-lines form the Drought Line Test in Nicaragua with excellent adaptation and superior characteristics to those presently used to produce hybrid, and should prove useful in hybrid production.

Eight yield trials of improved varieties were conducted, and on-farm verification trials of a dual-use sorghum variety in El Salvador was conducted on 17 farms and in Nicaragua on an improved white grain sorghum variety on 99 farms.

Characterized the severity of sorghum midge infestation, and released an extension circular about this insect and its control.

The INTSORMIL project in Honduras and Nicaragua co-published extension bulletins on the lepidopterous ("langosta") insect complex and sorghum midge based on research results.

In El Salvador a market survey was conducted with bakers in the San Salvador metropolitan area. This survey found 39 bread bakers interested in using grain sorghum flour as a substitute for wheat flour, and 7 bread bakers presently substituting 25% grain sorghum flour for wheat flour in break baking.

INTSORMIL sponsored the Global 2000: Sorghum and Millet Diseases III Workshop, Guanajuato, Mexico 25 - 29 Sept. 2000. Many INTSORMIL collaborators from Central America and the U.S. participated and presented papers.

Short-term training was provided to two plant pathologists and one food scientist from the region, and numerous seminars were presented by INTSORMIL U.S. Principal Investigators.

Completed Master of Science education program for one scientist from the region.

Publications and Presentations

Journal Articles

Espinal, R., R. Mateo and H. Sierra. 2000. Comportamiento de Sorgos Graníferos PCCMCA 1999. Tech. Rep. No. EAP-SAG- INTSORMIL-13. El Zamarano, Honduras. 12p.

Lopez, J.I., H.N. Pitre and D.H. Meckenstock. 2001. Changes in fall armyworm (Lepidoptera; Noctuidae), fitness over five generations of larval feeding on resistant tropical landrace sorghum. Ceiba 41: (In Press).

Lopez, J.I., H.N. Pitre and D.H. Meckenstock. 2001. Influence of nitrogen fertilizer on resistance to fall armyworm (Lepidoptera: Noctuidae) in tropical landrace sorghum. Ceiba 41: (In Press).

Rodriguez-Herrera, R., W.L. Rooney, D.T. Rosenow, and R.A. Frederiksen. 2000. Inheritance of grain mold resistance in grain sorghum without a pigmented testa. Crop Sci. 40: 1573 - 1578.

Vergara, O.R. and H.N. Pitre. 2001. Complexity of intercropped sorghum-maize production systems in southern Honduras. Ceiba 41: (In Press).

Vergara, O.R. and H.N. Pitre. 2001. Planting date, weed management and insecticide application practices for control of lepidopterous pests in intercropped sorghum and maize in souther Honduras. Trop. Agric. (In Press)

Book Chapters and Proceedings

Bueso, F., J. Medina, P. Carrillo, L.W. Rooney and E. Suhernro. 2001. Quality and shelf life of alkaline cooked products made with food-type sorghums versus corn, p. 116 - 120. 2001 IN Proc. Sorghum Industry Conference & 22nd Biennial Grain Sorghum Research and Utilization Conference, 18 - 20 February, Nashville, TN.

Zelaya, N., H. Yeggy, e.L. S.U. Suhendro and L.W. Rooney. 2001.Characterization of table tortillas from sorghum high in phenolic compounds, p. 2 - 4. IN Proc.of the Tortilla Industry Association Seminar, 20 - 23 May, City of Industry, CA.

Dissertations and Theses

Zelaya, N. 2001. Characterization of tortillas and tortilla chips from sorghum varieties high in phenolic compounds. M.S. Thesis. Texas A & M University, College Station, TX. 129 pp.

Zeledon, J.J. 2000. Occurrence, host plant relationships and management of sorghum midge, *Stenodiplosis sorghicola* (Coq.) (Diptera: Cecidomyiidae), on sorghum in Nicaracgua. M.S. Thesis. Mississippi State University, Mississippi State, MS.

Miscellaneous Publications

Zeledon, J.L., H.N. Pitre, J. Vanegas and H. Obregon. 2000.La mosquita de la panoja del sorgo. Instituto Nicaraguesnse de Technologia Agropecuaria, Centro Nacional de Investigaciones Agricoles. 6 pp.

Abstracts

Zelaya, N., H. Yeggy, E.L. Suhendro and L.W. Rooney. 2001. Characterization of table tortillas from sorghum high in phenolic compounds, p. 55. 2001 Sorghum Industry Conference & 22nd Biennial Grain Sorghum Research and Utilization Conference, 18 - 20 Feb., Nashville, TN.

Zelaya, N., H. Yeggy, E.L. Suhendro and L.W. Rooney. 2000. Characterization of table tortillas from sorghum high in phenolic compounds. AACC 85th Annual Meeting, 5 - 9 Nov., Kansas City, MO.

Horn of Africa

Gebisa Ejeta
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Coordinators

Gebisa Ejeta, Regional coordinator, Purdue University, Department of Agronomy, West Lafayette, IN 47907
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Collaborative Program

INTSORMIL/Horn of Africa is an initiative to regionalize our collaborative research efforts in Eastern Africa. Before the start of the current regional effort, INTSORMIL had a productive collaborative program with the Agricultural Research Corporation (ARC) in Sudan. This collaboration has resulted in an array of technical developments that have impacted on sorghum agriculture in Sudan. Sudanese scientists have been trained in INTSORMIL institutions. U.S. scientists have traveled extensively in Sudan and worked alongside their Sudanese counterparts. Joint workshops and conferences were organized and attended. Results of joint research efforts have been published and distributed widely. Extensive raw and improved germplasm have been identified, assembled, and catalogued for the benefit of U.S. and Sudanese agriculture.

Under the Horn of Africa initiative, 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, 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 consultancy 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. A major agreement was developed between INTSORMIL, USAID/REDSO/East, and the Inter-Governmental Agency for Development (IGAD) with funds allocated through the Greater Horn of Africa Program. Through this initiative INTSORMIL spearheaded a study on availability and use of technologies that alleviate problems associated with dryland agriculture. This comprehensive study is expected to provide direction for future agricultural research and transfer of technologies for drought prone environments of the Horn of Africa.

Research Disciplines and Collaborators

Sudan

Sorghum Breeding and Genetic Evaluation – Abdellatif Nour, ARC; Gebisa Ejeta, Darrell Rosenow, INTSORMIL.

Millet Breeding - El Haj Abu El Gasim, ARC.

Plant Pathology Program - El Hilu Omer, ARC.

Entomology Program - 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, Abera 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, INTSORMIL.

Uganda

Sorghum and Millet Pathology – Peter Esele, NARO; Gebisa Ejeta, INTSORMIL.

Striga Management – Joseph Oryokot, NARO; Gebisa Ejeta, INTSORMIL.

Eritrea

Sorghum Breeding – Tesfamichael Abraha, DARE; Gebisa Ejeta, INTSORMIL.

Eritrea – Neguse Abraha, DARHRD

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, 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 1. Sorghum and millet production.

	Sorghum			Millet		
Countries	Area 1000 ha	Yield kg ha^{-1}	Production 1000 mts	Area 1000 ha	Yield kg ha^{-1}	Production 1000 mts
Eritrea	60	842	51	15	546	8
Ethiopia	890	1236	100	280	1000	280
Kenya	120	745	90	85	682	58
Sudan	4684	785	2386	1150	192	221
Uganda	255	1498	382	407	1602	652

Table 2. Production constraints of sorghum and millet across eastern Africa countries.

	Eritrea	Ethiopia	Kenya	Sudan	Uganda
Varietal Development	X	X		X	X
Striga	X	X	X	X	X
Crop Protection					
Pest	X	X	X	X	X
Diseases	X	X	X	X	X
Drought	X	X	X	X	X
Production	X	X	X	X	X
Technology Transfer	X	X	X	X	X
Training – Long-term	X	X	X		X
- Short-term	X	X	X	X	X
Socio-economics				X	
Utilization	X	X	X		X
Information Exchange				X	X
Germplasm Introduction	X	X	X		X
Soil/Water Conservation	X		X		
Seed Production and Marketing	X	X	X	X	X

These constraints include lack of improved germplasm, drought, *Striga*, insects and diseases (anthracnose, leaf 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 has 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 to 10 years fallow/2 to 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 to 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 Progress

Sorghum Breeding

Development of Drought Tolerant, Long Cycle Sorghum Varieties for Dry Lowland Areas of Ethiopia

Moisture stress is the most important threat to sorghum production in the low dryland areas of this country. These production areas cover over 60% of the arable land. The typical characteristic of rainfall in these areas is of bimodal nature. The first small rain is received during the months of March and April with the second main rainy season from June to September. Crops planted during the month of April should resist the intermittent dry spell in May and resume normal growth in June for harvest in October or November. Such long maturing varieties are required not only for their higher grain yield but also for higher stover yield for animal feed, local construction material and fuel wood.

The Ethiopian sorghum improvement program has developed several short maturing sorghum varieties for the dry lowland areas. These varieties are suited to the main rainy season, (June and September) and have been very important when April small rains fail to come. However, whenever the first rain comes in April farmers in this part of the country prefer to grow long cycle sorghums because of the reason stated above.

This research project was initiated with technical support from INTSORMIL, Purdue University in particular. The objective of this project was to identify and further develop long maturing drought tolerant sorghum cultivars for the moisture-stressed areas of Ethiopia. Initial effort was directed to evaluation of indigenous germplasm for drought tolerance. Sorghum lines were collected from the major lowland sorghum producing areas of Ethiopia. In addition, several lines were received from the Biodiversity Institute of Ethiopia in Addis Ababa. These lines have been selected and used as line per se or for further improvement in our crossing program.

Over the last five years, a total of 450 long maturing sorghum lines were screened for drought tolerance under the bimodal rainfall conditions. Among these, 219 lines were advanced for yield tests. Even though only few varieties yielded more than the local checks, most of these lines grew taller than the checks producing higher stover yields, which is important for the eventual utilization of sorghum by the small-scale farmers. Moreover, the lines selected possessed better grain quality.

Developments of Host Resistance Against *Striga*

The overall objective of the *Striga* project in Ethiopia has been to develop resistant sorghum varieties for the *Striga* prone areas with low altitude and rainfalls. The first approach was the introduction and evaluation of *Striga* resistant lines from Purdue University in sick plots across sorghum testing sites. Lines that supported lower number of *Striga* with better overall agronomic performance and have higher grain quality are promoted to replicated multi-locational yield tests. We have also inter-crossed new sources of resistance with our elite, adapted cultivars. Segregating lines are selected under *Striga* pressure in the *Striga* endemic testing sites. In addition, in our sorghum population improvement schemes, we have been trying to introgress resistance genes from known sources such as SRN-39 using male sterile sorghum population originally introduced from Texas A & M University.

Release of Two *Striga* Resistant Varieties

Four varieties were identified to be adaptable to the Ethiopian condition among *Striga* resistant sorghum varieties developed by Purdue University. The varieties were submitted to the national variety release committee (NVRC) for official release. As a result two varieties P9401 and P9403 have been recommended for full commercial production. These varieties combine excellent grain quality and drought tolerance. Thus, they have been highly preferred by the farmers. And the farmers named them "Gubiye" and "Abshir". Gubiye is the name of a place in north Wello where this variety performs excellent as compared to local varieties under high *Striga* infestation. And "Abshir" in the local vernacular literally means, "we are encouraged". By this name the farmers want to refer that they are encouraged to grow sorghum as they had been discouraged by the extreme *Striga* damage. All the varieties tested and recommended for release supported significantly less number of *Striga* as compared to the local variety which potentially increased *Striga* seed bank in the soil year after year.

We are also using these varieties extensively in our crossing program in an effort to further develop higher yielding *Striga* resistant and drought tolerant cultivars to local germplasm background.

Sorghum Agronomy - (Kidane Georgis, EARO and Jerry Maranville, INTSORMIL)

Seedling Establishment Behavior and Growth of Sorghum Varieties under Variable Soil Moisture Deficit

A pot experiment was conducted over two years (1997 and 1998) under glasshouse condition for using sandy loam soils to study the germination behavior and seedling growth of sorghum varieties under variable soil moisture deficit (20-30%, 40-50%, 60-70% and 80-90% field capacity). The varieties tested included M-36121, (148 x E-35-1)-1-4-1 × CS 3541 derive-5-3-2, 12 × 34/F_4/3/E/1, IS 2284 and 76 T_1 #23. Percent germination, seedling shoots and root length (cm/plant), seedling shoot and root dry weight (gm/plant) were measured. Germination percentage was not significantly affected by the moisture deficit levels, while germination of sorghum seeds were significantly affected by varietal differences. On average, varietal differences were in the order: IS 2284 > 76 T_1 #23 > M-36121 > 12 × 34/F_4/3/E/1 > (148 x E-35-1)-1-4-1 x CS 3541 derive-5-3-2.

Seedling shoot and root length (cm/plant), shoot and root dry weight (gm/plant) data showed that the effects of moisture deficit levels was highly significant. Highest values for the measured variables were recorded at 80 to 90% and lowest at 20-30% field capacity moisture deficit levels. In general, varieties 76 T_1 #23 and (148 × E-35-1)-1-4-1 × CS 3541 derive-5-3-2 had the lowest over all seedling shoot and root dry weights (gm/plant) while the other three had comparable high values.

Nitrogen Use Efficiency, Dry matter Accumulation and Partitioning under Rainfed Conditions

This field experiment evaluated the N use efficiency (NUE) of five sorghum varieties grown at five levels of N (0.23, 46, 69 and 92 kg ha^{-1} N). Sorghum varieties were grown during the wet season (June to November, 1997, 1998 and 1999). Due to lack of chemicals for soil and plant analysis the N use efficiency was not computed. However, the analysis of variance indicated that the main effects of both N levels and the genotypes were statistically significant, but the interaction effect was non-significant. The highest yield (4240 kg ha^{-1}) was, therefore, produced by application of 69 kg ha^{-1} of N followed by 92 kg ha^{-1} 4213 kg ha^{-1}). Among the genotypes, 12x34/F4/3/E/1 produced the highest grain yield of 4913 kg ha^{-1} and IS2284 the lowest (2913).

Sorghum Pathology - (Girma Tegegne, IAR and Larry Claflin, INTSORMIL)

Studies on Sorghum Covered Kernel and Loose Smut

The incidence of covered and loose smut diseases in sorghum under small-scale production is increasing. Although the beneficial effect of seed dressing chemicals against sorghum smut is well recognized, progress in transferring this technology has been limited because of the high cost of chemical to small-scale farmers. To overcome this problem, a collaborative research project has been initiated with INTSORMIL to generate various methods such as cultural practices (planting date), validate and improve animal urine (cow and goat urine) application as seed treatment, and investigate potential botanical plants.

Early planting of sorghum used to be a common practice to reduce sorghum covered smut incidence in most of the sorghum growing areas in Ethiopia. This practice has no more value since the rainfall pattern has been fluctuating (usually sorghum is planted between mid March and April). To alleviate this problem the sorghum breeders at Melkassa have developed early maturing sorghum varieties that are planted late in the season (in June). To evaluate management options for control of sorghum covered smut for early maturing sorghum varieties, research was conducted at Melkassa and Miesso. The results have indicated that as planting date is delayed, covered smut incidence increases. Therefore, promoting the early maturing sorghum varieties without sorghum covered smut management packages would lead to a significant yield loss.

Not much work has been reported on the use of animal urine as sorghum seed treatments in the past. Traditionally this practice has been used as sorghum seed treatment in the northern part of Ethiopia and its effect has been long recognized. According to information obtained from farmers, urine treatment appears to reduce seed germination and emergence. An experiment was conducted to validate the potential effect of this traditional practice and improve the adverse effect on seed germination and emergence. The result demonstrated that soaking artificially inoculated sorghum seed with covered smut for 20 minutes, (in animal urine diluted with water and stored for a week) effectively controlled sorghum covered smut. Over the last five years our research results consistently demonstrated the benefit of this practice for smut control.

The role of plant products in controlling plant diseases and information about their use is scant. However, the use of these plant products by small-scale farmers in specific localities has been well recognized in Ethiopia. We recently learned that Ethiopian farmers use the botanicals to treat sorghum seed prior to planting against sorghum covered and loose smut in slurry. This practice is not widely known and no research has been attempted. Over the last five years, an attempt has been made at Melkassa Research Center to investigate the potential effect of botanicals against sorghum covered and loose smuts. About four botanicals have been collected and evaluated against both smuts. The result has been encouraging. Currently two of the botanicals have shown a significant effect in reducing smut incidence as compared to the control.

Sorghum Entomology (Tsedeke Abate, EARO and Henry Pitre, INTSORMIL)

Studies on Stalk Borers of Sorghum

The objective of the study is to develop an integrated pest management (IPM) program for sorghum stalk borers in Ethiopia. An experiment consisting of four dates and three insecticide treatments (application in the whorls or cypermethrin granules at 4 and 6 weeks after seedling emergence, and an untreated check) were conducted at Melkassa, Ziway, Arsi-negele, and Mieso in 1997. The extended drought did not allow growing sorghum over the intended period of planting at Ziway and Mieso and therefore no useful data were obtained at these two locations. A summary of data obtained from Melkassa and Arsi-Negele is given here.

At Melkassa, the sowing date had significant effects on the number of borers per plant ($P < 0.01$), percent chaffy head ($P < 0.01$), percent peduncle damage ($P < 0.01$), and seed yield ($P < 0.01$). In general, the number of stalk borers per plant, percent chaffy heads and peduncle damage were highest and seed yields were lowest in the last sown plots. On the other hand, differences among insecticide treatments were significant for borers per plant ($P<0.05$), percent chaffy head ($P<0.05$), and peduncle damage ($P<0.05$) while none significant for grain yield. At Arsi-Negele, only the sowing date showed a significant effect ($P<0.05$) for seed yield; the lowest yield obtained from plot sown last, but it did not appear that the low yield was due to stalk borer damage as the insect counts and infestation levels were very low.

In 1998, at Melkassa the sowing date had significant effect on the number of stalk borers and percent peduncle damage. The smallest number of stalk borers were observed in the second sown plots. Percent peduncle damage was also in the second sown plots. On the other hand no significant effect was observed between insecticide treatments on stalk borer number and percent peduncle damage. At Miesso sowing date had significant effect on stalk borer number and percent peduncle damage. Highest number of stalk borer per plant and percent peduncle damage were observed in the first and last sown plots. Differences among insecticide treatments were nonsignificant for both cases.

Surveys were conducted starting from late December 1996 in many parts of sorghum growing areas of Ethiopia and the results have shown that stalk bores are widely distributed in the country. Several factors (altitude, crop variety, and cultural practices) appear to influence stalk borer incidence and abundance. *Chilo partellus, Busseola fusca and Sessamia* species of stalk borers are known in this country. Among these three *C. partellus* is the most important in stalk borer Ethiopia. Many parasitoids and predators of stalk borers larvae and pupae are known in the country. The braconid *Cotesia sesame* is the most important larval parasitoid; others include the pupal parasitoids *Pediobius furvus, Euvipio rufa* and *Dentichasmias busseolae.* Several species of earwigs, spiders and ants are important predators.

