2003

INTSORMIL 2003 ANNUAL REPORT

John M. Yohe
University of Nebraska-Lincoln, jyohe1@unl.edu

Thomas Crawford Jr.

Kimberly Christiansen

Joan Frederick

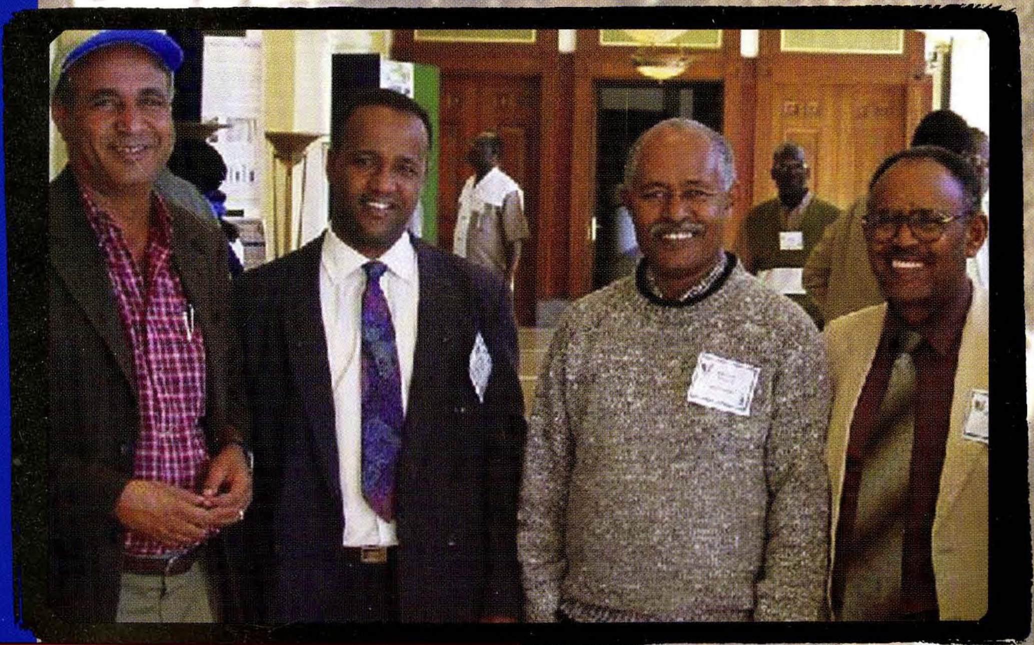
2003 Annual Report

INTSORMIL

Sorghum/Millet Collaborative Research Support Program (CRSP)

INTSORMIL

Sorghum/Millet International Research



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

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From the left: Kidane Georgis, agronomist, EARO HQ; Shimelis Admasu, food scientist, MARC; Abuhay Takele, agronomist completing Ph.D. training in South Africa and Tadesse G. Medhin, Senior Advisor to the Director General, EARO all attended the 2002 INTSORMIL PI Conference in Addis Ababa, Ethiopia. The theme of the conference was "Increasing Profitability of Sorghum and Millets."

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Fighting Hunger and Poverty with Research
. . . A Team Effort

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

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Report Coordinators
John M. Yohe, Program Director
Thomas Crawford, Jr., Associate Program Director

Kimberly Christiansen and Joan Frederick

For additional information contact the INTSORMIL Management Entity at:

INTSORMIL
113 Biochemistry Hall
University of Nebraska
Lincoln, Nebraska 68583-0748

Telephone: (402) 472-6032
Fax: (402) 472-7978
E-Mail: SRMLCRSP@unl.edu
http://intsormil.org

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INTSORMIL INSTITUTIONS

Kansas State University
Mississippi State University
University of Nebraska - Lincoln
Purdue University
Texas A&M University
USDA-ARS, Tifton, Georgia
West Texas A&M University

INTSORMIL Institutions are affirmative action/equal opportunity institutions.

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Introduction and Program Review

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

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

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

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

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

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

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

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

The Sorghum and Millet Collaborative Research Support Program (INTSORMIL CRSP) conducts collaborative research using partnerships between U.S. university scientists and scientists of the NARS, IARCs, PVOs and other CRSPs. INTSORMIL is programmatically organized for efficient and effective operation and captures most of the public research expertise on sorghum and pearl millet in the United States. ***The INTSORMIL mission is to use collaborative research as a mechanism to develop human and institutional research capabilities to overcome constraints to sorghum and millet production and utilization for the mutual benefit of the U.S. and Less Developed Countries (LDCs).*** Collaborating scientists in NARS developing countries and the U.S. jointly plan and execute research that mutually benefits all participating countries, including the United States.

INTSORMIL takes a regional approach to sorghum and millet research in western, southern, and eastern Africa, and in Central America. INTSORMIL focuses resources in the four regions supporting the general goals of building NARS institutional capabilities, creating human and technological capital to solve problems constraining sorghum and millet production and utilization. INTSORMIL's activities are aimed at achieving sustainable global impact, promoting economic growth, enhancing food security, and encouraging entrepreneurial activities. The six universities currently active in the INTSORMIL CRSP are Kansas State University, Mississippi State University, University of Nebraska, Purdue University, Texas A&M University and West Texas A&M University. In addition, scientists of the Agricultural Research Service of the U.S. Department of Agriculture at Tifton, Georgia participate in INTSORMIL. What were formerly referred to as "host" countries are now referred to as "collaborating" countries to indicate the closer and more collaborative relationships that have developed between the United States and those countries as a result of all that has been accomplished during the past twenty-two years of the INTSORMIL CRSP.

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

Although significant advances have been made in improvement and production of sorghum and millet in the developing countries of regions which INTSORMIL serves, population growth rates continue to exceed rates of increase of cereal production capacity. There remains an urgent need to continue the momentum of our successes in crop improvement, improved processing and marketing of sorghum and millet, and strengthening the capabilities of NARS scientists to do research on constraints to production, utilization and marketing of sorghum and millet.

INTSORMIL maintains a flexible approach to accomplishing its mission. The success of the INTSORMIL program can be attributed to the following strategies which guide the program in its research and linkages with technology transfer entities.

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

- ***Conserving biodiversity and natural resources***: Results of the collaborative research supported by INTSORMIL include development and release of enhanced germplasm, development and improvement of sustainable production systems, development of sustainable technologies to conserve biodiversity and natural resources. The knowledge and technologies generated by INTSORMIL research also enhance society's quality of life and enlarge the range of agricultural and environmental choices available both in developing countries and the United States. Thus, INTSORMIL promotes conserving millet and sorghum germplasm, conserving natural control of arthropod pests and diseases of sorghum and millet, developing resource-efficient cropping systems, developing integrated pest management programs, developing cultivars with improved nutrient and water use efficiencies, and evaluating impacts of sorghum/millet technologies on natural resources and biodiversity.

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

- ***Supporting information networking:*** INTSORMIL research emphasizes working with both national agricultural research systems and sorghum and millet networks to promote effective technology transfer from research sites within the region to local and regional institutions. Technology transfer is strengthened by continued links with regional networks, International Agricultural Research Centers, and local and regional institutions. Emphasis is placed on strong linkages with extension services, agricultural production schemes, private and public seed programs, agricultural product supply businesses, and nonprofit organizations, such as NGOs and PVOs, for efficient transfer of INTSORMIL-generated technologies. Each linkage is vital to development, transfer, and adoption of new production and utilization technologies, with the ultimate goal being economic and physical well-being to those involved in production and utilization of these two important cereals both in developing countries and the United States.

- ***Promoting demand-driven processes:*** INTSORMIL economic analyses are all driven by the need for stable markets for the LDC farmer and processor, so these analyses focus on prioritization of research, farm-level industry evaluation, development of sustainable food technology, processing and marketing systems. INTSORMIL seeks alternate food uses and new processing technologies to save labor and time required in preparation of sorghum millet for food and feed and add value to the grain and fodder of the two crops. Research products transferred to the farm, to the livestock industry and to processors and marketers of sorghum and millet are aimed at spurring rural and urban economic growth and providing direct economic benefits to producers and consumers. INTSORMIL assesses consumption shifts and socioeconomic policies to reduce effects of price collapses, and does research to improve processing to yield products of sorghum and millet which are attractive and useful to the consumer. Research by INTSORMIL agricultural economists and food scientists seeks to reduce effects of price collapse in high yield years, and to create new income opportunities through diversification of markets for sorghum and pearl millet. INTSORMIL socioeconomic projects measure impact and diffusion and evaluate constraints to rapid distribution and adoption of introduced, new technologies.

- The INTSORMIL program addresses the continuing need for development of technologies for agricultural production, processing and utilization of sorghum and pearl millet for both the developing world, especially in the semiarid tropics, and the United States. There is international recognition by the world donor community that national agricultural research systems (NARS) in developing countries must assume ownership of their development problems and move toward achieving resolution of them. The INTSORMIL program is a proven model that empowers the NARS to develop the capacity to assume the ownership of their development strategies, while at the same time resulting in significant benefits to the U.S. agricultural sector. These aspects of INTSORMIL present a win-win situation for international agricultural development, strengthening developing countries' abilities to solve their problems in the agricultural sector while providing benefits to the United States.

Administration and Management

The University of Nebraska, Lincoln (UNL) hosts the Management Entity (ME) for the Sorghum/Millet CRSP and is the primary grantee of USAID. UNL subgrants are made to the participating U.S. universities for the research projects between U.S. scientists and their collaborating country counterparts. A portion of the project funds, managed by the ME and U.S. participating institutions, supports regional research activities. The Board of Directors (BOD) of the CRSP serves as the top management/policy body for the CRSP. The Technical Committee (TC), External Evaluation Panel (EEP) and USAID personnel advise and guide the ME and the Board in areas of policy, technical aspects, collaborating country coordination, budget management, and review.

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

The members of the 2002 - 2003 Technical Committee are:

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

Members of the External Evaluation Panel approved by USAID are:

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Education

Within INTSORMIL's regions of collaborative research and the United States, education of collaborating scientists contributes to the capability of each collaborating country research program to stay abreast of economic and ecological changes which alter the balance of sustainable production systems. The strengthening of collaborating country research institutions contributes to their capability to predict and be prepared to meet the challenges of economic and ecological changes which affect production and utilization of sorghum and millet. A well balanced agricultural research institution must prioritize and blend its operational efforts to conserve and efficiently utilize its natural resources while meeting 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 24 Education (July 1, 2002 - June 30, 2003)

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

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

Another important category of education which INTSORMIL supports is non-degree research activities, namely post-doctoral research and research of visiting scientists with INTSORMIL PIs in the United States. During Year 24, 2 female scientists and 15 male scientists improved their education as either post-doctoral scientists (5) or visiting scientists (12). Their research activities were in the disciplines of plant breeding, economics, food science, pathology and *Striga* research. These scientists came to the United States as post-doctoral scientists or visiting scientists from Botswana, Burkina Faso, Ethiopia, Indonesia, Italy, Mexico, Nicaragua, Niger, Senegal, South Africa, Zambia, Zimbabwe, and the United States.

Networking

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

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

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

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

Over the years, established networking activities have been maintained with ICRISAT in India, Mali, Niger, Central America and Zimbabwe; SAFGRAD, WCASRN/ROCARS, WCAMRN/ROCAFREMI, ASARECA, ECARSAM and SMIP/SMINET in Africa; CLAIS and CIAT of Central and South America and SICNA and the U.S. National Grain Sorghum Producers Association for the purpose of coordinating research activities to avoid duplication of effort and to promote the most effective expenditures of research dollars. There also has been efficient collaboration with each of these programs in co-sponsoring workshops and conferences, and for coordination of research and long-term training. INTSORMIL currently cooperates with ICRISAT programs in East Africa, West Africa and with SMIP/SMINET in Southern Africa. Unfortuneately, during INTSORMIL's 2002 - 2003 year, the West and Central African Sorghum and Millet Networks were terminated due to the withdrawal of funding and plans were in place to terminate funding of the Sorghum and Millet Improvement Program in the SADC countries later in 2003. Sudanese collaborators have provided leadership to the Pan African *Striga* Control Network. INTSORMIL collaboration with WCAMRN/ROCAFREMI in West Africa had much potential in allowing INTSORMIL utilization scientists to collaborate regionally. ROCAFREMI was a good mechanism for promoting millet processing at a higher level than has been seen before in West Africa. During the last four years, INTSORMIL, the Bean/Cowpea CRSP and World Vision International have been working with

NARS researchers and farmers in five countries under the West Africa Natural Resource Management Project, creating and using a technology-transfer network in West Africa. That project was terminated in 2003. INTSORMIL will continue to promote free exchange of germplasm, technical information, improved technology, and research techniques.

Regional Activities and Benefits

West Africa (Burkina Faso, Ghana, Mali, Niger, Nigeria, Senegal)

The activities in the Western Region of West Africa proceeded well in 2002 in spite of low and erratic rainfall over much of the area. A positive was the second full year of INTSORMIL collaborative activities in Ghana and Senegal with activity in breeding, pathology, entomology, agronomy, and *Striga*. The strong Mali research program in IER continues to show leadership in the region by enhancing germplasm exchange, scientist to scientist cooperation, and collaborative research activities among scientists in several West African countries.

One concern that remains regards the best way to organize, and coordinate research activities among the various countries in West Africa. Adding the countries of Ghana, Senegal, Burkina Faso, and Nigeria strengthens the research effort across the region, but the limited funding for these new countries is still a problem. Also, the time and funding required for U.S. PIs to travel to more countries in West Africa is a concern. Also, the reduced number of PIs with active collaboration and travel in the area has been a problem. The addition of new projects and PIs is positive and should help in the future. Positive moves in that area include Dr. John Leslie's travel and efforts on behalf of pathology, however pathology needs assistance beyond grain toxin studies. The recent addition of Dr. Jeff Wilson as a new PI will contribute to the millet breeding and millet pathology area. Dr. Clint Magill may also become involved in collaborative research in the region. Dr. Bonnie Pendleton has already shown a strong effort in strengthening collaboration in entomology. Dr. Mitch Tuinstra has an interest in the area and plans travel there. There is still somewhat of a deficiency in the food technology and sorghum agronomy area. The PI Conference in Nov. 2002 provided an excellent forum for scientific exchange and collaborative research development. However, time constraints and the expectations of ideas for the next grant extension did not allow for meaningful discussions in many areas.

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

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

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

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

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

On-going collaborative research has progressed in each of the countries, namely Ethiopia, Eritrea, Kenya and Uganda. Sorghum breeding efforts in Ethiopia have particularly gone well. Work on development and evaluation of experimental sorghum hybrids has resulted in identification of elite hybrids with potential for wide cultivation in the lowland areas of the country. Efforts on *Striga* control have focused on regional testing of an integrated package of technologies that included tied-ridging as a water conservation measure, nitrogen fertilization, and resistant sorghum cultivars. This activity is managed and implemented as a pilot project with supplemental funding from the Office of Foreign Disaster Assistance (OFDA) of USAID. In Eritrea, sorghum lines were evaluated at research locations in Goluj, Shambuka and Hagaz, and seed was multiplied at Goluj and Shambuko. All trials and seed multiplication in Eritrea were affected by drought, and most cultivars failed to produce grain. In Eritrea, the second largest crop is pearl millet, and in 2002, collaborative research was conducted on farmers' fields to evaluate crosses of land races with introduced lines for resistance to diseases, especially downy mildew. Exotic pearl millet varieties were also tested and compared to local landraces. The only collaborative research supported by INTSORMIL in Kenya was on testing of *Striga*-resistant sorghum, since two of the three collaborating scientists from Kenya are currently studying for PhD degrees in South Africa and the United States. In Uganda, research continues in sorghum pathology, and a new U.S. principal investigator has begun collaborative research with his Ugandan counterpart on sorghum agronomy.

Host country PIs in each country have taken keen interest in collaborating with US PIs where partnership has been developed. Because of expanded collaborative involvement in several countries, more US PIs are needed to provide collaborative linkages with host country scientists. New PIs joining INTSORMIL are expected to take advantage of the opportunities for collaboration in the HOA region, where host country scientists and programs continue to appreciate and welcome technical support provided by INTSORMIL.

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

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

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

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

Central America (El Salvador, Nicaragua)

Since 1999 the Central America program has increased activity in El Salvador and Nicaragua., INTSORMIL plans to initiate new activity in Honduras in the coming year. The research activities developed for 2000 - 2001 were successfully completed, and administrative procedures for reporting research results and financial expenditures were developed. A conference was held to report research results and plan collaborative research priorities for 2002 - 2006, and 11 of the research reports were published in the regional journal *La Calera.* Communication and coordination of the many groups involved in the program continue to be a challenge. Graduate education and short-term training of scientists in national programs are needed, and priority needs were determined in 2002 - 2003. A plan based on the needs of highest priority is currently being implemented. On the whole, given the short time in implementing the present collaborative model in Central America, the program is functioning well, due to the commitment of scientists in the region, and the regional, collaborative research program has resulted in selection of improved cultivars with increased yield and nitrogen use efficiency. Researchers participating in the INTSORMIL Central America Regional Program have also developed management strategies for fall armyworm and sorghum midge, identified priority disease problems, developed sorghum flour substitution technology, and implemented research on nitrogen rates and nitrogen use efficiency of sorghum germplasm adapted to the region. Improved germplasm, production practices and pest management methods are being moved to producers through validation and demonstration trials, collaboration with extension services and NGOs, and through workshops with producers.

Regional Benefits by Technical Thrust

Germplasm Enhancement and Conservation

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

In the first year of this project, progress toward meeting these objectives has been made. Project collaborators at multiple locations have been identified. These individuals have contributed cultivars and experimental germplasm for evaluating genotype x environment interactions in grain yield, quality, and disease and pest resistance. Collaborators have reached consensus on project objectives, methods and timetable to achieve these objectives. A replicated set of selected pearl millet germplasm was distributed among collaborators. Multi-location experiments have been established in Ghana, Mali, Niger, Nigeria, and Senegal. The germplasm is being assessed for characteristics that contribute directly or indirectly to stability of grain yield and quality.

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

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

PRF 207 addresses major biotic and abiotic constraints (drought, cold, grain mold, and other diseases) that limit productivity of sorghum in many areas of the world. Over the years significant progress has been made in some of these areas. Superior raw germplasm have been identified, mode of inheritance established, chemical and morphological traits that contribute to productivity as well as to tolerance to these stresses have been identified. Selected gene sources have been placed in improved germplasm background, some of which have already been widely distributed in a number of African countries.

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

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

A good portion of the PI's time is devoted to evaluating, identifying, and deciding which germplasm lines and parental lines to release and how to release or distribute various materials. A larger number of potential releases were evaluated for potential release next year, as the P.I. tries to close out some major portions of his project prior to retirement.

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

Progress was made in all research areas in INTSORMIL's project TAM 223 aimed at enhancing sorghum germplasm for resistance to insects and improving efficiency for sustainable agricultural systems. Germplasm was obtained and evaluated for resistance to economically important insect pests. Selections were made to combine insect resistance with other favorable plant traits. Germplasm was identified for advanced testing with resistance to selected insects and diseases that will contribute to production of high grain yield and widely adapted hybrids. A study to apply the results of previous molecular mapping studies on greenbug resistance and stay-green to compare the effectiveness of molecular versus conventional selection was completed. Collaboration with LDC scientists resulted in progress to develop improved, high-yielding varieties or hybrids. Progeny were identified that combine several favorable traits into a single genotype. As research continues to generate new technology the importance of testing on-farm and soliciting producer input on research activities will increase.

During the life of this project significant research progress has been achieved. Technology (seed containing improved germplasm) developed by this project has been adopted by private industry and used in hybrid production or breeding programs. Collaboration with research programs in Nicaragua, El Salvador, and Southern Africa (South Africa, Botswana, and Zambia) has significantly increased TAM 223 activity. Impact assessment studies show a high rate of return on investment from research conducted by this project.

Sustainable Production Systems

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

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

Besides the new marketing activity, economists in PRF 205 continue to do impact analysis. Graduate students in PRF 205, as in other INTSORMIL projects, develop their skills as researchers by actually doing research under the guidance of their major professor, an INTSORMIL principal investigator. In the summer of 2003, graduate student Nega Wubeneh and Dr. Sanders, the principal investigator of PRF 205, went into the field in Tigray to continue the evaluation of the new *Striga*-resistant sorghum cultivars and associated technologies introduced there. Graduate student Rafael Uaiene spent the winter of 2003 interviewing farmers in central Mozambique. He is evaluating the role of marketing strategy in the introduction of new technologies for maize and sorghum as well as the importance of both in increasing farmers' incomes. Mr.Yigezu will begin his M.S. research in the fall of 2003 analyzing the introduction of N'Tenimissa and associated technologies including the importance of marketing improvements.

With other funding from USAID/Africa the principal investigator of PRF 205 and his graduate students have been studying the potential impact of biotechnology focusing, our attention on the costs to West Africa of not introducing Bt cotton. Another project has been an analysis of the effects of technology and policy on farm income and technology introduction in cacao production in Cameroon and Ghana. Both projects broaden our scope and give us ideas for our INTSORMIL research.

INTSORMIL's project UNL 213 which focuses on cropping systems to optimize yield, water and nutrient use efficiency of pearl millet has been extremely productive in graduate education of West African collaborating scientists, agronomic research which has led to publication in scientific journals, the publication of extension bulletins, the transfer of improved practices to pearl millet producers, and strengthening the activities of the West and Central Africa Pearl Millet Research Network. In the United States, the project has identified through research and documented the potential for pearl millet as a new grain crop in the Great Plains, and developed production practice recommendations for planting date, row spacing, and nitrogen fertilizer application. Research activities expanded from West Africa to Central America in 2001.

The major managerial issue facing project UNL 213 is balancing INTSORMIL efforts with other responsibilities in National Research Systems and in U.S. universities. Although electronic communication has improved the situation, communication remains problematic both in planning and reporting research activities. There is continuing difficulty in identification of potential graduate students from West African and Central American countries largely due to the need for English language skills. Funding of graduate student studies is becoming increasing difficult with flat budgets along with increased costs (especially overhead and stipend), and due to fewer supplemental funding opportunities from other sources. Although effective programs have been established, the future is somewhat uncertain due to the weak institutional strength of national programs. The collapse of the West and Central Africa Pearl Millet and Grain Sorghum Research Networks has reduced opportunity for meeting to share research results and plan research activities. Nebraska research on pearl millet is severely constrained by the lack of a pearl millet breeding program in the Great Plains, and the lack of private sector investment in developing pearl millet as an alternate grain crop.

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

Sustainable Plant Protection Systems

Identifying the correct causal agent(s) for grain mold requires that at the least the major species being recovered be correctly identified, thus formal taxonomic descriptions of these new species needs to continue. In the project which concentrates on agroecology and biotechnology of stalk rot pathogens of sorghum and millet (KSU 210), molecular diagnostic tools are being developed for these species, but validating them requires a sufficient sample to determine their validity. Studies of mycotoxin production under field conditions are needed, and the mycotoxigenic profiles of newly described species continue to need to be developed. The identification of a compound that can be misidentified as zearalenone when "quick and dirty" techniques are used should relieve some concerns about mycotoxins in sorghum and ease trade barriers. As before, species identification appears to be critical in estimating the risks posed by mycotoxins, and many of the *Fusarium* species common on sorghum do not make high levels of many of the common mycotoxins (but are toxic). The Scientific Writing and *Fusarium* Laboratory workshops have become successful, visible outreach efforts that will continue. Scientific writing workshops are offered opportunistically while the PI travels. *Fusarium* Laboratory Workshops are held in odd-numbered years at KSU in Manhattan, and in even-numbered years at a location outside the United States. The 2002 workshop was held in Sydney, Australia; the 2004 workshop is scheduled for Pretoria, South Africa; the 2006 location has not been set, but either Europe or Southeast Asia is the most likely at the moment.

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

Work with the fusarium collections is progressing. Visiting scientist Dr. Giuseppe Mulé, from Italy did collaborative research in the laboratory of the PI of KSU 210. Her focus had been on the strains from finger millet in Uganda, which are proving to be both diverse and puzzling. Work with the Tanzanian strain set has progressed to the point that the analysis of the identified species is essentially complete, and has led to the identification of a series of strains that represent a number of previously undescribed and uncharacterized species. The toxicology work needs a collaborator who can test the effects of toxins in commercial animal feeds, and who can model their effects in laboratory systems by using human and animal cell lines as models. Scientific Writing and *Fusarium* Laboratory workshops serve as interdisciplinary venues for scientists in developed and developing countries that work on various crops to exchange information and to interact with one another in an informal setting. Iowa State Press is interested in publishing books to go with each of these courses. A contract has been signed by Brett Summerell and the PI of KSU 210 to prepare a manual to accompany the Fusarium Laboratory Workshop.

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

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

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

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

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

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

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

The project, PRF-213, supports research and training of scientists combatting a widespread parasitic weed in Africa which can severely decrease yields of sorghum and millet. Witchweeds (*Striga* spp.) are obligate parasitic weeds of significant economic importance. Control methods available to date have been costly and beyond the means of farmers in developing countries. While combining several control measures may be necessary for eradication of *Striga*, crop losses to *Striga* can be effectively minimized through host-plant resistance. Our goal is to exploit the unique life cycle and parasitic traits of *Striga*, especially the chemical signals required for germination, differentiation, and establishment.

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

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

Utilization and Marketing

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

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

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

Of great importance to developing demand-driven value chains is food with value-added characteristics and nutritional benefits for a range of nutritional needs. The INTSORMIL project dealing with food and nutritional quality of sorghum and millet (TAM 226) complements research being done in PRF 212. The importance of grain supply chain management is being recognized as a vital part of crop improvement programs and utilization of grains. Investigators in INTSORMIL project TAM 226 have tried to publicize the need for this approach to provide for sustainable utilization of sorghum and millets in food products. New markets for value-enhanced white food sorghums are being promoted by the US Grains Council from our research on food sorghum processing and prototype products. In Japan, value-enhanced white food sorghums are processed into several commercial snack foods. Sorghum flour was demonstrated effective in nearly 20 traditional Japanese foods by Japanese chefs and food processors.

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

The antioxidant level in certain bran fractions of special sorghums is higher than that of blueberries. These brans and their extracts are useful as food ingredients in a number of applications. Extrusion processing of sorghum reduced the tannins into smaller polymers with improved health promoting effects.

Several parental sorghum lines released from our program are used in commercial hybrids grown in Mexico and the United States. ATx635 hybrids have outstanding milling properties. The protein content of food sorghums is higher than that of other commercial sorghums. A method was developed to effectively evaluate milling properties of sorghums when light colored meals were desirable. Antifungal proteins(AFP) are related to grain mold resistance in sorghum. However, the measurement of AFP levels must be accomplished when the sorghums are exposed to molding conditions. Thus, it may be easier for breeders to evaluate mold resistance by subjective methods. The AFP levels remain high in resistant cultivars that are exposed to high levels of mold infection.

Biotechnology

Biotechnology encompasses a number of concepts and techniques based on recent knowledge of genetics, biochemistry, computer science. INTSORMIL scientists employ techniques of biotechnology, such as marker-assisted selection to accelerate plant breeding and laboratory assays to accelerate selection of *Striga*-resistant germplasm. INTSORMIL scientists see biotechnology as a means, not an end. INTSORMIL's ends to which the tools of biotechnology may be applied are summarized in its four main objectives, namely 1) promote economic growth, 2) improve nutrition, 3) increase yield, and 4) improve institutional capability to do research on sorghum and millet.

Future Directions

During the past 24 years, INTSORMIL has educated over 1000 scientists by degree programs, visiting scientist experiences, post-doctoral training, workshops, conferences, and scientific publications. About one-third of those trained are Americans and two-thirds are from developing countries. The bridges built by this training are crucial to maintain scientific and peaceful linkages between the United States and developing countries. The collaborative research supported by INTSORMIL continues to produce benefits for both developing countries and the United States. Food production, utilization and marketing in both developing countries and the United States are strengthened by INTSORMIL. The health benefits of the two nutritious cereals, sorghum and millet, are enjoyed by millions of people. Five hundred million people directly consume sorghum, 300 million people directly consume pearl millet, and sorghum is a key element in the food chain of the United States, being a key feed for livestock. What, then is the future for collaborative, international sorghum and millet research supported by INTSORMIL? The future is bright.

There continues to be a need for highly qualified researchers for these two crops both in developing countries and the United States. INTSORMIL fulfills a unique role in providing postgraduate training (M.S. and Ph.D. level) to meet this need. As the demand for water in cities continues to put greater pressure on the use of water for irrigated crop production, sorghum and millet, which are for the most part rainfed, will gain increased importance in meeting the caloric needs of developing countries, particularly in the semi-arid tropics, and of the livestock feed industry in the United States. Recent INTSORMIL research on the nutritional benefits of sorghum and millet form a strong base for future research to enable the commercialization of nutritionally superior sorghum Based on its achievements, the INTSORMIL team is well positioned to contribute even more effectively to ending hunger and raising incomes. With its increasing strength of scientific expertise in developing countries, INTSORMIL is now able to more effectively reduce constraints to production and utilization of sorghum and millet to the mutual benefit of developing countries and the United States. Advances in sorghum and millet research over INTSORMIL's first 24 years and the training of sorghum and millet scientists by INTSORMIL in the United States, Africa and Central America now enable scientist from developing countries and the United States to jointly plan and execute mutually beneficial collaborative research. These collaborative relationships are keys to INTSORMIL*s success and will continue as fundamental approaches to meeting the INTSORMIL mission. In the future, INTSORMIL will target NARS collaborative ties that reflect regional needs for sorghum and/or millet production. These ties are in the sorghum and millet agroecological zones of western, eastern, and southern Africa, and Central America. By concentrating collaboration in selected sites, INTSORMIL optimizes its resources, builds a finite scientific capability on sorghum and millet, and creates technological and human capital that have a sustainable and global impact.

Future strategies of INTSORMIL will maintain INTSORMIL's current, highly productive momentum, build on its record of success, and accomplish a new set of goals. INTSORMIL's global strategy for 2001 - 2006 is intended to contribute to the shift of sorghum and pearl millet from subsistence crops to value-added, cash crops, and proposes to produce scientific knowledge and technologies to: contribute to economic growth, improve nutrition, increase yield, and improve institutional capability to meet global, regional and national needs.

Sustainable Plant Protection Systems

Agroecology and Biotechnology of Stalk Rot Pathogens of Sorghum and Millet

Project KSU 210
John F. Leslie
Kansas State University

Principal Investigator

John F. Leslie, Department of Plant Pathology, Kansas State University, Manhattan, Kansas 66506-5502

Collaborating Scientists

Dr. Mamourou Diourté, IER, Bamako, Mali
Dr. Elhamy El-Assiuty, Plant Pathology Research Institute, Agricultural Research Center, Giza, Egypt
Dr. J. Peter Esele, Sererre Agricultural and Animal Production Research Institute, NARO, Soroti, Uganda
Dr. Walter F. O. Marasas, PROMEC, South African Medical Research Council, Tygerberg, South Africa
Drs. L. E. Claflin, L. A. Heaton & D. J. Jardine, Dept of Plant Pathology, Kansas State University, Manhattan, Kansas 66506
Dr. J. S. Smith, Department of Animal Sciences & Industry, Kansas State University, Manhattan, Kansas 66506
Dr. R. L. Bowden, USDA-ARS Plant Science & Entomology Research Unit, Manhattan, Kansas 66506
Dr. M. B. Dickman, Department of Plant Pathology, University of Nebraska, Lincoln, Nebraska 68583

Summary

Zearalenone is an important mycotoxin produced by some *Fusarium* species, but these species are not commonly associated with either sorghum or millet as they are most common under cool, wet conditions. Yet reports of zearalenone can be relatively common, even though species known to produce the toxin cannot be recovered from the associated grain sample. With my collaborators we examined a number of the traditional and newly described *Fusarium* species from sorghum and millet in Africa. When analyzed by thin layer chromatography, a spot that comigrates with zearalenone often can be identified. This compound also has a multi-peak UV spectrum similar to that of zearalenone, but the two compounds can be distinguished with reversed-phase HPLC. Based on mass spectral and NMR analyses, this compound was identified as 8-O-methyl-bostrycoidin (8-OMB), a previously identified *Fusarium* secondary metabolite of unknown, but presumably minor, mycotoxicity. Use of the correct chemical technology to identify this compound in sorghum and millet grain should permit freer trade of sorghum and millet grain and should increase the perception of sorghum and millet as wholesome foods that are relatively free of mycotoxin contaminants.

One approach to disease control is by breeding for disease resistance, but biological control is a desirable, sustainable alternative or supplement to the breeding process. Many fungi harbor dsRNA molecules, which can confer phenotypes such as hypovirulence or altered colony morphology and pigmentation. In some species of *Fusarium*, dsRNA molecules are found in every strain examined. We examined 100 *F. proliferatum* (the most widespread of the *Fusarium* species infecting sorghum) isolates, but found only four that carried dsRNAs. None of these strains had a visibly unusual phenotype. None of these dsRNAs were transmitted through sexual crosses in which the dsRNA-containing strain served as the male parent. Each isolate harbored a distinct set of dsRNAs, which ranged in size from approximately 700 bp to approximately 3,100 bp. Multiple bands were observed in three strains, and these sets of dsRNAs were transmitted as sets at a high frequency (e" 97%) to vegetatively produced microconidia. These dsRNAs are probably localized in the mitochondria, as they co-purified with mitochondria and were protected against ribonuclease A digestion in mitochondrial preparations. The fourth strain had only a single dsRNA band that was only rarely (d" 3%) transmitted to the microconidia. These data suggest that dsRNAs are unlikely to be useful as biological controls for *Fusarium* infestations of sorghum and millet.

Objectives, Production and Utilization Constraints

- Determine the presence of viable fungi and related mycotoxins in sorghum and millet grain.

- Use genetic and molecular traits to assessing genetic variability in populations of Fusarium and Colletotrichum from Mali, Tanzania, India, Uganda, South Africa, and the United States.
- 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.
- Conduct Scientific Writing and Fusarium Identification training workshops.
- Edit Proceedings of 2000 Global Sorghum and Millet Pathology Conference.

Constraints

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. Grain errantly identified as containing zearalenone can be prevented from entering international trade channels.

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 often is limited because resistant germplasm is either unavailable or has undesirable characters from which the resistance trait must be separated. Biological control is an alternative to or supplement for resistance breeding. A common form of biological control in fungi is to use double strand RNA (dsRNA) molecules that can infect strains and behave as viruses to reduce the pathogenicity of the fungal population. In successful instances, e.g. the control of Chestnut blight caused by *Cryphonectria parasitica* in Europe, the control is sustainable in that it results in a permanent change in the fungal population and is stably maintained by dsRNA replication and transmission with the fungus on a year-in year-out basis.

Research Approach and Project Output

Research Methods

Strains and culturing techniques. We examined 100 strains of *F. proliferatum* from both symptomatic and asymptomatic plants collected across the United States for the presence of dsRNA molecules. We evaluated strains of *F. acutatum*, *F. andiyazi*, *F. begoniae*, *F. brevicatenulatum*, *F. bulbicola*, *F. circinatum*, *F. concentricum*, *F. denticulatum*, *F. guttiforme*, *F. konzum*, *F. lactis*, *F. nisikadoi*, *F. phyllophilum*, *F. pseudoanthophilum*, *F. pseudocircinatum*, *F. pseudonygamai*, and *F. ramigenum* for the ability to produce zearalenone and its analog.

Strains were preserved as spore suspensions in 15% glycerol and frozen at -70°C. Vegetative cultures were grown on minimal medium (7) solidified with 2% agar in slants or petri dishes, or as liquid cultures in 125 ml Erlenmeyer flasks. Incubations on solid media were at 25Ú C under a 12 h light-12 h darkness diurnal cycle. Nucleic acids were extracted from young, rapidly growing liquid cultures. Vegetative growth measurements were made in race tubes containing either minimal or complete medium. Sexual crosses were made on carrot agar with standard tester strains from the Fungal Genetics Stock Center (University of Kansas Medical School, Kansas City, Kansas) serving as the female parents. Cultures for toxin production were grown on cracked corn.

TLC, HPLC, GC/MS, and NMR. Compounds were extracted from cracked corn cultures with acetonitrile: water (75:25) and filtered to clarify. TLC (Thin Layer Chromatography) plates were developed with chloroform: methanol (98:2), and spots identified following irradiation with UV (ultraviolet) light or treatment with concentrated H_2SO_4. Zearalenone coeluting bands were scratched off the plates into acetonitrile: water (60:40), filtered to clarify, and the filtrate concentrated with a rotary evaporator. The compound was detected by HPLC (High Performance Liquid Chromatography) at a wavelength of 235 nm, and the eluate fraction(s) of interest were pooled and reconcentrated several times by rotary evaporation before being used for structural determination analyses. Structural analyses were made with IR (Infrared spectrometry), GC/MS (Gas Chromatography/Mass Spectrometry), NMR (Nuclear Magnetic Resonance), and ESIMS (Electrospray Ionization Mass Spectrometry) using the HPLC purified compound.

Toxicity assays. Toxicity of the zearalenone analog was evaluated in brine shrimp bioassays and in the commercially available Microtox assay. The Microtox assay measures reductions in bacterial bioluminescence as evidence of toxicity, and returns EC_{50} values, i.e. the concentration of the compound that reduces bioluminescence by 50%. Brine shrimp are cultured for 24 hours in 24-well microtier dishes containing one of 13 levels of the test compound (between 0.5 and 300 ìg/ml). Dead shrimp are counted microscopically, and then the living shrimp are killed by the addition of acetone, and the total number of shrimp in each well is counted.

Mitochondria and nucleic acid isolation. Mycelia were ground to a powder in liquid nitrogen in a mortar with buffer and â-mercaptoethanol and extracted with phenol-chloroform-isoamyl alcohol. Nucleic acids were precipitated with sodium acetate and ethanol, pelleted by centrifugation, and resuspended in sterile distilled water. Single-stranded nucleic acids were precipitated by the addition of ½ volume of 7 M LiCl, incubated on ice for 6 h, pelleted by centrifugation and discarded. Double-stranded nucleic acids were precipitated from the supernatant with ethanol at -20ÚC, pelleted by centrifugation, and resuspended in sterile distilled water. The dsDNA in each sample was digested with RNase-free DNase. The remaining dsRNAs were separated on 1.0% agarose gels and stained with ethidium bromide. The sizes of dsRNAs were estimated by comparison with dsDNA molecular weight markers.

Mitochondria and mitochondrial nucleic acids were isolated from mycelia ground to a powder in liquid nitrogen with buffer. Mycelial debris and nuclei were removed in two slow speed centrifugations (1,000 × *g* for 10 min), and the mitochondria collected in two somewhat faster centrifugations (3,000 × *g* for 10 min), and pellets from these centrifugation steps pooled. Mitochondrial nucleic acids were extracted, purified, and evaluated as described above for total cellular nucleic acids. To determine if dsRNAs were located inside the mitochondria, ribonuclease A was added to pelleted mitochondria before they were disrupted. After incubation for one hour on ice, the reaction was stopped with the addition of Superase-In ribonuclease inhibitor and the incubation continued for another 10 minutes before the nucleic acids were extracted, purified and evaluated as described above.

Research Findings

Zearalenone analog. Seven of the strains tested produced a compound with identical migration to zearalenone on the TLC plates. In all cases this compound eluted two minutes before zearalenone on a C_{18}-HPLC column. The analog also has an absorption peak at 500 nm that is not found for zearalenone. There was no evidence for zearalenone production by any of these cultures.

The zearalenone analog was found to have an elemental composition of $C_{16}H_{13}O_5N$ and a molecular weight of 299. It contained aromatic C–H, aliphatic C–H, C=O, CH_2, C–OH, and C=CH_2 based on IR analyses, and the presence of these components was confirmed in the NMR, GC/MS, and ESIMS analyses. Based on these analyses, the zearalenone analog was identified as 8-OMB (Fig. 1). 8-OMB was first isolated from *Fusarium verticillioides* by Prof. Marasas's group in South Africa in 1979, as part of a search for the cause of equine leukoencephalomalacia; a search that culminated in the discovery of the fumonisin class of mycotoxins some 10 years later. This group did not do any TLC analyses, however, and thus failed to detect the similarity between 8-OMB and zearalenone under these simple analytical conditions. Strains of both *F. andiyazi*, which is common on sorghum, and *F. pseudonygamai*, which is common on millet, produced detectable levels of this compound. Thus, reports of zearalenone in sorghum and millet grain based on TLC analyses are likely to be false positives in which 8-OMB was present instead. For surety, reports of zearalenone in both sorghum and millet should be accompanied by a mycological analysis in which strains from at least one of the *Fusarium* species that are known to produce zearalenone was recovered.

8-OMB was moderately toxic to brine shrimp, with a LD_{50} of 38 ìg/ml. In the Microtox system, the EC_{50} of this com pound was 59 ìg/ml and the EC_{20} 21 ìg/ml, again indicating moderate toxicity. 8-OMB was more toxic in the Microtox system than either zearalenone (13 ìg/ml) or some other common mycotoxins, e.g. patulin (7 ìg/ml), ochratoxin A (18 ìg/ml), penicillic acid (15 ìg/ml), and aflatoxin B_1 (23 ìg/ml). Toxicity of 8-OMB to vertebrates and other higher animals is unknown, but may be worthy of further study.

DsRNAs for biological control. Four of the 100 *F. proliferatum* isolates, D-591, D-599, D-720, and D-890, contained double-stranded nucleic acids that were susceptible to ribonuclease and resistant deoxyribonuclease establishing that these low molecular weight, double-stranded elements were dsRNA (Fig. 2). Isolate D-591 contained at least four dsRNAs (approximately 3,100, 3,000, 2,700, and 700 bp), isolate D-

A

B

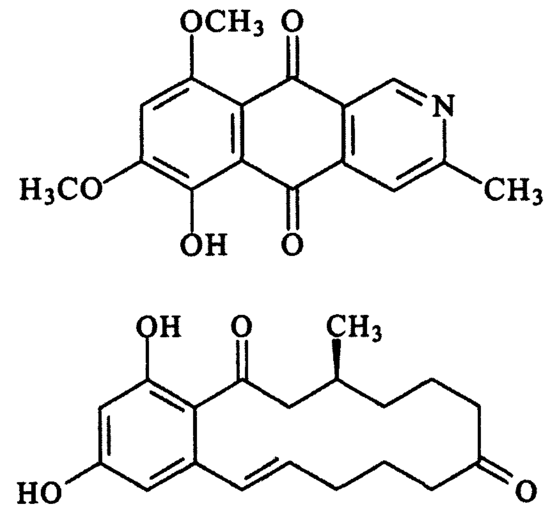

Figure 1. Chemical structures of 8-O-methyl-bostrycoidin (8-OMB) (A) and zearalenone (B)

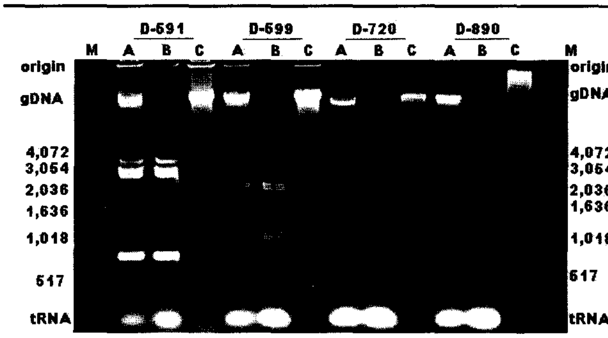

Figure 2. Nuclease digestions of total nucleic acids extracted from *F. proliferatum* strains. Strain numbers are indicated above the gel, "A" lanes are untreated total nucleic acids, "B" lanes are DNase-digested nucleic acids, and "C" lanes are RNase-digested nucleic acids. Positions of the gel origin, fungal genomic DNA (gDNA), transfer RNA (tRNA), and base-pair lengths of dsDNA molecular weight standards ("M" lanes) are indicated at the sides of the gel.

599 contained at least eight (approximately 2,400, 2,100, 2,050, 1,500, 1,050, 1,000, 800, and 700 bp), and isolate D-720 contained at least seven (approximately 2,200, 2,000, 1,900, 1,200, 1,100, 1,000, and 950 bp). Isolate D-890 contained at least one dsRNA of approximately 2,200 bp. Isogenic lines were made for D-599, D-720 and D-890 that lacked the dsRNA(s) by chance through asexual segregation during condial spore production. The phenotypes and growth rates of the dsRNA-containing strains and the dsRNA-free strains derived from them were not significantly different on either complete or minimal medium, as determined by “race-tube” assays.

Mitochondria were prepared from an isolate that lacked dsRNAs, D-599-11 (the final two digits indicate a single-conidiospore culture of the original parent). An aliquot of the preparation was “spiked” with dsRNAs extracted from isolate D-591-25 and treated with ribonuclease A to demonstrate that ri bonuclease A was active enough to degrade dsRNAs outside the mitochondria (Fig. 3A). Mitochondria from isolates D-591, D-599, and D-720 contained dsRNAs that were not digested by ribonuclease A (Fig. 3), while the mitochondria from isolate D-890 did not contain dsRNA. Thus, the multiple subunit dsRNAs all are located in the mitochondria, and the presumptive single subunit dsRNA from strain D-890 has a cytoplasmic origin. These dsRNA-carrying *F. proliferatum* strains join strains of *Ophiostoma novo-ulmi*, *Rhizoctonia solani*, and *Cryphonectria parasitica* as representatives of the only four fungi known to carry mitochondrial viruses. Depending on the functionality of the dsRNAs in *F. proliferatum*, it is possible that these dsRNAs belong to a previously undescribed virus genus. This determination, however, requires the subcloning and sequencing of all of the dsRNAs from each of these strains.

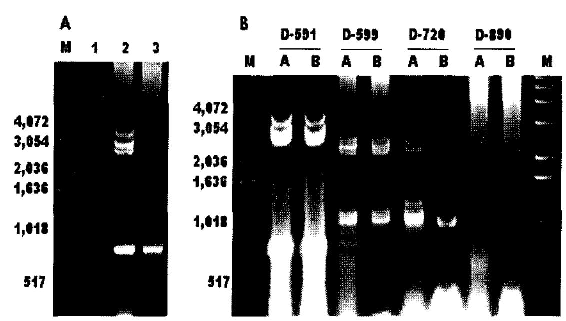

Figure 3. RNase protection of dsRNAs in mitochondria. A. Lane 1, mitochondrial nucleic acids from D-720-29; lane 2, mitochondrial nucleic acids from D-720-29 "spiked" with dsRNAs from D-591; lane 3, mitochondrial nucleic acids from D-720-29 "spiked" with dsRNAs from D-591 and treated with RNase A. Base-pair lengths of dsDNA molecular weight standards (lane "M") are indicated to the side of the gel. B. Strain numbers are indicated above the gel, "A" lanes are dsRNAs from untreated aliquots of mitochondria, and "B" lanes are dsRNAs from RNase A-treated aliquots of mitochondria. Base-pair lengths of dsDNA molecular weight standards (lanes "M") are indicated to the side of the gel.

Sixty single-conidiospore cultures of each of the four isolates were analyzed for vegetative transmission of the dsRNAs. All of the single-spore cultures of isolate D-591 contained all of the dsRNAs, although the dsRNA elements of several of the cultures had different relative staining intensities in ethidium-stained agarose gels. Only 3% (2/60) of the single-spore cultures of isolates D-599 and D-720 lacked dsRNAs, while 97% (58/60) of the single-spore cultures of isolate D-890 lacked dsRNA.

In sexual crosses, the dsRNA-containing isolates were female-sterile, preventing a direct test of the expected cytoplasmic heritability of the dsRNA molecules. Female sterility could not be directly attributed to the dsRNA molecules, however, since vegetative derivatives of dsRNA-containing cultures that contained no detectable dsRNAs also were female sterile. None of the dsRNAs were transmitted through crosses in which a dsRNA strain served as the male parent. Thus, there is no evidence to suggest that these dsRNA molecules can be successfully transmitted through the sexual cycle. How the mycovirus in D-890 is maintained under field conditions is unclear as it appears to be transmitted very poorly through vegetative reproduction, and not at all through sexual reproduction.

Mycoviruses of pathogenic fungi are of interest because some of them alter the virulence of their host, and may be useful as biological control agents. The most intensively studied case of hypovirulence is induced by *Cryphonectria hypovirus 1* (CHV1) in *C. parasitica*, the causal agent of chestnut blight. Several of the dsRNAs in *O. novo-ulmi*, the causal agent of Dutch Elm Disease, decrease virulence, and like the dsRNAs reported here, are mitochondrial. Mycovirus-infected strains of *Fusarium graminearum* with decreased virulence on wheat also are known, and may be useful as a biological control. The mycoviruses from *F. proliferatum* are unlikely to be useful as biological control agents since they do not obviously affect the phenotype of strains carrying them, although this possibility has not yet been strictly disproven. Freshly recovered isolates might be more likely to harbor dsRNAs than isolates in my collection because we routinely select for cultures that grow stably and robustly, which could eliminate many of the virus-carrying isolates.

Networking Activities

Editorial and Committee Service (2002)

- Editor of *Applied and Environmental Microbiology*
- Member of the International Society for Plant Pathology, *Fusarium* Committee

Research Investigator Exchanges

Dr. Leslie made the following international scientific exchange visits (2002)

- Malaysia – January 19-25
- Australia – January 26 – August 20
- Egypt – July 3 – August 3
- South Africa – September 22 – October 11
- Ethiopia – November 9-23
- Kenya – November 24-25

Seminar, Workshop & Invited Meeting Presentations (2002)

- Participated in *Fusarium* Laboratory Workshop in Sydney, Australia from June 23-28; 41 participants and five instructors from nine countries
- Editor for Proceedings of Sorghum/Millet pathology conference in Guanjuato, Mexico
- California Academy of Sciences, San Francisco, California – 1/02.
- Department of Biological Sciences, Stanford University, Stanford, California – 1/02.
- AustralAsian Plant Pathology Society, Mudgee, Australia – 2/02.
- CSIRO Publishing, Melbourne, Australia – 3/02.
- Department of Botany, Melbourne University, Melbourne, Australia – 3/02.
- Waite Institute, University of Adelaide, Adelaide, Australia – 3/02.
- Department of Biology, Flinders University, Adelaide, Australia – 3/02.
- Faculty of Agriculture, University of Sydney, Sydney, Australia – 3/02.
- St. Paul's College, University of Sydney, Sydney, Australia – 3/02.
- Royal Botanic Gardens – Sydney, Sydney, Australia – 5/02.
- CSIRO Plant Sciences – Canberra, Australia – 5/02.
- CRC for Tropical Plant Protection, University of Queensland, Brisbane, Australia – 5/02.
- Queensland Department of Primary Industries, Indooroopilly, Australia – 5/02.
- ATUT Final Project Review Seminar, Alexandria, Egypt – 07/02.
- FABI, University of Pretoria, Pretoria, South Africa – 10/02.
- PROMEC, Medical Research Council, Tygerberg, South Africa – 10/02.

During 2002 Fusarium cultures were provided to:

- Dr. Ranajit Bandyopadhyay, IITA, Ibadan, Nigeria
- Drs. Robert L. Bowden, Larry E. Claflin, Louis A. Heaton & Douglas J. Jardine, Department of Plant Pathology, Kansas State University, Manhattan, Kansas.
- 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. D. Geiser, Department of Plant Pathology, Pennsylvania State University, University Park, Pennsylvania.
- Prof. Dr. Laszlo Hornok, Agricultural Biotechnology Center, Institute for Plant Sciences, Godollo, Hungary.
- Prof. Dr. Yin-Won Lee, Department of Plant Pathology, Seoul National University, Su-Won, South Korea.
- Dr. Antonio Logrieco, Istituto Tossine e Micotossine da Parassiti Vegetali, Bari, Italy.
- Prof. Dr. W. F. O. Marasas, PROMEC, South African Medical Research Council, Tygerberg, South Africa.
- Dr. J. Scott Smith, Department of Animal Sciences & Industry, Kansas State University, Manhattan, Kansas.
- Dr. Brett Summerell, Royal Botanic Gardens-Sydney, Sydney, Australia.
- Dr. Bettina Tudzynski, Westfaelische Wilhelms University, Muenster, Germany.
- Drs. Mike Wingfield & Brenda Wingfield, Forestry & Agricultural Biotechnology Institute, University of Pretoria, Pretoria, South Africa.

Other collaborating scientists (Host country)

- Dr. Ranajit Bandyopadhyay, IITA, Ibadan, Nigeria
- Dr. Sofia Chulze, Department of Microbiology, National University of Rio Cuarto, Rio Cuarto, Argentina.
- Drs. M. Flieger & S. Pazoutova, Institute of Microbiology, Czech Academy of Sciences, Prague, Czech Republic
- Dr. Laszlo Hornok, Agricultural Biotechnology Center, Godollo, Hungary
- Dr. Sandra Lamprecht, Department of Plant Pathology, Stellenbosch University, Stellenbosch, South Africa
- Dr. Yin-Won Lee, Department of Plant Pathology, Seoul National University, Su-Won, South Korea
- Drs. Antonio Logrieco, Antonio Moretti & Giuseppe Mulé, Institute of the Science of Food Production, CNR, Bari, Italy
- Dr. Anaclet S. B. Mansuetus, Department of Biological Sciences, University of Swaziland, Kwaluseni, Swaziland
- Dr. Neal McLaren, Agricultural Research Council, Potchefstroom, South Africa

- Dr. Maya Piñeiro, Mycotoxins Unit, Laboratorio Tecnologia del Uruguay, Montevideo, Uruguay
- Prof. Baharuddin Salleh, School of Biological Sciences, Universiti Sains Malaysia, Penang, Malaysia
- Dr. Brett A. Summerell, Royal Botanic Gardens, Sydney, Australia
- Drs. Michael and Brenda Wingfield, FABI, University of Pretoria, Pretoria, South Africa

Other collaborating scientists (U.S.)