Experiment on the population dynamics of stalk borers and their natural enemies were conducted at Melkassa on monthly interval starting from late January 1997 for 24 months. The main plot was maize and sorghum and the sub plot was neem powder applications (applied 30 days after emergence and 30 + 45 days after emergence and untreated check). The result has shown that population of *C.partellus* was small in June and July. On other hand natural enemies' number was varied in the season. Neem seed powder applied twice at 30 and 45 days after emergence found to better control of stalk borers than the check and one application (30 dae). Highest infestations of stalk borers were observed in sorghum than Maize throughout the season.

Surveys were conducted in 1996-97 and 1997-98 for two years in major sorghum growing areas of central, southern, north, eastern, and western Ethiopia. Results obtained so far indicate that, although a good number of parasitoids and predators attack stalk borers under natural conditions, their incidence is lower than expected and they do not seem to keep pest numbers below economic levels. However, this was site specific – i.e., pest numbers and accompanying damage levels were very high in a few areas whereas they did not seem to be limiting factor for crop production in the majority of the surveyed areas. Varietal effects and cultural practices also showed differences. Thus, in the intermediate future, stalk borer IPM should attempt to integrate cultural practices and use of neem treatment. Biological control with introduced natural enemies can be tested in limited areas in the intermediate term; use of host plant resistance can be entertained as long-term strategy.

Food Science (Senait Yetneberk, Abera Debelo, EARO; Bruce Hamaker and Gebisa Ejeta, INTSORMIL)

Evaluation of Sorghum Varieties for Variability in *Injera* Keeping Quality

Ten varieties of sorghum with different color group were evaluated for variety differences in *Injera* keeping quality. Tef was used as standard check. Organoleptic evaluation was conducted by panel group of 10 people and sorghum growing farmers. The parameters considered were color, moisture content, texture, flavor, shelf life before initiation of mold development, and general acceptance. The experiment has been conducted four times at different seasons. *Injera* was stored in a method recommended from previous work, i.e., in *mesob* (a straw basket) with polyethylene lining. Sampling was done at 6, 12, 24, 36 and 48 hrs. Organoleptic evaluation was conducted before storage and after according to the parameters required. According to results of before and after storage, varietal differences showed different levels of consumer acceptability. Similarly, there was variability in shelf life among the verities.

Eritrea - Pearl Millet Breeding (Neguse Abraha, DARHRD)

Crossing Between Selected Land Races and Introduced Materials

Five selected Land races (Bultug Mebred, Bultug Keren, Gudmay, Tokroray, and Zibedi) and 5 introduced materials (ICMP 95490, Ugandi, ICMV 221, ICMP 96593, and ICMP 97754) were used in our intercropping program.

Reciprocal crosses were made between each pair and enough seed from 235 populations was produced for further selection.

Assessment of Downy Mildew Incidence in Eritrea

Rationale for the survey: Pearl millet is the second largest food crop in Eritrea, grown mainly by small farmers in low lands and mid lands. Pearl millet downy mildew, caused by the fungus, *Sclerospora graminicola,* is one of the major production constraints in pearl millet in most of the semi-arid tropics. Downy mildew is widely distributed in Eritrea and occurs in epidemic form on farmer Land races, making it the major millet diseases in Eritrea. The Eritrean government requested assistance in conducting a systematic survey of the prevalence and severity of downy mildew in farmers' fields, to better understand the distribution and economic importance of the disease.

The pathogen: Sclerospora graminicola, the causal agent of downy mildew in pearl millet, is an obligate pathogen. It causes systemic disease, by infecting millet seedlings at plumule stage and developing through the plant system causing infection in developing leaves and finally in panicles. It produces two types of symptoms: chlorosis in the leaves followed white downy mycelial growth on the abaxial side of the leaves, and malformed panicles with leafy structures in place of normal florets (the characteristic "green ear" symptom). Downy mildew is both a seed-borne and soil-borne pathogen, but the main source of inoculum for the build-up of the pathogen in fields sown to susceptible varieties is infected leaf tissue from preceding crops in the soil.

Survey methodology: The survey was conducted in eight sub-zones: Keren, Hamemalo and Hagaz in Ansaba Zone, and Mogolo, Barentu, Gogne, Haycota, and Dghe in Gash Barka zone. Local administrators and/or personnel from Ministry of Agriculture accompanied the team in the survey of millet fields in their areas. The survey covered 32 fields planted with land races, and 7 fields planted with ICMV 221 (4 in Keren, 1 in Hamemalo and 2 in Hagaz sub-zones). The latitude, longitude and altitude of the visited fields were recorded by GIS equipment to position the fields in the map of Eritrea. Downy mildew incidence was recorded in five randomly chosen sub-plots (1 m x 1 m) in each field. Percent downy mildew incidence was calculated from the ratio of diseased to total plants.

Supporting data: Crop growth stage and crop sequences in previous years were recorded for all fields. Diseased tissue samples were collected for further studies on the variation in pathogenicity among the sampled pathogen populations. Total rainfall data and number of rainy days in each sub-zone were collected from the department of agriculture in each zone. Rainfall and crop sequence data were used to ascertain if there were relationships between these factors and disease development.

Most of the areas that were surveyed were planted to land race cultivars. The crop was at the anthesis to soft-dough stage at the 6 locations; downy mildew was present in most fields.

Downy mildew incidence was very high on Land races grown in the Keren (40 to 78%), Gogne (20 to 94%), Hagaz (32 to 86%), Hamemalo (36 to 56%) sub-zones of Ansaba and in Barentu (13 to 48%) and Haikota (1 to 46%).

In contrast, downy mildew incidence was very low (<1%) in fields in Mogolo and Dghe. There was no obvious reason for this marked difference among sub zones.

ICMV 221 had <5% incidence in 6 fields and was free from downy mildew at Bog in the Hagaz sub-zone. ICMV 221 had good seed set but was subject to bird damage as it was maturing earlier than local land race varieties.

The variation in downy mildew incidence at different locations did not appear to be related to either the variation in total rainfall received or in the number of rainy days, indicating that there may be variation in virulence among local populations of the pathogen.

'Millet after millet' cropping sequence was the most predominant system practiced by most of the farmers. Although there was variation in disease incidence among different cropping sequences, there was no consistent effect of sequence.

Thirty samples of infected tissue were collected from different land races in different locations, to study the variation in the population of the pathogen. Dr. Wendy Breeze, at the University of North Wales, Bangor, UK, will assess the pathotype variability.

Sorghum Breeding - (Tesfamichael Abraha, DARE and Gebisa Ejeta, INTSORMIL)

In 2000, eight entries with three replication and four rows per plot were planted at Hagaz Station. These were the varieties which were selected by farmers in on-farm tests during the past 4 years at Shambuko research station. Two varieties were selected (PP 290 and ICSV 210) and are now under seed multiplication.

The objective of this trial was to select a promising variety which is early maturing, high yielding, resistant to disease, pest and with good grain quality.

The genotypes differed significantly from each other in plant height, days to 50% flowering and 100 grain weight, however not mean grain yield. Though the genotypes failed to show difference in grain yield it is worth mentioning that ICSV 210 and LARSVYT 58-85 were higher yielding with 40.2 and 40.1 qt/ha respectively. With respect to flowering PP 290 (59 days to flower) was the earliest while Gadam el Hamam and ICSV 111 IN were late with both 69 days to flower. The genotype ICSV 210 with 176.4 cm was the tallest while MEXICO R-LINE 5 was the shortest with 126.9 cm.

All the trials at Hagaz station were supplemented with additional of 10 irrigation frequencies. As a result it is difficult to draw a conclusion for rejection or accepting a genotype because some of these genotypes could do better in moisture stressed environment. Therefore it was agreed to repeat this experiment for further verification and evaluation which was advised to be tried in under rain-fed conditions at Goluj Research Station. Additional variety trials were also conducted contributing to further selection of new germplasm for extensive evaluation next season.

Two successive rounds of introduction and screening of exotic germplasm have been carried out, resulting in identification earlier of Dinkmash and now of PP 290 and ICSV 210. All these lines are rather late for dry years in the western lowland. Earlier, better adapted varieties are therefore required. Considering this fact, a breeding program that is based on local varieties and in crosses with the best introductions that have been identified over the last few years was initiated to provide more appropriate land race –derived materials. The goal of this project is to diversify the sorghum germplasm base in Eritrea.

The hybridization of the land race based crosses is intended to get improved yield, early maturity with adaptation to the existing environment of Western Lowland, short uniform plant height, good grain quality for "Injera" making, and resistant to diseases and pests.

A seed multiplication activity was undertaken using varieties earmarked for release (PP 290 and ICSV 210) during the off-season of 2000. However, because of the border problem with Ethiopia, 11 hectare of seed multiplication of these two promising varieties were completely destroyed a week before harvest.

Sorghum Breeding - (C.K. Kamau, KARI and Gebisa Ejeta, INTSORMIL)

In a preliminary yield trial of 31 sorghum entries at Katumani 8 of the selections were dropped and the seven top yielders were promoted to Advanced Yield Trial (AYT). Twenty-three selections were retained for further testing as a preliminary yield trial for second season.

Additionally, an advanced yield trial of 21 entries were tested during the short rains during 2000. Nine entries were selected for further evaluation. During the 2000 long and short rain seasons, yield trials were also conducted at Katumani, under the national performance trial. The trials comprised 16 varieties replicated four times in randomized complete block design. Plot size was 4 rows 4 meters long planted 75 cm apart. Seeds were drilled in the row and thinned to a spacing of 20 cm between plants. Only the middle two rows were harvested for analysis and evaluation. Entries were assessed for grain yield, stand count, days to 50% flower head exertion and plant height. The effects of the seasons were also assessed.

The two seasons (2000LR and 200SR) were significantly different with respect to stand (stand establishment), days to flower (maturity), exertion, plant height, and grain yield ($P<0.01$).

Varieties were different in stand count, exertion, plant height ($P<0.01$) but not in days to flower and grain yield. The C.V were generally high. Of the sixteen varieties tested, eight entries performed better than the check variety. There was significant site by entry interaction for stand, exertion, plant height but grain yield and day to flower.

In another trial nine varieties introduced for high malting quality were tested for yield beside traits like stand establishment, day to flower (earlines) head exertion and plant height. There were significant differences between season in stand establishment, day to flower exertion plant height and grain yield ($P<0.001$). The short rain season was much better than the long rain season.

The varieties were different in stand establishment; exertion, plant height and grain yield but not in days to flower. There was significant season by variety interaction stand, head exertion plant height and grain yield but not for day to flower.

A breeder-seed increase of KARI-Mtama-I, ICSV III, IS76, Serena and Seredo. In the same activity seed was increased for elite lines in NPT, AYT, PYT and malt quality sorghum trial to back up on- farm research and other activities of the breeding program. These seed increase blocks were also used as a show-and-tell for visitors. Varieties about to enter on-farm testing were demonstrated. In this activity a local chief was invited to talk about dryland crop farming in Kimutwa Machakos prior to the on-set of the 2000 short rain season. After the demonstration, 31 farmers interested in growing sorghum were each given 2kg of KARI-Mtama-1, ICSV 111 or Seredo sorghum varieties. They were trained on necessary management to achieve the highest yields possible. In coming seasons, interested farmers agreed to be sorghum growers. Harvest of threshed grain on farmers' fields ranged from 107 to 430 kg. Land planted on the variety is variable depending farmer efficiency in use of the seed and management.

Screening Sorghum for Resistance to *Striga* - (C. Mburu, KARI)

A *Striga* resistant sorghum nursery trial comprising twenty-five introductions from Purdue University (USA) were tested in Alupe sub-Center of the Regional Research Center at Kakamega in the Lake Victoria region of Kenya. The *Striga* resistance nursery was planted, during the 1999 short rainy and 2000 long rainy season. Farmers' local variety was included as a check. The trial was planted in RCBD with 4 replications. Each entry was planted in 3 row plots, each row being 5 m long. Plant and row spacing were 15 cm and 75 cm respectively. The recommended fertilizer rate in the region (20 kg N and 20 kg P2 05 per hectare) was applied. Weeding was done twice before the emergence of *Striga* weed. Thereafter, other weeds were hand-pulled leaving only *Striga*. Data collected include days to flowering, plant height, yield, and *Striga* count among others. Harvesting was done at physiological maturity, and seed kept for planting during the succeeding seasons.

The seasons were significantly different in *Striga* count, day to flower, plant height, midge damage and yield $P<0.01$ but not for stand count. Entries had significant differences in stand per plot, days to flower (DFLW), midge damage (score), *Striga* count (*Striga*), plant height (plant ht [cm], and grain yield (kg ha^{-1}) ($P<0.01$). There was significant entry (variety) by season interaction for grain yield only.

Institution Building

Field and lab supplies as well as expendables were purchased for Eritrea, a laptop for Kenya and a plot thresher, triple beam scale, Ph Meter and soil compaction tester, as well as other supplies were purchased for the Ethiopian program. In addition, each of the programs has submitted a list of supplies and materials and these are being ordered for ocean freight shipment to Ethiopia and Eritrea.

Gebisa Ejeta traveled to Kenya and Ethiopia 8 – 20 December 2000. The meeting in Kenya was initiated by Gebisa with the objective of bringing ICRISAT, INTSORMIL and Horn of Africa sorghum and millets researchers to develop an understanding of future collaboration in the region. Those participating in these meetings included Dr. B.N. Mitaru and C.K. Kamau, KARI/Kenya, Dr. Aberra Debelo, EARO/Ethiopia, Abraha Negusa, DARHRD/Eritrea, and Dr. Peter Esele, NARO/Uganda.

Dr. Aberra Debelo, Ethiopia/EARO Host Country PI, traveled to Columbus, Mississippi to participate in the INTSORMIL Board of Directors' meetings May 14-16, 2001. He also visited Purdue University for a week to meet with Gebisa Ejeta and other INTSORMIL collaborators on campus to discuss opportunities for collaboration and work plans for the next five years.

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

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Coordinators

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Dr. Tebago Seleka, Economist, Botswana College of Agriculture, Sebele, Gaborone, Botswana

Collaborative Program

Organization, Management, Implementation and Financial Inputs

The INTSORMIL Southern Africa regional program involves six projects:

001 - *Breeding:* Development of pearl millet R_4 top cross hybrids, using popular Namibian and Zambian varieties;

00-2 - *Pathology:* Disease management research, identification and use of resistance to control sorghum diseases;

00-3 - *Food quality:* Sorghum food quality research;

00-4 - *Pests:* Genetic resistance to sugarcane aphid and integrated pest management in Botswana and South Africa;

00-5 - *Production and Marketing:* Identification of factors limiting commercial production and marketing of sorghum in Botswana; and,

00-6 - *Ergot:* Control of sorghum ergot.

Through a Memoradum of Agreement with SADC/ICRISAT/SMIP the regional program is integrated with regionally planned sorghum and pearl millet research. The MOU allowed INTSORMIL funds to be disbursed to collaborating NARS scientists, of which there are now 14 in 5 countries. Discipline scientists and the SMINET regional coordinator at the ICRISAT SMIP Center at Matopos, Zimbabwe are also involved. Due to INTSORMIL's previous management of a major post graduate training program for the Southern Africa region (25 Ph.D.s and 50 M.S.'s from 9 countries completed their degrees), many of the collaborating scientists in Southern Africa are INTSORMIL trained and had INTSORMIL PI's as their major advisors. Activities in each project are planned annually in conjunction with NARS collaborators. Where SADC/ICRISAT/SMIP (called SMIP hereafter) has scientists in the research discipline, these are also involved. The plans are reviewed at the SMIP's Annual Steering Committee Meeting to ensure they continue to fit in the profile of work needed on the development of sorghum and pearl millet production in the region.

Collaboration with Other Organizations

Research on pearl millet and sorghum breeding is organized with NARS scientists in collaboration with the SMIP Technology Transfer program (SMINET) at Matopos, Zimbabwe, which ensures complementarity to existing SMIP and NARS sorghum and pearl millet programs.

Grain quality research is collaborative with the University of Pretoria, CSIR (South Africa [SA]), Agriculture Research Corporation, South Africa, and SMIP. The CSIR has strong interactions with the private sector in the region which will assist in transfer of information to help private entrepreneurs. Sorghum and pearl millet production constraints are being investigated with the Botswana College of Agriculture. Entomology research is with the ARC Summer Grain Crop Institute, Potchefstroom, SA and the Department of Agricultural Research, Gaborone, Botswana. Plant pathology and ergot research is with the ARC Summer Grain Crops Institute, Potchefstroom, SA; Crops and Soil Research, Mt. Makulu Research Station, Chilanga, Zambia; Department of Agricultural Research, Gaborone, Botswana; and the Plant Protection Research Institute, Harare, Zimbabwe. Pearl millet breeding activity is with the Ministry of Agriculture, Water and Rural Development, Tsumeb, Namibia and the Ministry of Agriculture, Kaoma Research Station, Kaoma, Zambia.

The Planning Process

Research projects in breeding, pathology, entomology, and food quality were based on on-going linkages. Production and marketing, and ergot research projects, were based on availability of regional expertise. The future program will be shaped by priorities decided by SADC/NARS (SADC = Southern Africa Development Community) and the availability of matching INTSORMIL scientists and funds. INTSORMIL collaborative research in SADC will be developed as part of the SMIP Regional Research and Technology Transfer program (SMINET) to ensure full integration with other sorghum and pearl millet research and development projects in the region.

As of October 1999, donor funding for Phase IV of the SMIP program to ICRISAT at Matopos focused entirely on technology transfer, with no further crop improvement research. Since ICRISAT has few core funded scientists in the SADC area, INTSORMIL's participation in regional crops research is regarded as essential by SMINET and collaborating countries.

Sorghum and Pearl Millet Constraints Researched

Production and Utilization Constraints

Sorghum and pearl millet are major food crops in the SADC region, and sorghum is used to make opaque beer. Sorghum is the major cereal in Botswana and parts of Zambia, Mozambique, Malawi, and Tanzania, while pearl millet is the major cereal in Namibia and parts of Tanzania, Mozambique, Zambia, and Zimbabwe. Many constraints associated with low resource agriculture are present including low grain yield potential, infertile soils, variable moisture availability, numerous insect pests and diseases, and poor market facilities. Genetic improvement can economically address some constraints by increasing grain yield potential and stress resistance, and by improving grain quality to meet end-use requirements. However, market channels should be improved since sorghum varieties with the required quality to meet commercial consumer requirements frequently have inconsistent production. The availability of a consistent supply of improved quality sorghum and pearl millet for processing into value added urban products is a major problem limiting utilization. Food companies will use but cannot consistently acquire sufficient quantities of high quality sorghums for processing. A strong need exists for developing a system of identity preserved production, marketing, and processing.

New varieties and hybrids with increased grain yield potential, drought tolerance, and other desirable traits are being developed by national programs. Additional sorghums and pearl millets are continuously being introduced into various SADC regions. It is imperative that all improved cultivars have the required levels of resistance to major endemic disease pathogens and pests along with excellent environmental adaptation in the regions they are intended for production.

Identification of regionally adapted sorghum or pearl millet cultivars or hybrids with stable grain yield and multiple stress resistance will help the NARS improvement teams in developing lines, varieties, and hybrids for the diverse environments and production systems in each country and throughout similar environments in the SADC region. Sorghum ergot is prevalent through the region and may be severe in hybrid seed production fields. Research on control involves the use of genetic resistance, location, time of planting and possibly chemicals.

Constraints Addressed by Project Objectives

Breeding: Raise grain yields by developing A_4 CMS pearl millet hybrids with local adapted varieties as male parents in Namibia and Zambia.

Pathology: Reduce grain yield loss by identifying adapted, agronomically desirable sources of resistance to drought stress and charcoal rot to include sources with resistance to sugarcane aphid (Botswana, Zimbabwe, Zambia). Identify adapted, agronomically desirable sources of resistance to the major foliar pathogens: leaf blight, anthracnose, and sooty stripe (Zimbabwe, Zambia).

Food Quality: Improve sorghum food quality by evaluating qualities of Zimbabwean sorghums. Examine methods of using high polyphenol sorghums in foods through dry milling, malting and brewing.

Insects: Reduce yield losses by identifying, evaluating, and incorporating sugarcane aphid resistance into sorghum varieties and hybrids adapted to Southern African agricultural systems. Develop integrated pest management strategies for sorghum insect pests in Southern Africa.

Production and Marketing: Through structural village surveys and country-wide equilibrium analysis, identify alternative feasible sources of supply for sustainable sorghum processing in Botswana and their distributional economic welfare impacts. These analyses can then be extended throughout the region.

Ergot: Reduce the risk of ergot through analyses of weather data, and develop control strategies involving host plant resistance, management to improve pollination, and chemical control.

Mutuality of Benefits

The productivity and utilization of both sorghum and pearl millet will ultimately be improved both in SADC countries and the U.S. through joint research. Germplasm flow is useful in both directions. Basic research from the USA can often be adapted for use in developing countries where grain yield potential, adaptation, stress resistance,

Table 1. Mean grain yield and associated characteristics of the first backcross generation (BC1) and experimental hybrids at Longe and Simulumbe, Zambia during the 2000-2001 season.

Pedigree	Grain yield kg ha^{-1}	Plant height (cm)	Head number	Head length (cm)
NEC	794	230	24	38
(841B-P3 × NEC) BC1	1536	255	29	32
(97C 77229 × NEC) BC1	1706	270	30	30
(IP 18293 × NEC) BC1	2500	245	21	32
(PT 732B-P2 × NEC) BC1	3036	250	45	26
(Tift 23DB-P1 × NEC) BC1	2361	245	21	26
Mean of BC1's	2230	253	29	30
LUBASI	1428	255	14	28
(LGP-1-B-10 × Lubasi) BC1	2460	295	30	28
(PT 732 B-P2 × Lubasi) BC1	2917	220	31	30
(IP 18293 × Lubasi) BC1	1964	255	38	40
(P1449-2 × Lubasi) BC1	1123	215	31	34
(841B-P3 × Lubasi) BC1	1845	220	24	26
(863 B-P3 × Lubasi) BC1	2798	220	24	30
Mean of BC1's	2183	237	29	32
ZPMBC	1805	245	24	30
(LGP-1-B-10 × ZPMBC) BC1	2036	195	6	24
(841B-P3 × ZPMBC) BC1	2234	235	40	36
(ICMP 85410-P7 × ZPMBC) BC1	1926	215	12	30
(97C 77229 × ZPMBC) BC1	2631	220	27	38
(Tift 23DB-P1 × ZPMBC) BC1	972	245	26	30
(PRT2/89-33 × ZPMBC) BC1	1607	235	32	44
(IP 18293 × ZPMBC) BC1	2202	240	30	52
Mean of BC1's	1909	227	25	36
TUSO	1480	320	32	34
(IP 18293 × TUSO) BC1	1631	265	22	32
(W 504 × TUSO) BC1	3016	260	36	38
(LGP-1-B-10 × TUSO) BC1	1389	215	40	34
(PT 732 B-P2 × TUSO) BC1	2817	250	20	35
(PRL T2/89-33 × TUSO) BC1	2540	245	33	30
(841 B-P3 × TUSO) BC1	2698	195	53	40
(863 B -P3 × TUSO) BC1	1766	235	43	28
(Tift 23DB-P1 × TUSO) BC1	2381	235	35	38
(97C77229 × TUSO) BC1	2083	235	27	38
Mean of BC1's	2254	237	35	35

Table 1. Continued.

Pedigree	Grain yield kg ha^{-1}	Plant height (cm)	Head number	Head length (cm)
SEPO	1865	275	34	38
(IP 18293 × SEPO) BC1	1091	280	27	50
(PRL T2/89-33 × SEPO) BC1	2956	285	29	26
Mean of BC1's	2024	283	28	38
NLC	1190	250	36	30
(ICMP 85410-P7 × NLC) BC1	1786	255	8	34
(PT 732 B-P2 × NLC) BC1	2012	230	44	38
(W504 × NLC) BC1	833	185	51	38
(863 B-P3 × NLC) BC1	1893	215	26	50
(LGP-1-B-10 × NLC) BC1	1032	220	8	34
(PRL T2/89-33 × NLC) BC1	1893	265	44	34
(P 310-17 × NLC) BC1	2996	235	51	30
Mean of BC1's	1778	229	34	37
NloC	1131	240	27	36
(ICMP 85410-P7 × NloC) BC1	1686	260	33	40
(Tift 23DB-P1 × NloC) BC1	1496	246	7	30
(LGP-1-B-10 × NloC) BC1	1091	DM	DM	DM
(PT 732 B-P2 × NloC) BC1	873	DM	DM	DM
(PRL T2/89-33 × NloC) BC1	774	DM	DM	DM
(863 B-P3 × NloC) BC1	766	DM	DM	DM
Mean of BC1's	1115			
ZPMV 92008	504	DM	DM	DM
(97C77229 × ZPMV 92008) BC1	635	DM	DM	DM
(P 310-17 × ZPMV 92008) BC1	496	DM	DM	DM
(ICMP 85410-P7 × ZPMV 92008) BC1	DM	DM	DM	DM
Mean of BC1's	565	DM	DM	DM
GRAND MEAN OF BC1's	1757			
GRAND MEAN OF POLLEN DONORS	1275			
88006 A4 × TRM R4	734	DM	DM	DM
88006 A4 × TRM R4R5	496	DM	DM	DM

DM=Data missing

and grain quality 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. For example, research in South Africa on sources of ergot resistance, understanding environmental conditions conducive to disease spread, and methods of research are now of vital interest to U.S. scientists. Nutritional components of food quality researched in collaborative projects have relevance to grain values for livestock feed.

Research Progress

Pearl Millet Breeding - Zambia

During the 2000-2001 season the backcrossing program involving 45 crosses initially made in 1998 continued. Enough seed of the second backcross generation (BC2's) was obtained for continuation of the program as well as field evaluation the following season.

Seed from the first backcrosses (BC1) was evaluated at two locations in Zambia, Longe and Simulumbe. On average the BC1's produced 37% more grain yield (1757 kg ha^{-1}) than the 8 pollen donor or recurrent parents (1275 kg ha^{-1}) used in the program (Table 1). Backcrosses derived from Tuso were generally better (2254 kg ha^{-1}) followed by those derived from NEC (2230 kg ha^{-1}), Lubasi (2183 kg ha^{-1}) and Sepo (2024 kg ha^{-1}). Two crosses involving NEC and Tuso produced more than 3 tons/ha. Tuso, Lubasi and Sepo are released varieties while NEC is an early maturing composite. Sepo is a blend of local land races. Surprisingly downy mildew was not seen despite the conditions being conducive. However, some of the backcrosses showed incidences of smut and ergot. Phenotypically, heads of the backcrosses greatly resembled those of the recurrent parents while the purple coloration originating from some seed parents was retained.

Experimental hybrids 88006 A4 × TRM R4 and 88006 A4 × TRM R4 R5 from the University of Nebraska program were early, short and exhibited poor vigor. Other A and B lines - 4600P 77141, 4700P 77142, 48 88006 A4, 49 88006B, 51 8401M (A4) CMS, 52 8401 M (A4) and 53 8401B - could not withstand the unusually heavy and continuous rains. Neither crossing nor maintenance was successful.

Sorghum Breeding - Zambia

The overall goal of the breeding program is to develop alternative cereal crops for areas that are marginal in the production of maize and therefore deficit in food. The increased production and use of sorghum is expected to provide household food security and increased income for subsistence farming sector. The program has four specific objectives: 1)Develop high yielding varieties and hybrids suitable for food, feed, brewing for different agroecological regions with good general resistance to all economically important diseases and pests. 2)Develop appropriate agronomic management practices for each agro - ecological region and farming system and work as a catalyst in the transfer of technology. In order to meet this objective the team is closely working with developmental teams within the research branch and various provincial units and other extension agencies including NGO's. 3)Maintain pre-basic and basic seeds of all released and pre-released varieties, hybrids and their parents. 4)Identify various biotic and abiotic production constraints of sorghum and develop control measures.

In 2000-2001 season collaborative research with INTSORMIL involved the exchange of germplasm and trials in breeding and pathology. The following trials were received: Anthracnose Resistant Germplasm Nursery (ARGN), International Sorghum Virus Nursery (ISVN), Southern Africa Breeding Nursery (SABN), Sugarcane Aphid Test (SCAT), Drought Line Test (DLT), Drought Hybrid Test (DHT). The trials were received too late for planting at the various testing sites. Breeding lines were also obtained from the Texas A&M University sorghum breeding program. The trials will be evaluated in the coming season. However, the breeding program continued with the evaluation of promising lines for yield and other desirable agronomic traits.

One of the main program objectives is to generate genetic diversity through collection, introduction, and hybridization of potential parental lines. A total of eight trials were evaluated at one or more locations in the major Zambian sorghum production regions. Program emphasis has shifted to target not only small-scale farmers but also commercial end users. The development of sorghum varieties suitable for food, brewing, feed and forage is now a major emphasis.

It is important to evaluate promising lines for grain yield and other agronomic traits, and to maintain and increase seed of released varieties. A non-replicated trial was evaluated at Golden Valley, and visual selections made in test crosses, introductions, F_2 populations, F_3, F_4, F_5, and F_6 progenies. Seed of released varieties was maintained and increased. The material evaluated included 40 A-/B-line pairs; 206 lines for seed increase; 134 experimental crosses and 79 test crosses. Seed of ZSV-15, SDS 2691, MMSH-1257, Sima, ICSA 23A and B, and Kuyuma were increased in isolation fields. Selected materials will undergo additional evaluation next season. The season provided conditions conducive to select for diseases in dry environments of Lusitu.

Failure of seed production and distribution systems have been cited as some of the reasons for the low adoption of sorghum and millet varieties. Seed of released varieties (Kuyuma and Sima) and hybrids (MMSH - 375, 413 and 1257) cannot be produced by seed companies citing low demand. The research program and NGO's have embarked on seed multiplication activities at the village level. The approach used is to identify one or two prominent farmers in the village that will produce seed for sale in the village itself. Extension officers monitor the seed growers. Seed of released varieties such as Kuyuma, Sima and parental lines were produced in isolation. The program was also involved monitoring sorghum and millet seed production activities of SHAPES, an NGO in the drought prone areas of Zambia.

Field days were organized where small scale farmers and end-users participated. Farmers were offered a chance to view promising improved varieties and products. Interest was generated with the kind of products that can be made from sorghum and millet.

However trials for forage, brewing, feed and food were evaluated at Golden Valley Agricultural Research Trust and Lusitu. Trials have just been harvested and yield data is being collected. Hybrids MMSH-413, MMSH-625, MMSH-1040 and MMSH-1257 (a food type) were outstanding at both Lusitu and Golden Valley Agricultural Research Trust.

Plant Pathology - Zambia and South Africa

Research in Zambia was primarily on three diseases - pearl millet downy mildew(*S. graminicola*), ergot, and anthracnose. Pearl millet downy mildew is prevalent in all areas where susceptible local varieties are grown. The potential grain yield loss can reach 90%. It is necessary that resistant sources be identified for use in the breeding program. Objectives of the research were to: 1) Establish a downy mildew sick plot and 2) identify sources of resistance. During the 1999-2000 season 60 lines were planted in a one replicate trial at Longe in Kaoma. Analysis of the data led to the conclusion that 25% of the samples were highly susceptible, 20% were moderately susceptible and 55% were tolerant to pearl millet downy mildew. Statistical analysis could not be done since the trial was one replicate only. In the next season the number of entries will probably increase to include material from the EU-SADC project based in Namibia. Research on ergot was primarily in two areas - chemical control, and the effect of pollen amount/viability and pre- or post-flowering weather conditions on disease development. The research on chemical control was inconclusive due to low disease incidence in the plots. Research confirmed previous observations that incidence is less in hybrid production blocks with abundant pollen shed and viability from adjacent pollinator rows. Additionally, ergot incidence increased with later planting dates.

Ergot research in South Africa was primarily to develop a multi-variate risk analysis model that will incorporate as many as possible of the relevant variables that affect ergot severity in commercial hybrid, seed production systems.

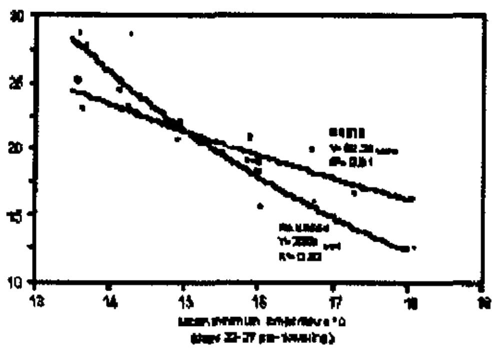

Figure 1. Relationship between mean minimum temperatures days 23-27 pre-flowering and nonviable pollen production by sorghum hybrids.

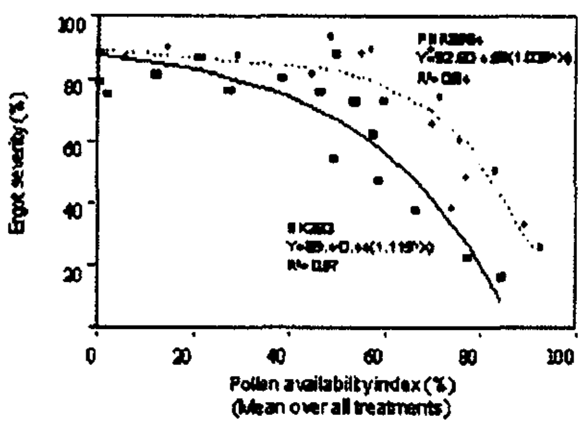

Figure 2. Relationship between pollen availability index and mean ergot severity over all blocks.

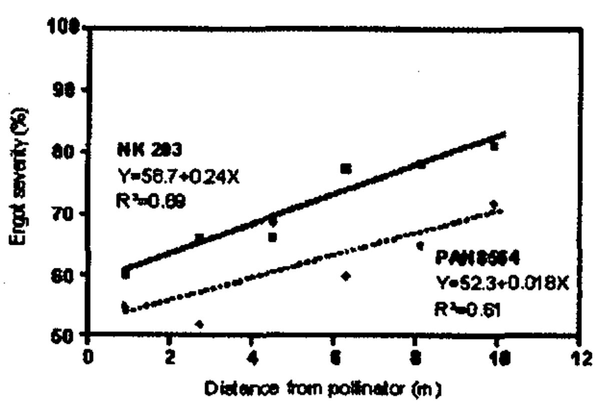

Figure 3. Relationship between pollen availability index and mean ergot severity over all blocks.

The study is conducted in three areas in South Africa with Cedara as primary site and Bethlehem and Potchefstroom as secondary sites.

At time of reporting, only data from Cedara were available. Pollen production was reduced by low mean minimum temperatures days 23-27 pre-flowering (Figure 1) which is in accordance with a previous study (McLaren & Wehner, 1992). Differences between pollinators were not as pronounced as previously reported (INTSORMIL, 2000) where NK283 yielded a significant decrease in pollen viability with reduced temperature compared with PAN8564 which showed no significant reduction. Reductions in pollen vigor at 13.4 @C, the lowest temperatures recorded during 2000-2001, were between 25 and 29%.

The relationship between "available pollen" (PAI) and mean ergot severity in each block is given in Figure 2. Particularly in PAN8564, a distinct increase in ergot severity occurred as pollen availability decreased from 100 to approximately 70 % when maximum ergot severity was obtained. The threshold for NK283 was considerably lower at approximately 40% pollen availability, indicating a greater pollination ability. This result, too, is in contrast to previous results and indicate a need for investigation of possible pollinator x season interaction.

As indicated in Figure 3, a gradient in ergot severity was evident with distance from the pollinator rows. Distance from the pollinator row resulted in an increase in ergot severity at a rate of 2.41 and 1.83 % (NK283 and PAN8564) for each meter distance from the pollinator row.

The ergot x pollen x weather interaction during the critical phases of crop development was determined using stepwise multiple regression analysis (Statgraphics Plus version 5). A highly significant relationship (R@=0.91) between independent variables and ergot was recorded for NK283 according to the model Y=607.81-3.7448*Ln(PAI)+ 0.026*D-19.29*(MaxT), where PAI =pollen availability index, and MaxT=mean maximum temperature days 1-4 post-flowering. A poor relationship (R@=0.41) was recorded for PAN8564 according to the model 170-7.732*Ln(PAI)+0.019*D-3.291MaxT.

Indications are that relatively small variations in available pollen as well as distance from the pollinator parents can result in large differences in disease severity. Pollen availability appears to be more critical during early flowering than temperature. It is thus important that seed producers take these factors into account to minimize the impact of ergot on seed production.

In South Africa, five different strains from each of five different species of *Fusarium* were tested for pathogenicity towards sorghum seedlings in an in vitro seedling assay. These species include: *F. verticillioides* (syn. *F. moniliforme*), *F. andiyazi*, *F. thapsinum*, *F. nygamai*, and *F. pseudonygamai*, which are all common sorghum pathogens that are difficult to distinguish on the basis of morphology alone. *Fusarium andiyazi* was significantly more pathogenic to the seedlings than were *F. verticillioides*, *F. nygamai*, and *F. pseudonygamai* with respect to disease severity, root length, shoot length, and root dry mass. However, *F. andiyazi* was significantly less pathogenic to sorghum than *F. thaps inum*, with respect to all of these parameters as well as root dry mass. *F. andiyazi* and *F. thapsinum* have both been identified in the United States and in several parts of Africa (South Africa, Tanzania, Ethiopia, and Nigeria) and have only been described within the last five years. The difference in disease severity between these two species and *F. verticillioides* is likely one of the reasons why grain mold and stalk rot have been so difficult to obtain resistance to in conventional breeding programs.