- Drs. A. E. Desjardins & R. D. Plattner, USDA National Center for Agricultural Utilization Research, Peoria, Illinois
- Dr. G. N. Odvody, Texas Agricultural Experiment Station, Corpus Christi, Texas

Publications and Presentations (2002)

Journal Articles, Books & Book Chapters

Fotso, J., J. F. Leslie & J. S. Smith. 2002. Production of beauvericin, moniliformin, fusaproliferin, and fumonisins B_1, B_2 and B_3 by ex-type strains of fifteen *Fusarium* species. *Applied and Environmental Microbiology* **68:** 5195-5197.

Jurgenson, J. E., R. L. Bowden, K. A. Zeller, J. F. Leslie, N. J. Alexander & R. D. Plattner. 2002. A genetic map of *Gibberella zeae* (*Fusarium graminearum*). *Genetics* **160:** 1452-1460.

Jurgenson, J. E., K. A. Zeller & J. F. Leslie. 2002. An expanded genetic map of *Gibberella moniliformis* (*Fusarium verticillioides*). *Applied and Environmental Microbiology* **68:** 1972-1979.

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Leslie, J. F. & W. F. O. Marasas. 2002. Will the real *Fusarium moniliforme* please stand up! In: *Sorghum and Millets Diseases* (J. F. Leslie, ed.), pp. 201-209. Iowa State Press, Ames, Iowa.

Porter, J. K., C. W. Bacon, W. P. Norred, E. M. Wray, G. A. Kuldau, A. E. Glenn, & J. F. Leslie. 2002. Mycotoxins from fungal-infected sorghum: *Claviceps* vs. *Fusarium* and the *Striga* connection. In: *Sorghum and Millets Pathology 2000* (J. F. Leslie, ed.), pp. 229-235. Iowa State Press, Ames, Iowa.

Book Review

Leslie, J. F. *Molecular Fungal Genetics*; eds. R. P. Oliver & M. Schweizer; Cambridge University Press, New York, 377 pp. Reviewed in *Quarterly Review of Biology* **77**(2002): 69-70.

Agroecology and Biotechnology of Fungal Pathogens of Sorghum and Millet

Project KSU 211
Larry E. Claflin
Kansas State University

Principal Investigator

Dr. Larry E. Claflin, Department of Plant Pathology, Kansas State University, Manhattan, KS 66506

Collaborating Scientists

Dr. Jeff Dahlberg, USGSPA, Lubbock, TX 79408
Ing. Reina F. de Serrano and Carlos Borja, CENTA, Apartado Postal 885, San Andres, La Libertad, El Salvador
Dr. John Leslie, Department of Plant Pathology, Kansas State University, Manhattan, KS 66506
Dr. Stephen Mason, Department of Agronomy, University of Nebraska, Lincoln, NE 68583-0915
Mr. Henry Nzioki, National Dryland Farming Research Center-Katumani, P. O. Box 340, Machakos, Kenya
Ing. Sergio Pichardo, UNA, Apartado Postal 453, Managua, Nicaragua
Dr. Henry Pitre, Mississippi State University, Mississippi State, MS 39762
M.C. Jesus Narro Sanchez, INIFAP, Apdo. Postal 112., C.P. 38010, Celaya, Guanajuato, Mexico.
Dr. Mitch Tuinstra, Department of Agronomy, Kansas State University, Manhattan, KS 66506

Summary

Eight different species of *Fusarium* were evaluated for pathogenicity in an effort to develop a screening protocol for stalk rot variability in sorghum. A strain of *F. thapsinum* (mating population F) from sorghum was the most virulent isolate tested in the experiments. *F. thapsinum* yielded higher disease scores on all three sorghum genotypes; while an isolate of mating population A (*F. verticillioides*) from corn was the least aggressive. Isolates of *F. thapsinum* are recommended for evaluating sorghum germplasm. Statistical analysis showed that scoring genotypes 14 days post inoculation with an inoculum dose of 10^3 conidia ml^{-1} or higher would differentiate differences in stalk rot resistance among genotypes. The optimum assay was a suspension of 10^4 to 10^6 conidia ml^{-1} with an incubation period of 28 days or longer. Disintegration of *C. africana* spores by freezing in liquid nitrogen followed by thawing provided the best template for PCR amplification of conidia DNA. BTX 378, 96GCPOB143 and LG 35 were very susceptible to anthracnose and lines R9113, 88 PR 1057, 90 EON 343, and 91 BE 7414 exhibited tolerance. Ergot was detected in BTX 623 at Managua and B-35 and SC 326-6 in San Blas, Nicaragua. Fungicides applied 55, 75, and 95 days after planting significantly reduced the incidence of zonate leaf spot in sorghum in El Salvador.

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 was established with MSU-205.

- U.S./Mexico/Nicaragua/El Salvador: Ascertain disease incidence through surveys coupled with utilization of the ADIN nursery from Texas A & M University at various locations. Genetic variability of accessions within the ADIN will be determined if disease severity occurs.

- U.S./Nicaragua: Determine the number of races/pathotypes of *Colletotrichum graminicola*: (*C. sublineolum* and *C. falcatum*) that occur in Nicaragua with DNA fingerprint ing techniques. This is a portion of the Ph.D. thesis project of Sergio Pichardo at Mississippi State University.

- U.S./El Salvador: Continue to evaluate germplasm for genetic variability to rust and evaluate fungicides for control of various sorghum diseases..

- U.S./Central America/Africa: Develop a rapid and reliable protocol to detect *Claviceps africana* (causal agent of ergot) spores and hyphal propagules in sorghum seed and feed grains.

- U.S./Africa: Continue to evaluate germplasm and screening protocols for ascertaining genetic germplasm tolerant/ resistant to *Fusarium* stalkrot.

Constraints

Grain sorghum received limited attention in Central America in previous years as corn was the crop favored by commercial and subsistant growers. A 10-fold increase in less than 10 years in the poultry industry has provided an impetus for sorghum production. Sorghum diseases were poorly characterized and the incidence and severity were unknown. Surveys were conducted and the use of genotypes in the ADIN has shed valuable information on sorghum diseases in El Salvador and Nicaragua. Interestingly, the major diseases, anthracnose and gray leaf spot are of the highest incidence with one or the other predominating in a particular year. For example, anthracnose was predominant in 2002 and gray leaf spot in 2001.

Anthracnose is a significant constraint to yields of grain sorghum in numerous LDC's. The disease may be partially controlled by chemicals but they are either unavailable or the cost may be prohibitive for farmers. Incorporation of resistant or tolerant germplasm into acceptable cultivars would partially alleviate losses due to anthracnose. The correct species identification of the causal agent of anthracnose remains in flux.

Fusarium stalk rot is one of the most prevalent diseases of sorghum wherever the crop is grown. The causal organism is found in living plant tissues, crop debris, and soils in different geographical regions. At least 12 different *Fusarium* species have been reported as pathogens of sorghum although, for nearly 100 years, *F. moniliforme* was widely reported as the specific epithet. *F. moniliforme* consists of numerous species, strains, and isolates that are important pathogens on a wide range of economically important plants. Recently, this fungal complex was classified into eight mating populations and a large number of asexual phylogenetic species. Reducing losses due to stalk rot have been through breeding efforts to develop resistant cultivars. The complex nature of the disease coupled with the environment and lack of reliable inoculation protocols that mimic natural infection have limited the potential for screening large numbers of genotypes. Previously, *Fusarium* sp. infested toothpicks were inserted in the basal stalk to evaluated limited numbers of genotypes.

A need exists for a rapid and reliable diagnostic procedure to detect *Claviceps africana* in sorghum seeds and feed grains due to strict and rigid quarantine regulations of numerous countries. A PCR-fingerprint of this fungus was evaluated for use in detecting spores and hyphal fragments in sorghum seeds.

Research Approach and Project Output

Research Approach

Single isolates from four mating populations of *G. fujikuroi* (A, D, F, G) and four recently described species within the *G. fujikuroi* complex were evaluated for virulence against three sorghum genotypes with variable disease reactions. The causal agents included *F. verticillioides, F. proliferatum, F. thapsinum, F. nygamai, F. andiyazi, F. pseudoanthophilum, F. brevicatenulatum,* and *F. pseudonygamai*. The sorghum genotypes included SC599, BRedlan, and SU629 which are resistant, susceptible, and highly susceptible to *Fusarium* stalk rot, respectively (unpublished data). The experiments were conducted under greenhouse conditions since five of the *Fusarium* spp. have not been reported in the U.S. Seeds were treated with Captan and then planted into 1- liter pots filled with potting mix. Pots were arranged in a randomized complete block with four replications. Plants were thinned to a single plant per pot seven days after emergence and were watered and fertilized as needed. Entries were grown at 27° C with natural lighting supplemented with overhead high-pressure sodium lamps. In 2001, irrigation water was withheld for 1 week after flowering to induce leaf rolling and mild drought stress. In 2002, plants received water as needed throughout the duration of the study.

Each *Fusarium* sp. was grown (23 to 25° C) in 500 ml Erlenmeyer flasks containing potato dextrose broth and then placed on a rotary shaker (60 rpm). Conidia were separated from the mycelial mass by straining the culture suspension through four layers of cheesecloth. Conidial concentrations were ascertained with a hemacytometer. Inocula suspensions were adjusted to 5×10^4 conidia ml^{-1} with 10 mM (pH 7.2) phosphate buffered saline (PBS). *Fusarium proliferatum* (strain KSLM) was used to determine the optimum inoculum concentration and period of time after inoculation to evaluate germplasm. KSLM is an isolate from a *Fusarium* stalk rot infected sorghum plant in Kansas.

Fourteen days after anthesis, an Idico filler-plug gun equipped with a stainless steel modified needle was used to deliver one ml of inoculum of each isolate into the basal portion of the stalk of individual plants. Twenty-eight days after inoculation, plants were harvested, split lengthwise, and rated for disease incidence and severity by measuring the internal length of necrotic lesions and counting the number of nodes crossed by the lesion.

In 2000, two sorghum hybrids SA3042 x SC35 (susceptible) and Redlan x SC599 (resistant) were tested against inocula concentrations of 0, 10^3, 10^4, 10^5 and 10^6 conidia ml^{-1} and 14, 21, 28, 35 and 42 days PI. In 2001, the number of test genotypes were diversified and increased from two to ten hybrids.

At flowering, 25 plants from each whole plot unit were tagged with different colored tape. Fourteen days after flowering, the tagged plants (five plants for each inoculum dose in each whole plot unit) were inoculated in the basal stalk using an Idico filler-plug gun equipped with a modified syringe and needle that was calibrated to deliver 1.2 ml of inoculum. Fourteen days after inoculation, one plant for each of the inoculum dose levels was harvested in each whole plot unit and scored for disease severity. Plants were harvested every seven days until 42 days after inoculation. Disease severity was scored by splitting stalks lengthwise and measuring lesion lengths (cm) and counting the number of nodes crossed by *F. proliferatum*.

Ergot conidia obtained from naturally infected sorghum was mixed with healthy sorghum seeds at a concentration of 10^5 spores/ml. DNA from ergot spores was obtained by the following treatments with the spore suspension:

Sonicated for one minute;
Placed in a microwave until the suspension boiled;
Centrifuged at 14,000 rpm for 5 minutes, water was discarded and the pellet resuspended in 4N NaOH overnight at room temperature. HCl was added to lysate and adjusted to pH 7; DNA precipitated with 2 vol EtOH and centrifuged at 14,000 rpm for 10 min and supernatant discarded. Pellet was air dried and dissolved in water.

Approximately 100 Fl of spores suspension was frozen in liquid nitrogen and then immediately thawed. One Fl of conidial suspension was placed on a glass slide, covered with a plastic cover slip and crushed by applying pressure on the slip. Slide and cover slip were washed with 100Fl of water and then placed in a 1.5ml tube. One hundred Fl of a 2X lysis buffer (20mM Tris HCl, pH 7.3, 1.5 mM $McCl_2$, 50 mM KCl, 0.01% proteinase K, 0.01% SDS) was added. The sample was incubated at 37 C for 1 hr, 95 C for 10 min and then cooled to 40 C. DNA was precipitated by adding 2 vol of EtOH and centrifuging. The sample was air dried and dissolved in water.

The above procedures were also used with one and two-day-old germinated spores.

Four Fl of intact ergot spores in a suspension and each of the above treaments were used as templates for PCR amplification utilizing PCR Master mix (Promega) and PCR temperature profiles adjusted for each specific pair of primers. PCR products were separated in 2% agarose gels with EtBr and visualized with UV light and photographed.

Primers used included: ITS5, 10R, OPA 01, CGA RAM and a pair that was designed in the laboratory for the trihydrophobine sequence which has GN-rich areas that may vary in length for different ergot geographical areas. A pair of primers designated CPMK2 and obtained from another ergot fungus, *Claviceps purpurea* (causal agent of ryegrass ergot), was also used.

ADIN: The All Disease and Insect Nursery (ADIN) accessions (courtesy of D.T. Rosenow, TAM, Lubbock, TX) were planted at San Blas and Managua, Nicaragua and Izalco and San Andres in El Salvador. The ADIN in El Salvador were utilized in a control study with fungicides (Cycosin and Elosal) applied at 35, 55, 75 and 95 days after planting. The target diseases included zonate leaf spot, anthracnose, rust and northern leaf blight.

Research Output

Prokaryotes: Considerable effort has been devoted in Nicaragua and El Salvador to detect prokaryotic plant pathogens that are disseminated by insects. This is a joint effort with MSU-205. The association of prokaryotes with insects is common in the tropics with other crops and is assumed to also occur in sorghum. Rainfall has been inconsistent in Nicaragua and prolonged droughty conditions have occurred for the past two years. The insect-pathogen relationship is normally found when climatic conditions are favorable for producing lush plants.

Ergot: Disintegration of *C. africana* spores by freezing in liquid nitrogen followed by thawing provided the best template for PCR amplification of conidia DNA. Primers tested showed different patterns of amplification which depended on method of DNA isolation and age of conidia (dormant, days after germination). Research continues on selecting primers, optimum spore morphology and use of hyphae as DNA templates.

***Fusarium*:** The average pathogenicity scores were highest for the *F. thapsinum* isolate followed by isolates from *F. pseudonygamai* and *F. andiyazi* while the *F. verticillioides* isolate was generally the least virulent. Variations in disease scores among pathogens ranged from 6.53 cm to 10.08 cm in lesion length and 1.61 to 2.24 nodes crossed by the disease lesion. Comparisons of means revealed that the *F. thapsinum* isolate produced significantly longer lesions than isolates of *F. verticillioides* and *F. nygamai*. Mean disease scores for the pathogen species were generally consistent between the two experiments and few interactions were detected.

Mean lesion length of *F. proliferatum* inocula concentrations for the year 2000 ranged from 6.31 (control) to 18.15 cm (10^6 conidia ml^{-1}) and days PI from 7.22 cm (14 days) to 17.31 cm (42 days). Similarly in 2001, mean lesion length ranged from 5.13 cm (control) to 20.46 cm (10^6 conidia ml^{-1}) for inocula concentrations, and from 8.01 cm (14 days) to 16.52 cm (42 days) for days PI. A similar trend was observed for the number of nodes crossed (data not shown). Mean number of nodes crossed in 2000 ranged from 0.61 (control) to 3.21 after inoculated with the highest inoculum concentration and from 1.11 (14 days PI) to 3.03 after 42 days PI.

Similarly, in 2001, the number of nodes crossed ranged from 0.41 (control) to 3.42 (10^6 conidia ml^{-1}) for inocula concentrations and from 1.00 to 2.79 for days PI. The two-way interaction effects were generally not significant except for genotype by inocula concentrations and genotype by days PI for lesion length in 2001 although these interactions failed to change rankings. The increase of disease severity with increasing inocula levels was comparatively lower among entries that involved resistance sources (SC1154, SC1039, and SC134) resulting in significant genotype by inocula interactions. Genotype x concentration x incubation interaction effect was not significant except for lesion length in 2000. In general, interaction effects were much lower than the main effect of the factors.

The mean square for the highest inoculum dose and 42 days PI was relatively lower than the preceding levels in the first year of the experiment. Lesion length mean square for inoculum dose ranged from 400 (control) to 2381 (10^5 conidia ml^{-1}) in 2000, and from 192 (control) to 1359 (10^6 conidia ml^{-1}) in 2001. Similarly, mean square for days PI ranged from 1286 (14 days PI) to 1778 (28 days PI) in 2000, and from 284 (14 days PI) to 905 (35 days PI) in 2001.

Significant differences in mean disease score were detected among genotypes for both scoring methods. Inoculum concentration and days PI significantly ($P \leq 0.01$) affected the severity of Fusarium stalk rot in both testing seasons. Inoculum concentration effects were more significant than days PI. Disease severity generally increased with higher inocula levels and days PI.

Significant differences in disease severity were detected among the genotypes tested. SC599 was the most resistant variety and SU629 and BRedlan were the most susceptible in each experiment. The lesion lengths for SC599 averaged only 3.37 cm compared to 11.61 cm for SU629. A significant genotype by experiment interaction was detected for the two disease severity traits; however, the pattern of disease reactions among genotypes in each experiment was similar. Remarkably, the genotype by pathogen interaction was not significant indicating that the genotypes responded similarly to infection by each pathogen isolate.

ADIN Nicaragua: The all disease and insect nursery was planted at two locations in Nicaragua, Managua (Table 1) and San Blas. The San Blas location was extremely dry and the incidence and severity of sorghum diseases were extremely low (data not shown). Anthracnose was the major disease found in Managua. The lines BTX 378, 96GCPOB143 and LG 35 were very susceptible to anthracnose and the lines R9113, 88 PR 1057, 90 EON 343, and 91 BE 7414 exhibited less than 10% severity (Table 1). Ergot was detected in BTX 623 at Managua and B-35 and SC 326-6 in San Blas. Downy mildew was detected by Ing. René Clará at Esteli, Nicaragua which is about 150 km North of Managua. The incidence and severity remain unknown, however, UNA and INTA personnel will monitor the situation closely.

Table 1. ADIN results from UNA/INTA, Managua, Nicaragua (2002)[a]

Accession	Anthracnose (% severity)
B-35	20
SC 326-6	22.5
SC 414-12E	20
SC 630-11E(II)	20
R 9188	42.5
86 EO 366	17.5
90 EON 328	15
90 EON 343	5
91 BE 7414	5
87 BH 8606-6	10
88 BE 2668	17.5
94 CW 5045	17.5
96 CA 5986	17.5
96 CD 635	27.5
96 CD 677	17.5
99 BD 3726/98CD187	17.5
99 CA 2244	40
99 CA 2519	40
99 CA 1422	17.5
99 PR 1159/B LD6	20
LG 70	10
LG 35	55
B8 PR 1011	17.5
B8 PR 1059	37.5
B8 PR 1051	17.5
98 BRON 125	40
B8 PR 1013	35
B8 PR 1057	8
TX 2880	17.5
GR 108-90M24	17.5
95 BRON 155	35
95 BRON 151	22.5
96 GCP OB 124	17.5
96 GCP OB 143	60
96 GCP OB 157	20
96 GCP OB 160	20
96 GCP OB 172	15
MB 108 B	17.5
97 BRON 179	17.5
98 BRON 122	20
88 B 928	20
R 9113	5
97 BRON 304	9
B 9104	27.5
B 9107	30
87 EO 109	25
B 9601	40
88 B 943	25
94 B 1055	25
B 9105	27.5
R 9603	27.5
B 9307	30
R 9120	35
91 B 2978	42.5
TX 2911	42.5
R 9618	32.5
R 9519	22.5
Malisor 84-7	35
SRN 39	32.5
Sureño	32.5
TX 2783	25
TX 2767	5
TX 2783	37.5
BTX 635	25
BTX 623	40
BTX 631	45
TAM 428	35
TX 430	40
TX 7078	40
BTX 378	67.5

[a]Results recorded by Ings. Sergio Pichardo and Yanet Guttierrez.

El Salvador: Fungicides proved effective in reducing incidence of zonate leaf spot (*Gloeocercospora sorghi*) at Izalco and San Andres. Control was significant at 55, 75, and 95 days after planting but not significant when fungicides were applied 35 days after planting. In addition, significant differences were noted in reducing incidence of anthracnose, northern leaf blight and rust when fungicides were applied 95 days after planting.

Networking Activities

Workshops

Yanet Gutierrez, Sergio Pichardo and Jesus Narro visited Kansas State University in June, 2003 to attend the Fusarium shortcourse and discuss forthcoming collaborative research plans.

Research Investigator Exchanges

Yanet Gutierrez from UNA, Managua, Nicaragua worked in the lab of Dr. L. E. Claflin on a training session from July 29 - August 13, 2002.

Dr. L. E. Claflin surveyed sorghum fields and discussed mutual research in El Salvador and Nicaragua in December, 2002.

Research Information Exchange

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. In addition, speciality equipment and supplies were purchased with funds from KSU 211 and distributed to the laboratories.

KSU 211 provided the necessary funds for the following collaborators to attend the Fusarium shortcourse at Kansas State in June, 2003:

Yanet Gutierrez (Nicaragua)
Sergio Pichardo (Nicaragua)
Jesus Narro (Mexico)

KSU 211 provided funds to Sergio Pichardo for travel to Starksville, M.S. to initiate a Ph.D. program at Mississippi State University.

Forty copies of each ICRISAT compendia entitled, "Manual Para la Identificacion de las Plagas Insectiles del Sorgo, and Manual Para la Identificacion de las Enfermedades del Sorgo y Mijo" were purchased and sent to El Salvador and Nicaragua for distribution.

Publications and Presentations

Reed, J. D., M. R. Tuinstra, N. W. McLaren, K. D. Kofoid, N. W. Ochanda, and L. E. Claflin. 2002. Analysis of combining ability for ergot resistance in grain sorghum. Crop Sci. 42:1818-1823.

Reed., J. D., B. A. Ramundo, L. E. Claflin, and M. R. Tuinstra. 2002. Analysis of resistance to ergot in sorghum and potential alternate hosts. Crop Sci. 42:1135-1138.

Claflin, L. E., and L. M. Giorda. 2002. Stalk Rots of Sorghum. Pages 185-190 in: Sorghum and Millets Diseases. J. F. Leslie, ed. Iowa State Press, Ames, Iowa, 516 pp.

Tuinstra, M. R., T. T. Teferra, L. E. Claflin, R. G. Henzell, A. Borrell, N. Seetharama, G. Ejeta, and D. T. Rosenow. 2002. Breeding for Resistance to Root and Stalk Rots in Sorghum. Pages 281-286 in: Sorghum and Millets Diseases. J. F. Leslie, ed. Iowa State Press, Ames, Iowa, 516 pp.

Presentations

Italy (9/10/02-9/20/02). Organized and presented a session on control at the 6th International Conference on Pseudomonas syringae Pathovars and Related Pathogens, Maratea, Italy and discussed bioterriorism programs with FAO scientists (Rome).

Nicaragua (12/1/02-12/4/02). Delivered supplies and evaluated ADIN nurseries for disease incidence and severity as part of the INTSORMIL program.

El Salvador (12/4/02-12/8/02). Delivered equipment, books, supplies, evaluated ADIN nurseries, and research plots under the auspices of INTSORMIL.

Miscellaneous Publications

Claflin, L. E. 2002. Agroecology and biotechnology of fungal pathogens of sorghum and millet. Pp. 11-17 in INTSORMIL Ann. Repts., A Technical Res. Rept. of the Grain Sorghum/Pearl Millet Collaborative Research Support Program (CRSP), University of Nebraska, Lincoln.

Enhancing the Utilization of Grain Sorghum and Pearl Millet through the Improvement of Grain Quality via Genetic and Nutrition Research

Project KSU 220

Mitchell Tuinstra and Joe Hancock, Kansas State University
William Rooney and Clint Magill, Texas A&M University

Principle Investigators

Dr. Mitch Tuinstra, Kansas State University, Department of Agronomy, Manhattan, KS 66506
Dr. Joe Hancock, Kansas State University, Department of Animal Sciences and Industry, Manhattan, KS 66506
Dr. William Rooney, Texas A&M University, Department of Soil & Crop Sciences, College Station, TX 77843
Dr. Clint Magill, Texas A&M University, Department of Plant Pathology & Molecular Biology, College Station, TX 77843

Collaborating Scientists

Dr. Carlos Campabadahl, Centro de Investigaciones en Nutricion Animal, Universidad de Costa Rica, San Jose, Costa Rica
Dr. Medson Chisi, Private Bag 7, Mt. Makulu Research Station, Chilanga, Zambia
Ing. René Clará, Centro Nacional de Technologia, Agricola de El Salvador, San Salvador, El Salvador
Dr. Salissou Issa, INRAN Rainfed Crops Program, INRAN, BP 429, Niamey, Niger
Dr. Issoufou Kapran, INRAN Rainfed Crops Program, INRAN, BP 429, Niamey, Niger
Dr. Chris Little, Department of Biology, UT-Pan American University, Edinburgh, TX 78541
Dr. Paul Marley, National Ag Research Project Office, IAR, Ahmadu Bello University, P.M.B. 1044, Samaru, Zaria, Nigeria
Dr. Paco Sereme, Director General, INERA, 01 B.P. 476, Ouagadougou, Burkina Faso
Dr. Aboubacar Touré, IER/Sotuba Research Station, BP 262, Bamako Mali
Dr. Eva Weltzien Rattunde, ICRISAT, P.B. 320 Bamako, Mali

Summary

Improve Nutrition

The emphasis of this project is to develop high yielding sorghum varieties and hybrids with enhanced nutritional and grain quality characteristics for use as human food and in animal feed. Recent nutritional studies have focused on comparisons of large-seeded hybrid sorghum genotypes with conventional hybrid sorghum and maize varieties for differences in feed value. Poultry feeding trials were conducted using broiler chicks to provide information on the metabolizable energy value of the various cereal grains. These analyses indicated that certain large-seeded hybrid sorghums were equivalent in feeding value to maize and were significantly better than conventional sorghum varieties. Breeding efforts have been initiated to transfer these enhanced feed quality characteristics into improved sorghum varieties.

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

Increase Yield

Natural tolerance to heat and drought permit sorghum to be grown in areas unsuited for production of other cereal crops. Past breeding efforts have significantly enhanced yield potential in semi-arid environments, but little attention has been focused on feed value and grain quality. Germplasm sources to improve the nutritional value of sorghum have been identified. The focus of this project is to deliver these traits to sorghum producers and end-users through the development of sorghum cultivars with enhance feed-value and grain-quality characteristics. Breeding efforts have been initiated to transfer these

enhanced feed quality characteristics into high-yielding sorghum varieties adapted for production in Africa, Central America, and the United States. This will be accomplished through conventional breeding strategies and by adapting marker-assisted selection technologies as appropriate.