Food Quality

Graduate students in the Food Science Department, University of Pretoria, are from many other African countries. The graduate students are conducting research on aspects of sorghum utilization with Professor John Taylor. Many participate in the Regional Master of Science program which consists of joint programs between CSIR and University of Pretoria. Thus, INTSORMIL interactions with this program at the University of Pretoria informs many future African food industry leaders of the potential role of sorghum and pearl millet as food and industrial ingredients. INTSORMIL can provide assistance to the region by involvement in these programs where possible. Ms. Leda Hugo, Mozambique, is a Ph.D. student at the University of Pretoria working on the effect of malting sorghum on its use in composite breads. She is a professor at Eduardo Mondlane University (Maputo, Mozambique) and completed her M.S. at Texas A&M University. Lloyd Rooney serves on her Ph.D. committee.

Dr. Trust Beta published several manuscripts related to dry milling, malting and brewing applications of local Zimbabwean sorghum cultivars. Her work was cooperative with the Matopos grain quality lab in Bulawayo, Zimbabwe. Unfortunately, she resigned from the University of Zimbabwe and is now a researcher at Iowa State University.

Ms. S. Yetneberk (Ethiopia) has started her Ph.D. program and L. Rooney is co-director of her committee. Her project is related to determination of factors affecting the quality of injera from sorghum cultivars present in Ethiopia.

Mr. J. Awika from Kenya completed his M.S. degree and is continuing on a Ph.D. in food science and technology on nutraceuticals from sorghum. He has received several scholarships from national and local sources due to his outstanding academic performance. He is partially supported by INTSORMIL.

Insect Pest Management

The Southern Africa research program directed at development, evaluation, and deployment of sorghum genotypes resistant to the sugarcane aphid, *Melanaphis sacchari*, continued. 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 Segeolane, Marupantse, Macia, Town, SV1, and A964. The lines were crossed to elite germplasm, and backcrosses of selected F_1s to adapted cultivars made, to introduce additional favorable traits including foliar disease resistance. The breeding populations were planted at Corpus Christi and Lubbock, Texas for U.S. selection.

A 100-entry test for sugarcane aphid resistance was developed and sent to Southern Africa. The test was evaluated for resistance to sugarcane aphid in a greenhouse screening at the ARC, Potchefstroom, South Africa (Table 2). Thirty-eight experimental entries sustained damage less than or equal to several resistant checks (WM#322, Ent. 62/SADC, FGYQ353, TAM428). The sugarcane aphid resistant breeding materials are mostly in the F_4 or F_5 generation. The breeding lines will undergo additional selection in Texas, and screening and agronomic evaluation in Southern Africa. The lines should contain wide adaptation, sugarcane aphid resistance, disease resistance (primarily sooty stripe and anthracnose), and other favorable traits. Traits needed to enhance use include tan plant, white pericarp, and appropriate height and maturity. The midge line test was also evaluated for resistance to sugarcane aphid. Several experimental entries were identified with good levels of resistance. The lines also have excellent resistance to sorghum midge and will be included in the 2002 sugarcane aphid test.

Institution Building

Equipment and Supplies

The MOA with the SMIP program allowed INTSORMIL research projects to became 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 and a head thresher to the Zambian pearl millet breeding program at Kaoma, Zambia. Twenty thousand pearl millet pollinating bags were also supplied to each of these programs and to Botswana.

One computer and one printer was ordered for the Zambia pearl millet breeding program.

Training of Host Country Researchers

Ms. Trust Beta, Zimbabwe, completed her Ph.D. program in food quality research in the University of Pretoria

Table 2. Mean damage score and aphid abundance in the 2001 Sugarcane Aphid Test, Potchefstroom, South Africa.

Pedigree	Damage†	Abundance‡
Sima (IS23250)	1.0	1.0
CE151	1.0	2.0
WM#177	1.0	1.0
WM#322	1.0	2.0
PRGC/E#222878	1.0	1.0
PRGC/E#222879	1.0	1.5
PRGC/E#69414	1.0	1.5
SDSL89426	1.0	1.5
(Macia*TAM428)_HD1_	1.0	1.0
(Macia*TAM428)_LL2	1.0	2.0
(CE151*BDM499)_LD17_BE2	1.0	3.0
(87EO366*TAM428)_HF2	1.0	1.5
GR128_92M12	1.0	1.0
(Tx436*GR108_90M24)_LG8	1.0	1.0
(6OB128/(Tx2862*6EO361)*CE151)_LG19_	1.0	2.0
(SDSL89426*6OB124/GR134B_LG56_)_LG5_CG1	1.0	1.0
(SV1*Sima/IS23250)_LG6	1.0	1.5
(6BRON126/(87BH8606_14*GR107_90M46)*EPSON2_40/E15/SADC)_LG2_LG1	1.0	3.0
(CE151*TAM428)_CG1	1.0	1.0
(CE151*TAM428)_LG1	1.0	2.0
(Segaolane*WM#322)_LG2_LG2	1.0	1.0
(Segaolane*WM#322)_CG1	1.0	1.5
(Segaolane*FGYQ336)_CG5	1.0	2.0
(Town*EPSON2_40/E#15/SADC)_CG3	1.0	2.5
(6OB124/(GR134B_LG56)*EPSON2_40/E#15/SADC)_CG2	1.0	2.0
(6OB128/(Tx2862*6EO361)*CE151)_LG3_LG1	1.0	1.0
(6OB128/(Tx2862*6EO361)*CE151)_LG4_CG1	1.0	1.5
(6OB128/(Tx2862*6EO361)*CE151)_LG25_CG1	1.0	1.5
(6OB128/(Tx2862*6EO361)*CE151)_LG27_LG1	1.0	1.0
(CE151*A964)_CG1	1.0	1.5
(EPSON2_40/E#15/SADC*TAM428)_CG1	1.0	2.0
(5BRON139/((6EO361*GR107der)_LG7)*CE151)_LG2	1.0	2.0
(6BRON161/((7EO366*Tx2783)_HG54)*CE151)_CG3	1.0	2.5
Ent.62/SADC	1.5	2.0
(Macia*TAM428)_LL7	1.5	2.0
(Tx2883*(Tx2880*(GR108_90M24*(Tx2862*(Tx430*(Tx2862*PI550607))))))_PR2_	1.5	3.5
(SDSL89426*6OB124/GR134B_)_LG5_	1.5	2.0
(Tx430*Sima/IS23250)_LG5_	1.5	1.5
(EPSON2_40/E#15/SADC*A964)_CG3	1.5	2.0
(6BRON126/(87BH8606_14*GR107_90M46)*EPSON2_40/E#15/SADC)_LG1_LG1	1.5	2.5
(6BRON126/(87BH8606_14*GR107_90M46)*EPSON2_40/E#15/SADC)_LG3_CG1	1.5	2.5
(Segaolane*CE151)_LG2	1.5	2.0
(Macia*TAM428)_CG2	1.5	2.5
(A964*FGYQ336)_LG4_LG2	1.5	2.0
(5BRON131/((80C2241*GR108_90M30)_HG46)*WM#177)_LG1	1.5	1.5
(6BRON161/((7EO366*Tx2783)_HG54)*CE151)_LG1	1.5	1.5
FGYQ336	2.0	2.5
FGYQ353	2.0	2.0
TAM428	2.0	1.5
(CE151*BDM499)_LD17_BE1	2.0	2.0
(Macia*TAM428)_LL9	2.0	2.0
6OB124	2.0	2.0
(Tx2783*VG15/M50009)_LG9_	2.0	3.0
(EPSON2_40/E#15/SADC*A964)_LG2_CG1	2.0	2.5
(EPSON2_40/E#15/SADC*5BRON131/(80C2241*GR108_30)_HG46_)_CG5	2.0	2.0
(EPSON2_40/E#15/SADC*TAM428)_LG3_CG1	2.0	2.5
(Town*EPSON2_40/E#15/SADC)_LG1_CG2	2.0	3.0
Pedigree	Damage†	Abundance‡
(Town*EPSON2_40/E#15/SADC)_LG12_CG3	2.0	3.0
(Town*EPSON2_40/E#15/SADC)_CG2	2.0	3.0
(Macia*TAM428)_LG8_LG1	2.0	3.0
(6OB124/(GR134B_LG56)*WM#177)_LG2	2.0	3.0
(6OB128/(Tx2862*6EO361)*CE151)_LG1_CG1	2.0	2.5
(6OB128/(Tx2862*6EO361)*CE151)_LG5_CG1	2.0	1.5
(6OB128/(Tx2862*6EO361)*CE151)_LG5_LG1	2.0	3.0
(6OB128/((Tx2862*6EO361)_LG30)*EPSON2_40/E#15/SADC)	2.0	2.5
(6BRON126/((87BH8606_14*GR107_90M46)_HG10)*CE151)_CG1	2.0	2.0
MB108B	2.5	4.0
(6OB124/(GR134B_LG56)*WM#177)_CG1	2.5	2.0
(CE151*TAM428)_LG2_CG1	2.5	2.0
(Macia*TAM428)_LG4_LG1	2.5	3.0

Table 2. - Continued

(A964*FGYQ336)_LG13_LG1	2.5	3.0
(6OB124/(GR134B_LG56)*WM#177)_LG7_CG2	2.5	2.5
(6OB124/(GR134B_LG56)*EPSON2_40/E#15/SADC)_CG4	2.5	2.0
(6OB128/(Tx2862*6EO361)*CE151)_LG10_CG1	2.5	3.0
(6BRON161/(7EO366*Tx2783)*CE151)_LG5_CG2	2.5	3.5
(6BRON126/((87BH8606_14*GR107_90M46)_HG10)*CE151)_CG2	2.5	2.5
(6BRON126/((87BH8606_14*GR107_90M46)_HG10)*CE151)_CG5	2.5	2.0
(Town*EPSON2_40/E#15/SADC)_LG1	2.5	2.5
(6OB128/((Tx2862*6EO361)_LG30)*CE151)_CG5	2.5	4.0
Kuyuma	3.0	3.0
(6OB124/(GR134B_LG56)*WM#177)_LG2_CG1	3.0	2.5
(Town*EPSON2_40/E#15/SADC)_LG9_LG1	3.0	3.5
(6OB124/(GR134B_LG56)*EPSON2_40/E#15/SADC)_LG14	3.0	3.5
(6BRON126/((87BH8606_14*GR107_90M46)_HG10)*CE151)_CG9	3.0	3.0
(5BRON131/((80C2241*GR108_90M30)_HG46)*WM#177)_LG1	3.0	4.0
Segaolane	3.5	3.5
(Sima/IS23250*6OB129/(Tx2862*6EO361))_LG4_LG1	3.5	3.0
(Town*EPSON2_40/E#15/SADC)_LG6_CG3	3.5	3.0
(6BRON126/((87BH8606_14*GR107_90M46)_HG10)*CE151)_CG4	3.5	4.0
(6BRON126/((87BH8606_14*GR107_90M46)_HG10)*CE151)_LG1	3.5	2.0
(Town*EPSON2_40/E#15/SADC)_LG4	3.5	3.5
Macia	4.0	3.5
(TAM428*SV1)_HD10	4.0	3.0
(Tx2883*(Tx2864*(Tx436*(Tx2864*PI550607))))_PC1	4.0	4.0
(Segaolane*FGYQ336)_LG3_CG1	4.0	4.0
(Segaolane*FGYQ336)_LG1	4.0	3.5
(6OB128/(Tx2862*6EO361)*CE151)_LG16_LG1	4.0	4.0
(Segaolane*FGYQ336)_LG1	4.5	4.0
(Town*EPSON2_40/E#15/SADC)_LG1	4.5	3.5
MEAN	2.0	2.4
LSD	1.5	1.3

† Rated on a scale of 1 = no aphids or damage, 2 = light damage (few small bottom leaves significantly damaged), 3 = medium damage (few leaves with large damage), 4 = many leaves with damage and dying, 5 = plants dead or dying.

‡ Rated on scale of 1 = no aphids, 2 = light infestation (few aphids on few leaves), 3 = medium infestation (small colonies on many leaves), 4 = heavy infestation (many aphids on many leaves).

under Dr. Taylor, co-advised by Dr. Lloyd Rooney. Research equipment and partial subsistence costs were provided by INTSORMIL. Her work was cooperative with the Matopos grain quality lab in Bulawayo, Zimbabwe. Unfortunately, due to the political situation in Zimbabwe she resigned from the University of Zimbabwe and is now conducting research at Iowa State University.

Dr. Peter Setimela, sorghum breeder, Department of Agricultural Research, Sebele Research Station, Botswana, has initiated his research program. Dr. Setimela will be developing sorghum lines and hybrids for Southern Africa production systems.

Mr. M. Mogorosi, sorghum/pearl millet scientist, Botswana commenced a five month training program at the University of Nebraska in June 2000, on breeding and seed production.

Mr. F. Muuka, pearl millet breeder, was selected for a short-term training assignment with Dr. Wayne Hanna (USDA-ARS/INTSORMIL).

Host Country and U.S. Scientist Visits

Gary Peterson and Tom Crawford participated in the 15th Steering Committee Meeting of the SADC/ICRISAT Sorghum and Millet Improvement Program (SMIP) held at Matopos, Zimbabwe, 4-5 October 2000.

Gary Peterson and Tom Crawford visited Zimbabwe, Mozambique, Namibia, and Zambia 6-12 October 2000 to discuss the INTSORMIL Grant Extension proposal and goals for the next five years. In Zimbabwe, met with ICRISAT representatives to discuss collaborative activities with SMINET. Met with Department of Research and Special Services scientists in breeding, plant pathology, and cereal quality to discuss research. In Mozambique, met with the Instituto Nacional de Investigação Agronómica Director General and scientists, USAID, and World Vision to discuss initiation of INTSORMIL activity in-country and the Inter-CRSP training program. In Namibia, met with representatives of the Ministry of Agriculture, Water and Rural Development, and USAID, to discuss INTSORMIL activity and plans for the next five years. In Zambia, met with Ministry of Agriculture, Department of Agricultural Research scientists and USAID to discuss INTSORMIL/Zambia activity and five-year plans.

John Leslie was in Potchefstroom and Tygerberg, South Africa, 4 -18 December 2000. In Potchefstroom planning was initiated with Neal McClaren, Summer Grains Research Institute, Agricultural Research Council to begin collaborative work on grain mold of sorghum. In Tygerberg work was complete on a manuscript for a book chapter and for a description of a new *Fusarium* species from sorghum Prof. Walter F. O. Marasas at PROMEC, Medical Research Council.

Gary Peterson visited South Africa, Botswana, and Zambia 2-14 April 2001. In South Africa, met with collaborators and administrators at the Agricultural Research Corporation - Grain Crops Institute to discuss current and future research activity. In Botswana, met with Department of Agricultural Research scientists to discuss current and future research activity. In Zambia, met with Ministry of Agriculture, Department of Agricultural Research scientists to discuss research. Evaluated pearl millet breeding at Kaoma and Mongu. Attended the Mt. Makulu Research Station Field Day.

Human Resource Strategy

Through a previous regional USAID program INTSORMIL trained a large number of sorghum and pearl millet scientists from the SADC region. Mr. M. Mogorosi started in June 2000 a five month training program in breeding and seed production with UNL-218. Each year one collaborator will be selected for short-term training in the U.S. Mr. F. Muuka, pearl millet breeder from Zambia, was selected for training in 2001. Additional short- or long-term training will occur as individuals and funds are identified.

Networking

An efficient sorghum and millet research and technology transfer network exists in the SADC region conducted by the SMIP program. The Memorandum of Agreement 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 political situation in Zimbabwe is imposing significant restrictions on activity in Zimbabwe. The primary grain quality collaborator at the University of Zimbabwe, Harare (Dr. Trust Beta) resigned due to the political situation. Interaction with the University of Pretoria, Council for Science & Industrial Research, South Africa in sorghum and pearl millet utilization research efficiently utilizes scarce resources and personnel. Graduate students in the Food Science Department at the University of Pretoria are from many other African countries. Many of them are participating in the Regional Master of Science program which consists of joint programs between CSIR and University of Pretoria. The regional program has the goal of providing education for African scientists on African crops that are of importance in the region. Sorghum and millets are a key components of these food systems. Thus, interactions with this program informs many future African food industry leaders on the potential role of sorghum and millets as food and industrial ingredients. INTSORMIL can provide assistance to the region by involvement in these programs where possible. Through allocation of resources INTSORMIL has started encouraging regional scientists to collaborate across countries.

Germplasm Exchange

Several hundred sorghum lines and cultivars were provided to evaluate for reaction to various diseases, adaptation, drought response, and sugarcane aphid resistance in the SADC region in the 2000-2001 growing season (collaborative with TAM-222, TAM-223, TAM-228, and B. Rooney (TAMU).

West Africa – Eastern Region

Bruce Hamaker
Purdue University

Coordinators

Dr. Issoufou Kapran, INRAN/INTSORMIL Coordinator, B.P. 429, Niamey, Niger
Dr. Bruce Hamaker and Dr. John Axtell (deceased), Professors & Regional Coordinators, Food Science and Agronomy Departments, Purdue University, West Lafayette, IN 47907

Description of Collaborative Program

This year saw the sad and unexpected passing away of Dr. John Axtell. John was instrumental in building and championing the Niger INTSORMIL program, and was the graduate student advisor and mentor of Issoufou Kapran, the Niger INTSORMIL coordinator. His loss was greatly felt in this program and among the collaborating PIs in Niger and the U.S.

This project was begun, and continued until recently, as the Niger country program under the framework of an interdisciplinary and multi-institutional endeavor involving INRAN, U.S./INTSORMIL institutions (Purdue University, Texas A&M University, and University of Nebraska), and ICRISAT. In the last two years, the program has evolved to a regional effort including Niger, Burkina Faso, and Nigeria. In 1999-2000, Burkina Faso was brought into the INTSORMIL program with projects in agronomy and millet breeding. In the past year, two projects were initiated with researchers in northeastern Nigeria (Maiduguri) in millet breeding and utilization.

Sorghum/Millet Constraints Researched

Sorghum and pearl millet are staple food crops of Niger, Burkina Faso, and northern Nigeria. In Niger, sorghum acreage increased from less than half a million hectares in 1961 to more than two million hectares in 2000. Grain yield declined from 0.6 t ha^{-1} to 0.2 t ha^{-1} during the same period. Sorghum and millet production in Niger is severely limited by biotic and abiotic stresses including drought, poor soils, insect pests (especially midge and headbugs), and diseases including long smut and *Striga*. In the 1998 strategic plan for sorghum and millet prepared by the Institut National de Recherches Agronomiques du Niger (INRAN), emphasis was placed on technology transfer, development of varieties with better yield stability, and plant protection. Improved utilization of these cereals, such as through commercial processing to products or animal feed use, is also key to expanding demand and markets, as well as generating income at the entrepreneurial level.

INTSORMIL's support for sorghum and millet improvement has been significant in terms of human resource enhancement and vision for technologies that can be transferred and adopted by farmers and other end-users. For example, sorghum breeders and food technologists work together to demonstrate feasibility of the use of improved seeds to increase food production, diversify uses for local consumers, and stimulate entrepreneurial businesses.

Research Methods

Collaborative research in the regional program includes: for Niger, sorghum and millet breeding, cereal quality and processing technology, entomology, agronomy, pathology, physiology, and economics; for Burkina Faso, agronomy under the direction of Steve Mason; and, in the next year, for Nigeria, millet breeding and utilization. Research methods appropriate for each of these disciplines are used for this research.

Research Progress

Sorghum breeding and seed production (Niger): Issoufou Kapran, John D. Axtell, Leland R. House (consultant)

In its hybrid breeding component, INRAN has shifted to a market-oriented logic. Parental lines with good adaptation were selected and crosses made within maturity groups to ensure easiness of seed production. Four maturity groups were defined and representative germplasm are shown in Table 1. Germplasm exchange has been critical to the hybrid development program. A new group of 6 advanced hybrids, based on preliminary trials in 1999, were tested across locations and compared to the previously released NAD-1 hybrid. A summary description of these hybrids is given in Table 2. Most of these were earlier maturing than NAD-1 and showed better grain quality (contrary to NAD-1, their parents were of tan plant color giving rise to less off-colors in injured grain).

Seed production with farmers has continued as a strong focus of the hybrid project. INTSORMIL provided support to contract with farmers for NAD-1 seed production in three locations: Jirataoua (Maradi), Galmi-Moulela (Konni), and Tiaguirire (Kolo). About two tons of good hybrid seed were produced, but even so this was well below expectations because of the difficult growing season experienced in 2000. Both hands-on and lecture room training were conducted

Table 1. Maturity groups and selected lines for hybrid synthesis in Niger, summer 2000

Group	Entry name	Days to 50% flowering	Source
1(Early)	P9503A	65	PU
	P9511A	64	PU
	P9513A	64	PU
	P9533A	63	PU
	AHF8	66	TAMU
	IK406	66	INRAN
	90SN7	66	INRAN
	MACIA	66	TAMU
2 (Medium)	P9501A	69	PU
	P9502A	69	PU
	P9521A	70	PU
	P9526A	73	PU
	98-3594 'A3'	73	PU
	SEPON82	73	INRAN
	90SN1	71	INRAN
	CEF357/6-2-1	71	WCARSN
	N7112R	71	UNL
	ST9007-5-3-1	75	INRAN
3 (Medium late)	98-3582'A1'	78	PU
	98-3600 'A4'	80	PU
	98-3606 'A5'	78	PU
	98-3612 'A6'	78	PU
	91M223A	80	UNL
	ST9007-1-2-1	81	INRAN
	ST9007-5-4-2	78	INRAN
	ST9007-5-2-1	78	INRAN
	MR732	78	INRAN
	ICSV745	81	ICRISAT
4 (Late)	98-3588 'A2'	87	PU
	ICSV9001	89	ICRISAT

Table 2. Elite sorghum hybrids under test in Niger, summer 2000

Designation	Maturity	Height	Grain quality
AHF8xMACIA	Early	1.7-2 m	Good
P9503xMACIA	Early	1.7-2 m	Good
P9511AxMACIA	Early	1.7-2 m	Good
P9513AxMACIA	Early	1.7-2 m	Good
P9504AxMR732	Early	1.7-2 m	Good
223AxMR732	Medium late	1.5 m	Good
NAD-1	Medium late	1.7-2 m	Average

with positive feedback by farmers. At Tiaguirire, activities were jointly conducted with WINROCK support.

Sorghum/Millet Quality and Utilization
K. Saley, M. Moussa, M. Oumarou, I. Kapran, A. Aboubacar, and B. Hamaker

The overall objective of this project is the development and commercialization of value-added sorghum and millet products with emphasis also on utilization of locally and/or regionally fabricated food processing equipment. The non-availability of appropriate processing technology of sorghum/millet, the recent devaluation of the CFA, the progressive urbanization, the newly approved free trade agreement in West Africa, and the possibility of processing quality sorghum/millet products suitable for use in high status foods are reasons that should motivate creation and promotion of new sorghum/millet processing technologies. With the financial assistance from the Niger INTERCRSP and INTSORMIL programs, an entrepreneurial scale processing unit for high quality flours and agglomerated products (couscous and others) was installed in 1995 at the INRAN Food Technology Laboratory for research, demonstration and testing. The unit consists of an agglomerator/siever designed by CIRAD (France), a couscoussier (Nigeral-Niger), food mixer (Kenwood electronics), a decorticator and mill (URPATA, Senegal), a solar dryer (ONERSOL, Niger), and a sealer for packaging.

During the past year, studies were conducted for optimization of couscous processing and 500 kg of high quality NAD-1 sorghum couscous was produced. Results indicated the efficiency of the processing equipment to process high quality commercial NAD-1 sorghum couscous and associated products. Table 3 shows production capacity of the unit at the different processing steps associated with couscous production. The drying step is still the most limiting in terms of production capacity. This points to the need for either additional or more efficient solar driers or an additional gas drier to complement solar drying. Microbiological analysis of processed NAD-1 sorghum couscous confirmed that the processed NAD-1 sorghum couscous is safe to consume. For aerobic bacteria mesophiles, E. coli, and molds, values were far below limits set by FAO/WHO (Table 4).

The first phase of a market survey of NAD-1 sorghum couscous was conducted with the collaboration of food processors distributors and agro-economists. Consumer acceptance and perception of the NAD-1-sorghum couscous in 6 quarters in Niamey indicated highly positive responses to sensory characteristics (taste, color, texture and flavor) and other key marketing questions related to NAD-1 couscous. The study revealed the possibility to process and commercialize sorghum NAD-1 couscous and associated products. Carl Nelson assisted in design of the market study and Jupiter Ndjeunga traveled to Niger to assist with design and implementation.

NAD-1-sorghum couscous promotion/sales/exhibition days were held on August 12, September 27, and October 15, 2000. A national and international private investors' meeting was held on October 7-8, 2000.

Institution building

Field equipment has been continuously supplied for research activities, including seed envelopes and pollinating bags for breeding nurseries and a computer for data management, packaging supplies and labels for the couscous marketing study, and a digital camera. For seed research, major support is through consulting with L.R. House but also equipment has been supplied such as mobile seed cleaners, dust blowers (for pollen dispersal), and portable motor pumps for irrigation. A notebook computer was supplied to the economics project in Niger.

Mamane Nouri, agronomist from Niger, is working on his Ph.D. and Pale Siebou, agronomist, from Burkina Faso, is working on his Masters. Both are at the University of Nebraska and studying under the supervision of Steve Mason. Tahirou Abdoulaye, economist from Niger, is working on his Ph.D. at Purdue University with John Sanders.

Networking

INTSORMIL supported joint activities with the regional sorghum network (WCARSN or ROCARS) and started new linkages.

WINROCK, through McKnight Foundation funding, supported hybrid seed production in a project initiated by INTSORMIL. This project involves contracting with farmers and training them in modern techniques. A training manual produced by INRAN/INTSORMIL collaborators was translated into local Hausa and Zarma languages using Arabic scripts that farmers can read.

The IFAD regional project on sorghum/millet technology transfer and PSNII-FIDA, a local project in Tillabery, are interested in NAD-1 hybrid research. Farmers at Gidan Iddar who were recruited in 1995 by INTSORMIL to produce NAD-1 seed are now closely supervised by INRAN/IFAD project staff with a strong training component by INTSORMIL collaborators. In Tillabery, INTSORMIL demonstrations of NAD-1 grew from 400 m^2 in 1999 to 27 ha in 2000 with farmer yield averaging more than 2 t ha^{-1}. These farmers are supported by PSNII-FIDA, a natural resource management project. The plan for 2001 is for collaborative effort to train selected farmers in producing NAD-1 seed for their peers.

Table 3. Couscous unit production capacity to date.

Processes	Production Capacity
Decortication	150-250 kg/h
Milling	200-300 kg/h
Sieving	100 kg/h
Hydration	30 kg/h
Granulation	40 kg/h
Steaming	20 kg/h
Solar Drying	40 kg/24 h-48h
Packaging	30 packets/h

Table 4. Microbiological analysis of 5 couscous samples.

	Parameters determined		
Couscous samples	Aerobic bacteria Mesophile/g	E. Coli/g	Moulds yeasts/g
Couscous (P1)	83.10^3	Absent	70
Couscous (P2)	72.10^3	Absent	0
Couscous (P3)	30.10^3	Absent	10
Couscous (P4)	23.10^3	Absent	30
Couscous (P5)	29.10^3	Absent	0
FAO-WHO Ranges	10^6	10	10^4

With assistance from INTSORMIL consultant, Lee House, seed producers in Niger organized a national seed trade association named APPSN which plans to join the African Seed Trade Association (AFSTA) created in Pretoria (South Africa). INTSORMIL supported Issoufou Kapran's participation in the launching of AFSTA.

Initial contacts were made with AFRICARE and World Vision International in Niger. Africare heads a consortium of four NGO's receiving funding from USAID for a food security development project in Niger.

Research Accomplishments

This was a year of transition for the West Africa – Eastern Region project, both because of the loss of Dr. Axtell and subsequent changing of the U.S. coordinators, as well as a further expansion of the Niger country project to one with greater regional focus. In March 2001, B. Hamaker traveled to Niamey to meet with Niger INTSORMIL PIs and two invited potential collaborators from northeast Nigeria. A two day meeting took place with project progress presentations made by Niger PIs followed by discussions on individual and regional project future objectives and workplans. Nigerian participants, I. Nkama and I. Angarawai from the University of Maiduguri and the Lake Chad. Research Institute, were subsequently asked to participate in the regional program in areas of millet hybrid development and millet grain quality and utilization. S. Mason has developed a collaborative project with T. Jean Baptiste in Burkina Faso on the use of tied-ridges for water conservation.

In a meeting planned for spring 2002, some additional scientists from both Nigeria and Burkina Faso, as well as U.S. collaborating PIs, will be invited to explore further expansion of INTSORMIL's effort in the region.

Entomology - H. Kadi Kadi and I. Kapran

In Niger, insects feeding at different developmental stages cause low yield and grain quality of sorghum. The most important insect pest of sorghum is the sorghum midge, *Stenodiplosis sorghicola* (Coquillet). The midge is the most common pest of sorghum causing damage to the flower panicles.

The objective of the entomology project is to identify sorghum lines resistant to sorghum midge either through screening of new materials (developed by breeders and received from ICRISAT) or by developing new resistant sorghum lines through crossing of high performing varieties that have agronomically acceptable characters. The headcage technique, developed and standardized by ICRISAT, was used to screen sorghum lines for resistance to sorghum midge under field conditions. Periods of maximum midge density adjusted by sowing dates were achieved so that the most susceptible stage of the sorghum flowering coincided with the greatest sorghum midge abundance. Crosses between 4 sorghum varieties (Mota Maradi, IRAT 204, ATx 623 and MR 732) with introduced sorghum resistant varieties (ICSV 745 et ICSV 88032) were made in a complete randomized bloc design with 4 replications.

The highest midge damages were recorded at the 2nd planting date because midge outbreaks were favored by heavy rainfall in September which coincided with the sorghum flowering stage. Sorghum lines 99 SSD F9-1, 99 SSD F9-5, 99 SSD F9-18, 99 SSD F9-21, 99 SSD, F9-29, 99 SSD F9-33, 99 SSD F9-35, and ICSV 745 were found to be resistant to midge. These lines have the lowest (25-18%) grain loss even though some have highly damaged spikelets. The results showed that after two years of screening, lines ICSV745, 99 SSD, F9-21, 99 SSD F-33 and 99 SSD F9-35 were confirmed to be resistant to sorghum midge.

Screening of sorghum lines introduced from ICRISAT showed variability in infestation by midge. More midge adults were trapped on MM, DJ 6514, ICSR 155, ICSV 88032, ICSV 93074, ICSV 93084, ICSV 90004 and ICSV 9001.

Significant differences ($F = 1.43$, $P = 0.45$) were recorded among lines for grain loss. Estimations of grain loss revealed that only 7 sorghum lines (MM, ICSV 93077, 99 SSD

F9-35, ICSV 90001, ICSV 90002, ICSV 90011 and ICSV 90013) had <20% grain loss; however these sorghum lines had the highest long smut scores of 3 to 4. Five sorghum lines had highest grain losses estimated at 66.7% for ICSV 93071, 51.6% for ICSV 93072, 40.9% for ICSV 93082, 52.5% for 99 SSD F9-21 and 45.1% for ICSV 90005.

Lines DJ 6514, ICSV 197, ICSV 745, ICSV 93077, 99 SSD F9-35, ICSV 90001-02, ICSV 90011-12 were judged to be resistant to sorghum midge. Most of these lines were highly infested (DJ 6514 and ICSV 90011) with adult midges, but the estimated percentages of grain losses were low, 30 and 6.4% respectively. Three lines highest in resistance were ICSV 90001, ICSV 90002 and ICSV 90013 with low grain loss of 16.7, 18.2 and 2.1%, respectively.

Millet Breeding - G. Jada and W. Hanna

One introduced millet hybrid population from Tifton, Georgia, was compared to the two best millet genotypes of INRAN (ZATIB and CT6) under two fertility levels (with and without fertilizer). Planting was made on June 12, 2000 on a coarse sandy soil, acid, with a low degree of fertility, after a deep soil plowing with a tractor.

After planting, a 21-day period (3 weeks) of intense drought occurred. ANOVA-2 and the *t*-test were utilized to analyze the data. No significant differences were found between the fertilized and unfertilized plot in yield and yield components, except in the tillering capacity. The hybrid W9 had the highest tillering capacity in fertilized as well as non-fertilized plots, with respectively 74,038 and 45,882 heads/ha, but did not yield better than the landrace genotypes of Niger.

Socioeconomics - T. Abdoulaye and J. Sanders

Fieldwork continued on the economics of millet fertilization in western Niger in collaboration with ICRISAT scientists. Declining soil fertility is one of the main constraints to increasing crop production according to farmers. The main objectives of the research are to determine profitability of existing millet fertilization technologies and their potential for adoption by farmers. Abdoulaye spent three months in Niger collecting data through interviews with 100 farmers in the regions of Boboye and Fakara (five villages). Information was gathered on farmers' resources, consumption and investments patterns. Millet is the main crop of the region. This report includes information from two villages, Bogol Mamar and Nianbéré Kaïna.

Farm interviews showed that farmers are trying several options to increase soil fertility, including manure, crop residues, compost heaps and inorganic fertilizer. Organic availability is however very limited, but it is still the most used input by farmers

Preliminary analysis shows that more trials and demonstrations will lead to higher fertilizer use. More farmers from Niambéré participated in trial (40%) and or visited on-farm trial (47%) than in Bogol Mamar (12 and 24%, respectively), coinciding with higher fertilizer use in Niambéré. More importantly they seem to have better understood that organic and inorganic fertilizers need to be combined on those light sandy soils.

There is an indication that more on-farm trials and demonstrations where farmers receive hands-on training on the inorganic fertilizer technologies are important to increase adoption rates in the region. Once they are convinced about the performance of the inorganic fertilizers, then they start asking questions about profitability. This is being more systematically investigated using regression models.

In both of the above villages, average investments in inorganic fertilizer are still very low (Table 5). The amounts of fertilizer some farmers apply are rather symbolic and unlikely to have any impact on production. Those who apply micro- or moderate doses, especially when mixed with seeds, have better seedling vigor and, hence, gain some yield impact. However, the important thing is that adoption is starting and is likely to continue as the economic environment improves. Both villages seem to be intensifying using more labor. The much higher labor spending is Niambéré is due to the labor requirement for plowing on the low land, where cassava and other high value crops are grown. Seed expenses are mainly for cowpea and vegetables for irrigated gardening during the off-season (contre saison).

Preliminary data analysis indicates that millet fertilization technologies are profitable but their wide adoption is still hindered by poor development of input-output markets. Our study centers on one of the driest areas where agriculture is possible, but still farmers are starting to adopt fertilization technologies. This suggests that the potential for adoption exists, but further efforts are needed to improve the economic environment in order to increase adoption of new technologies.

On-farm Study on Ridges Cultivation on Grain Sorghum in Niger: S. Sirifi, J. Maranville, I. Kapran

In the 1999 and 2000 cropping seasons, on-farm study on ridges cultivation on grain sorghum was undertaken in Niger. Results from the dry location showed significant differences between un-tied and tied ridges, and between ridges and local cultural practices for grain and stover yields. Grain yield from the use of un-tied ridges, tied ridges and local cultural practices were 1919.9 kg ha^{-1}, 1115.8 kg ha^{-1} and 189.6 kg ha^{-1}, respectively. Thus, yield from tied ridges was twice as high than that from un-tied ridges and ten times higher than yield from local cultural practices.

Results of the 1999 season were much better than the ones observed in the 2000 season due to drought. During both cropping seasons, hybrid NAD-1 tended to perform better on tied ridges compared to un-tied ridges and local cultural practices, in term of plants stand, growth and production.

Table 5. Average farm expenses per household in each village

	Bogol Mamar	Niambéré Kaïna
Seed	2478 FCFA	2589 FCFA
Labor	5030 FCFA	16571 FCFA
Inorganic Fertilizer	800 FCFA	5211 FCFA

Note: $1=700 FCFA

West Africa - Western Region

Darrell T. Rosenow
Texas A&M University

Regional Coordinators

Dr. Aboubacar Touré, Host Country Coordinator, IER, B.P. 438, Sotuba, Bamako, Mali
Dr. Darrell T. Rosenow, U.S. Country Coordinator, Texas A&M University, Texas Agricultural Experiment Station, Route 3, Box 219, Lubbock, TX

Collaborative Program

Program Structure

The INTSORMIL collaborative program in Mali is a multidisciplinary research program. The program centers around Malian scientists and each Malian scientist develops research plans cooperatively with a US counterpart which provides for effective research planning, communication, and coordination. Each year INTSORMIL collaborators travel to Mali as appropriate to observe field trials, consult, review progress and plan future activities with Malian scientists. Occasionally, IER scientists also travel to the US for research review, planning, and coordination. The planned project activities then become part of the annual Amendment to the MOA between INTSORMIL and IER.

The program includes all aspects of sorghum/millet improvement with major emphasis on breeding or germplasm enhancement, utilization and quality, nutrient use efficiency, soil management, insect pests, diseases control strategies, and *Striga* control.

A new thrust to the program centered in Mali in the year 2000-2001 was to initiate collaborative INTSORMIL research in Senegal and Ghana. A small amount of funds were added to the Mali budget to initiate this research. This was accomplished through a meeting in Mali, and discussions with key scientists from Ghana, Senegal, and Mali in the fall of 2000 with some collaborative research activities developed in breeding, pathology, entomology, and *Striga* for 2001. A MOU between INTSORMIL and ISRA (Institute of Agricultural Research) in Senegal was signed in early 2001. An existing MOU with SARI (Savannah Agricultural Research Institute) in Ghana (involving research between Dr. S.S. Buah and J.W. Maranville) was utilized to include the new collaborative efforts in Ghana.

Financial Input

The USAID Mission has in the past provided significant financial support to IER research program through the SPARC Project which ended in June 1997. In addition to the Malian Government, the Ciba Giegy Foundation (Syngenta) and World Bank support the IER research program.