Improve Institutional Capacity

A training program is being developed to transfer the technology and knowledge needed to effectively utilize improved sorghum and millet cultivars for animal feeding and human food. Technical assistance and technology transfer in Central America is being pursued through interactions with Dr. Carlos Campabadahl, one of the leading nutritionists in Central America. Dr. Hancock has lectured with Dr. Campabadahl at LANCE and RAPCO short courses for animal nutritions. These week-long short courses in animal feeding and nutrition include leaders in the animal feeding industry from Mexico, Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica, Panama, the Dominican Republic, Columbia, Venezuela, and Ecuador. Technology transfer efforts in West Africa were initiated by hosting Dr. Salissou Issa, Head of the Animal Husbandry Unit at the INRAN Rainfed Crops Program in Niger, on a tour of the animal research facilities at Kansas State University to plan training programs directed towards the needs of key poultry producers and feed millers in West Africa. These efforts will include demonstration experiments and workshops in Africa in cooperation with Dr. Salissou Issa.

Promote Economic Growth

The marketing and utilization of sorghum grain often has been limited by lower grain quality and feed value compared to other cereals. Given the complexity of these traits, plant breeders traditionally have placed little emphasis on end-use value of sorghum for human and animal consumption. Our research project attempts to address this weakness in sorghum and millet crop improvement through the integration of traditional plant breeding with biotechnology to develop elite hybrids and cultivars with improved nutritional and grain quality traits. Sorghum genotypes with enhanced feed-value and grain-quality characteristics have been identified and these genes are being incorporated into improved genetic backgrounds for deployment in regions of Africa, Central America, and the United States.

Objectives, Production and Utilization Constraints

Objectives

- Identify and map genes associated with improved grain and feed quality characteristics.
- Develop robust biotechnology tools for tagging genes that contribute to grain mold resistance and enhanced nutritional value.
- Develop techniques to rapidly quantify feed quality of sorghum and millet for poultry and to quantify food quality of sorghum.
- Develop high-yielding sorghum cultivars with improved feed quality and grain mold resistance using both conventional breeding techniques and marker-assisted selection technology.
- Provide technology transfer and technical assistance in promoting the use of improved sorghums and millet in poultry feeding in the developing regions of West Africa and Central America.

Constraints

New entrepreneurial opportunities for production of animal feeds and products in developing countries including meat and eggs are needed to move sorghum and millet from subsistence crops to value-added commodities. However, the marketing and utilization of sorghum grain often has been limited by lower grain quality and feed value than other cereals. Sorghum kernels are exposed to the environment as they mature and grain mold problems are common; however, even in the absence of contaminating fungi, sorghum grain typically has lower digestibility and metabolizable energy values as compared to other cereals.

Research efforts are needed to address food quality and feed efficiency traits in sorghum and millet. Components of feed quality are frequently defined in terms of animal performance or metabolizable energy value. These traits can be measured in animal feeding trials, but these experiments are costly and not amenable to high-throughput testing as required in a plant breeding program. This research project attempts to address this weakness in sorghum and millet through the integration of laboratory assays for feeding quality, traditional plant breeding, and biotechnology to develop elite hybrids and cultivars with improved nutritional and grain quality traits. The recognition of the true nutritional value of grain sorghum by animal producers will lead to greater health and productivity in regions of the world where hunger and poverty are major issues.

Genes for grain quality and host-plant resistance can be identified and tagged with DNA-based markers to facilitate crop improvement. Some good resistance sources have been identified but the inheritance of these traits is complex and screening under field conditions is environmentally dependent and often unreliable. Breeding projects to assemble these genes into improved cultivars should proceed rapidly with the aid of marker-assisted selection complemented by performance tests made in multiple environments.

Research Approach and Project Output

Research Methods

Collaborative research efforts in Africa and Central

America are supported through short and long-term training programs, germplasm exchange and evaluation, and complementary basic research support activities. These research efforts are conducted in three regional programs including West Africa, Southern Africa, and Central America. Current training activities include graduate student education, short-term information exchange, training visits to the United States for collaborating researchers, and workshop activities in animal production and nutrition. Several collaborating researchers from Niger, Zimbabwe, and Mozambique were hosted in research exchange and planning activities in 2002-2003.

Crop improvement efforts to develop cultivars adapted to environments in West Africa, Southern Africa and Central America utilize elite varieties and cultivars that are adapted to each of the regions. The lines used to create these populations are selected through evaluations of elite U.S. and host country germplasm in the target region. This material is evaluated in the target region in conference with collaborating plant breeders. Improvement efforts in Western and Southern Africa focus on the development of early-maturing, drought-tolerant cultivars and hybrids while efforts in Central America are on improved food-type and Macio Criollos cultivars. These efforts are focused on the development of photoperiod sensitive hybrids using Ma5 and Ma6.

The underlying objective for research to identify and map genes related to grain quality is to develop a better understand the genetic control of important quality traits and generate genetic markers that can be used by sorghum improvement programs in the near future. Combining these traits into one genotype is a significant challenge that could be facilitated by the use of molecular technology. The development of these technologies should enhance the efficiency of combining grain quality factors including feed quality characteristics and grain mold resistance into varieties with high yield potential. Mapping populations are being developed and characterized in cooperation with collaborators at domestic and international sites. These populations are being genotyped in laboratories in the U.S. using various types of genetic markers.

Technical assistance and technology transfer efforts in poultry production and nutrition are currently focused on workshop and short course activities. In 2003, Dr. Hancock contributed to the LANCE Short Course, a week-long short course in animal nutrition. The participants included 30 industry leaders in animal feeding/nutrition with representatives from Mexico, Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica, Panama, the Dominican Republic, Columbia, Venezuela, and Ecuador. Plans are being made to expand these technical assistance activities to key poultry producers and feed millers as in West Africa.

Research Findings

Analysis of Sorghum and Maize for Differences in Poultry Feed Quality

Raw sorghum germplasm sources that allow for improvement of seed size via increased grain-fill rate and duration have been publicly released and are currently being utilized to produce hybrids of increased seed size and yield potential. Recent genetic studies have indicated that normal-seeded hybrids generally produced lower crude protein, slightly lower crude fat, and higher starch values than that of the large-seeded hybrids; however, the impact that these differences in composition might have on metabolizable energy (ME) values in feed rations is not clear.

The objective of this study was to compare the feed quality of large-seeded grain sorghum hybrids with hybrids of normal seed size. The varieties evaluated in this study included eight sorghum hybrids produced from crosses between two commercial U.S. females and two large-seeded and two normal-seeded male parent lines. The female parent lines used in this study were ASA3042 and AWheatland. The male parents included two normal-seeded lines (Tx2737 and Tx435) and two large-seeded lines (KS115 and Eastin-1). These hybrid sorghums and a hybrid maize check were produced under dryland conditions at two locations in Kansas in 2000 and 2001. The resulting 36 grain samples were evaluated for crude fat, protein, fiber, moisture, nitrogen, ash, and gross energy content. Feeding assays using broiler chicks were conducted to provide information on the ME content of the various cereal grains.

A combined analysis of seed weight and composition across the four locations revealed significant differences among sorghum hybrids (Table 1). Hybrids produced from crosses with male lines Eastin-1 and KS115 had seed weights ranging from 2.69 to 4.14 grams per 100 seed and were significantly greater than hybrids produced from crosses with Tx435 and Tx2737 whose seed weights ranged from 2.25 to 2.53 grams. Hybrids produced using KS115 averaged 3.95 grams per 100 seeds and were significantly greater than the other hybrids. Maize hybrids averaged 28.35 grams per 100 seeds and were nearly 10 times larger than the sorghum hybrids.

Analysis of composition differences among the hybrid sorghum and maize varieties indicated that crude protein for the sorghum samples ranged from 12.1 to 14.1% (Table 1). The hybrid sorghums were generally greater in protein than hybrid maize with a few exceptions. The hybrid maize check had the greatest crude fat content and was significantly higher than most of the hybrid sorghums (Table 1). Hybrids produced from KS115 were the exception and did not significantly differ from maize for fat content. Notable differences or trends among grain samples were not apparent for fiber, ash, nitrogen free extract, or gross energy content.

Significant hybrid, environment, and hybrid by environment interaction effects were noted for ME in the combined analysis. The most significant factor influencing ME values was the hybrid effect. However, given hybrid by environment interactions, differences in ME were reported on an individual environment and combined average basis (Table 2). Individual hybrid ME values across the four environments ranged from 3.121 Mcal kg-1 for AWheatland x Tx435 up to 3.736 Mcal kg-1 for ASA3042 x KS115. In the combined analysis, the ASA3042 x KS115 hybrid had the greatest average ME content of 3.591 Mcal kg-1, followed by the hybrid check at 3.508 Mcal kg-1. The average ME content of the KS115 hybrids was higher than the other male hybrid groups with a ME value of 3.484 Mcal kg-1. The Tx2737 hybrids had an average ME content of 3.387 Mcal kg-1, followed closely by the Tx435 hybrids, which averaged 3.362 Mcal kg-1. The Eastin-1 hybrids had the lowest average ME value of 3.313 Mcal kg-1.

Comparisons of the hybrids used in this study indicated that KS115 hybrids produced grain with exceptionally large seed size and an increased level of fat content. These seed characteristics appear to be beneficial to sorghum-based poultry diets, resulting in increased animal performance that was comparable to that of maize. Results from this study indicate that the use of KS115 as a means of increasing seed size and yield potential in grain sorghum improvement programs may also contribute to enhanced feed quality.

Grain Mold Resistance

A critical component of the KSU220 project was the improvement of grain mold resistance using marker assisted selection (MAS). Previous work had detected five QTL influencing grain mold resistance from Sureño in the recombinant inbred line progeny from the cross of RTx430 x Sureño. From this work, experiments were initiated to determine the efficacy of MAS for grain mold resistance in sorghum.

Table 1. Combined analysis of seed weight, crude protein, and crude fat for hybrid sorghum and maize varieties produced at two Kansas locations in 2000 and 2001

Entries	Seed weight	Crude protein	Crude fat
	g 100seeds-1	*%*	*%*
ASA3042 x KS115	3.76	13.5	3.6
AWheatland x KS115	4.14	12.9	3.8
ASA3042 x Eastin-1	2.69	14.1	3.4
AWheatland x Eastin-1	2.93	13.3	3.5
ASA3042 x Tx435	2.39	13.2	3.4
AWheatland x Tx435	2.53	12.1	3.1
ASA3042 x Tx2737	2.25	12.7	3.4
AWheatland x TX2737	2.36	12.3	3.4
Hybrid maize	-	10.2	3.8
GRAND MEAN	2.88	12.7	3.5
LSD (0.05)	0.26	2.2	0.4

Table 2. Metabolizable energy (ME) contents for individual location and hybrid treatments

	Environment				
Entries	Ottawa ME	Manhattan ME	Belleville ME	Manhattan ME	Average ME
	Mcal kg-1				
ASA3042 x KS115	3.623	3.736	3.425	3.581	3.591
AWheatland x KS115	3.519	3.478	3.200	3.310	3.376
ASA3042 x Eastin-1	3.426	3.334	3.204	3.187	3.288
AWheatland x Eastin-1	3.416	3.367	3.340	3.227	3.337
ASA3042 x Tx435	3.146	3.615	3.398	3.277	3.359
AWheatland x Tx435	3.121	3.268	3.512	3.363	3.316
ASA3042 x Tx2737	3.450	3.586	3.463	3.318	3.454
AWheatland x TX2737	3.275	3.325	3.272	3.407	3.320
Hybrid maize	3.322	3.495	3.728	3.489	3.508
GRAND MEAN	3.366	3.467	3.393	3.351	3.394
LSD (0.05)	0.259	0.273	0.234	0.205	0.196

Five populations were developed to test the efficacy of MAS for grain mold resistance. In each population, Sureño was used as the grain mold resistant parent with one of five elite parental lines (Tx430, Tx436, Tx2903, Tx635, and Tx631). From each cross, F2 progeny were selected based on maturity and short plant height. A total of 1,000 F2:3 lines (approximately 200 lines per population) were evaluated for agronomic desirability and grain mold resistance in Weslaco, Beeville and College Station, Texas. From this evaluation, a total of 100 F3:4 lines were selected and advanced in a winter nursery. In the F_4 generation, DNA samples from each line were taken for QTL marker analysis.

In the summer of 2002, 87 $_{F4:5}$ lines were evaluated in six locations across Texas in randomized complete block with two replications per location. Parental lines and standard grain mold resistant lines were included as checks in all environments. The trials were located in Beaumont, Beeville, College Station (2), Corpus Christi (2), Victoria, and Weslaco. In College Station and Corpus Christi, two trials were planted in separate fields for a total of eight environments. In addition to agronomic traits, grain mold ratings were collected on each genotype in all locations.

Since five distinct populations were evaluated in this study, it was clear that there would be varying degrees of polymorphism between Sureño and the respective adapted parents. An array of molecular markers linked to the sorghum grain mold QTL were screened for polymorphism using DNA from the parental lines. Those markers that proved to be polymorphic between 'Sureño' and any of the adapted parents were subsequently amplified, visualized, and scored in the respective populations. Both SSR and AFLP markers were utilized in this studied, and the method of visualization depended upon both the particular marker system and the nature of the polymorphism itself. All AFLP markers were visualized using the LiCor gel system. SSR markers were either visualized via super fine resolution agarose gel or silver stained polyacrylamide.

Table 3. Grain mold rating means of homozygous classes within each linkage group associated with a grain mold resistance QTL from Sureño by Klein et al. (2001) using grain mold resistance ratings from eight environments in Texas in 2002

		QTL Marker				
Population	Allele Source	LG-D	LG-E	LG-F	LG-G	LG-I
		grain mold rating[†] *(0 to 9)*				
Tx430 x Sureño	Tx430	4.72 *	5.02 *	5.40 *	5.15 *	5.15 **
	Sureño	4.10	4.48	4.35	4.66	4.31
	LSD	0.05	0.05	0.05	0.05	0.01
Tx436 x Sureño	Tx436	4.44	4.68	4.61	4.57	-
	Sureño	4.59	4.56	4.64	4.66	-
	LSD	ns	ns	ns	ns	
Tx631 x Sureño	Tx631	4.80	4.80	4.48	4.77	4.55 *
	Sureño	4.87	4.64	4.62	4.71	4.83
	LSD	ns	ns	ns	ns	0.05
Tx635 x Sureño	Tx635	4.16	-	4.32	4.00 *	-
	Sureño	4.18	-	4.31	4.32	-
	LSD	ns	-	ns	0.05	-
Tx2903 x Sureño	Tx2903	5.08 *	5.52	5.20 *	5.21 *	5.07
	Sureño	5.22	4.91	4.76	4.91	5.13
	LSD	0.05	ns .	0.05	0.05	ns
Combined	Adapted	4.68	4.68	4.88 *	4.75	4.95
	Sureño	4.73	4.71	4.57	4.64	4.85
	LSD	ns	ns	0.05	ns	ns

[†] Grain mold rating, 1 = resistant to 9 = susceptible

To test the effectiveness of MAS, lines from each population were classified for QTL marker alleles at each of the five loci. Comparisons in level of grain mold resistance were then made between classes with Sureño or adapted parent allele for each locus (A, B, C, D, and E). Comparisons were made within populations and across the entire study. If MAS enhances grain mold resistance, then the group with the Sureño allele should have greater grain mold resistance than the group with the adapted parent allele.

Grain mold pressure varied widely among environments (Table 3), ranging from a mean of 2.937 in Beaumont (least grain mold pressure) to 7.345 in Beeville where the most disease pressure was encountered. When the mold scores within all environments were compared, it was found that the eight respective environments effectively formed four groups of environments, which had mean grain mold scores that were not statistically different. Since selection had been practiced for various phenotypic traits (for height and agronomic desirability) in earlier generations, the populations used in this study were not of a suitable structure for the construction of a linkage map. As would be expected, the five adapted parents varied to a large extent with respect to the proportion of the molecular markers that were polymorphic between them and Sureño. RTx430 showed the greatest amount of polymorphism, while BTx635 showed the least.

Comparisons of the marker allele classes across all populations indicated that only one of the five QTL enhanced selection for grain mold resistance (Table 3). The presence of the Sureño allele in LG-F enhanced mold resistance across all environments. The remaining three QTL showed no effect on mold incidence in the combined analysis. However, when the data were analyzed by specific population, MAS was clearly effective in the population derived from crosses with RTx430 (Table 3), but in the remaining four populations, the markers did not particularly enhance selection efficiency, producing significant improvements in only 5 of 17 contrasts (Table 3).

These results indicate that while MAS can be effective, there are limitations to the application of the technique. The utility of MAS was clearly valuable in the Tx430 population, which is not surprising since these QTL were mapped in this population. However, these QTL are clearly less valuable in the other populations evaluated in this study. Therefore, while selection efficiency maybe enhanced through MAS, its utility is limited to populations in which mapping is completed. A positive result from the current work is that the markers did appear to be applicable across environments. In fact certain QTL appeared to have stronger effects in specific types of environments. If the applicability across populations were solved, the use of specific QTLs based on the environment could prove particularly useful.

Other supporting grain mold resistance research activities have focused on an analysis of the role of defense response pathways in preventing grain mold of sorghum. Panicles of four cultivars were inoculated at anthesis with conidial suspensions of *F. thapsinum* and *C. lunata*, the fungi most often found in naturally molded grain. RNA was extracted from the immature floral tissues at various times following inoculation. Levels of mRNA for four known defense-response genes, phenylalanine ammonia lyase, chalcone synthase, b-1,3-glucanase and chitinase were examined by hybridization to PCR generated clones of the respective genes. Expression of each gene increased rapidly following inoculation with either fungus. Although differences were seen in response to the two pathogens, the general pattern was similar in Sureño (resistant), RTx2911 (highly resistant), SC170 (intermediate resistance), and RTx430 (very susceptible) to grain mold. The results imply that factors other than the timing of activation or level of expression of these particular defense response genes account for cultivar differences seen when the plants are challenged at the time of flowering.

Highly conserved sequences within cloned disease resistance genes from other species were also used to search for homologs in the sorghum EST database and to generate candidate resistance gene analogs (RGAs) via PCR. Thus far, 13 of the clones sequenced have features characteristic of resistance genes. Hybridization of these clones to two sorghum BAC libraries has identified 19 different BAC clones that include RGAs.

Evaluation of Tan Plant Hybrids

The improvement of grain quality remains an important goal of many sorghum breeding programs. The TPHT (Tan Plant Hybrid Test) and IFST (International Food Sorghum Test) are grown to test adaptation and productivity of new commercial and experimental tan plant hybrids with improved grain quality. The TPHT was grown in multiple locations in Texas and Kansas. The IFST was grown in locations in Africa, Latin America and Texas. The results of the IFST (Table 4) indicate that many food quality hybrids are competitive with traditional hybrids in the full season category, but further improvements are still needed to develop early- and mid-season food quality hybrids. (Results of the TPHT are not presented, but are available at http://sorghum.tamu.edu). These will be continued to further the development of this material into Central America and Southern Africa.

Networking Activities

Workshops and Meetings

INTSORMIL Principal Investigators Conference – November 17-20, 2003, Addis Abbaba, Ethiopia.

2003 Sorghum Industry Conference – February 16-18, 2003, Albuquerque, New Mexico.

Table 4. Combined analysis of performance characteristics of hybrids evaluated in the 2002 International Food Sorghum Adaptation Test at six locations in the U.S. and Central America

Hybrid	SD[†]	PL	GL	GM	DY	HT	EX	DS	LO	MS	TW	YD
ATX631*RTX437	W	T	b	4.0	70.8	47.6	3.8	3.3	1.0	13.3	55.8	6,257
ATX642*RTX430	R	P	-	4.8	70.3	43.8	5.5	4.1	1.0	13.4	55.2	6,085
A0PR59*5BRON154	R	T	t	1.3	78.5	47.6	3.7	3.6	1.0	13.6	58.9	5,832
ATX378*RTX430	R	P	-	3.6	68.8	48.8	4.8	4.9	1.8	13.0	54.9	5,797
A8PR1057*5BRON139	R	T	t	1.3	55.6	44.1	1.7	3.7	1.1	14.6	59.8	5,784
ATX631*RTX436	W	T	b	3.1	72.8	47.1	3.8	3.5	1.3	14.0	57.5	5,770
ATX2752*RTX430	R	P	-	4.0	69.5	44.1	3.4	4.3	1.3	14.2	54.7	5,729
ATX623*RTX430	W	P	-	4.0	70.1	50.9	4.5	5.0	1.6	12.2	54.7	5,722
AHF14*RTX436	W	T	st	4.0	72.0	44.0	3.4	3.2	1.0	13.6	54.0	5,623
AHF14*96GCPobs124	R	T	st	2.6	72.0	43.9	2.7	3.4	1.1	13.7	56.9	5,595
A9701*RTX437	R	T	t	3.0	68.5	45.0	4.0	4.4	1.0	13.7	53.3	5,590
ATX631*R9818	W	T	b	3.1	74.6	48.7	3.7	3.4	1.3	14.0	57.5	5,587
AHF14*96GCPobs172	R	T	t	2.8	71.8	41.8	2.9	3.4	1.1	14.9	60.1	5,484
AHF8*96GWO92	R	T	st	1.3	76.3	42.5	3.7	4.0	1.0	14.9	59.9	5,480
ATX631*R9317	W	T	t	3.6	73.9	46.7	3.5	3.4	1.5	14.1	58.7	5,455
ATX631*R9528	W	T	lb	3.3	73.6	48.1	3.7	2.9	1.4	14.0	57.4	5,447
ATX631*R9693	W	T	st	3.3	72.5	48.1	3.8	4.1	2.8	14.0	58.5	5,395
AHL8*R9317	W	T	st	4.5	72.8	41.8	4.7	3.0	1.3	13.9	43.2	5,263
A9614*RTX436	W	T	st	3.8	74.9	49.2	4.6	4.2	2.4	14.1	56.9	5,243
A8PR1057*Tx436	R	T	t	3.5	74.1	43.8	3.4	3.7	1.1	14.5	59.2	5,201
A9717*RTX2903	R	T	st	2.6	72.6	42.9	4.3	3.5	1.4	14.0	57.1	5,180
ATX631*R9759	W	T	t	2.6	71.8	51.6	3.7	4.6	3.5	13.9	55.4	5,116
ATXARG-1*R9818	W	T	t	3.3	73.8	43.7	3.6	3.6	1.1	13.6	39.2	5,048
A0PR59*5BRON139	R	T	t	1.6	78.8	43.9	3.0	3.9	1.0	14.7	55.6	5,046
A9601*RTX436	W	T	lb	3.8	73.1	46.5	5.8	4.1	2.6	13.9	56.1	5,010
ATX635*RTX436	W	T	st	3.8	76.5	51.1	4.2	4.2	1.4	14.4	59.9	5,009
A9701*RTX436	R	T	st	2.5	70.6	44.6	5.0	4.0	1.3	13.6	57.0	4,949
ATX631*R9839	W	T	t/sn	3.3	55.5	50.0	2.9	4.9	1.8	14.1	58.6	4,920
AHL8*R9528	W	T	st	3.8	73.1	45.3	4.1	4.3	1.0	14.2	41.7	4,906
A9717*RTX436	W	T	st	5.1	69.9	42.0	4.7	3.6	1.3	13.1	56.7	4,899
A8PR1049*Tx436	W	T	st	4.3	74.5	44.4	3.8	3.6	1.4	13.7	56.3	4,827
ATX631*RTX2903	R	T	lb	1.8	74.6	45.0	3.7	3.4	1.4	14.3	56.2	4,743
ATX631*R9752	W	T	t	3.5	75.4	48.9	3.6	3.9	2.3	13.6	55.3	4,741
AHF8*5CA4625	R	T	t	2.8	74.8	42.9	3.0	4.0	1.0	14.5	59.5	4,724
ATXARG-1*R9759	W	T	t	2.6	74.0	45.6	4.0	3.8	2.3	13.9	57.3	4,719
ATXARG-1*RTX436	W	T	t	4.0	75.3	42.2	3.5	3.8	1.4	13.8	41.7	4,687
ATX631*R9809	R	T	st	2.5	75.0	48.0	3.2	5.4	2.6	13.6	55.5	4,681
ATX631*5CA4213-1	R	T	t	2.8	52.8	46.1	2.6	4.4	1.3	15.1	58.6	4,668
ATXARG-1*R9693	W	T	t	4.0	73.9	43.2	3.9	4.4	1.9	13.8	58.0	4,660
AHF14*5CA4205-3	R	T	st	2.5	75.8	42.0	3.2	3.9	1.0	14.6	60.0	4,644
ATXARG-1*R9839	W	T	t	4.1	57.9	43.2	2.1	4.7	1.3	13.8	40.2	4,546
AHF8*R9752	W	T	sn	3.5	74.3	45.5	4.0	3.9	1.3	13.9	58.1	4,460
AHF14*5CA4208	R	T	t	2.3	75.9	43.5	3.0	3.5	1.0	14.7	42.6	4,426
ATXARG-1*R9805	R	T	t	3.0	74.0	43.9	4.7	4.4	2.0	13.6	57.2	4,425
ATX631*R9840	W	T	sn	3.1	74.5	49.3	3.3	4.2	3.3	14.3	57.7	4,386
ATX631*5CA4631	W	T	t	2.5	53.9	49.9	3.2	3.9	2.1	15.0	59.5	4,346
A8PR1057*5BRON155	R	T	t	1.8	54.9	42.1	2.9	4.2	1.0	14.8	41.4	4,316
ATX631*R9805	R	T	bf	2.5	73.0	47.5	5.2	4.9	2.6	13.7	59.4	4,253
ATX635*R9840	W	T	st	3.3	67.8	49.5	4.2	5.1	2.8	14.0	57.7	4,049
ATX635*R9809	R	T	t	2.1	78.1	52.2	5.1	6.4	2.9	13.7	59.3	3,883
GRAND MEAN				3.1	71.2	45.9	3.8	4.0	1.6	14.0	55.1	5,052
CV				23.0	7.0	4.6	28.4	21.4	67.9	9.4	24.7	17
LSD (0.05)				1.1	4.1	2.3	0.9	0.9	1.0	1.2	13.2	665

[†] SD = seed color (R = red, W = white, Y = yellow); PL = plant color (P = purple, R = red, T = tan); GL = glume color (t = tan, b = brown, r = red, sn = siena, st = straw, lb = light brown); GM = grain mold rating (1 = none to 9 = susceptible); DY = mid-anthesis (days); HT = plant height (inches); EX = head exsertion (inches); UN = uniformity (1 to 4 scale); DS = desirability (1 to 9 scale); LO = root and stalk lodging (1 to 9 scale); TW = test weight (lbs/bushel); YD = grain yield (lb/acre)

Participated in the Sorghum Germplasm committee meetings in Wichita, KS and Albuquerque, NM in October 2002 and February 2003, respectively.

Research Investigator Exchanges

Hosted Mr. Leo Mpofu (Zimbabwe) for sorghum breeding training in College Station in July 2002.

Hosted Mr. Joaquim Mutaliano (Mozambique) during his English Language training at Texas A&M from August to December 2002.

Hosted Drs. Issofou Kapran and Salissou Issa (INRAN-Niger) during a visit to Kansas State, Texas A&M, and Purdue Universities in October 2002.