Research Disciplines and Collaborators

Genetic Enhancement (Breeding) - Sorghum and Millet

Sorghum: TAM-222 - D.T. Rosenow; TAM-223 - G.C. Peterson; IER - Aboubacar Touré, Abocar Oumar Touré, Abdoulaye G. Diallo, and Ali Boubacar Touré

Millet: ARS-204 - W.W. Hanna; IER - Moussa Sanogo.

Sustainable Crop Protection Systems

Insects:TAM-225 - G.L. Teetes (retired 8-31/00); TAM-223 - G.C. Peterson, IER - Yacouba Doumbia and Mme Diarisso Niamoye Yaro.

Diseases:TAM-224 - R.A. Frederiksen (retired 8/31/00); TAM-222 - D.T. Rosenow; IER - Mamourou Diourté; Mme Diakite Mariam Diarra and Ousmane Cissé.

Striga:PRF-207- G. Ejeta; IER - Mountaga Kagnatao.

Sustainable Crop Production Systems

Agronomy/Drought/Nutrient Use (Sorghum): UNL-214 - J.W. Maranville; IER - Abdoul W. Touré.

Agronomy, Crop Residues (Millet): UNL-213 - Steve Mason; IER - Samba Traoré and Minamba Bagayoko.

Soil Management InterCRSP: TAM-223 - G.C. Peterson; IER - Mamadou Doumbia.

Grain Utilization and Quality: TAM-226 - L.W. Rooney; IER - Mme Aïssata Bengaly Berthé and Mme Coulibaly Salimata Sidibé.

On-Farm and InterCRSP: IER - Aboubacar Touré, Oumar Coulibaly; and Philippe Dembele - World Vision

Economics and Marketing: PRF- 205 - J.H. Sanders; Icofil IER - Bakary Coulibaly; Purdue - Jeffrey Vitale.

Senegal: Ndiaga Cisse (sorghum breeder) and Demba M'Baye (pathologist)

Ghana: Ibrahim Atokple (sorghum breeder) and Samuel S. Buah (agronomist)

Collaborating Institutions

Institute of Rural Economy (IER), Bamako, Mali
SARI (Savannah Agricultural Research Institute) - Ghana
ISRA (Institute of Agricultural Research) - Senegal
Texas A&M University
University of Nebraska
Purdue University
USDA/ARS (Georgia)
USAID/Bamako
Novartis/Ciba-Geigy Foundation
ICRISAT/WASIP/Mali
WCASRN/ROCARS (Regional Sorghum Network)
ROCAFREMI (Regional Millet Network)
World Vision International and InterCRSP (WVI)
Soil Management CRSP

Sorghum/Millet Constraints Researched

Plant Production Constraints

The yield level and stability in sorghum and millet production is of major importance in the country. Drought is a serious constraint to production over much of Mali. Diseases, insect infestations and *Striga* significantly affect both sorghum and millet production in Mali. Head bugs and associated grain molds adversely affect sorghum yield and grain quality. Anthracnose is a very severe sorghum disease in Mali and long smut is severe in the drier regions of the country. Sooty stripe can be a severe leaf disease problem. *Striga* is a major constraint for both sorghum and millet.

Land Production Constraints

Low soil fertility combined with the low yield and unstable yields of Malian cultivars affect sorghum and millet production in Mali. Major soil related constraints to production in Mali are phosphorus and nitrogen deficiency, and water stress.

Technological and Socioeconomic Constraints

There is a lack of farm credit policy which would encourage adoption of improved sorghum and millet new cultivars. In addition, the prices of these two cereals are low and unstable. New, shelf-stable foods and industrial sorghum and millet based products are needed to encourage production.

Research Methods

The collaborative program in Mali emphasis research in breeding (germplasm enhancement), entomology, pathology, agronomy (soil, water, fertility relationships), weed science (*Striga*), cereal technology (quality and utilization), marketing, and technology transfer. An effect to develop new food products from sorghum and millet is emphasized along with new cultivars with improved food quality traits. Major breeding activities involve the use of new genetic materials to develop cultivars to increase or stabilize yields of grain with enhanced food quality traits. Research methods appropriate for each of these are used in this research program.

Research Results

Details of some of the research related to Mali are presented in individual PI project reports in this publication. This Host Country Annual Report will emphasize research done by IER in Mali.

Sorghum Breeding

The sorghum breeding program in IER is a large and diverse program. 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 U.S. Emphasis in the program centers on developing tan-plant true guinea cultivars, and on improving the head bug/grain mold resistance of high yielding tan-plant non-guinea breeding lines and guinea by non-guinea intergrades. Essentially 100% of the breeding effort is directed to white-seeded, tan-plant genotypes. Breeding for the dry northern areas also involves 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, Kolombada, and 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.

New breeding crosses are made annually to assure the gradual improvement of new breeding materials through recombination of the best materials. In the 2000 rainy season, 53 new crosses were made at Sotuba, and the F_1s grown during the 2000-2001 off-season nursery along with 31 parents for making new crosses.

In breeding progeny plots at various locations, individual plant selections are made for advance by the pedigree method. In 2000, 820 panicles were selected in F_2 populations, 921 in F_3s, 653 in F_4s, and 141 in F_5s. The F_5 selections move to the off-season for seed increase and then entry into yield trials the following year. The F_5's included 40 early, 57 medium, and 44 late-maturity lines.

The yield trials of improved varieties in 2000 were divided into three groups (GI, GII, GIII) corresponding to the years in tests (I = first year, II = second year, etc.) within the Early and Medium Maturity Tests, with only one Late Maturity Test. Data from the highest yielding entries, and the entries to be advanced to on-farm trials in 2001 are presented in Table 1, along with the mean test yield, or local check yield where appropriate. In the Medium Maturity GIII Test, two items, 97-SB-F5DT-97 and 97-SB-F5DT-082, without the highest yield but with yield stability across year and locations, were selected for advance to on-farm trials.

After evaluation of the breeding material and the sorghum on farms of the Bema (Northern Mali) area, it was decided to increase emphasis on the Durras to develop breeding material for that area. Also, after evaluating the Mali Collection Growout in St. Croix in May, it was observed that there are some very unique, high yield potential Durras, Durra Dochnas, and Dochnas from Northern Mali, that should (and will) be included in the crossing and breeding program for Northern Mali.

An INTSORMIL Drought Test of 75 entries was evaluated for drought response at Cinzana and Bema. Pre-flowering drought stress was quite severe, especially at Cinzana. Seventeen entries which showed good drought tolerance and grain yield potential at both locations were identified and are given in Table 3 of the TAM-222 (D.T. Rosenow) Annual Report in this publication. The reaction of these cultivars is quite consistent with evaluations under

Table 1. Performance data selected best improved varieties from sorghum yield trials, Mali, 2000.

Designation	Pedigree	Days to 50% flowering	Plant height (m)	Grain yield (kg ha^{-1})
Early - GI (first year evaluation) - Cinzana				
Malisor 92-1				3032
99-BE-F5P-66	(89-SK-F4-53-2PL*Nagawhite)			2624
99-BE-F5P-122	((Sureño*85-F4-204)*N'tenimissa)			2567
(Mean test yield)				1665
Early - GII (two year evaluation)				
98-CZ-F5P-82	((Bimbiri S.*S34)*CSM219)(Cinzana)			2419
(Mean test yield)				1665
98-BE-F5P-74-1	((Bimbiri S.*S34)*(CSM388*Sureño))(Bema)			2620
(Mean test yield)				1476
Early - GIII (third year evaluation - 2 locations) - 3 year mean data				
97-CZ-FSP-3*	(Bagoba*ICSV1171)	78	1.72	2011
97-BE-FSP-24*	(Malisor 84-6*CE151)	73	1.97	1752
CSM3 (Improved Local)		68	2.89	1675
Local		74	3.47	1702
(Mean test yield)				1486
Medium - GI - Sotuba				
99-SB-F5-DT-170-1	(N'tenimissa*CSM388)			2967
Local check				1967
Medium - GI - Kolombada				
99-SB-FS-DT-205	(N'Tenimissa*Seguetana CZ)			2000
Medium - GII - Cinzana				
98-SB-F_2-78	((Bimbiri S.*S34)*M92-2)			2800
CSM388 (Improved Local)				2417
98-SB-F_2-82	((Bimbiri S.*S34)*M92-2)			2383
Medium - GIII (Three years evaluation - 2 locations)				
97-SB-F5DT-15*	(SB-66-42*92-SB-F4-97)	90	1.58	2343
97-SB-F5DT-138*	(S34*Malisor 84-7)	87	2.00	2170
97-SB-F5DT-150*	(92-SB-F4-14*92-SB-F4-97)	90	1.59	2131
97-SB-F5DT-97*	(Bimbiri S.*92-SK-F4-58)	85	3.92	1843
97-5B-F5DT-82*	(Bimbiri S.*92-SK-F4-56	87	3.79	1769
CSM388 (Improved Local)		91	4.03	1703
Local Check		88	3.72	2061
Mean test yield				1522
Late Maturity Test				
97-SB-F5DT-74-1*	(N'Tenimissa*Tiemarting)			1900
97-SB-F5DT-74-2*	(N'Tenimissa*Tiemarting)			1875
96-CZ-F4P-99*	(N'Tenimissa*Tiemarting)			2117

* = Entries to be advanced to on-farm trials in 2001.

pre-flowering stress in the U.S. and with previous observations of the good drought resistance of Caudatums (Feteritas and zerazeras) across the drier production areas of Africa.

Hybrid Sorghum Project

A new program on hybrid development was initiated in Mali. The Rockefeller Foundation is funding through ICRISAT and IER, a project to develop true Guinea hybrids for Mali and West Africa. In addition to Dr. A. Toure working with ICRISAT (Dr. Fred Rattunde) on the R.F. guinea hybrid project, Dr. Toure is also identifying and developing both male and female parental lines which are Guinea derivatives, mostly with Caudatum, thereby greatly improving the chances for heterosis and higher yielding hybrids.

A large number of Guinea cultivars and Guinea derivative breeding lines were crossed to various male sterile (A_1 cytoplasm) and the hybrids evaluated in 2000 (Table 2) for fertility restoration reaction (B = non restorer, and R = restorer), and the presence of the B_1 gene, one of the two genes involved in the presence of the high tannin testa in sorghum. Essentially all developed A-lines from INTSORMIL and ICRISAT are dominant B_2, so that a male parent B_1, b_2 will produce a brown seeded (testa present) F_1, dominant B_1-, B_2-. For successful hybrids using Guineas, a female that is b_1b_2 or B_1b_2 is needed. All true Guineas except one, CSM-63E possess dominant B_1, while a number of the Guinea derivative lines are recessive b_1. Additional crosses were made of new breeding lines for evaluation of B/R reaction. The best B-lines were planted for additional backcrossing to the male sterile F_1. A good number of both true Guineas and Guinea derivative lines showed a good B-line reaction, with potential for developing female parental lines.

Pearl Millet Breeding

In an experiment with 18 pearl millet hybrid land races and population land races from Tifton, Georgia, they were compared to two local cultivars (Boboni and Toroniou C1) (Table 3). Materials from Tifton were earlier and generally lower yielding. The maturity difference between the introductions and local materials was 18-26 days. These early maturing varieties should be tested for their adaptability in areas like Macina, Niono and Banamba with very short rainy seasons. Materials like Mansoori, Iniari, and (Ex-bornu *Mansuri) showed good tolerance to downy mildew and the variety P3Kolo had the longest panicle.

Yield among varieties was significantly different and the best varieties were Boboni (local check) with 2870 kg ha^{-1};

Table 2. Fertility reaction and B1 gene evaluation of hybrids with selected Malian Guinea (G) cultivars, and improved Guinea derivative lines, Mali, 2000.

Varieties[1/]	Fertility reaction[2/]	Testa (B1) reaction [3/]
CSM-335 (G)	B	P
57-26 (G)	B	P
CSM-660 (G)	B	P
CSM-485 (G)	B	P
IPS0001. (G)	B	P
FOLOMBA-1 (G)	B	P
FOLOMBA-2 (G)	B	P
97-SB-F5DT-160	B	A
97-SB-F5DT-154	B	A
MIKSOR-86-30-41 (G)	B	P
CSM-207 (G)	B	P
SEGUETENA CZ (G)	B	P
97-SB-F5DT-150	B	A
96-CZ-F4P-98	B	A
98-SB-F5DT-59	B	A
96-EP-GII-1015	B	A
97-SB-F5DT-64	B	-
98-KI-EAT-101	B	A
98-BE-F5P-82	B	-
N'TENIMISSA	B	P
99-SB-F4DT-322	B	P
97-SU-F5DT-151	B	P
CSM-205 (G)	PB	P
CSM-207 (G)	PB	P
CMDT-48 (G)	PB	P
97-SB-F5DT-170	PB	A
CSM-485 (G)	PR	P
CZ-329 (G)	PR	P
99-SB-EADT-126	PR	A
97-SB-F5DT-76-2	PR	-
99CLO-634 (CSM388C) (G)	PR	P
99CLO633 (CSM207C) (G)	PR	P
TIEMARIFING (G)	PR	P
CSM-63 E (G)	R	A
CSM-219 (G)	R	-
IS 40162 (G)	R	A
IS 40173 (G)	R	A
CZ-262 (G)	R	A
CGM19/9/1-1	R	P

1/ "G" following the variety designation indicates a true Guinea cultivar. All others are Guinea derivative lines.
2/ B = non-restorer (0% seed set or very low), R = Restores (80% or greater seed set), PB and PR indicate partial restoration with PB being closer to a B and PR being closer to an R. All reactions are with A1 cytoplasm.
3/ Presence (P) or Absence (A) of testa in F_1hybrids. P = B_1 present in male parent.

Table 3. Evaluation of pearl millet hybrid landraces and population landraces, Cinzana, Mali, 2000.

Varieties	Flowering (days)	Plant height (cm)	Panicle length (cm)	Downy mildew (%)	Grain yield (kg ha^{-1})
WA 8 Ex-Bornu × Ugandi	62 c	199 bc	21 e	33.33	1335 bc
WA 9 Ex-Bornu × Mansori	62 c	201 bc	25 e	33.38	835 bc
WA 10 Ex-Bornu × Iniari	59 c	207 b	26 de	20.88	735 c
WA 11 Ex-Bornu × P3Kolo	67 bc	214 b	37 bc	27.13	1870 b
WA 12 Ex-Bornu × Ugandi	60 c	196 bc	12 f	24.705	935 bc
WA 13 Ex-Bornu × Mansori	60 c	197 b	25 e	18.37	1665 bc
WA 14 Ex-Bornu × Iniari	61 c	210 bc	26 de	23.58	1070 bc
WA 15 P3 Kolo × Ugandi	65 bc	204 bcd	27 de	41.66	1135 bc
WA 16 P3 Kolo × Mansori	67 bc	187 bcd	34 bc	41.66	1400 bc
WA 17 P3 Kolo × Iniari	60 c	204 bc	32 cd	36.48	935 bc
WA18 Ugandi × Mansori	66 bc	191 bc	26 de	25.13	1400 bc
WA 19 Ugandi × Iniari	59 c	194 bc	25 e	50.62	1670 bc
WA 20 Iniari × Mansori	58 c	191 bc	25 e	36.16	665 c
Ex- Bornu	66 bc	171 cde	27 def	54.54	605 c
Ugandi	65 bc	153 e	15 f	14.76	470 c
Mansori	66 bc	156 de	27 de	9.00	535 c
Iniari	65 bc	143 e	26 de	16.00	670 c
P3Kolo	64 bc	187bd	47 a	33.07	935 bc
Toroniou C1 (local check)	72 ab	248 a	39 b	22.14	1800 b
Boboni (local check)	78 a	249 a	36 bc	31.74	2870 a

(Ex-bornu * P3kolo), 1870 kg ha^{-1} Toroniou C1 (local check), 1800 kg ha^{-1}, and (Ugandi * Iniari) 1670 kg ha^{-1}.

Four areas of Mali were identified for collection of land races; Bla, San, Koutiala and Yorrosso. Fifty land races have been collected and are now being characterized at Cinzana and N'Tarla.

Institution Building

IER sorghum and millet programs received, through INTSORMIL collaboration, a vehicle, two computers, a printer, a copy machine, a fax machine and various field and laboratory research equipment and breeding supplies.

Many Malian scientists trained at INTSORMIL institutions are senior staff making important contributions in sorghum and millet research within the IER including:

Dr. Aboubacar Touré (Texas A&M) - Currently Sorghum Breeder, Mali National Coordinator for sorghum, Mali INTSORMIL Coordinator, and on INTSORMIL Technical Committee.

Dr. Mamourou Diourté (Texas A&M and Kansas State) - Currently Head Sorghum Pathologist.

Dr. Samba Traore (Nebraska) - Currently Agronomist and Mali National Coordinator for Millet.

Dr. Mme Diarisso Niamoye Yaro (Texas A&M) - Currently sorghum entomologist, and head of a Vegetable Station in IER.

Dr. Mamadou Doumbia (Texas A&M) - Currently Director of Soil Laboratory and soil scientist with IER.

Mr. Abdoul W. Touré (Nebraska) - Currently sorghum agronomist.

Mr. Adama Coulibaly (Kansas State) - Currently sorghum agronomist

Mr. Sidi Bekaye Coulibaly (Nebraska) - Previously sorghum physiology/agronomy and sorghum breeding and INTSORMIL Coordinator. Currently working on Ph.D. at Texas A&M/Texas Tech.

Mr. Bakary Coulibaly (Purdue) - Currently economist with Icofil, IER.

Dr. Bourema Dembelé (Purdue - Short Training) - Currently Deputy Research Director, IER. Previously weed scientist *Striga* and National Coordinator for sorghum.

Mme Aissata Bengaly Berthé (Texas A&M - Short Training) - Currently sorghum utilization and quality PI

Students currently in training include Niaba Témé who successfully completed his B.S. and is currently an M.S. student at Texas Tech University and Sidi Bekaye Coulibaly, who has served as INTSORMIL Host Country Coordinator, is now a Ph.D student at Texas Tech/Texas A&M University.

Mr. Moussa Sanogo, millet breeder spent six weeks in training with Dr. Wayne Hanna in Georgia the summer of 2000.

Bocar Sidibé, Abocar Toure, and Sibène Déna received short term training in the USA provided by INTSORMIL in breeding and plant pathology.

Dr. Aboubacar Toure, sorghum breeder, is a member of the steering committee of the West and Central Africa Sorghum Research Network, WCASRN (ROCARS).

U.S. scientists traveling to Mali included: Dr. D.T. Rosenow, Sorghum Breeder (November - Program Review and April - ROCARS Meeting), Dr. S.C. Mason, agronomist (December and April - ROCAFREMI Meeting), Dr. Carl Nelson, Economist (April), and Dr. W.W. Hanna, Millet Breeder (March 2000).

Malian scientists travel included: Dr. Aboubacar Toure to West Africa Sustainable Sorghum Improvement through Integrated Insect Management Workshop, Ouagadougou, Burkina Faso (December 5, 2000); Fourth Australia Sorghum Conference, Queensland, Australia (February 5-12, 2001); Participatory Plant Breeding in Africa Workshop, Bouake, Ivory Coast (May 7-11, 2001); Preservation and Utilization of Sorghum Biodiversity in West Africa Workshop, Montpellier, France (June 30-July 5, 2000); Mali Sorghum Collection Quarantine Growout (characterization and evaluation), St. Croix, U.S.Virgin Islands., (May 20-25, 2001) and to Lubbock, Texas (May 26-30, 2001), Mr. Niaba Teme, M.S. student at Texas Tech, to Mali Collection Growout (May 20-25, 2001). Drs. Aboubacar Toure and Mamourou Diourte to Senegal and Ghana to visit the new INTSORMIL collaborators and their research programs, January 2-15, 2001.

Drs. Ndiaga Cisse (sorghum breeder) and Demba M'Baye (pathologist) from Senegal and Drs. Ibrahim Atokple (sorghum breeder) and S.S. Buah (agronomist) from Ghana traveled to Bamako, Mali, November 5-9, 2001. They met with Darrell Rosenow and key Malian scientists to develop collaborative research plans involving INTSORMIL, Ghana, Senegal, and Mali scientists.

Networking

An efficient sorghum and millet research and technology transfer network exists though WCASRN and ROCAFREMI. The INTSORMIL/IER collaborative program is integrated on a regional basis. Technologies developed in Mali are transferable to most countries in West Africa specially in the areas of head bugs, drought and grain mold which are common across West Africa and are world-wide problems. Exchange of elite germplasm with useful traits is ongoing among breeders in the region. The emerging interaction with NGOs, the University of Mali (IPR de Katibougou), farm organizations, and extension in conducting on-farm research and tests is a positive one that efficiently utilizes scarce resources and personnel. The program is using this approach to evaluate new improved breeding cultivars and other technologies in the West Africa Region. Efforts are underway to reinforce coordination of research programs and activities with other countries in West Africa. Collaborative INTSORMIL research has been initiated in Ghana and Senegal for the 2001 season, and some initial efforts have been taken to tie some of this in with researchers and programs in Burkina Faso, Nigeria, and Niger.

The program has also interacted with ICRISAT, TROPSOILS, NOVARTIS, etc. There has been a long history of collaboration with ICRISAT in Mali especially in breeding, entomology, and weed science. The program has assembled, planted, increased and characterized the Mali Sorghum Collection in collaboration with USDA-ARS, ICRISAT, ORSTOM, CIRAD, and seed is in storage in Mali and has been introduced into the U.S. Approximately 450 (the late maturing group) items from the Mali Sorghum Collection were grown in quarantine on St. Croix, U.S.Virgin Islands in early 2000 with seed increased and characterization completed. The other two thirds of the Collection was grown out and seed increased and characterization completed in St. Croix in the winter of 2000-2001. The development of a working group for active use is ongoing. After the seed is processed, complete sets will be sent, as appropriate to ICRISAT, ORSTOM, and Mali.

New Ghana and Senegal Collaboration

In November 2000, arrangements were made to bring two scientists each from Ghana (Drs. S. Buah, Agronomist and I. Atokple, Sorghum Breeder) and Senegal (Ndiaga Cisse, Sorghum Breeder and Demba M'Baye, Pathologist) to Bamako to meet with Darrell Rosenow, Aboubacar Toure, and other key Malian IER scientists to initiate INTSORMIL collaborative activities in these two countries as mandated by the Board and TC. Dr. Buah already had previously initiated a collaborative program in agronomy with Maranville. The discussions were all very fruitful and positive with three initial areas of collaboration among Malian, Ghana, and Senegal scientists agreed upon: 1) Sorghum Breeding with the establishment of a germplasm exchange program centering on a West African Regional Breeding Nursery to which all breeders would contribute new breeding germplasm or cultivars annually, and would be assembled and distributed by Dr. Toure in Mali; 2) Sorghum Pathology centered initially on a West African Disease Nursery to which all pathologists and breeders would contribute entries annually and would be assembled and distributed by M. Diourte in Mali; and 3) *Striga* research with initially a *Striga* nursery of known or suspected *Striga* resistant local cultivars and selected lines from Gebisa Ejeta evaluated at several sites (assembled in Mali) and also a look at some of the sources by Dr. Ejeta for types of resistance involved. In addition, INTSORMIL in the U.S. will provide breeding germplasm for midge resistance, drought resistance, grain mold resistance, other disease resistance, and elite sources of worldwide germplasm for the new breeding programs in Ghana and Senegal. Requests were made by scientists in Ghana and Senegal for the future development of collaboration in millet breeding, entomology (head bugs and midge), cereal technology and utilization, and agronomy. Dr. Buah will continue his collaborative activities in Ghana in 2001 based on already developed cooperation with Maranville.

The representatives from Ghana and Senegal represented all NARS in their countries and made suggestions of other scientists they felt should be included such as the millet breeders in Ghana and Senegal. The three collaborative areas should also have application to Niger, Burkina Faso, and Nigeria, and hopefully they can be brought into the effort of collaboration among West African Scientists. The response of scientists from Mali, Ghana and Senegal to collaboration among the West African scientists was excellent. In January, Drs. Toure and Diourte (Pathologist) went to Senegal and Ghana to visit with NARS as a followup to the November meeting in Bamako.

In April 2001, while participating in the Mid-Term Evaluation of ROCARS at Bamako, Mali, a meeting was held with D. Rosenow, Aboubacar Toure, Mamourou Diourte, and Drs. Atokple, Buah (Ghana), and Cisse, M'Baye (Senegal) to finalize collaborative INTSORMIL, IER, ISRA, SARI plans for the 2001 crop season. Also, a larger meeting was held with the above scientists, Dr. Steve Mason, as well as interested persons from Niger, Burkina Faso, and Nigeria where the nature of the new collaborative work involving Ghana, Senegal, and Mali was explained. The plans for the West African breeding, disease, and *Striga* nurseries were discussed as well as opportunities for other INTSORMIL trials such as for drought resistance, midge resistance, and anthracnose. Scientists in Niger, Burkina Faso, and Nigeria expressed interest in some of the materials but with the understanding that any potential funding for those activities would depend upon future development of collaboration, MOUs, etc. through the Niger - Eastern West Africa Region program.

Research Accomplishments - Summary

The most significant impact of INTSORMIL has been the strengthening of the IER both through staff training and research capacity building. Interdisciplinary and cooperative research in sorghum and millet which are in place at the IER are mainly due to INTSORMIL/IER collaborations. The multidisciplinary approach to solving technical problems have been promoted by INTSORMIL, and is functioning well in Mali.

Breeding

•Eight local photosensitive sorghum cultivars have been improved through mass selection and are grown by farmers on a significant area in Mali (CSM 388, CSM 219E, CSM 63E, Foulatiéba, Séguétana CZ, CMDT 45 , CMDT 39).

•The white-seeded, tan-plant Guinea type breeding cultivar, N'Tenimissa, was released. It's yield is equal to or slightly superior to local checks. It has good farmer acceptance regarding yield and food use. Flour from N'Tenimissa is currently being marketed commercially (20% N'Tenimissa and 80% wheat flour) in a cookie called déli'ken by the private company, GAM, in Bamako.

•Several white, tan plant true Guinea breeding lines were identified: 96-CZ-F4-99 (late maturity); 97-SB-F5-74-1, 97-SB-F5-74-2 (medium maturity); and 97-SB-F5-63, 97-SB-F5-64 (early maturity), all from the cross (N'Tenimissa*Tiémarifing). They have been evaluated on-farm with promising results. They have somewhat superior grain quality and show less stem breakage than N'Tenimissa.

•Varieties of millet selected for the tallest expression of the D2 dwarfing complex (1.7 to 1.9 m) have given good performance in millet/legume intercropping studies.

•Testing in Texas and Mali has demonstrated that the drought response in Mali is similar to the drought response in West Texas increasing probability of success in breeding for enhanced drought tolerance.

•The Mali Sorghum Collection of indigenous cultivars from Mali was successfully grown in 1997, was characterized and seed increased and distributed. A small working collection has been identified. There was greater diversity in the collection than anticipated. Approximately one-third of the Collection was grown in St. Croix in spring 2000 with seed increased and characterization completed. The remaining two-thirds was grown in a St. Croix quarantine growout in winter, 2000-2001, and seed increased and characterization completed. A tentative Working Collection was identified.

Entomology

•The adverse effect of head bugs on the grain food quality of introduced sorghum across West Africa was first recognized and documented in Mali.

•The INTSORMIL collaborative sorghum entomology research program in Mali has discovered the best source of genetic resistance to head bug (*Eurystylus marginatus*), a major constraint to the quality of grain sorghum in Mali, in an IER Malian developed cultivar, Malisor 84-7.

•An easy, efficient technique for screening for head bug resistance using bagged vs. non-bagged heads has been developed and is used cooperatively by the breeders and the entomologists.

•Observations indicate that head bug infestations in on-farm trials is much lower than in Station Nurseries. This means that sorghum with somewhat lower levels of head bug resistance may well work at the farm level, even though they may show significant damage under certain Station infestations.

Pathology

•Grain yield increase of 20% can be obtained by treating millet seed with Apron Plus®.

•Protection from head bugs will be a requirement for evaluation of grain mold resistance.

•Long smut (*Tolyposporium ehrenbergii*) is severe in the drier regions of Mali. Anthracnose (*Collectostrichum graminicola*) is a very serious sorghum disease in Mali.

•Studies were conducted on covered kernel smut (*Sphacelotheca sorghi*) by using traditional fungicides and the results showed that "Gon" (*Canavalia ensiloformis*) used in seed treatment had the same effects as Apron Plus® 50DS and Oftanol.

Agronomy

•INTSORMIL/IER research has demonstrated that millet or sorghum planted after peanut or cowpea results in 36 to 63% yield increases.

•INTSORMIL collaborative research has shown an increase in pearl millet grain yield and biomass production due to previous cowpea crops and equivalent to the application of 30 to 40 kg ha^{-1} N.

•The joint INTSORMIL/TROPSOILS collaborative program has addressed soil chemical properties associated with nutrient deficiencies toxicities in sandy soils of the Cinzana Station. Some Durra varieties from Niger and northern Mali show tolerance to soil toxicity (Bagoba, Babadia Fara, and Gadiaba)

•A method of screening large numbers of sorghum and millet lines for early generation and selection for seedling stage drought resistance using a charcoal pit has been adapted and is used.

•Nitrogen use efficiency (NUE) of improved sorghum cultivars has been better than that of local cultivars at higher N rates, while local cultivars had better NUE at zero and very low N rates.

•Without fertilizer application all tested cropping systems (including legume rotations) mine the soil of nutrients.

•Crop rotation with cowpea and leaving crop residues in the field (either incorporated or on the surface) increases the sustainability and productivity of pearl millet cropping systems.

Weed Science

•Several *Striga* resistant lines from Purdue evaluated in Mali showed good *Striga* resistance, but had inferior grain quality compared to local cultivars.

Striga resistance using lab screening to *Striga* asiatica in the U.S. works under field conditions to *S. hermonthica* in Mali.

•New sources of resistance to *Striga* were identified: Séguétana CZ, CMDT 45, CMDT 30, CMDT 39.

Grain Quality and Utilization

•Mini tests for evaluating milling and tô properties were developed and currently are used in the laboratory. Sorghum with hard endosperm and thick pericarps was definitely required for efficient traditional hand pounding. The size and shape of the pearl millet kernels affects dehulling properties significantly.

•Head bugs damage reduced sorghum milling yields and produced tô with unacceptable texture and keeping properties.

•Parboiling can convert sorghum and millet into acceptable products. It improves dehulling yields, especially for soft grains. The cooked milled products can be eaten like rice.

•The combination of cowpea and millet flour (1:3) significantly improved the nutritional status of young children. This technology has been transferred to many villages especially in the Cinzana area.

•Mileg, a weaning food using primarily millet flour has been developed by private enterprise and marketed in stores in the Bamako area. The product was developed using technology developed in the IER Cereal Technology laboratory.

•New white-seeded, tan-plant, tan-glume guinea-type breeding cultivars, have good potential for use in developing new high quality, value added food products. They posses excellent guinea traits and yield potential.

•Déli'ken, a cookie using 20% N'Tenimissa flour and 80% wheat flour has been developed by private enterprise GAM and marketed in stores in Mali.

Economics/Marketing

•The domestic cereal economy has been helped by devaluation with the increased relative price of sorghum and millet to rice. A future devaluation is expected to result in much more substitution of traditional cereals now that there is only a minimal rice tariff.

•In spite of substantial introduction of new sorghum and millet cultivars, there has been minimum aggregate impact on yields. Only where inorganic fertilizers and improved water retention or irrigation were combined with new cultivars, have there been large yield increases. Given the low soil fertility and irregular rainfall in semi-arid regions, both increased water availability and higher levels of principal nutrients will be necessary for substantial yield increases. Improved cultivars alone are unlikely to have a significant effect upon yield.

•The lack of a consistent supply of high quality sorghum and millet grain is the major constraint limiting value-added grain processing.

•Lack of farm credit for millet and sorghum, compared to cotton and maize, discourages adoption by farmers of improved millet and sorghum technology, especially in the Sudano-Guinean (higher rainfall) zone.

Educational Activities

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Year 22 Degree Education

INTSORMIL gives high priority toeducating host country scientists who will have major responsibilities for sorghum and millet research in their home countries. Education is also provided for young U.S. scientists who plan for careers in international development work.

The most frequently used mode of educational activities 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, 33 students from 17 different countries were enrolled in an INTSORMIL advanced degree program. Approximately 51% 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 educating women which is reflected in Figure 2. In 2000-2001, 27% of all INTSORMIL graduate participants were female. Thirteen of the 33 students received full INTSORMIL scholarships and an additional 20 students received partial INTSORMIL funding as shown in Figure 3.

All 33 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 2000-2001 there were 14.

Degree programs and short-term 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 14 visiting host country scientists were provided the opportunity to upgrade their skills in this fashion during 2000-2001.

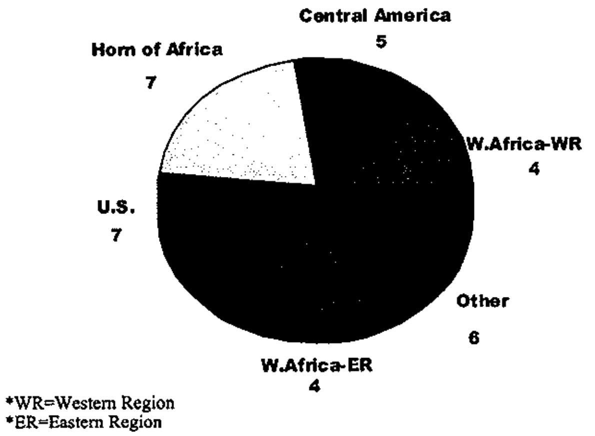

Figure 1. Degree participants by region.

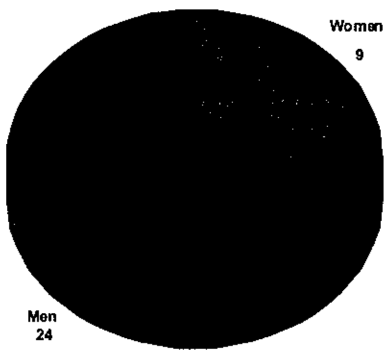

Figure 2. Degree participants by gender.

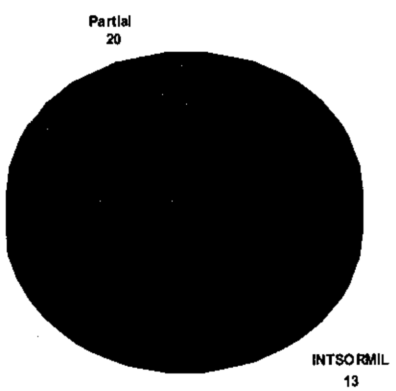

Figure 3. Degree participants source of funding.

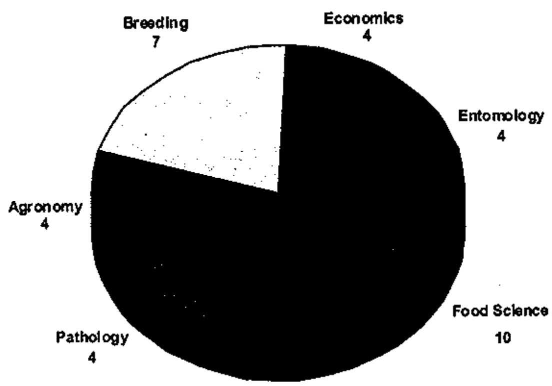

Figure 4. Degree participants by discipline breakdown.