Hosted Dr. R. G. Henzell, Sorghum Breeder from Hermitage Research Station in Queensland, Australia, during a visit to Kansas State and Texas A&M Universities during October 2002.

Germplasm and Research Information Exchange

Coordinated the Tan Plant Hybrid Trial. This trial is designed to evaluate commercially available tan plant (improved grain quality) sorghum hybrids for agronomic adaptation and grain quality parameters. The test included 40 hybrids from eight companies and was grown in nine locations across Kansas and Texas. Included in this trial were breeding lines from TAM223, TAM222 and TAM220C.

Distributed germplasm from TAM220C for evaluation in Central America and Southern Africa.

Distributed germplasm from KSU220A for evaluation in Niger and South Africa.

Publications and Presentations

Journal Articles

Moran, J.L., and W.L. Rooney. 2003. Comparative agronomic performance of iso-cytoplasmic grain sorghum hybrids. Crop Sci. 43:777-781.

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Low Input Ecologically Defined Management Strategies for Insect Pests on Sorghum

Project MSU 205
Henry N. Pitre
Mississippi State University

Principal Investigator

Henry N. Pitre, Entomologist/Professor, Mississippi State University, Box 9775, Mississippi State, MS 39762

Collaborating Scientists

Rafael Obando Solis, Agronomist, INTA, Apdo Postal 1247, Managua, Nicaragua
Carmen Gutierrez, Entomologist, INTA, Apdo Postal 1247, Managua, Nicaragua
Sergio Pichardo Guido, Plant Pathologist, UNA, Managua, Nicaragua
Marta Zamora, Entomologist, UNA, Managua, Nicaragua
Yanette Gutierrez, Plant Pathologist, UNA, Managua, Nicaragua
René Clará Valencia, Sorghum Breeder, CENTA, Apdo Postal 885, San Salvador, El Salvador
Mario Ernesto Parada Jaco, Entomologist, CENTA, Apdo Postal 885, San Salvador, El Salvador
Reina Guzman De Serrano, Plant Pathologist, CENTA, Apdo Postal 885, San Salvador, El Salvador
Francisco Varga, Agronomist, ANPROSOR, Managua, Nicaragua
Larry Claflin, Plant Pathologist, Kansas State University, Manhattan, KS 66506

Summary

With the conclusion of research activities in Honduras during the past 23 years, crop pest management research was expanded in Nicaragua and El Salvador in 1999-2002, with emphasis on insect pest constraints to sorghum production in improved cropping systems on large agricultural farms on the Pacific coastal plain. Unlike the activities of the past 23 years when this project worked with low input, subsistence farming systems in Honduras, activities in Nicaragua and El Salvador emphasize development of insect pest management tactics and strategies on sorghum in improved technology production systems. Collaborative research activities with the Instituto Nicaraguense de Technologia (INTA), the Universidad Nacional Agraria (UNA), the Nicaraguan National Sorghum Producers Association (ANPROSOR) in Nicaragua, and the Centro de Technologia de Agricola (CENTA) in El Salvador have included investigations on insect biology, behavior, ecology and population dynamics of the sorghum midge and fall armyworm, the two principal insect pests on sorghum in this region of Central America. Information from these investigations is used in developing cultural, biological and chemical control tactics for implementation in insect pest management systems for specific pests or complex of pests. Popular articles have been published for farmer utilization in the application of sorghum midge pest management in Nicaragua and El Salvador. Complementary research on insect pest behavior and damage to sorghum is in progress in the United States for improving sorghum midge and fall armyworm pest management strategies. The collaborative research activities among INTSORMIL and research and farmer organizations have been fruitful in developing greater research capacity and furthering institution building activities in this ecogeographic zone. Graduate student education and professional workshops have increased agricultural capabilities of professionals in this region of Central America. The MSU 205 principal investigator will continue to support graduate student education, to conduct sorghum research in Central America and the United States, to collaborate with scientists in governmental organizations and agricultural universities, and to work with non-governmental organizations to develop improved insect pest management practices for sorghum production.

Objectives, Production and Utilization Constraints

Nicaragua

- Refine investigations to determine fall armyworm occurrence, seasonal population levels, and extent of damage to sorghum by this pest. Conduct pest management studies with fall armyworm.
- Prepare manuscripts for publication in scientific journals and popular article for distribution into farm communities.

- Meet with Central America collaborator scientists in INTA, UNA UNAN and ANPROSOR to develop collaborative sorghum crop protection research plans for 2002.
- Complete second year of research and academic programs for MSU 205 Ph.D. student.

El Salvador

- Collaborate with scientists in CENTA to evaluate insecticides and application procedures for fall armyworm management and evaluate sorghums for resistance to this lepidopterous pest.

United States

- Continue 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

Nicaragua

MSU 205 initiated research activities in Nicaragua in 1999, after initially developing collaborative relationships with scientists at INTA in Managua in 1998. Unlike research activities in Honduras during the past 23 years in subsistence farming situations, entomological research in Nicaragua emphasized insect pest constraints to sorghum production in large, improved technology systems on the Pacific coastal plain. The principal insect pest constraints to sorghum production on the coastal plain are recognized to be sorghum midge, fall armyworm and chinch bug. Research was completed on 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 manuscript, representing this research was published in the international journal, *Tropical Agriculture*. A second journal paper considering the occurrence of sorghum midge on sorghum during the second crop-growing season on the Pacific coastal plain of Nicaragua was published in *La Calera* the scientific journal of the National Agricultural University of Nicaragua. A popular article, "La Mosquita De La Panoja Del Sorgo", was published by INTA and prepared for distribution into farm communities in 2002. The information in this publication will assist farmers in sorghum midge pest management.

The student from Nicaragua that completed the Master of Science degree in entomology is continuing entomology studies for the Ph.D. degree at Mississippi State University. This research emphasizes economic thresholds and evaluations of fall armyworm and sorghum midge management practices in monoculture sorghum in the United States.

Entomological investigations were initiated with UNA, with additional participation with ANPROSOR in 2002 following meetings to discuss constraints to sorghum production in Nicaragua. Collaborative crop protection research was discussed and plans were made for the 2002-2005 growing seasons, which begins in August. There was specific interest in crop protection training. Particular emphasis was given to developing plans for collaborative, multisciplinary, on-farm crop protection investigations with MSU 205, INTA, UNA and ANPROSOR collaborating. Collaborative research activities among these organizations was limited in 2002, although meetings among scientists from each organization to discuss research plans for the future did occur. This was evident in the joint planning and conduct of meetings among scientist and with producers.

Studies were conducted by INTA scientists to evaluate alternative treatments for managing sorghum midge and leaf-footed bugs on sorghum panicles. Treatments included biological organisms, plant and insecticide chemicals, and crop barriers. Sorghum midge infestations and damage were less in insecticide treatment compared with the barrier crop treatment; the biological treatments provided interesting comparisons, but more research is needed to substantiate the results obtained.

The MSU 205 PI (Henry Pitre) and KSU 211 PI (Larry Claflin) conducted a five-day sorghum plant protection workshop in Managua in 2002. The workshop was sponsored by INTA and UNA and was attended by 38 agricultural professionals from INTA, UNA and ANPROSOR (in Nicaragua) and CENTA (in El Salvador). Technical presentations included entomology and plant pathology pest management principles, pest management tactics and strategies, defining integrated pest management programs and specific insect and disease agent pest constraints to sorghum production in Nicaragua and the region and related pest management programs. Field trips were taken to observe insects and related plant damage, as well as plant diseases on sorghum. This workshop provided the stimulus for several sorghum pest management meetings that were conducted by UNA, INTA and ANPROSOR in a collaborative effort. Two meetings were held, one with producers from the hills and the coastal plain, and the other with farmers from the coastal plain. Forty producers attended each workshop. Production problems were identified to include specific insect pests, fungal diseases, and mycotoxins in grain. Specific needs were addressed to include: workshops on IPM and post harvest problems, and information on identification, weed control, variety selection and fertilization.

Plans were made for a collaborating scientists at UNA to begin a Ph.D. program in June, 2003 at Mississippi State University. This scientists will receive additional training in plant pathology, with specialized training in insect pest management. Research activities will be collaboratively directed by scientists at Mississippi State University and Kansas State University. The student participated in the Fusarium Laboratory Workshop held at Kansas State University in June.

El Salvador

Entomological research with scientists in CENTA in El Salvador was initiated in 2001. 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 (particularly fall armyworm). The objectives of research for 2001-2002 involved determining the extent of damage and economic significance of fall armyworm on sorghum. This objective included elucidation of the occurrence and aspects of population dynamics and control tactics for this pest. Observations on populations of this caterpillar on and damage to sorghum in the All Disease and Insect Nursery (ADIN) was made during the crop growing season. This was coordinated with collaborating sorghum breeder and plant pathologists in CENTA and Kansas State University (KSU 211), respectively. The results of these investigations were reported in the MSU 205 Year 23 annual report, and published as three separate papers in the scientific journal *La Calera*. The results of the investigations indicate that sorghum plants damaged by fall armyworm in early vegetative stages can compensate for this damage during later stages of plant development. This further indicates that insecticides should be used with complete knowledge of the stage of plant development at the time of fall armyworm infestation and potential for this pest to cause irreversible feeding damage to the developing plants. The infestation level at critical times during sorghum development should be given particular attention in recommending fall armyworm control measures using recommended insecticides. Additional research is needed to refine the recommendations for fall armyworm pest management on sorghum during different phenological stages of the crop.

Studies involving the examination of economic threshold levels for fall armyworm on whorl-stage sorghum in 2002 corroborated the results of similar studies conducted in 2001. These studies were conducted at three locations. Plants infested with fall armyworms at levels ranging from 0 to 80 percent had similar yields at harvest.

Sorghums in the ADIN were again evaluated in 2002 in El Salvador and sorghum fields were sampled to determine occurrence of insect pests during the growing season. A stem borer was recognized to cause damage to sorghum in some areas; the extent of damage was not determined. Also, a lepidopterous larvae, the pink scavenger caterpillar, was observed to infest sorghum panicles. Plans have been made to conduct research on these pests in 2003.

Plans were completed for the collaborating entomological scientists and CENTA to begin formal English language training in August 2003 at the University of Nebraska. The scientists will begin a Ph.D. program in entomology at Mississippi State University in January 2004.

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. Preliminary studies conducted with fall armyworm to determine infestation levels suitable for artificial infestations, survival of fall armyworm larvae in stages of development at infestation and over time after infestation, time of day most suitable for infestation, and other infestation procedures. This information was used in 2002 to observe fall armyworm larval behavior and to refine economic threshold levels using two strategies, one involving number of insects per plant and the other percentage of plants infested. Yield data was recorded for treatments. Information from these studies can improve the application of pest management practices for fall armyworm on sorghum.

Sorghum fields for treatment infestations including one, two, three or four inoculations were compared with un-infested plants in 2002. No significant differences in yield were recorded among treatments regardless of the number of larval infestations. This information further suggests that FAW larvae damage to sorghum throughout plant development (whorl to boot stages) may not significantly reduce yield when plants are not stressed. Insecticide application to control this pest on sorghum may not be warranted.

Further investigations to evaluate the total effects of FAW feeding damage and economic thresholds for this pest on sorghum are planned for 2003. These studies include 1) Effect of multiple infestations of FAW on sorghum yield and 2) FAW damage to sorghum panicles.

Networking Activities

The sorghum crop protection workshop in Nicaragua organized by INTSORMIL (MSU 205) KSU 211, INTA, UNA and ANPROSOR served as the stimulus for the development of meetings between scientists, farm organizations and sorghum producers. Such meetings were conducted in 2002-2003 and additional meetings are planned for 2003. They included aspects of integrated insect pest and plant disease management. The workshops were successful because of detail coordination by scientist and administrators at INTA, UNA and ANPROSOR.

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

Networking with ANPROSOR provides opportunities to conduct on-farm research with cooperation from many farmers associated with this national sorghum producers association.

The popular articles on sorghum insect pests provide information for farmers to manage these pests on sorghum to improve yield. Publications are distributed by INTA into farm communities with assistance from local agricultural professionals.

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Striga Biotechnology Development and Technology Transfer

Project PRF 213

Gebisa Ejeta
Purdue University

Principal Investigator

Dr. Gebisa Ejeta, Department of Agronomy, Purdue University, West Lafayette, IN 47907

Collaborating Scientists

Dr. Fasil Redda, Weed Scientist, EARO, Ethiopia
Mr. Zenbaba Gutema, Sorghum Breeder, EARO, Ethiopia
Dr. Issoufou Kapran, Sorghum Breeder, INRAN, Niger
Dr. Aboubacar Touré, Sorghum Breeder, IER, Mali
Dr. N'Diaga Cisse, Sorghum Breeder, INERA, Senegal
Dr. Asmelash Abraha, Plant Protection Officer, DARE, Eritrea
Mr. Umburu, Weed Scientist, KARI, Kenya
Dr. Peter Esele, Plant Pathologist, NARO, Uganda
Dr. Hamis Sadaan, Sorghum Breeder, Tanzania
Dr. Mbwanga, *Striga* Specialist, Tanzania

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

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

Breeding for Durable Resistance to Striga in Sorghum

The use of crop cultivars with resistance to *Striga* has been widely acknowledged as the most practical and economically feasible control measure, particularly for subsistence farmers in *Striga* endemic regions of Africa and India. Host-plant resistance is also central to integrated *Striga* management approaches when combined with other innovative and input-based farming practices. However, progress from past efforts in breeding *Striga* resistant crops has been rather limited. The reasons for the slow progress vary from complexity of the trait to lack of research support as well as lack of a functional and rational approach to selection strategy. In recent years, significant advances have been made in sorghum, maize, and cowpeas leading to development of cultivars with good levels of *Striga* resistance. Nevertheless, crop cultivars with durable resistance to *Striga* have not yet been identified.

With a research paradigm that focuses on dissecting *Striga* resistance into simple highly heritable components, development of bioassays that allow identification of disrupted host-parasite associations, and adoption of molecular marker technologies, it is now possible to develop crop cultivars with multiple mechanisms of *Striga* resistance. Crop genotypes that possess multiple genes for *Striga* resistance, based on distinct mechanisms, are likely to have genetic resistance that is durable across several environmental conditions as well as across ecological variants of the parasite. In this report, we discuss the strategy we have adopted and the progress we have made in breeding sorghum cultivars with durable resistance to *Striga* in a collaborative research approach engaging a number of scientists from several organizations.

The central theme of our *Striga* research program at Purdue University is to develop a better understanding of the biology of host-parasite interaction in the life cycle of *Striga* parasitism. We focus on the characterization of evidences for signal and resource exchange between the host and parasite. Our objective is to isolate a specific signal exchange or interaction between the host and parasite and, based on such an observation, develop appropriate laboratory assays for screening genetic variants of sorghum that may lack or produce an essential signal or a defense response. Our working hypothesis is that mechanisms of resistance could be defined on the basis of host-dependent developmental processes and the essential signals exchanged. Hence, disruption of one of these signals or resources results in failure to establish parasitism. The basic rationale and theoretical assumptions behind our approach have been outlined in an earlier report

The lack of simple, rapid, and reliable laboratory procedures for evaluating crop germplasm has hampered progress in breeding for *Striga* resistance. In the last few years, reliable bioassays have been developed for germplasm screening and generation of genetic information. In our breeding program we routinely employ the Agar Gel Assay for germplasm screening as well as for examining host-parasitic interactions during the early infection process. Disruption in signal exchange at the important stages of germination and haustorial initiation early in life cycle can be detected by this assay. We have more recently developed two other in vitro techniques, the Extended Agar Gel Assay and the Paper Roll Assay described at this conference. These new assays allow critical observation of genetic differences among host genotypes at later stages during attachment, penetration, and development of the parasite on host tissue. We have used these three assays to identify genetic variants and characterize mechanisms of *Striga* resistance associated with: a) low germination stimulants (*lgs*) production, b) low haustorial factor (*lhf*) production, c) hypersensitive response (*HR)*, and d) incompatible response (*IR*) to infection.

We generated several recombinant inbred populations segregating for genes conditioning resistance due to each of the mechanisms of resistance identified. These populations are genotyped using SSR markers to identify molecular markers linked with genes controlling *Striga* resistance. Introgression and pyramiding of genes for multiple mechanisms of *Striga* resistance is facilitated by both the bioassays as well as these molecular markers. Evaluation of field *Striga* resistance of genetic stocks, segregating populations, and recombinant inbred lines have been conducted in *Striga* infested fields in several countries. Although we had earlier tested against *Striga asiatica* at Whiteville, NC, all our recent field-tests have been conducted against *Striga hermonthica* in Africa in collaboration with several national research programs.

With availability of simple laboratory bioassays, isolation of genetic variants of host plants that disrupt parasitic association at critical stages has been made possible. We have particularly exploited the mechanism of *Striga* resistance based on the low production of host plant root exudates required for germination. Diverse sorghum genotypes with little or no stimulant production capacity have been identified. The genetics of low germination stimulant (*lgs*) production has been established. A number of improved sorghum varieties with *Striga* resistance due to *lgs* have been developed and effectively disseminated to *Striga* endemic areas in several African countries. Introgression of genes for low haustorial factor (*lhf*), hypersensitive response (*HR*), and incompatible response (*IR*) to *Striga* infection into improved sorghum germplasm are currently all underway in our sorghum breeding program.

The difficulty of empirical breeding of *Striga* resistance in the field, associated with the complexity of the trait and its interaction with the environment, coupled with the gradual improvement in the cost effectiveness of PCR technologies have made use of molecular markers a viable alternative in *Striga* resistance breeding worldwide. In our sorghum research program, we have generated a sorghum linkage map of 1628 centiMorgans (cM), with an average interval of 9.5 cM between adjacent loci. Putative QTL associated with field resistance to both *S. asiatica* and *S. hermonthica* have been detected. Two of these QTL are mapped on the same linkage group with *lgs*, but independently from factors conditioning *Striga* resistance due to other mechanisms. Several studies are underway to test different mapping populations at a number of locations with an international network of collaborators to identify key QTL that are universal for use in marker assisted selection for *Striga* resistance.

There appears to be a paucity of major gene sources of *Striga* resistance among germplasm pools of cultivated sorghums. Among landraces and improved sorghum lines that we screened using the different bioassays, variants with *lhf, HR,* and *IR* have been rare, but sources of *lgs* have been more commonly obtained. In contrast, there has been a greater preponderance of genetic variation for many of these traits among sorghum germplasm in wild and related species. This has opened great opportunities for introgressing genes from these wild species into cultivated sorghum lines for greater protection, either sequentially or via gene stacking approaches.

Improved sorghum varieties with resistance to *Striga* have been developed and released in several African countries. However, the wide use of these cultivars by farm communities is limited primarily because of lack of strong seed production and distributing agencies. Furthermore, some ecologies in Africa favor local landraces that are uniquely adapted to these niches where introduced cultivars do not do as well. In the highlands of Ethiopia and in the high rainfall areas of West Africa where long duration Dura and Guinea sorghums, respectively, are cultivated, improved *Striga* resistant Caudatum are not accepted because of problems of grain deterioration even when agronomically adapted. Such niches also exist in Tanzania where the so-called rice-type Guinea sorghums are favored. In these specialized niches, there is a need to incorporated *Striga* resistance genes into favored local landrace cultivars. Some of these varieties have been farmer-selected for *Striga* tolerance. We are currently undertaking an introgression of genes for *Striga* resistance and tolerance into selected landraces for Ethiopia, Sudan, and Tanzania in East Africa, and Niger and Mali in West Africa.

In addition to combining *Striga* tolerance from African landraces with major gene resistance sources from our genetic stocks, we have also embarked on stacking major genes resistances based on different mechanisms into improved sorghum lines. We hypothesize that pyramiding genes for *Striga* resistance based on different mechanisms would enhance durability of resistance sources as well as stability of performance under changing environmental conditions. Preliminary evidence, from field testing under *Striga hermonthica* in Africa, of experimental sorghum lines that combine mechanisms of *Striga* resistance based on *lgs, HR,* and *IR* suggest that there is stronger field resistance expression in those lines than in single mechanism resistance sources.

Networking Activities

Workshop and Program Reviews

We have been involved in a number of engagements in our *Striga* research and development this past year. Two major programs have been underway in Ethiopia and Eritrea directed at the promotion of an integrated *Striga* management using a mix of technologies, including *Striga* resistant sorghum cultivars, nitrogen fertilization, as well as tied-ridges as a water conservation measure. In Ethiopia, over one thousand demonstration plots have been planted in four regions of the country with very exciting and promising results. Plots planted to the IPM technology yielded consistently higher and up to four times the yield of the untreated farmer-managed plots. Project efforts in Eritrea were similar, but scaled down in number with only one hundred demonstration plots this first year. The second, but very important, objective of the project in both countries focuses on promoting a functional seed multiplication efforts based on sale of good quality seed for a premium price. Keen farmers were identified, trained, and encouraged to engage in seed business. While early results of the quality of seed from these organized multiplication efforts have been good, it is too early to judge if the concept of seed as a business entity has taken hold yet.

A training workshop was held in Ethiopia to kick of the demonstration and seed multiplication activities. In addition, presentations on the *Striga* biotechnology research were made both at the First Sorghum and Millet Improvement Workshop in Nazret, Ethiopia and at the 2002 INTSORMIL PI Conference in Addis Ababa, Ethiopia.

Research Investigator Exchange

We have had visitors from India, Ethiopia, Uganda, Burkina Faso, visit our *Striga* research facility at Purdue University. In addition, Dr. Hamidou Traore, a Fulbright fellow spent a year at Purdue conducting *Striga* research in our facility. His work focused on identification of sorghum lines with multiple mechanisms of *Striga* resistance.

Germplasm Exchange

Seed of *Striga* resistant sorghum lines have been filled on a request basis. In addition, an International *Striga* Resistant Sorghum Nursery has been organized and distributed to a number of African national programs, who have agreed to collaborate on free will. This past year, the nursery has been sent to Ethiopia, Uganda, Kenya, Eritrea, Niger, Mali, and Zimbabwe.

Publications

Refereed Papers

Mohamed, A., A. Ellicott, T. L. Housley and G. Ejeta. 2003. Hypersensitive response to *Striga* infection in sorghum. Crop Sci. 43: 1320-1324.

Rich, P.J., C. Grenier and G. Ejeta. 2003. Sources of *Striga* resistance mechanisms in wild relatives of sorghum. Crop Sci. (In Press).

Conference Proceedings

Grenier, C. A. Mohamed, P.Rich, T. Housley and G. Ejeta. 2002. Bioassays to characterize and dissect mechanisms of resistance to *Striga*. *In*: Devries et al (eds) Proc Int. Conf. On Biotechnology, Breeding and Seed Systems for Africa. INTSORMIL, Kamapala, Uganda. (In Press).

Kapran, I., C. Grenier, A. Ellicott, A. Toure, Z. Gutema, A. Babiker, H. Sadaan and G. Ejeta. 2002. Introgression of genes for *Striga* resistance into African landraces of sorghum. *In*: Devries et al (eds) Proc of Int. Conf. On Biotechnology and Seed Systems for Africa, Kampala, Uganda (In Press).

Published Abstracts

Mohamed, A., A. Ellicott, T. L. Housley and G. Ejeta. 2002. Hypersensitive response to *Striga* infection in sorghum. INTSORMIL Int. Principal Investigators Conference, Addis Ababa, Ethiopia.

Invited Presentations

Ejeta, G. 2002. Advances in *Striga* biotechnology and control at INTSORMIL, Principal Investigators Conference, 17-20 November, Addis Ababa, Ethiopia.

Ejeta, G. 2002. Increasing crop yields through hybrids: Prospects for sorghum hybrids in Ethiopia. First National Workshop on Sorghum and Millets in Ethiopia, 11-14 November, Nazret, Ethiopia.

Ejeta, G. 2002. Biotechnology based approaches to the study of host plant resistance to *Striga* in sorghum. First National Workshop on Sorghum and Millets in Ethiopia, 11-14 November, Nazret, Ethiopia.

Ejeta, G. 2002. Host-plant resistance to *Striga* in sorghum. Training Workshop on *Striga* Resistant Sorghum Seed Seed Production and Dissemination. Melkassa, Ethiopia.

Sustainable Management of Insect Pests

Project WTU 200
Bonnie B. Pendleton
West Texas A&M University

Principal Investigator

Bonnie B. Pendleton, Assistant Professor of IPM, Entomology, Div of Agriculture, Box 60998, West Texas A&M Univ, Canyon, TX 79016

Collaborating Scientists

Dr. Niamoye Yaro Diarisso, Entomologist/Coordinatrice Scientifique des Cultures Irriguées, IER/CRRA, BP 258, Bamako, Mali
Dr. Yacouba O. Doumbia, Entomologist, IER/SRA/CRRA, BP 438, Sotuba, Bamako, Mali
Mr. Hamé Abdou Kadi Kadi, Entomologist, INRAN/CERRA, BP 240, Maradi, Niger
Dr. D. C. Munthali, Entomologist, Private Bag 0027, Botswana College of Agriculture, Gabarone, Botswana
Dr. Gary Peterson, Professor, Texas A&M Univ Ag Research & Ext Ctr, Rt 3, Box 219, Lubbock, TX 79403
Dr. Robert Bowling, Extension Agent–Pest Management, Texas Cooperative Extension, 310 E. 1st Street, Dumas, TX 79029
Dr. Roxanne Shufran, Entomologist, Texas A&M Univ Ag Research & Ext Ctr, 6500 Amarillo Blvd West, Amarillo, TX 79160-1796

Summary

The PI traveled to Mali in October to review collaborative research to manage insect pests and develop integrated pest management (IPM) approaches for sorghum and pearl millet in the field and storage. The biology of and resistance to insect pests of sorghum and pearl millet was researched with Mr. Abdou Kadi Kadi in Niger. A Malian came to West Texas A&M University to learn English and begin graduate studies. The graduate program of one student from the United States was completed. Graduate students assessed effects of temperature on fecundity and longevity of different biotypes of greenbug on sorghum, fitness of greenbug biotype I on resistant and susceptible sorghums and wild grasses, and effects of different amounts of soil moisture and nitrogen on the biology of greenbugs. Graduate students began assessing effects of resistant sorghum on coccinellids feeding on greenbugs from the sorghum and began assessing resistance of sorghum and cowpeas to storage weevils. Sorghums and a new insecticide developed by commercial companies were evaluated against greenbugs. The PI advised agricultural consultants, extension personnel, and the National Grain Sorghum Producers on management of insect pests. The PI and graduate students participated in sorghum and entomology meetings.

Objectives, Production and Utilization Constraints

Objectives

West Africa

- Assist scientists from Mali and Niger with collaborative research to develop and transfer strategies, especially nonchemical methods, to manage insect pests and improve yield and income from sorghum and pearl millet.
- Identify a Malian to begin graduate studies in IPM and entomology in the United States.

Southern Africa

- Assist scientists in Botswana and South Africa with research to evaluate resistance and develop IPM strategies for insect pests of sorghum in the field and storage.

United States

- Study the biology, ecology, and population dynamics of insect pests so effective management strategies and longer-lasting plant resistance can be developed. Assess fitness of greenbugs on wild and cultivated grasses to better understand insect-plant interactions. Assess effects of temperature on the biology of greenbug biotypes to determine the optimum temperature for evaluating resistance to greenbug in sorghum.
- Assess effects of agronomic practices on the abundance of and damage caused by insect pests. Study effects of soil moisture and fertility on abundance of greenbugs on sorghum.
- Collaborate with breeders, commercial seed industry, and molecular biologists to develop sorghum germplasm for greater yield potential and tolerance to major insect pests.

- Supervise graduate student research in entomology and IPM.
- Advise agricultural consultants, extension personnel, commodity organizations, and the sorghum industry with managing insect pests of sorghum.
- Participate in professional and scientific meetings and activities.

Production Constraints

West Africa

Abiotic stresses and such biotic constraints as insects, diseases, and *Striga* limit production of sorghum and pearl millet in West Africa. The most damaging insect pests are panicle-infesting bugs; sorghum midge, *Stenodiplosis sorghicola*; sugarcane aphid, *Melanaphis sacchari*; and stalk borers on sorghum, and millet head miner, *Heliocheilus albipunctella*, on pearl millet. Sorghum midges can destroy 100% of kernels. Panicle-infesting bugs and associated infection by pathogens reduce yield and quality and render grain unusable for human consumption. Stalk borers bore into sorghum and kill the central shoot or break the peduncle. Larvae of millet head miner cut flowers and tunnel in kernels of pearl millet. Other insects can become pests when agronomic practices are changed and new crop varieties are used. Effective management of insect pests requires a multi-disciplinary team with knowledge of entomology, plant pathology, agronomy, plant breeding, and cereal quality.

Southern Africa

Sugarcane aphid, sorghum shoot fly, *Atherigona soccata*; sorghum midge, stalk borers, and termites infest and reduce yields of sorghum in the field. Beetles destroy stored sorghum grain. Few taxonomic keys are available for correct identification of insects from the region.

United States

Major insect pests include greenbug, sorghum midge, and panicle-infesting bugs and caterpillars. Ecosystem disruption caused by monoculture of sorghum increases the severity of pests and results in increased production costs and reduced yield. Insecticides prevent damage and yield loss, but overuse results in increased production costs, disruption of the ecosystem, outbreaks of secondary arthropod pests, resurgence of the targeted pest, and environmental contamination. Biology, insect-plant interactions, amounts of damage, and economic and ecological costs associated with the use of chemicals to control insect pests need to be understood better. Biological and cultural management tactics such as use of resistant cultivars are needed to prevent damage by insect pests. Development of resistant sorghums requires collaboration among plant breeders, entomologists, and molecular biologists.

Research Approach and Project Output

This project emphasizes collaborative research and education. The IPM approach is used to develop strategies to manage insect pests economically, ecologically, and environmentally. For effective IPM, the insect pest must be identified correctly; its biology, ecology, and population dynamics understood; abundance determined in relation to crop damage and yield loss; economic threshold determined; and direct control tactics used, especially conservation of natural enemies, agronomic practices, resistant varieties, and chemicals only when necessary. Information and technology from the research is transferred to extension personnel, farmers, and others.

West Africa

Tiecoura Traore from Mali came to West Texas A&M University to learn English and begin graduate studies in IPM and entomology in fall 2003. From 18-29 October, sorghum research was reviewed and collaborative research projects planned with scientists in Mali. Dr. Diarisso evaluated ash and extracts from local plants to control panicle-infesting bugs in the field and beetles of stored sorghum grain. Twenty-five kilograms of leaves from neem trees and from *Calotropus procera* were pounded and mashed in 30 liter of water. The juice was filtered and sprayed on bug-resistant Malisor92-1 and susceptible S34 sorghums as seedlings, at the end of flowering, and at the hard-dough stage. Bugs were counted the day before and week after treatment. Sorghum plots were infested with 51.2, 31.8, and 37.5 bugs in the plots not treated, treated with neem, and treated with *Calotropus*, respectively. There was no significant difference in the number of bugs on plants sprayed with juice from neem or *Calotropus*. Damage was greater on nontreated sorghum than treated Malisor92-1. Leaves of the two plants contained flavonoids, sterols, triterpenes, and other chemical compounds.

In collaboration with Dr. Peterson, Dr. Diarisso, and Mr. Abdou Kadi Kadi, sorghum lines and landraces were evaluated for resistance to insect pests in Mali and Niger. Resistance of 74 sorghums to panicle-feeding bugs and sorghum midge was evaluated at Samanko, Mali. At 50% flowering, sorghum midge larvae per 10 rachis branches per panicle of sorghum in each plot were counted. The percentage of damaged kernels per panicle was calculated. At maturity, the kernels were assessed using a scale of 1 to 9 for damage by sorghum midge. Damage ranged from 1 to 4.5. Four sorghums with scores of 1 for sorghum midge, 2 to 2.5 for bugs, and 2 to 2.5 for grain mold were only slightly damaged. Numbers of bugs ranged from 2.6 to 8.1 per panicle.

Southern Africa

In collaborative research with the PI and Dr. Peterson, Dr. Munthali evaluated 100 sorghum lines from the United States for resistance to sugarcane aphid, stalk borers, and termites at the Botswana College of Agriculture. Each sorghum was planted in two single-row plots 7 m long. Seeds were sown with 30 cm between plants and 50 cm between rows. A total of 25 seeds was planted per plot. Plants were examined every two weeks. The number of plants infested with sugarcane aphids was recorded four and eight weeks after plant emergence. Sugarcane aphids were more abundant on sorghum in January than March. Abundance in January ranged from 14.8% infested plants of 02CG6312-1 to 100%. Only 02L227-BK sorghum was resistant to both sugarcane aphids and termites, while 02L264 was resistant only to termites. Percentage of plants attacked by stalk borers in January ranged from 10% of 02CG6239-BK and 02L286-BK to 88.6%. The proportion of plants with deadhearts ranged from 0% of 02CG6372-BK to 85.7%. Nine and 14 sorghums had only 0-25% of plants with damaged leaves and deadhearts caused by stalk borers.

Dr. Munthali also evaluated 19 sorghums developed in the SADC region. Each sorghum was planted in four 7- by 7-m plots in a randomized complete block design. Abundance of insects was assessed using the method of House (1985). Coccinellids were counted on all plants in each plot. Abundance of and damage by stalk borers also were assessed on all plants in each plot during the vegetative growth to determine damage to leaves and at grain filling to evaluate damage to stalks. All plants in each plot were dissected and larvae were counted by species. Plants infested with sugarcane aphids decreased from 38.6 to 9.3% from January to March, but all sorghums were equally susceptible (Table 1). Significantly more coccinellids were found in January (5.2 per plant) than March (1.5), but abundance did not vary significantly among the sorghums. The most abundant coccinellid was *Hippodamia variegata* (4.5 beetles per plot). The number of stalk borers did not vary significantly among the sorghums, but infestation was significantly greater in January than March. Damage to Marupantse (2.2) was significantly least in March. Overall, 64.2% of plants were infested per plot. Damage to leaves and stalks was great (78 and 54.2%, respectively), and 40% of plants had deadhearts. The sorghum significantly affected the number of emergence holes per stalk; Marupantsi had fewest holes. Spotted stem borer, *Chilo partellus*, was the most abundant (54.5%) of the stalk borers.

United States

Boot-stage sorghum in Moore County, Texas was used to evaluate 0.56 kg ha^{-1} of Lorsban® (chlorpyrifos) and 0.040 to 0.099 kg/ha of experimental F1785 (FMC Corporation) for suppression of greenbug and effect on coccinellids. Greenbugs and coccinellids on 10 consecutive whole plants in a row were counted. Treated sorghum was infested with significantly fewer greenbugs 3 and 7 days after treatment than was nontreated sorghum. Coccinellids were not influenced by insecticide. Chemically treated leaves in petri dishes were used to assess resistance of field-collected Banks grass mites, *Oligonychus pratensis*. Mites from frequently treated fields on the Texas High Plains were as much as 7,000-fold more resistant to bifenthrin but not dimethoate or propargite than were mites from fields that had never been treated in New Mexico. The PI also evaluated 237 sorghum lines developed by Pioneer Hi-Bred International, Inc. for resistance to greenbug biotype I.

Master's student Kishan Sambaraju assessed the fitness of biotype I greenbugs on wild grasses and resistant and suscep-

Table 1. Effects of sorghums on sugarcane aphid, stalk borers, and coccinellids in Botswana.

	Sugarcane aphid			Stalk borer		
Sorghum	% attacked plants/plot	Damage score	Coccinellids/plot	Damage score	Emergence holes	Larvae/plot
SDSR 91014	23.8 a	2.6 a	2.3 a	4.6 ab	6.6 ab	5.5 abc
BSH 1	25.4 a	2.8 a	2.4 a	4.8 ab	6.8 ab	9.2 ab
SDSH 98009	26.5 a	3.2 a	3.1 a	4.8 ab	8.8 a	8.0 ab
ICR 89028	16.8 a	2.8 a	1.9 a	4.1 ab	6.5 ab	9.0 ab
Segaolane	22.6 a	2.5 a	2.7 a	5.0 a	8.4 a	11.0 a
Tegemeo	31.5 a	3.4 a	4.0 a	5.0 a	6.7 ab	4.9 bc
Marupantsi	18.5 a	2.6 a	2.0 a	3.6 b	2.5 b	3.2 c
Masie	23.9 a	2.8 a	2.0 a	4.9 ab	8.0 a	4.7 bc
SDSR 91039	27.6 a	3.2 a	2.7 a	5.0 a	6.8 ab	6.9 ab
SV 2	24.0 a	3.4 a	2.8 a	4.6 ab	10.5 a	5.2 bc
ICSH 93107	14.6 a	2.2 a	2.7 a	5.0 a	7.4 ab	5.0 bc
Town	24.8 a	2.9 a	4.3 a	4.9 ab	12.6 a	5.7 abc
SV 1	34.7 a	3.4 a	3.6 a	5.0 a	7.8 a	11.1 a
SDSH 98012	29.3 a	3.2 a	5.4 a	5.0 a	13.3 a	9.4 ab
SDS 6013	29.4 a	3.0 a	3.5 a	5.0 a	6.0 ab	6.6 ab
Mmabaitse	27.6 a	3.6 a	3.7 a	5.0 a	10.0 a	8.0 ab
Mahube	11.6 a	2.8 a	2.9 a	4.9 ab	4.8 ab	2.9 c
LARSVYT 46-85	23.9 a	3.2 a	2.1 a	4.9 ab	9.5 a	11.2 a
Phofu	18.3 a	2.4 a	2.3 a	4.8 ab	7.5 ab	5.5 abc
Overall average	23.9	2.9	2.8	4.7	7.5	6.5

tible sorghum and wheat. Greenbugs are thought to survive on wild grasses when cereal crops are not available. Seeds of susceptible RTx430 sorghum; resistant LG-35 sorghum; susceptible Custer wheat; resistant GRS1201 wheat; barnyardgrass, *Echinocloa crus-galli*; Johnsongrass, *Sorghum halepense*; jointed goatgrass, *Aegilops cylindricum*; and Arriba western wheatgrass, *Agropyron smithii*; were sown in a greenhouse. Three, 2.5-cm^3 plastic cages each containing a single greenbug were clipped onto leaves of plants in each of six pots, for a total of 18 clip cages on each kind of grass. The original greenbug was removed after it produced a nymph. The nymph was retained until it produced offspring, which were counted and removed daily. The number of days the greenbug lived was recorded. The experiment was done three times. The pre-reproductive period of the greenbug was longest on barnyardgrass (7.5 days) and western wheatgrass (6.4 days) and shortest (5.2 days) on resistant wheat and jointed goatgrass (Table 2). Average fecundity was only 13.9 nymphs per greenbug on barnyardgrass and 22.4 nymphs on western wheatgrass, but 4.4 and 2.7 times that many on susceptible wheat (62.2 nymphs) and sorghum (61.5 nymphs). The total number of nymphs produced per greenbug differed significantly between susceptible versus resistant sorghum or wheat. Each greenbug lived only 14.8 days on barnyardgrass. Greenbugs lived longest on grasses of the genus *Sorghum* (29.4, 28.8, and 27.5 days on Johnsongrass, RTx430, and LG35, respectively). The eight grasses were adequate to good hosts for biotype I greenbugs. The worst wild host was barnyardgrass, and the best were Johnsongrass and jointed goatgrass, which are related to sorghum and wheat. The resistance mechanism in the resistant sorghum and wheat probably is antixenosis or tolerance, rather than antibiosis.

Table 2. Pre-reproductive period, fecundity, and longevity of biotype I greenbugs on grasses.

Grass	Pre-reproductive period (days)	Total fecundity (nymphs) per greenbug	Longevity (days)
Barnyardgrass	7.5 ± 0.3 a	13.9 ± 2.4 d	14.8 ± 1.0 cd
Western wheatgrass	6.4 ± 0.2 ab	22.4 ± 2.2 cd	17.7 ± 1.0 c
Jointed goatgrass	5.2 ± 0.1 b	54.1 ± 2.6 b	19.3 ± 0.8 bc
Johnsongrass	5.7 ± 0.1 b	57.1 ± 2.7 ab	29.4 ± 1.4 a
GRS1201 wheat	5.2 ± 0.1 b	47.3 ± 2.8 b	22.0 ± 1.2 bc
Custer wheat	5.4 ± 0.1 b	62.2 ± 3.1 a	22.9 ± 1.0 bc
LG35 sorghum	5.5 ± 0.1 b	48.9 ± 2.5 b	27.5 ± 1.4 ab
RTx430 sorghum	5.3 ± 0.2 b	61.5 ± 2.7 a	28.8 ± 1.3 ab

Means followed by the same letter in a column are not significantly different (Tukey's HSD).

Master's student Anastasia Palousek assessed effects of 10-23, 14-27, 18-31, and 22-35° C temperatures (daily low-high cycle) on the biology of greenbug biotypes E and I to determine the optimum temperature for evaluating resistance of sorghum to greenbugs. Twenty plants of RTx430 sorghum were used for each combination of temperature and biotype. A single greenbug enclosed in a clip cage was attached to each of two leaves on a sorghum plant that had seven true leaves. The infested sorghum was kept at 14:10 light:dark hours in an incubator. The original greenbug was discarded after it produced a nymph which was retained. When the greenbug in each cage began producing offspring, the nymphs produced per day were counted and removed. The greenbug was monitored until death. The pre-reproductive period was significantly longest for greenbugs at the coolest temperature of 10-23° C (9.4 days) and shortest at the warmest temperature of 22-35° C (Table 3). Greenbug biotypes E and I at the coolest temperature produced 2.8 and 5.1 times more nymphs (51.4 and 50.9) than did greenbugs at the warmest temperature (18.1 and 9.9). Greenbug biotypes E and I at the coolest temperature lived 5.0 and 7.2 times longer (60.3 and 61.9 days) than at the warmest temperature (12.1 and 8.6 days). Length of the pre-reproductive period, total fecundity, and longevity per greenbug differed significantly by the biotype of greenbug only at the warmest temperature of 22-35° C.

Master's student Suresh Veerabomma assessed effects of different soil water potentials (-33, -50, -100, and -300 kPa) and nitrogen (21, 50, 100, and 150 ppm) on abundance and longevity of biotype I greenbugs. A greenbug enclosed in a clip cage was attached to a leaf of each of 90 sorghum plants, 10 per treatment combination, in a greenhouse. The experiment was done twice. The length of the pre-reproductive period, daily number of nymphs produced, and longevity were assessed. Soil water potential, but not nitrogen, significantly affected greenbug fecundity, with almost twice as many nymphs produced per greenbug on sorghum in soil with -33 kPa of water potential (44.5 nymphs) as with -300 kPa (28.5 nymphs) (Table 4). Greenbug longevity was affected by different soil water potentials but not nitrogen. Longevity was 22.2 and 28.6 days on sorghum in soil with -300 and -33 kPa of water.

Table 3. Effects of temperature and biotype on greenbug biotypes E and I on sorghum.

Temp. (° C)	Pre-reproductive period (days)		Total fecundity (nymphs) per greenbug		Longevity (days)	
	Biotype E	Biotype I	Biotype E	Biotype I	Biotype E	Biotype I
10-23	9.4 ± 0.1aA	9.4 ± 0.2aA	51.4 ± 2.8aA	50.9 ± 2.7aA	60.3 ± 2.8aA	61.9 ± 2.7aA
14-27	6.6 ± 0.2bA	6.8 ± 0.1bA	50.2 ± 3.2aA	43.4 ± 2.4abA	38.0 ± 1.8bB	44.6 ± 1.5bA
18-31	6.5 ± 0.2bA	6.0 ± 0.3cA	40.2 ± 2.7bA	42.2 ± 4.4bA	26.5 ± 1.3cA	23.3 ± 1.2cA
22-35	5.0 ± 0.2cA	3.9 ± 0.2dB	18.1 ± 3.0cA	9.9 ± 2.3cB	12.1 ± 1.1dA	8.6 ± 1.0dB

Means followed by the same lower-case letter in a column or upper-case letter within a treatment in a row are not significantly different (LSD, $P = 0.05$).

Table 4. Effect of soil water and nitrogen on biotype I greenbugs on sorghum.

	Number of days of pre-reproductive period	Nymphs produced per greenbug	Number of days each greenbug lived
Water potential (kPa)			
-33	6.5 a	44.5 a	28.6 a
-50	6.4 a	40.6 a	27.5 a
-100	6.3 a	39.9 a	28.3 a
-300	6.4 a	28.5 b	22.2 b
Nitrogen (ppm)			
21	6.7 a	35.3 a	26.1 a
50	6.4 a	35.9 a	25.5 a
100	6.3 a	40.3 a	27.9 a
150	6.3 a	38.9 a	25.3 a

Means followed by the same letter for a treatment within a column are not significantly different (Tukey's HSD, $P = 0.05$).

Networking Activities

Workshops

The PI participated in and co-authored four posters presented at the 51th Annual Meeting of the Southwestern Branch of the Entomological Society of America (22-27 February 2003, Oklahoma City, Oklahoma). For the Biennial Conference of the National Grain Sorghum Producers (16-18 February 2003, Albuquerque, New Mexico), the PI served as entomology discipline chair, organized and moderated the entomology symposium, and co-authored five presentations. The PI gave three presentations at the Entomology Science Conference (6-8 November 2002, College Station, Texas), at the 50th Annual Agricultural Chemicals Conference (28 August, Lubbock, Texas), and at the Joint Meeting of the Greenbug Research Consortium and U.S. Department of Agriculture Western Coordinating Committee (WCC-066) on Integrated Management of Russian Wheat Aphid and Other Cereal Aphids (9-10 September 2002, Stillwater, Oklahoma). The PI participated in the INTSORMIL Principal Investigators' Conference (18-20 November, Addis Ababa, Ethiopia). During two sessions, 10 entomologists involved with INTSORMIL discussed aphids, armyworms, panicle-infesting bugs, shoot fly, sorghum midge, spittle bugs, stalk borers, white grubs, and storage insects as major pests of sorghum. Millet head miner, blister beetles, panicle-infesting bugs, shoot fly, stalk borers, and storage insects are pests of pearl millet. Better storage, biological control, biotechnology, botanical insecticides, cultural practices, habitat management, IPM, and plant resistance were discussed as ways to manage insect pests.

Research Investigator Exchanges

From 18-29 October 2002, the PI traveled in Mali and discussed and reviewed research and needs with scientists and administrators of the Institut d'Economie Rurale (IER) at Bamako, Cinzana, Samanko, Sikasso, and Sotuba and with ICRISAT sorghum breeders. Entomological emphasis was on managing panicle-infesting bugs, sorghum midge, stalk borers, sugarcane aphid, and storage beetles. Collaborative research in agronomy, breeding, entomology, plant pathology, maintaining sorghum diversity, and quality of stored grain was viewed at Sotuba. A project at Cinzana and Samanko used neem, *Calotropus*, and diazinon against *Erystylus* bugs on Malisor92-1 and S-34 sorghums. A cooperative project between Drs. Diarisso and Mamourou Diourte (plant pathologist) on stalk borers and anthracnose was seen at Sikasso. The sorghums in the All Disease and Insect Nurseries (ADIN) at the different research stations looked bad because of scarce rainfall and pests.

Research Information Exchange

The PI advised agricultural consultants, extension, and the National Grain Sorghum Producers on management of sorghum insect pests. The PI is assisting Dr. John Burd, USDA-ARS, Stillwater, Oklahoma, with a multi-year, multi-state study of greenbugs on wild and cultivated grasses. Two hundred thirty-seven sorghums developed for resistance to biotype I greenbug were evaluated for Pioneer Hi-Bred International, Inc. An experimental insecticide developed by FMC Corporation was evaluated for effect on greenbugs and coccinellids in the field. Supplies were provided for entomological research for Drs. Diarisso and Doumbia in Mali, Mr. Abdou Kadi Kadi in Niger, and Dr. Munthali in Botswana. Sorghum entomology reference materials were sent to Dr. Paul Tanzubil in Ghana and Dr. Johnnie van den Berg in South Africa.

Publications and Presentations

Publications

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51st Annual Meeting of the Southwestern Branch of the Entomological Society of America, February 22-27, 2003, Oklahoma City, OK – *Fecundity and longevity of greenbug, Schizaphis graminum, affected by biotype and temperature* presented by A.L. Palousek, B.B. Pendleton, B.A. Stewart, G.J. Michels, Jr., and C.M. Rush; *Greenbug fitness on sorghum and non-cultivated hosts* presented by K.R. Sambaraju, B.B. Pendleton, C.A. Robinson, R.D. Thomason, and M.D. Lazar; *Response of Banks grass mite populations to bifenthrin and dimethoate* presented by R. Shufran, R. Bowling, B. Pendleton, P. Porter, G. Cronholm, C. Patrick, and B. Lewis; and *Effect of different amounts of soil water and nitrogen on greenbug fecundity and longevity on sorghum* presented by S. Veerabomma, B.B. Pendleton, B.A. Stewart, C.A. Robinson, and G.J. Michels, Jr.

23rd Biennial Grain Sorghum Research and Utilization Conference, February 16-18, 2003, Albuquerque, NM – *Insecticide evaluations for greenbug (Homoptera: Aphididae) management in sorghum on the Texas High Plains* presented by R. Bowling, R. Shufran, B. Pendleton, C. Copeland, and S. Cox; *Fecundity and longevity of greenbug (Schizaphis graminum) affected by biotype and temperature* presented by A.L. Palousek, B.B. Pendleton, B.A. Stewart, G.J. Michels, Jr., and C.M. Rush; *Roundtable discussion by producers on management of sorghum insect pests and future research needs* by B. Pendleton; *Greenbug fitness on wild and cultivated hosts* presented by K.R. Sambaraju, B.B. Pendleton, C.A. Robinson, R.C. Thomason, and M.D. Lazar; and *Effect of different amounts of soil moisture and nitrogen on greenbug fecundity and longevity on sorghum* presented by S. Veerabomma, B.B. Pendleton, B.A. Stewart, C.A. Robinson, and G.J. Michels, Jr.

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Annual Meeting of the Entomological Society of America, November 17-20, 2002, Ft. Lauderdale, FL – *Response of Banks grass mite populations to bifenthrin, dimethoate, and propargite* presented by R. Bowling, P. Porter, G. Cronholm, C. Patrick, B. Lewis, R. Shufran, and B. Pendleton.

Entomology Science Conference, November 6-8, 2002, College Station, TX – A. Palousek and B. Pendleton. *Greenbug biology affected by biotype and temperature* presented by A. Palousek and B. Pendleton; *Greenbug fitness on wild and cultivated grasses* presented by K. Sambaraju and B. Pendleton; and *Effect of soil moisture and fertility on greenbugs* presented by S. Veerabomma and B. Pendleton.

Joint Meeting of the Greenbug Research Consortium and U.S. Department of Agriculture Western Coordinating Committee (WCC-066) on Integrated Management of Russian Wheat Aphid and Other Cereal Aphids, September 9-10, 2002, Stillwater, OK – *Effect of biotype and temperature on greenbug biology* presented by A.L. Palousek and B.B. Pendleton, *Fitness of biotype I greenbug on different grass hosts* presented by K. Sambaraju and B.B. Pendleton, and *Effect of soil moisture and nitrogen on fitness of greenbug biotype I on sorghum* presented by S. Veerabomma and B.B. Pendleton.

50th Annual Agricultural Chemicals Conference, August 28, 2002, Lubbock, Texas – *Fecundity and longevity of greenbug, Schizaphis graminum, affected by biotype and temperature* presented by A.L. Palousek, B.B. Pendleton, B.A. Stewart, G.J. Michels, Jr., and C.M. Rush; *Greenbug fitness on sorghum and non-cultivated hosts* presented by K.R. Sambaraju, B.B. Pendleton, C.A. Robinson, R.C. Thomason, and M.D. Lazar; and *Effect of different amounts of soil nitrogen and water on greenbug fecundity and longevity on sorghum* presented by S. Veerabomma, B.B. Pendleton, B.A. Stewart, C.A. Robinson, and G.J. Michels, Jr.

Sustainable Production Systems

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

Project PRF 205
John Sanders
Purdue University

Principal Investigator

John H. Sanders, Purdue University, Dept of Agricultural Economics, West Lafayette, IN 47907

Collaborating Scientists

Tahirou Abdoulaye, INRAN, BP 429, Niamey, Niger
Gebisa Ejeta, Purdue University, Dept. of Agronomy, West Lafayette, IN 47907
Kidane Georgis, EARO, PO Box 2003, Addis Ababa, Ethiopia
Barry I. Shapiro, ICRISAT, Patancheru AP 502 324, Hyderabad, India
Jeffrey D. Vitale, Texas A&M University, Dept. of Agricultural Economic, 2124 TAMU, College Station, TX 77843
Nega Wubeneh, ILRI, BP 5689, Addis Ababa, Ethiopia
Yigezu Yigezu, ILRI, BP 5689, Addis Ababa, Ethiopia

Summary

The four-country development pilot program in the Sahel introduced not only new technologies but also new marketing strategies. The principal results from these activities were:

- Sahelian farmers appreciated the access to inorganic fertilizer and improved varieties of millet even though yield gains were modest due to the bad weather of 2001-2002. Farmers received input credit for millet production and were able to repay it if they received higher prices than those paid at harvest time.

- By waiting to sell their grain until prices recover approximately six months after harvest, farmers in Senegal and Mali received higher prices. In Mali there was also a price premium for quality, 10 FCFA/kg above market price, while in Senegal farmers were able to obtain 25 FCFA/kg above market price.

- In Niger, the market price went quickly above the contract price; therefore, most farmers sold their grain outside the contract. The government replenished public grain stocks. In the new contract for 2002-2003, the price-determination method has been changed to the market price at time of sale plus a quality premium (10 FCFA/kg). So there is a learning-by-doing effect from these market sales.