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Year 22 INTSORMIL Degree Training Participants July 1, 2000 - June 30, 2001

Name	Country	Univ.	Discipline	Advisor	Degree	Gender	Funding
Regassa, Teshome	Ethiopia	UNL	Agron/Physiol	Maranville	PHD	M	P
Kathol, Delon	U.S.	UNL	Agronomy	Mason	MSC	M	P
Maman, Nouri	Niger	UNL	Agron/Physiol	Mason	PHD	M	P
Seibou, Pale	Burkina Faso	UNL	Agronomy	Mason	MSC	M	I
Nduulu, Lexingtons	Kenya	PRF	Breeding	Axtell	PHD	M	I
Ellicott, Alexis	U.S.	PRF	Genetics/Breeding	Ejeta	PHD	F	P
Gunaratna, Nilupa	U.S.	PRF	Breeding	Ejeta	MSC	F	I
Mohammed, Abdalla	Sudan	PRF	Breeding	Ejeta	PHD	M	I
Phillips, Felicia	U.S.	PRF	Breeding	Ejeta	MSC	F	P
Coulibaly, Sidi Bekaye	Mali	TTU	Breeding	Rosenow/Peterson	PHD	M	P
Teme, Niaba	Mali	TTU	Breeding	Rosenow	MSC	M	I
Asante, Victor	Ghana	PRF	Economics	Sanders	MSC	M	P
Kazianga, Harounan	Burkina Faso	PRF	Economics	Sanders	PHD	M	P
Tahirou, Abdoulaye	Niger	PRF	Economics	Sanders	PHD	M	I
Wubeneh, Nega G.	Ethiopia	PRF	Eonomics	Sanders	MSC	M	I
Gorena, Roberto Luis	U.S.	TAM	Entomology	Peterson/Teetes	PHD	M	I
Jensen, Andrea	U.S.	TAM	Entomology	Teetes	PHD	F	P
Carrillo, Mario	Argentina	MSU	Entomology	Pitre	MSC	M	I
Johnson, Zeledon	Nicaragua	MSU	Entomology	Pitre	PHD	M	I
Bugusu, Betty	Kenya	PRF	Food Quality/Util	Hamaker	PHD	F	I
Maladen, Michelle	India	PRF	Food Quality/Util	Hamaker	MSC	F	I
Mix, Nadege	France	PRF	Food Quality/Util	Hamaker	MSC	F	I
Suhendra, Budhi	Indonesia	PRF	Food Quality/Util	Hamaker	MSC	M	P
Awika, Joseph Mobutu	Kenya	TAM	Food Quality/Util	Rooney/Waniska	MSC	M	P
Awika, Joseph Mobutu	Kenya	TAM	Food Quality/Util	Rooney/Waniska	PHD	M	P
Bueso, Francisco (Javier)	Honduras	TAM	Food Quality/Util	Rooney/Waniska	PHD	M	P
Gordon, Leigh Ann	U.S.	TAM	Food Quality/Util	Rooney	MSC	F	P
Mitre-Dieste, Marcelo	Mexico	TAM	Food Quality/Util	Rooney	MSC	M	P
Zelaya, Nolvia	Honduras	TAM	Food Quality/Util	Rooney/Waniska	MSC	F	P
Narvaez, Dario	Colombia	KSU	Pathology	Claflin	PHD	M	P
Salah, Amgad	Egypt	KSU	Pathology	Leslie	PHD	M	P
Kollo, Issoufou	Niger	TAM	Pathology	Frederiksen	PHD	M	P
Montes, Noe	Mexico	TAM	Pathology	Odvody/Isakeit	PHD	M	P

* I = Completely funded by INTSORMIL
P = Partially funded by INTSORMIL
IC = InterCRSP Funding

KSU = Kansas State University
MSU= Mississippi State University
PRF = Purdue University
TAM= Texas A&M University
TTU = Texas Tech University
UNL = University of Nebraska - Lincoln
USDA= Tifton, Georgia

Year 22 INTSORMIL Non-Degree Educational Activities
July 1, 2000 - June 30, 2001

Name	Country	Univ.	Discipline	Advisor	Activity	Gender	Funding
Grenier, Cecile	France	PRF	*Striga* Physiology	Ejeta	VS	F	P
Rich, Patrick	U.S.	PRF	*Striga* Biology	Ejeta	PD	M	I
Mogorosi, Michael	Botswana	USDA	Breeding	Hanna	VS	M	I
Sanogo, Moussa	Mali	USDA	Breeding	Hanna	VS	M	I
Teme, Niaba	Mali	TAM	Breeding	Rosenow	VS	M	P
Toure, Aboubacar	Mali	TAM	Breeding	Rosenow	VS	M	I
Bittaye, Alieu	Gambia	PRF	Economics	Sanders	VS	M	P
Aboubacar, Adam	Niger	PRF	Food Quality/Util	Hamaker	PD	M	P
Herrera, Fidelia	El Salvador	TAM	Food Quality/Util	Rooney/Waniska	VS	F	I
dos Santos, Claudia	Brazil	KSU	Pathology	Claflin	VS	F	P
Guzman, Reina	El Salvador	KSU	Pathology	Claflin	VS	F	I
Lemoine, Benoit	France	KSU	Pathology	Claflin	VS	M	P
Pichardo, Sergio	Nicaragua	KSU	Pathology	Claflin	VS	M	I
Seabra, Maria	Brazil	KSU	Pathology	Claflin	VS	F	P
Chulze, Sofia	Argentina	KSU	Pathol/Mycology	Leslie	VS	F	P
Jurgenson, Jim	U.S.	KSU	Pathol/Genetics	Leslie	VS	M	P
Kerenyi, Zoltan	Hungary	KSU	Pathol/Genetics	Leslie	PD	M	P
Zeller, Kurt P.	U.S.	KSU	Pathology	Leslie	PD	M	P

VS = Visiting Scientist
PD = Post Doctoral

Year 22 Conference/Workshop Activities
July 1, 2000 - June 30, 2002

Workshop/Conference	Location	Date	Participants: Male	Female	Total
ROCARS Mid-Term Network Evaluation	Bamako, Mali	April 21-28, 2001	1		1
Fusarium Workshop	Manhattan, KS	June 10-15, 2001	15	14	29
Scientific Writing Workshop	Tygerberg, South Africa	Dec. 11, 2000	10	13	23
West Africa/Western Region Planning Meeting	Bamako, Mali	Nov. 5-11, 2000	4		4
Scientific Writing Workshop	Penang, Malaysia	Nov. 13-16, 2000	64	33	97
Scientific Writing Workshop	Dokki, Egypt	Oct. 18, 2000 April 29-30, 2001	80	40	120
Scientific Writing Workshop	Kampala, Uganda	Oct. 12, 2000	38	27	65
Global 2000: Sorghum and Pearl Millet Diseases III	Guanajuato, Mexico	Sept. 23-30, 2000	112	28	140
Total			324	155	479

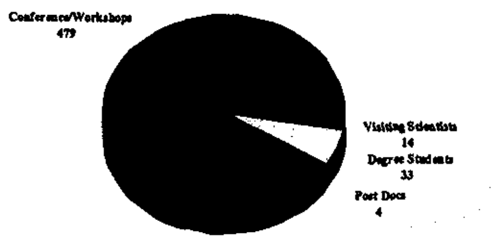

Figure 5. Total participants in educational activities.

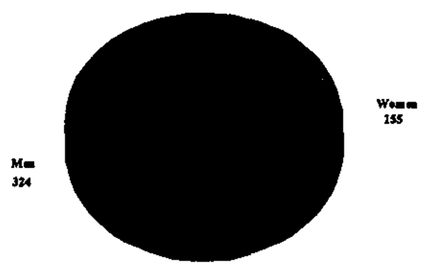

Figure 6. Total conference/workshop participants by gender.

Appendices

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INTSORMIL Sponsored and Co-Sponsored Workshops 1979 - 2001

	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

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	Name	Where	When
52.	Regional Hybrid Sorghum and Pearl Millet Seed Workshop	Niamey, Niger	9/98
53.	INTSORMIL End Use Quality Assessment Workshop	Pretoria, South Africa	12/98
54	Central America Regional Planning Workshop	Zamorano, Honduras	10/99
55.	Global 2000 Conference, Sorghum and Pearl Millet Diseases III	Guanajuato, Mexico	9/00

Acronyms

AAA/SFAA	American Anthropological Association/Society for Applied Anthropology
ABA	Abscisic Acid
ADC's	Advanced Developing Countries
ADIN	All Disease and Insect Nursery
ADRA	Adventist Development and Relief Agency
A.I.D	Agency for International Development
AID/H	Agency for International Development in Honduras
ALDEP	Arable Lands Development Program
APHIS	Animal and Plant Health Inspection Service, U.S.
ARC	Agricultural Research Corporation, Sudan
ARC	Agriculture Research Council, South Africa
ARGN	Anthracnose Resistant Germplasm Nursery
ARS	Agricultural Research Service
ASA	American Society of Agronomy
ASARECA	Association for Strengthening Agricultural Research in Eastern and Central Africa
ATIP	Agricultural Technology Improvement Project
BAMB	Botswana Agricultural Marketing Board
BIFADEC	Board for International Food and Agricultural Development and Economic Cooperation
BFTC	Botswana Food Technology Centre
CARE	Cooperative for American Remittances to Europe, Inc.
CARO	Chief Agricultural Research Officer
CARS	Central Agricultural Research Station, Kenya
CATIE	Centro Agronómico Tropical de Investigación y Enseñanza, Costa Rica
CEDA	Centro de Enseñanza y Adiestramiento, SRN, Honduras
CEDIA	Agricultural Document and Information Center, Honduras
CENTA	Centro de Technologia de Agricola, El Salvador
CFTRI	Central Food Technological Research Institute - India
CGIAR	Consultative Group on International Agricultural Research
CIAB	Agricultural Research Center of the Lowlands, Mexico
CICP	Consortium for International Crop Protection

CIDA	Canadian International Development Agency
CIAT	International Center for Tropical Agriculture, Colombia
CILSS	Interstate Committee to Combat Drought in the Sahel
CIMAR	Centro de Investigación en Ciencias del Mar y Limnologia, Costa Rica
CIMMYT	International Maize and Wheat Improvement Center
CIRAD	Centre International en Recherche Agronomique pour le Dèveloppement
CITESGRAN	Centro Internacional de Tecnologia de Semillas y Granos - EAP in Honduras
CLAIS	Comisión Latinoamericana de Investigadores en Sorgho
CMS	Cytoplasmic Male-Sterility System
CNIA	Centro Nacional de Investigaciones Agricolas, Nicaragua
CNPQ	Conselo Nacional de Desenvolvimento Cientifico e Tecnologico
CNRA	National Center for Agricultural Research, Senegal
CORASUR	Consolidated Agrarian Reform in the South - Belgium
CRSP	Collaborative Research Support Program
CSIR	Council for Scientific and Industrial Research
CSIRO	Commonwealth Scientific and Industrial Research Organization, Australia
DAR	Department of Agricultural Research, Botswana
DARE	Division of Agricultural Research and Extension - Eritrea
DICTA	Direccion de Ciencia y Tecnologia Agricola - Mexico
DR	Dominican Republic
DRA	Division de la Recherche Agronomique, IER Mali
DRI-Yoro	Integrated Rural Development Project, Honduras-Switzerland
EAP	Escuela Agricola Panamericana, Honduras
EARO	Ethiopian Agricultural Research Organization
EARSAM	East Africa Regional Sorghum and Millets
EAVN	Extended Anthracnose Virulence Nursery
ECHO	Educational Concerns for Hunger Organization
EEC	European Economic Community
EEP	External Evaluation Panel
EIME	Ensayo Internacional de los Maicillos Enanos
ELISA	Enzyme-linked Immunosorbent Assay
EMBRAPA	Empresa Brasileira de Pesquisa Agropecuaria, Brazil

EMBRAPA-CNPMS	EMBRAPA-Centro Nacional para Maize e Sorgo
ENA	National School of Agriculture, Honduras
EPIC	Erosion Productivity Impact Calculator
ERS/IEC	Economic Research Service/International Economic Development
EZC	Ecogeographic Zone Council
FAO	Food and Agriculture Organization of the United States
FEDEARROZ	Federación Nacional de Arroceros de Colombia
FENALCE	Federacion Nacional de Cultivadores de Cereales
FHIA	Fundacion Hondurena de Investigacion Agricola, Honduras
FPX	Federation of Agricultural and Agro-Industrial Producers and Exporters
FSR	Farming Systems Research
FSR/E	Farming Systems Research/Extension
GASGA	Group for Assistance on Systems Relating to Grain after Harvest
GMB	Grain Marketing Board
GOB	Government of Botswana
GOH	Government of Honduras
GTZ	German Agency for Technical Cooperation
GWT	Uniform Nursery for Grain Mold
HIAH	Honduran Institute of Anthropology and History
HOA	Horn of Africa
IAN	Institute Agronomia Nacional, Paraguay
IANR	Institute of Agriculture and Natural Resources, University of Nebraska - Lincoln
IAR	Institute of Agricultural Research - Ethiopia
IARC	International Agriculture Research Center
IBSNAT	International Benchmark Soils Network for Agrotechnology Transfer
ICA	Instituto Colombiano Agropecuario/Colombian Agricultural Institute
ICAR	Indian Council of Agricultural Research
ICARDA	International Centre for Agricultural Research in the Dry Areas
ICC	International Association for Cereal Chemistry
ICRISAT	International Crops Research Institute for the Semiarid Tropics
ICTA	Instituto de Ciencias y Technologia Agricolas, Guatemala
IDIAP	Agricultural Research Institute of Panama

IDIN	International Disease and Insect Nursery
IDRC	International Development Research Center
IER	Institute of Rural Economy, Mali
IFAD	International Fund for Agricultural Development, Rome
IFPRI	International Food Policy Research Institute
IFSAT	International Food Sorghum Adaptation Trial
IGAD	Intergovernmental Authority on Development
IHAH	Instituto Hondureno de Antropologia e Historia
IICA	Instituto Interamericano de Cooperación para la Agricultura
IIMYT	International Improved Maicillo Yield Trial
IITA	International Institute of Tropical Agriculture
ILCA	Instituto Interamericano de Cooperación para la Agricultura
ILRI	International Livestock Research Institute - Niger
INCAP	Instituto de Nutricion de Centro America y Panama
IN.E.R.A.	Institut d'Environnement et de Recherche Agricoles
INFOP	National Institute for Professional Development
INIA	Instituto Nacional de Investigacions Agricola, Mexico
INIAP	National Agricultural Research Institute, Ecuador
INIFAP	Instituto Nacional de Investigaciones Forestales Y Agropecuarias - Mexico
INIPA	National Agricultural Research Institute, Peru
INRAN	Institut National de Recherches Agronomiques du Niger
INTA	Instituto Nicaraguense de Technologia Agropecuaria, Nicaragua
INTSORMIL	International Sorghum/Millet, Collaborative Research Support Program (CRSP)
IPA	Instituto de Pesquisas Agronomicas, Brazil
IPIA	International Programs in Agriculture, Purdue University
IPM	Integrated Pest Management
IRAT	Institute of Tropical Agriculture and Food Crop Research
IRRI	International Rice Research Institute, Philippines
ISAVN	International Sorghum Anthracnose Virulence Nursery
ISC	ICRISAT Sahelian Center
ISRA	Institute of Agricultural Research, Senegal
ISVN	International Sorghum Virus Nursery

ITA	Institut de Technologie Alimentaire, Senegal
ITAT	International Tropical Adaptation Trials
ITESM	Monterrey Institute of Technology, Mexico
ITVAN	International Tall Variety Adaptation Nursery
JCARD	Joint Committee on Agricultural Research and Development
KARI	Kenya Agriculture Research Institute
KIRDI	Kenya Industrial Research and Development Institute
KSU	Kansas State University
LASIP	Latin American Sorghum Improvement Project, Mexico
LDC	Less Developed Country
LIDA	Low Input Dryland Agriculture
LIFE	League for International Food Education
LUPE	Land Use and Productivity Enhancement
LWMP	Land and Water Management Project
MAFES	Mississippi Agricultural and Forestry Experiment Station
MC	Maicillo Criollo
ME	Management Entity
MFC	Mechanized Farming Corporation, Sudan
MHM	Millet Head Miner
MIAC	MidAmerica International Agricultural Consortium
MIPH	Honduran Integrated Pest Management Project
MNR	Ministry of Natural Resources, Honduras
MOA	Memorandum of Agreement
MOA	Ministry of Agriculture, Botswana
MOALD	Ministry of Agriculture and Livestock Development, Kenya
MOU	Memorandum of Understanding
MRN	Ministerio de Recursos Naturales, Honduras
MSU	Mississippi State University
NAARP	Niger Applied Agricultural Research Project
NARO	National Agriculturall Research Organization - Uganda
NARP	National Agricultural Research Project
NARS	National Agricultural Research System

NCRP	Niger Cereals Research Project
NGO	Non-Government Organization
NSF	National Science Foundation
NSP	National Sorghum Program
NSSL	National Seed Storage Laboratory, Fort Collins, CO
NU	University of Nebraska
OAS	Organization of American States
OAU	Organization of African Unity
OICD	Office of International Cooperation and Development
ORSTOM	L'Institut français de recherche scientifique pour le développement en coopération - France
PCCMCA	Programa Cooperativo Centroamericano para el Mejoramiento de Cultivos 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 Medical Research	Program for Research on Mycotoxicology and Experimental Carcinogensis, South African Council
PROFIT	Productive Rotations on Farms in Texas
PROMESA	Proyecto de Mejoramiento de Semilla - Nicaragua
PSTC	Program in Science & Technology Cooperation
PVO	Private Volunteer Organization
QTL	Quantitative Trait Loci
RADRSN	Regional Advanced Disease Resistance Screening Nursery
RAPD	Random Amplified Polymorphic DNA
RARSN	Regional Anthracnose Resistance Screening Nursery
RFLP	Restriction Fragment Length Polymorphism
RFP	Request for Proposals
RIIC	Rural Industry Innovation Centre, Botswana

ROCAFREMI	Réseau Ouest et Centre Africain de Recherche sur le Mil, Niger
ROCARS	Réseau Ouest et Centre Africain de Recherche sur le Sorgho - Mali
RPDRSN	Regional Preliminary Disease Resistance Screening Nursery
RVL	Royal Veterinary and Agricultural University, Frederiksberg, Denmark
SACCAR	Southern African Centre for Cooperation in Agricultural Research
SADC	Southern Africa Development Community
SAFGRAD	Semi-Arid Food Grains Research and Development Project
SANREM	Sustainable Agriculture and Natural Resource Management CRSP
SARI	Savannah Agricultural Research Institute - Ghana
SAT	Semi-Arid Tropics
SDM	Sorghum Downy Mildew
SDMVN	Sorghum Downy Mildew Virulent Nursery
SICNA	Sorghum Improvement Conference of North America
SIDA	Swedish International Development Agency
SMIP	Sorghum and Millet Improvement Program
SMINET	Sorghum and Millet Improvement Network
SPARC	Strengthening Research Planning and Research on Commodities Project, Mali
SRCVO	Section of Food Crops Research, Mali
SRN	Secretaria de Recursos Naturales, Honduras
TAES	Texas Agricultural Experiment Station
TAMU	Texas A&M University
TARS	Tropical Agriculture Research Station
TC	Technical Committee
TropSoils	Tropical Soils Collaborative Research Program, CRSP
UANL	Universidad Autonoma de Nuevo Leon, Mexico
UHSN	Uniform Head Smut Nursery
UNA	Universidad Nacional Agraria - Nicaragua
UNAN	Universidad Nacional Autónoma de Nicaragua UNAN-Leon - Nicaragua
UNILLANOS	Universidad Technologica de los Llanos
UNL	University of Nebraska - Lincoln
UPANIC	Union of Agricultural Producers of Nicaragua
USA	United State of America

USAID	United States Agency for International Development
USDA	United States Department of Agriculture
USDA/TARS	United States Department of Agriculture/Tropical Agriculture Research Station
VCG	Vegetative Compatibility Group
WASAT	West African Semi-Arid Tropics
WASIP	West Africa Sorghum Improvement Program
WCAMRN	West and Central African Millet Research Network (ROCAFREMI) - Mali
WCASRN	West and Central Africa Sorghum Research Network (ROCARS) - Mali
WSARP	Western Sudan Agricultural Research Project
WVI	World Vision International

INTSORMIL's collaborative research with scientists of the Institut d' Economie Rurale (IER) in Mali began in 1981. During the past twenty years, the research skills of many scientists in Mali have been strengthened through the Collaborative Research Support Programs, and particularly by the INTSORMIL CRSP. In a food science laboratory of IER, it's time to celebrate the success of 100% sorghum biscuits formulated by IER food scientists, using flour of the white, guinea-type N'Tenimissa sorghum variety developed by the collaboration of IER sorghum breeders and American scientists in INTSORMIL's collaborative research program. Left to right: Dr. Mamourou Diourté, plant pathologist; Mme Berthé Aissata Bengaly, food technologist; Mr. Bocar Sidibé, assistant sorghum breeder; Dr. John Leslie, plant pathologist, Kansas State University; and Dr. Aboubacar Touré, sorghum breeder and Head of Mali's National Sorghum Program.