- Quality improvement is the next big challenge for helping processors and for increasing farm incomes. Currently, "baches" (rugs) are being introduced to keep the threshing off the ground, but this is only the first step. In Senegal (Kaolack region), some entrepreneurs are already offering threshing services for hire. Introduction of those threshing machines in other villages greatly improved the quality of grain. This is an objective of the Sasakawa 2000 project in 2003-2004.

Objectives, Production and Utilization Constraints

This year our principal activity was to collaborate in the four-country contracts between farmers and processors in the Sahel. Dr. John Sanders and Tahirou Abdoulaye spent October 2002 with Ouendeba Botorou and national food scientists in the field interviewing processors and farmers. This was a new activity for us, concentrating on marketing-strategy improvements to facilitate the introduction of new technologies in sorghum and millet production in an ongoing development program being implemented by three different NGOs in four Sahelian countries.

Besides this marketing activity, we continue to monitor the introduction of *Striga*-resistant cultivars in Ethiopia. We are analyzing technology and marketing innovations for maize and sorghum in Mozambique and we began a program to evaluate the introduction of N'Tenimissa with associated technologies in Mali.

Research Approach and Project Output

Marketing Strategies in the Four Country Sahelian Project. We have a four-point approach to increasing farmers' incomes with marketing strategies, thereby enabling them to utilize higher input levels, especially improved seeds and inorganic fertilizers. This strategy responds to the following four problems, reducing the price received by farmers:

1 *Post- harvest price collapse.* Farmers have very important cash requirements at harvest including debts acquired before and during the crop season, school fees, taxes, migration expenses, weddings, and naming ceremonies. The strategy is to enable farmers, as with inventory credit and storage, to avoid selling during the post-harvest price collapse period but to receive cash as an advance against the value of the harvest.

2 *Good-weather price collapse.* The basic problem is that people can only eat so much of the basic staples. With good weather, people consume up to the maximum they can afford and then prices collapse. The strategy is to develop new markets, as for processed cereals and ultimately feed grains as income growth continues, to dampen or eliminate the between-year price collapse in normal or good-rainfall seasons.

3 *Poor grain quality.* Processors are generally willing to pay more for a higher-quality, more uniform product. Farmers need sufficient bargaining power to pressure the processors to pay the quality premium. This works better where the processors are producing a high-value product, as the yogurt-producer in Senegal.

4 *Government/NGO intervention in bad weather year.* A principal poverty instrument in the Sahel is to keep food prices low to benefit the urban poor (and the influential middle-class, government bureaucracy). The strategy is to moderate or eliminate the response of public policymakers and NGOs in their efforts to drive down the prices received by farmers by introducing cheap grain.

The seasonal price variability is dramatic in the very dry years as prices during the year can more than double for the basic staple (Fig. 1). In a more normal rainfall year, as in 2002-2003, prices for Malian millet went from 110 CFA/kg at harvest to over 160 CFA in six months. Farmers rather than merchants need to benefit from this price variation so that the farmers can pay for the increased input costs of improved seeds and inorganic fertilizer. As many farmers delay more of their grain sales, the seasonal price variability will be reduced and ultimately eliminated.

A more long-range goal is to help develop markets for processed foods made from millet and sorghum. Note that substantial gains have been made by food scientists with rice and wheat, especially in reducing the processing and cooking time. Similar catch-up gains are now being made in sorghum and millet. As a consequence of technology availability in these cereals and increasing incomes, new products from millet and sorghum are rapidly being introduced into West Africa. These products are very important to urban women, who have much higher opportunity costs for their time than rural women. An important part of our field project is the food-scientist technical assistance from INTSORMIL directly to the rapidly expanding group of food processors involved in this four-country program.

As these new markets are developed the processors are expected to be willing to pay for a more uniform (one variety), higher-quality product. For example, much of the threshing of the basic cereals takes place on the ground, resulting in the

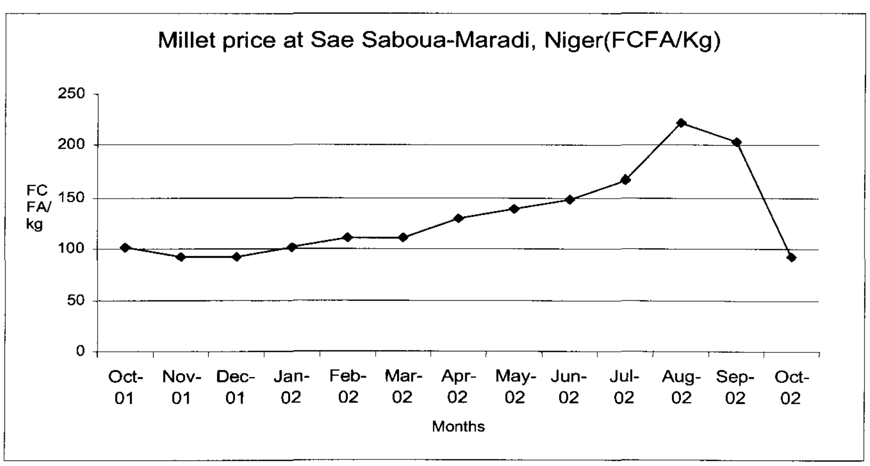

Figure 1. Farmer estimates of seasonal millet prices in the Maradi region of Niger for the crop year 2001-02
Source: Ouendeba et al., 2003.

inclusion of dirt and stones in the marketed grain. Women have to be hired by the processors to laboriously clean up the grain. Over time the processors are expected to be prepared to pay a quality premium for a higher-quality product and the easiest first innovation was to put the "bache" (rug) under the grain for the threshing. In the future, there is expected to be a high return for introducing mechanical threshers in the village.

The final change (4 above) may be the most important and also the most difficult. Most Sahelian governments act as if the only available poverty policy is to keep the prices of food staples low. NGOs reinforce this behavior by dumping food staples from developed countries. Both thus reduce the profitability of agricultural production and discourage farmers from using inputs or making investments in agriculture. There are other poverty policies besides depressing the agricultural sector. For example, NGOs could buy food staples from the higher-rainfall regions of developing countries in adverse climatic years and then use these staples in Food for Work programs in the low-rainfall regions in the same country.

In the long run, technological change will gradually reduce the costs of output, enabling food staple prices to decline while farmers (and consumers) still benefit. Some farmers can benefit from costs falling faster than prices. However, in the short run, it is important to avoid the food-price collapses from the combination of good weather and technological change. Moreover, avoiding the government- and NGO-induced distortions of driving down the profitability of agriculture in adverse climate years is also important.

Do these different strategies make a difference by enabling farmers to pay for the necessary inputs to modernize their agriculture? Figure 2 illustrates the ability of farmers to pay off the costs of improved seeds and fertilizer. The break-even point for paying for inputs with no quality premium is almost at 150 CFA/kg. With a 10 CFA price premium the break-even point is 115 CFA. With a 20 CFA/kg premium for quality, farmers can even make a small profit selling at the harvest price of 80 CFA/kg. Many processors are now prepared to pay a 10 CFA premium for keeping the rocks and dirt out of the millet. Further quality improvements are also feasible.

How well did the contact program between farmers and processors function in the first year of activity 2001-2002 in increasing the incomes of farmers? 2002 was a very dry year and yields were way down. Of the last six years in Mali 1997-1999 were good, 2000-2001 normal and this year bad. With yields down, quantities of millet and sorghum available for sale were generally below what farmers had contracted with the processors.

In Senegal and Burkina Faso, processors refused to buy at the higher prices requested after harvest and with a quality premium, so the NGOs coordinating this program, EWA and SG 2000, became the buyers. They gave good prices and repayment rates were high. There is a process between processors and farmers of learning about bargaining power. In the past, the processors, being more limited in number and communicating among themselves, had most of the market power. Now this begins to change as farmers organize into producers' associations with the help of these NGOs.

In both Senegal and Niger, the yield effects of new technologies were very important in increasing incomes (Table 1). Farmers are generally recognizing the need to buy inputs even with the poorer responses of the dry year. There is an awareness of the loss of soil fertility with higher population densities and the inadequacy of organic fertilizer. Fertilizer prices have been increasing so the importance of getting a good price for

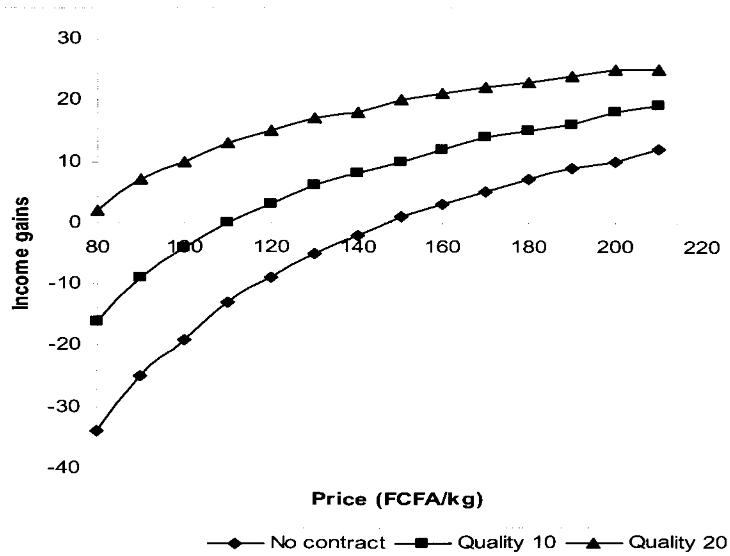

Figure 2. Income gains for participating farmers for three pricing scenarios, Kondogol, Mali, 2003
Source: Ouendeba et al., 2003.

Table 1. Per-hectare income gains[1] from the contract program in the three countries

	Niger	Mali	Senegal
Yield effect	11%	4%	16%
Price effect	2%	21%	11%
Total effect	13%	23%	27%

[1] Using harvest-time price from field interviews in the four-country development project.
Source: Estimated from the field interviews in the four country development project.

millet/sorghum is becoming generally recognized. This is the main focus of the program.

In Niger and Mali, active governmental intervention by importing food staples affected prices. In Niger, there has been purchasing to add to public cereal stocks, thereby driving prices upward and causing farmers to lose interest in the contract price. In Mali with the bad weather, the government and NGOs have been importing grains and driving down the sorghum/millet price after June 2003 but well before the next harvest.

In Senegal, EWA bought 12 tons of millet at CFA and then sold it to the yogurt producer for 200 CFA/kg. Of the various processors, EWA had the best understanding of the bargaining-power problem. Apparently farmers will need the interventions of these NGOs until they learn how to negotiate for their share. The price effect was the dominant effect in Mali and also very important in Senegal (Table 1).

Our first objective in this program is to enable farmers to increase their bargaining power and to get higher prices so they can afford to pay more for inputs. Farmers need to purchase fertilizer and improved cultivars since their soils have been mined of nutrients and new cultivars are needed to take advantage of higher input conditions.

But an important secondary purpose of this activity is to assure the supply to the processors and obtain for them a higher-quality product. The first requirement on the quality side is farmer utilization of a uniform and higher-quality variety and secondly to avoid threshing on the ground. Threshing techniques vary and the simplest improvement is to put a "bache" (sheet or rug) down on the ground. Then threshing can be done with sticks or by driving over the bache. Clearly the next technical improvement needs to be threshing machines at the farm level.

Shifts in Demand with the Rapid Growth of the Poultry Industry in Central America. The most significant shift in demand for sorghum is the structural change in diets as incomes grow. Consumers reduce their consumption of the basic grains (or in higher-rainfall regions, tubers) and consume higher levels of animal products (meat, milk, and cheese), fruits, and vegetables. Poultry consumption increases exponentially as production and consumption technology shifts result in rapid declines of the price of poultry relative to other meats. These changes continue for decades and are still going on in the US. Central America is well into these changes in consumption patterns (Fig. 3). For sorghum producers in Central America, this implies the need to compete with maize imports and domestic maize production. Both El Salvador and Nicaragua have been implementing policies for their sorghum producers to benefit from these demand shifts. We are studying the interaction between marketing strategies and the introduction of new technologies by sorghum producers in both El Salvador and Nicaragua.

Technology-Marketing Evaluation in Mozambique and Mali. In Mozambique during the winter of 2003, Rafael Uaiene spent three months in the field interviewing maize/sorghum producers in one of the principal zones of agricultural production in the country. He is presently analyzing the data for the comparison and contrast of the process of technological change-marketing strategy for maize and sorghum. An important component of this activity is the development of new markets through product processing of these two crops.

Dr. Sanders and Tahirou Abdoulaye spent two weeks with Ouendeba Botorou and Aboubacar Traore interviewing farmers and processors about the introduction of N'Tenimissa and progeny in Mali. Yigezu will be following up this activity, doing field surveying and then his analysis for his M.S. degree beginning in the fall of 2003.

Networking Activity

Dr. Sanders participated in the *Striga*-resistant sorghum and associated technologies workshop organized by Dr. Gebisa Ejeta in Nazareth, Ethiopia in November 2002. He presented a paper there with Nega Wubeneh's results from the introduction of *Striga*-resistant sorghums and associated technologies in Tigray, Ethiopia and interacted with participants. He began the planning for a more thorough evaluation of the introduction of the *Striga*-resistant sorghums and associated technologies in Ethiopia in 2004.

Dr. Sanders and Kidane Georgis presented a summary of their results from the six-country Horn study for IGAD in the

PI Meeting of INTSORMIL researchers and collaborators in Addis Ababa, Ethiopia in November 2002. Dr. Sanders also presented a paper at this same meeting, laying out the marketing strategy and the preliminary results from the four-country Sahelian project.

In July and August 2002, Amare Belay from the Tigray regional research station in Mekelle and Kidane Georgis, the Director of the Dryland Research Program in EARO (the Ethiopian Agricultural Research Organization) in Addis Ababa came to Purdue University to collaborate with us. Amare Belay was here for three weeks and Kidane Georgis for two months. This travel, per diem, and consulting fees were paid by Dr. Gebisa Ejeta's regional budget for the Horn of Africa.

Publications and Presentations

Publications

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Presentations

Ouendeba, B., Abdoulaye, T. and Sanders, J. H., "Food Staples in West Africa: Production and Marketing," Paper presented at the Ethiopian meeting of the INTSORMIL PIs, Addis Ababa, Nov. 2002.

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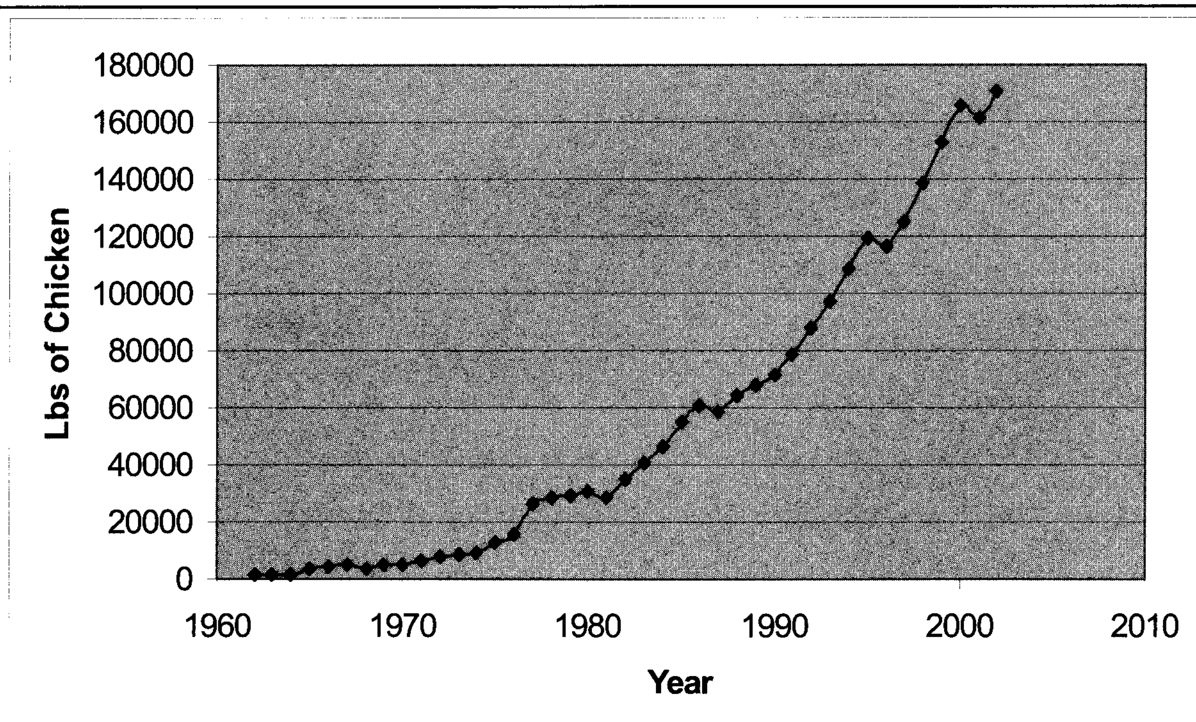

Figure 3. Growth of poultry production in El Salvador, 1962-2002
Source: Unpublished data from Aves (Chicken Producers' Association in El Salvador).

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

Project UNL 213
Stephen C. Mason
University of Nebraska

Principal Investigators

Dr. Stephen C. Mason, University of Nebraska, Dept of Agronomy, Lincoln, NE 68583-0915
Dr. Samba Traoré, Cinzana Research Station, IER, B.P. 214, Segou, Mali
Mr. Nouri Maman, INTARNA Research Station, B.P. 429, Maradi, Niger
Dr. Minamba Bagayoko, IER, Niono, Mali
Dr. Taonda Sibiri Jean Baptiste, INERA, Koudougou, Burkina Faso
Mr. Seyni Sirifi, INRAN, Kollo, Niger
Mr. Siebou Pale, INERA, Koudougou, Burkina Faso
Mr. José Wilfredo CasteZeda, CENTA, San Salvador, El Salvador
Mr. Max Hernández, CENTA, San Salvador, El Salvador
Mr. Orlando Téllez Obregón, INTA, Somoto, Nicaragua
Mr. Leonardo García Centeno, UNA, Managua, Nicaragua

Collaborating Scientists

Dr. Ouendeba Botorou, ROCAFREMI, Niamey, Niger
Mr. René Clará Valencía, Sorhgum Breeder, CENTA, San Salvador, El Salvador
Mr. Hector Deras, Sorghum Breeder, CENTA, San Salvador, El Salvador
Dr. Bruce Hamaker, Food Scientist, Purdue University, West Lafayette, IN 47907
Dr. Jeff Wilson, Millet Breeder, USDA-ARS, Tifton, GA 31793
Dr. Issoufou Kapran, Sorghum Breeder, INRAN, Niamey, Niger
Dr. Charles Wortmann, Soil Scientist, Univ. of Nebraska, Lincoln, NE 68583-0915
Dr. Martha Mamo, Soil Scientist, Univ. of Nebraska, Lincoln, NE 68583-0915
Prof. R. Klein, Agronomist, West Central Res. & Ext. Center, Univ. of Nebraska, North Platte, NE
Dr. Drew Lyon, Agronomist, Panhandle Res. & Ext. Center, Univ. of Nebraska, Scottsbluff, NE
Dr. Alex Martin, Weed Scientist, University of Nebraska, Lincoln, NE 68583
Dr. Glen Helmers, Agricultural Economist, Univ. of Nebraska, Lincoln, NE 68583
Mr. Julio C. Molina Centeno, Agronomist, Proyecto Investigación y Desarrollo, INTA, Estelí, Nicaragua
Mr. Quirino Argueta Portillo, Soil Scientist, CENTA, San Salvador, El Salvador
Mr. Rafael Obando Solis, Plant Breeder, CNIA/INTA, Managua, Nicaragua
Mr. Nanga Kaye Mady, Agronomist, Moundou, Chad
Dr. Gerrit Hoogenboom, Agronomist, Univ of Georgia (Sustainable Agriculture and Natural Resource Management) [SANREM] CRSP

Summary

Principle investigators in INTSORMIL Project UNL 213 continue with international research efforts related to nutrient management and use efficiency in West Africa and Central America. Preliminary microdose fertilizer application responses in West Africa have increased pearl millet grain (35%) and stover (56%) yields, but the results are variable across locations. Highest grain and stover yields have been produced with application of 20 kg ha^{-1} P and 30 kg ha^{-1} N which more closely matches the nutrient extraction by the crop. Research showed that an animal traction zai system produced similar yield to the traditional zai system across six different soil textures in Burkina Faso, but while only requiring 22 man-hours labor per hectare. In Central America, nitrogen application increased sorghum grain yields quadratically for both photoperiod sensitive and

insensitive varieties. Little difference in nitrogen use efficiency was found among the photoperiod insensitive varieties tested, indicating that broader screening of germplasm in Central America sorghum breeding programs will be needed to identify and develop high nitrogen use efficient photoinsensitive sorghum varieties. Nitrogen application of 90 to 115 kg ha^{-1} was necessary to optimize grain yields. In El Salvador, the photoperiod sensitive varieties SCP-805 and ES-790 for relay intercropping with maize were found to be high yielding and to have high NUE and % N Fertilizer Recovery. Grain yields were optimized with 47 kg ha^{-1} N application. Validation trials are underway on-farm in collaboration with non-governmental agencies to promote the use of the variety SCP-805 with moderate application of nitrogen fertilizer.

Research in the United States indicates that kernel weight is the most important yield component to explain yield variation across environments for pearl millet and grain, and therefore, merits more attention in plant breeding and crop management research. Crop rotation was shown to have economic advantages due to diversification benefits in addition to enhanced yields, reduced costs and greater yield stability. Study of "old" and "new" maize and sorghum hybrids indicate that maize had higher yield potential than sorghum in 1960, and that maize grain yield has increased more rapidly than grain sorghum for dryland production on high water holding capacity soils in the western corn belt. Plant breeding programs must increase sorghum grain yield potential to maintain or increase sorghum's role in Great Plains agriculture.

INTSORMIL Project UNL 213 emphasizes capacity development through graduate education, short-term training, and coordination of the Central America Region Program. A graduate student from Niger completed a Ph.D. degree, and students from Chad and the U.S. are working on M.S. degrees.

Objectives, Production and Utilization Constraints

Objectives

- Conduct multi-year research on microdose, N and P fertilizer application on pearl millet grain yield, nutrient removal, and changes in soil nutrient levels in Burkina Faso, Mali and Niger.
- Conduct research on mechanized zai production system for pearl millet in Burkina Faso, weed control interactions with fertilizer rates in Mali, and fertilizer rate by plant population for hybrid grain sorghum seed production.
- 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 to better understand the shift of dryland sorghum area to maize in the Western Corn Belt.
- Determine recommended production practices for pearl millet production in Nebraska.
- Conduct N rate and N use efficiency studies for grain sorghum production in El Salvador and Nicaragua to identify N use efficient varieties and determine N rate recommendations.
- Increase research human capital in West African countries where pearl millet is an important crop through graduate education, short-term training and through mentoring former students upon return to their home country.
- Collaborate with national extension services and NGO/PVOs in transferring improved pearl millet and grain sorghum agronomy practices.

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 inorganic and organic fertilizer management, developing varieties and cropping systems to improve nitrogen use efficiency of sorghum, water management of traditional and improved cultivars, and weed control strategies. Cropping system research efforts require long-term investments of well-trained, interested scientists and stable funding. Education of additional scientists in crop management 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 and as mentored collaborative activities upon return of former graduate students. Studies have been initiated with collaborators in Central America on nitrogen fertilizer management and identification of nitrogen use efficient genotypes for grain sorghum production which is also a critical issue in the region. In the U.S. Great Plains, production practice recommendations for planting date, nitrogen rate and water supply for high yielding, dwarf pearl millet hybrids are being determined to help adoption as an alternate 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)

Environment Effect on Pearl Millet and Grain Sorghum Yield Components (Nouri Maman, Ph.D. Thesis)

Research Methods

The experiment was conducted on a Keith silt loam under a linear move irrigation system with drop nozzles at the High Plains Agricultural Laboratory located at Sidney in western Nebraska (semi-arid environment) in 2000 and 2001. The experiment was 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, rainfed; (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 fill stage. Environments were considered to by year, location and water regime combinations. Grain and the yield components of panicles m^{-2}, kernels panicle-1 and kernel weight were determined at harvest and corrected to 14% water content. A similar study was conducted in eastern Nebraska at Mead (sub-humid environment) using a furrow irrigation system. Data were analyzed using analysis of variance and path correlation procedures.

Research Results

At Sidney no rainfall occurred during the 2000 growing season, thus low average (across water regimes) grain yields of 1.9 Mg ha^{-1} for pearl millet and 4.1 Mg ha^{-1} for grain sorghum were produced. In 2001, Sidney produced higher average yields of 3.9 Mg ha^{-1} for pearl millet and 5.0 Mg ha^{-1} for grain sorghum with good rainfall, and in Mead in both years the average grain yields were 5.1 Mg ha^{-1} for pearl millet and 6.1 Mg ha^{-1} for grain sorghum. The higher yields at Mead than at Sidney was the result of higher soil water holding capacity and a less stressful production environment.

In the semi-arid, non-irrigated environment at Sidney, all yield components were positively correlated with pearl millet and grain sorghum grain yield = 0.87 to 0.99), but due to the greater direct effect, kernel weight (p = 0.46) and panicles m^{-1} (p = 0.80) were the major contributors to yield (Table 1). In the sub-humid environment at Mead, kernel weight was the major contributor for pearl millet grain yield with a positive correlation = 0.81) and greatest direct effect (p = 0.77). Yield increase with irrigation in the semi-arid environment in western Nebraska resulted from increased panicles m^{-2}, kernels panicle $^{-1}$, and kernel weight for both crops. Yield increase in the sub-humid climate in eastern Nebraska with irrigation for pearl millet was mostly due to an increased kernels $panicle^{-1}$. Kernel weight, with greater positive correlation (r = 0.64 to 0.99) and greater direct effect (p = 0.40 to 0.98), was the major yield contributor for both crops in all sub-humid environments. In all sub-humid environments, except for grain sorghum panicles m^{-2} with no irrigation, kernel weight was the most important yield component for pearl millet and grain sorghum. It was concluded that

Table 1. Path analysis direct effects (underlined and bold) and indirect effects of number of panicles m^{-2}, kernel weight, and number of kernels per panicle of pearl millet and grain sorghum as affected by water regimes in 2000 and 2001 at Sidney, NE.

	Pearl millet				Grain sorghum			
	Panicles m^{-2}	Kernel weight	Kernel $panicle^{-1}$	r	Panicles m^{-2}	Kernel weight	Kernel $panicle^{-1}$	r
All water regimes								
Panicles m^{-2}	**0.16**	0.04	0.14	0.34	**0.17**	0.53	0.10	0.80
Kernel weight	0.01	**0.46**	0.41	0.87	0.14	**0.65**	0.07	0.86
Kernels $panicle^{-1}$	0.05	0.42	**0.45**	0.93	0.08	0.21	**0.21**	0.51
No-irrigation								
Panicles m^{-2}	**0.25**	0.38	0.30	0.92	**0.80**	0.35	-0.16	0.99
Kernel weight	0.20	**0.46**	0.31	0.97	0.76	**0.37**	-0.16	0.97
Kernels $panicle^{-1}$	0.23	0.43	**0.33**	0.98	0.72	0.33	**-0.18**	0.87
Boot irrigation								
Panicles m^{-2}	**0.19**	-0.75	-0.22	-0.78	**-0.12**	0.70	-0.06	0.52
Kernel weight	-0.16	**0.89**	0.26	0.99	-0.10	**0.88**	-0.15	0.63
Kernels $panicle^{-1}$	-0.15	0.86	**0.27**	0.98	0.02	-0.30	**0.46**	0.18
Mid-grain fill irrigation								
Panicles m^{-2}	**0.02**	-0.12	-0.05	-0.15	**-0.09**	0.81	0.01	0.73
Kernel weight	-0.004	**0.68**	0.32	0.99	-0.07	**0.98**	-0.08	0.83
Kernels $panicle^{-1}$	-0.003	0.65	**0.33**	0.98	0.002	-0.34	**0.22**	-0.12
Multiple irrigation								
Panicles m^{-2}	**0.27**	-0.49	0.19	-0.41	**0.01**	0.41	-0.10	0.31
Kernel weight	-0.22	**0.61**	0.40	0.79	0.001	**0.96**	-0.07	0.90
Kernels $panicle^{-1}$	-0.12	0.54	**0.46**	0.88	-0.002	0.22	**0.29**	0.07

plant breeding and crop management research to increase pearl millet and grain sorghum yield should increase emphasis on kernel weight.

Impact of Crop Rotation on Risk (Nouri Maman, Ph.D. Thesis)

Research Methods

To isolate the risk contribution to income stability from crop rotations, an analysis of two eastern Nebraska dryland rotation studies was done. One was a corn-soybean rotation with data from 1985 to 1998 and the second, a grain sorghum - soybean rotation study with data from 1981 to 1996. Historic yield, estimated operating expenses and grain price data were used to calculate net returns for continuous corn (or grain sorghum), continuous soybean, diversification without crop rotation, and rotational cropping systems. The four cropping systems were evaluated for average net returns and risk. Risk was calculated as the standard deviation of net returns (measure of stability of net returns) and totaling the dollar deficits for all years where net returns fell below $100 per acre.

Research Results

In the corn-soybean study the standard deviation of net return was $64 for continuous corn, $51 for continuous soybean, $46 for the diversification system, and $57 for the rotation which was basically mean of the two continuous systems. In this study, the net return variability was greater for the rotation system than for the diversification system, thus crop rotation reduced stability of crop yields. In contrast, in the grain sorghum-soybean study the standard deviation was $67 for continuous grain sorghum, $52 for continuous soybean of, $41 for diversification, and $40 for the rotation. In this study crop rotation increased average net returns, and both crop rotation and diversification systems reduced return variability. For both experiments, the rotations reduced risk in terms of net returns meeting a target return. This was due to the increased yield and reduced cost associated with use of crop rotation rather than continuous cropping.

Crop rotation exhibited potential economic advantages over continuous cropping. The was partially due to diversification (i.e., more than one crop being present in an individual year), but was also influenced by enhanced yields, reduced costs, and the potential increase in yield stability. The latter was much more evident in the grain sorghum-soybean study than the corn-soybean study.

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 as the best performing hybrids in the University of Nebraska Performance Tests and they were produced in three environments each year. The environments were sandy loam and silty clay loam soil types, and irrigated and dryland water regimes on the silty clay loam soil. Regression analysis was conducted to relate year of hybrid release to yield with the objective to determine if a difference in rate of yield increase was present between maize and grain sorghum for different production environments.

Research Results

Maize yields were higher than grain sorghum for all production environments and hybrids (Fig. 1). On the high water holding capacity silty clay loam soil, irrigation increased maize

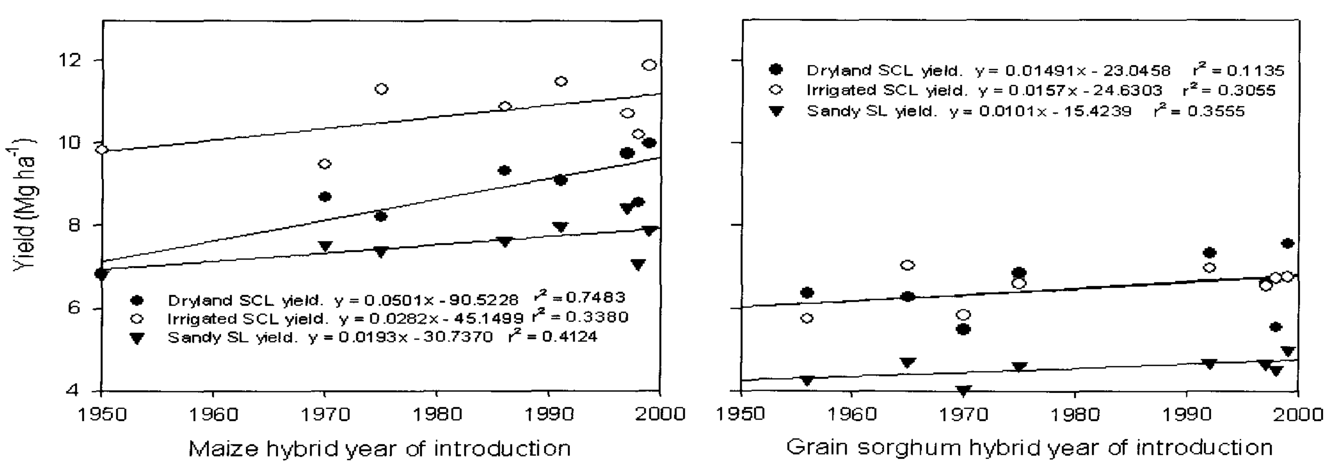

Fig. 1. Grain sorghum and maize grain yield as influenced by year of introduction for dryland silty clay loam soil, irrigated silty clay loam soil and dryland sandy loam soil environments, 1999 - 2001.

grain yield but not for grain sorghum. The rate of yield increase was similar for maize in the sandy loam soils, and grain sorghum in all production environments with the rate of increase being 0.05 ± 0.004 Mg ha^{-1} yr^{-1}. The rate of increase for irrigated maize was 0.0282 Mg ha^{-1} (28 kg ha^{-1}) and 0.0501 Mg ha^{-1} (50 kg ha^{-1}) for dryland maize produced in the high water holding capacity silty clay loam soil. These rates of maize yield increase, except for the dryland, high soil water holding capacity soil, are considerably lower than the 57 to 89 kg ha^{-1} yr^{-1} reported in the literature for dryland production in central Iowa (Duvick and Cassman. 1999. Crop Sci.39:1622 - 1630). This suggests that the ability to tolerate intermediate stress likely to occur in dryland production on high water holding capacity soils has been the major contribution of plant breeding to maize yield improvement in eastern Nebraska during the past 50 years. These rates of sorghum yield increase due to hybrid improvement are also less than the 23 kg ha^{-1} yr^{-1} reported in the literature for Bushland, Texas (Unger and Baumhardt. 1999. Agron. J. 91: 870 - 875). The higher yields and higher rate of yield improvement of maize on dryland, high soil water holding capacity soils partially explain the replacement of dryland grain sorghum with dryland maize in the western corn belt during the last 10 years.

International

Microdose Fertilizer Study (Taonda Jean-Baptiste - Burkina Faso, Minamba Bagayoko and Samba Traoré -Mali, and Seyni Sirifi - Niger)

Research Methods

Three-year central studies were initiated on-station in Burkina Faso (pearl millet), Mali (pearl millet on sandy soil and grain sorghum on heavy soil) and Niger (pearl millet) in 2001. A randomized complete designed study was used with four replications. Treatments consisted of zero, microdose (capfull of complete fertilizer in the seed hill at planting), micodose + 20 kg ha^{-1} P, microdose + 40 kg ha^{-1} P, microdose + 30 kg ha^{-1} N, microdose + 60 kg ha^{-1}, microdose + 20 kg ha^{-1} P + 30 kg ha^{-1} N, and microdose + 40 kg ha^{-1} P + 60 kg ha^{-1} N. Each plot was sampled prior to initiating the experiment so that soil nutrient levels after three-years could be determined. Grain and stover yield, and N and P uptake in the grain and stover were collected. In addition, satellite studies were conducted on farms using zero, microdose and microdose + 20 kg ha^{-1} P or 20 kg ha^{-1} P + 40 kg ha^{-1} N treatments. One replication was planted per farm, and in the data analysis farms were considered to be replications.

Research Results

Preliminary results indicated that the yield increase due to microdose fertilizer application was not uniform across locations in the three countries, nor between station and on-farm sites. However, on the average, microdose fertilizer application increased grain and stover yield by 35 to 61% on-station and on-farm (Tables 2 and 3). Clearly the microdose application is a low cost investment that has a high probability to increase grain yields across the West Africa pearl millet production area. On-station studies indicated that to maximize grain and stover yields required application of 20 kg ha^{-1} P and 30 kg ha^{-1} N in addition to the microdose application. A related study on grain sorghum in Burkina Faso in 2002 had a grain yield increase from 1.4 to 2.2 Mg ha^{-1} Earlier research (Bagayoko et al., 2000, J. Agric. Sci. 135: 399 - 407; Bagayoko et al., 2000, Plant Soil 128: 103 - 116)) indicated that P application and crop rotation with cowpea increased early season root growth leading to greater exploration of the soil profile for nutrients and increased early endomyccorhizal infections, thus stimulating plant growth and nutrient uptake. This increase in grain and stover yield removes more N and P than is applied with the microdose application, so may actually contribute to more rapid depletion of soil nutrients in these soils. One goal of this research is to continue these long-term studies to determine whether more rapid nutrient depletion occurs or not.

Weed Control X Fertilizer Study (Samba Traoré - Mali)

Research Methods

A randomized complete block designed experiment to evaluate the interactive effects of hand weeding method and fertilizer application on pearl millet grain and stover yield was conducted at the Cinzana Research Station in 2001 and 2002. Pearl millet was hill planted on ridges after fertilizer application. Hills were thinned after emergence to two plants per hill. Fertilizer treatments consisted of microdose (2 grams diammonium phosphate per hill), 6 grams of 15-15-15 per hill, and 4 T ha^{-1} manure incorporated during soil preparation plus 50 kg ha^{-1} diammonium phosphate broadcast applied after emergence. Mechanical weed control treatments consisted of complete control, weeding of ridges only, and no weeding. Grain and stover yield were determined, and data were analyzed using analysis of variance procedures.

Research Results

Analysis of variance indicated that yield differences were due to year X weed control and year X fertilizer treatments. No weed control X fertilizer interaction effects were present. In both years, rainfall was limited late in the growing season resulting in average grain yields of 800 to 900 kg ha^{-1}, and average stover yields of 3344 kg ha^{-1} in 2001 and 1635 kg ha^{-1} in 2002. Weed competition was much greater in 2002 than 2001, at least partially accounting for the lower stover production in 2002. In 2001 with low weed pressure present, mechanical weeding treatments had little effect on grain and stover yield, while in 2002 weeding of ridges increased grain yield by 470 kg ha^{-1} (93%) and complete weed control increased grain yield

Table 2. On-station mean pearl millet grain and stover yield as influenced by fertilizer treatment in West Africa. Values represent mean of location (Burkina Faso, Mali and Niger), year (2001 and 2002) and soil type (sandy and loam) in Mali.

Fertilizer Treatment	Grain Mean	Grain Range	Grain Increase	Stover Mean	Stover Range	Stover Increase
	Mg ha^{-1}		%	Mg ha^{-1}		%
Zero	0.46	0.11 to 0.88		1.6	0.5 to 4.1	
Microdose	0.62	0.34 to 1.10	35	2.5	1.1 to 6.3	56
Microdose + 20 kg ha^{-1} P	0.77	0.24 to 1.23	67	3.1	1.4 to 6.8	94
Microdose + 40 kg ha^{-1} P	0.81	0.46 to 1.40	76	2.9	1.2 to 5.3	81
Microdose + 30 kg ha^{-1} N	0.69	0.37 to 0.95	50	3.0	1.2 to 8.6	88
Microdose + 60 kg ha^{-1} PN	0.71	0.38 to 1.12	54	3.0	1.2 to 8.8	88
Microdose + 20 kg ha^{-1} P + 30 kg ha^{-1} N	0.97	0.60 to 1.33	111	3.7	1.5 to 8.4	131
Microdose + 20 kg ha^{-1} P + 30 kg ha^{-1} N	0.85	0.35 to 1.29	85	3.7	1.8 to 8.4	131

Table 3. On-farm mean pearl millet and sorghum grain and stover yield as influenced by fertilizer treatment in West Africa. Values represent means of locations (Burkina Faso, Mali and Niger) and year (2001 and 2002).

Fertilizer Treatment	Grain Mean	Grain Range	Grain Increase	Stover Mean	Stover Range	Stover Increase
	Mg ha^{-1}		%	Mg ha^{-1}		%
Zero	0.44	0.27 to 1.00		2.4	0.4 to 5.9	
Microdose	0.71	0.33 to 1.43	61	3.8	1.1 to 7.9	58

by 736 kg ha^{-1} (146%). The application of 6 gram diammonium phosphate did not increase grain or stover yield due to salt injury reducing emergence. The manure + 50 kg ha^{-1} diammonium phosphate treatment did not increase grain yields greatly in 2001, but in 2002 increased grain yields by 912 kg ha^{-1} (150%) over the microdose treatment. Climatic factors make it difficult to draw concrete conclusions from these two years results.

Mechanized (Animal Traction) ZaV Research (Taonda Jean Baptiste - Burkina Faso)

Research Methods

The traditional zaV system composed of planting pearl millet seed in a small hole with a small amount of manure which increases water infiltration on some soils and results in increased yield, but requires considerable land labor. Scientists at INERA have developed a mechanized zai using animal traction. The objective of this study was to determine the effectiveness of the mechanized zaV (with 300 g compost per hill) to the traditional zaV (with 300 g compost per hill) and a flat-planted control (without compost) across six different soil types (textures) in Burkina Faso. The study was conducted on 12 farms in the villages of Saria, Nandiala and Kindi in a 800 mm yr^{-1} rainfall zone. Each farm considered a replication. The soil types present on the farms was sandy (2 farms), sandy loam (5 farms), sandy clay (5 farms), clay (2 farms), gravelly clay (4 farms) and gravelly (6 farms).

Research Results

Pearl millet grain yields varied across soil types with control yields ranging from 246 to 686 kg ha^{-1} (Table 4). The use of the zaV or mechanized zaV consistently increased yields, with the yield increase being greatest on the gravelly soil. Pearl millet stover yield was increased by a similar magnitude. The combination of tillage, creation of a micro-catchment to increase water infiltration, and compost application certainly increased crop yield, and the human labor savings of approximately 278 man-hours ha^{-1} suggest that this is a viable technology for Burkina Faso production situations. The economics of adoption ultimately must include the cost and maintenance of the traction animal and equipment, and of the compost. A complete economic analysis is being conducted, with intent to actively promote transfer of this technology to producers.

Table 4. Planting system influence on pearl millet grain yield across soil types in Burkina Faso, 2001 - 2002.

Planting System	Sandy	Sandy Loam	Sandy Clay	Clay	Gravelly Clay	Gravelly	Mean
	kg ha^{-1} (% increase)						
Control (Flat)	457	246	473	686	492	289	441
Zaï	824 (80%)	433 (76%)	763 (61%)	1189 (73%)	824 (67%)	830 (187%)	811 (84%)
Mecanized Zaï	1032 (125%)	573 (133%)	787 (66%)	1111 (62%)	1003 (104%)	852 (195%)	893 (102%)

Production Practices for Hybrid Sorghum Seed Production (Seyni Sirifi - Niger)

Research Methods

A study was conducted in Lossa, Niger in 2001 and 2002 to determine recommended plant populations and nitrogen application rates for seed production of the sorghum hybrids NAD1 and F221. The experimental design was a randomized complete block with split plot treatment arrangement and three replications. Whole plots were four rows of the female inbred lines of Tx623A for NAD1 and 221A for F221 with a row of the male parent MR 732 on both sides. The sub-plots were a factorial combination of four plant populations (15,625; 20,833; 31,250; and 62,500 plants ha^{-1}) and four nitrogen rates (0, 22, 44 and 66 kg ha^{-1} as urea). were planted planted at four plant populations and four nitrogen rates. Date of flowering, plant height and seed yield data was collected.

Research Results

In 2002, seed was not produced due to nicking problems between male and female plants, and the yields were very low in 2001 ranging from 41 to 452 kg ha^{-1}. In general, the best yields were produced with a plant population of 31,250 plants ha^{-1} in combination with 66 kg ha^{-1} N. Crop conditions at the Lossa Station for planting time and supplemental irrigation are critical to justify hybrid seed production at this location.

Nitrogen Use Efficiency (NUE) of Photoperiod Insensitive Sorghum Varieties (Wilfredo CastaZeda, Leonardo García and Orlando Téllez - El Salvador and Nicaragua)

Research Methods

A three-year study was conducted at two locations in El Salvador and two locations in 2002-2003 in Nicaragua, and in 2002-2003 in El Salvador with the objective to determine if NUE differences exist among photoperiod insensitive sorghum varieties and optimal N fertilizer rates for grain sorghum production, and to identify high NUE varieties. At each location a factorial combination of four grain sorghum varieties were grown with four N fertilizer rates in a randomized complete block design with four replications. Grain and stover yield, and N concentration of grain and stover at harvest were collected in 2001 to allow determination of NUE. Data analysis was done using analysis of variance procedures, and orthogonal contrasts determined for N rate response. In 2002, 24 lines from the breeding program were grown with out N and with 112 kg ha^{-1} N, and evaluated for grain and stover yield, percentage N, and NUE in Nicaragua. These same breeding lines were evaluated for grain and stover yield, and agronomic characteristics in El Salvador and Nicaragua.

Research Results

Among the photoperiod insensitive varieties only small differences in grain, biomass and fertilizer nitrogen use efficiency were found, and it was concluded that screening of a broad base of germplasm used in breeding programs in El Salvador and Nicaragua would be needed to identify and develop varieties with high nitrogen use efficiencies. This research was initiated in 2002, and the lines ICSVLM-90510, ICSVLM-90520 and ICSVLM-89513, look promising based upon grain and stover yield without and with fertilizer N application, and agronomic conditions in both El Salvador and Nicaragua.

Grain sorghum yields usually responded to increasing N application rates in a quadratic manner, and yield maximized occurred with 90+ (Nicaragua) to 115 kg ha^{-1} by the highest rate used in either El Salvador or Nicaragua. In El Salvador, 115 kg ha^{-1} nitrogen increased average grain yield of photoperiod insensitive sorghum varieties from 2.5 to 4.5 Mg ha^{-1} in both years, while 90 kg ha^{-1} nitrogen in Nicaragua increased average grain yield from 1.7 to 3.6 Mg ha^{-1}. These impressive yield increases resulting from N application and economic analyses indicate that producers should increase N application rates to 90 to 115 kg ha^{-1} N to optimize economic return.

Nitrogen Use Efficiency (NUE) of Photoperiod Sensitive (Maicillo Criollos) Sorghum Varieties for Relay Intercropping with Maize (Wilfredo CastaZeda - El Salvador)

Research Methods

A two-year study was conducted at Santa Cruz Porillo and Izalco in El Salvador in 2002-2003 with the objective to determine if NUE differences exist among photoperiod sensitive sorghum varieties and optimal N fertilizer rates for grain sorghum production, and to identify high NUE varieties. At each location a factorial combination of six grain sorghum varieties were grown with N fertilizer rates of zero, 47, 95 and 142 kg ha^{-1} in a randomized complete block design with four replications. Grain and stover yield, and N concentration of grain and stover at harvest were collected to allow determination of NUE. Data analysis was done using analysis of variance procedures, and orthogonal contrasts to determine the N rate response.

Results

Across the four location-year combinations, the photoperiod sensitive varieties SCP-805 and ES-790 produced the highest grain yield and grain nitrogen use efficiency, and had high % N fertilizer recovery at both low and high N rates (Table 5). ES-790 had very high % N fertilizer recovery at the 47 kg ha^{-1} N rate, but SCP-805 had slightly higher yield, NUE and % N Fertilizer Recovery at high N rates. The varieties Santa Cruz,

Table 5. Yield and NUE differences among photoperiod sensitive (Maicillo Criollo) varieties in El Salvador, 2002 - 2003.

Variety	Yield		NUE		N Fertilizer Recovery		
	Grain	Stover	Grain	Biomass	47 kg ha^{-1} N applied	95 kg ha^{-1} N applied	142 kg ha^{-1} N applied
	---- Mg ha^{-1} ----		kg grain(biomass) kg^{-1} N		---- % ----		
SCP-805	4.1	6.1	59	136	50	51	44
ES-790	3.9	6.3	55	138	74	46	37
86-EO-226	3.3	5.6	47	131	10	24	17
Limay	3.1	7.6	42	143	42	40	30
Santa Cruz	1.6	7.7	25	140	40	60	33
Yalaguina	1.4	6.9	25	138	33	27	19

Limay and Yalaguina had higher stover and lower grain yield than the other varieties. The variety 86-EO-226 had high NUE, but low % N Fertilizer Recovery suggesting that it efficiently uses N within the plant, but has low ability to take up N from the soil. The variety SCP-805 is being validated on-farms with and without N fertilizer application in collaboration with several Non-Governmental Organizations (NGOs) during the 2003 growing season.

Photoperiod sensitive varieties were selected under low soil N conditions since these producers are poor and seldom apply N to sorghum. Averaged across varieties, yields increased quadratically with increasing N rate. Although the highest yield was produced at the highest N rate, 47 kg ha^{-1} N was the most economical and produced the highest NUE and % N Fertilizer Recovery. Application of 47 kg ha^{-1} N increased grain yield from 2.1 to 3.0 Mg ha^{-1} and stover yield from 5.0 to 7.1 Mg ha^{-1}. It was concluded that relatively low N rate applications should be recommended to producers of Maicillo Criollo sorghum varieties.

Networking Activities

Workshops

INTSORMIL Central America Regional Research Directors Meeting. Managua, Nicaragua, 3 Oct. 2002.

Programa Cooperativo Centroamericano de Mejoramiento de Cultivos y Animales (PCCMCA) Annual Meeting, La Ceiba, Honduras. 28 April - 2 May 2002.

American Society of Agronomy Meetings, Indianapolis, IN. 10 -14 Nov. 2002.

Seyni Sirifi, IFDC/Soil Management CRSP Soil Fertility Workshop. Lome, Togo. Oct. 2002.

Research Investigator Exchange

Nouri Maman (Niger) completed his Ph.D. degree (May 2003) and Delon Kathol (U.S.) will complete his M.S. degree in the coming year. Nanga Kaye Mady (Chad) started a M.S. degree in May 2003.

Research Information Exchange

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

Purchased chlorophyll meters for research use in El Salvador and Nicaragua. A packet of research articles was sent to help collaborators use the chlorophyll meters effectively in research.

Pearl millet growth and nutrient uptake data was shared with Dr. Gerrit Hogenboom, Univ. of Georgia and SANREM CRSP for modeling research and development of decision aid tools.

Visited INTSORMIL research efforts in El Salvador and Nicaragua in Oct 2002 and April 2003.

Publications and Presentations

Abstracts

Mason, S.C. and T.W. Crawford. 2003. INTSORMIL - Programa international de colaboración y apoyo para los programas de investigación de sorgo y mijo. PCCMCA XLIX Reunión Anual, 28 April - 2 May, 2003. La Ceiba, Honduras.

Mason, S.C. and R. Clara. 2003. El programa de INTSORMIL en Centro América 1999 a 2003. PCCMCA XLIX Reunión Anual, 28 April - 2 May, 2003. La Ceiba, Honduras.

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Soil and Water Management for Improving Sorghum Production in Eastern Africa

Project UNL 219
Charles Wortmann and Martha Mamo
University of Nebraska

Principal Investigators

Charles Wortmann & Martha Mamo, Dept of Agronomy & Horticulture, Univ of Nebraska, Lincoln, NE 68583-0915

Collaborating Scientists

Gebisa Ejeta, Purdue Univ, Department of Agronomy, Purdue University, Lilly Bldg State Street, West Lafayette IN 47907
Steve Mason, Univ of Nebraska, Dept of Agronomy & Horticulture, 279 Plant Science, Lincoln, NE 68583-0915
Gary Varvel, USDA-ARS, Univ of Nebraska, 279 Plant Science, Lincoln, NE 68583
Kidane Georgis, EARO-Addis Ababa, P.O. Box 2003, Addis Ababa, Ethiopia.
Zenbaba Gutema, EARO-Melkassa, Nazareth Agricultural Research Center, P.O.Box 436, Nazareth, Ethiopia.
Amare Belay, Mekelle Agricultural Research Center, P.O. Box 492, Mekelle, Ethiopia
Girma Abebe, EARO-Melkassa, Nazareth Agricultural Research Center, P.O.Box 436, Nazareth, Ethiopia
Getachew Alemayehu, EARO-Sirinka Agricultural Research Center, Sirinka, Ethiopia
Kaizzi Kayuki, NARO-KARI, P.O. Box 7065, Kampala, Uganda

Summary

Farmers working with researchers in Ethiopia have tentatively identified niches and opportunities for tillage alternatives and for tie-ridge and planting implements, and research is continuing in four semi-arid sorghum production areas. In northern Ethiopia, sorghum grain and biomass yields were 142 and 88% more with fertilizer application compared to no fertilizer in six on-farm trials. Research on water and nutrient management was initiated in Uganda in 2003 using participatory approaches. Research on P sorption for diverse soils of Ethiopia and Uganda is showing results of soil properties that are important to P sorption, including the importance of termite activity on sandy soils. Preparations have been made to begin data collection for a sorghum production database and atlas for eastern and southern Africa.

Sorghum yield was not increased with the use of starter fertilizers in eastern Nebraska in 2002 but it was a dry year; this research is continuing with six trials established in 2003. The results of research to validate a nitrogen credit to sorghum following soybean in rotation of 84 kg N ha^{-1} generally support this N credit but the results have not been fully consistent; more trials will be conducted to better understand this N rate by environment interaction in 2004. The potential of occasional tillage as a mean to improving agronomic and environmental aspects of no-till systems has been found to be feasible; additional research on occasional tillage is underway as a Ph.D. dissertation topic. Six graduate students are being partly or fully supported by this INTSORMIL project. Drs. Mamo and Wortmann visited collaborators and research areas in Ethiopia and Uganda and hosted two visiting scientists from Ethiopia.

Objectives, Production and Utilization Constraints

- Conduct nutrient management and water conservation research, such as use of tie-ridging or micro-catchments, in two semi-arid areas in Ethiopia.
- Conduct on-farm trials and/or collaborate in on-going station trials to verify N credit to sorghum following soybeans in rotation after soybeans.
- Conduct research on starter fertilizers for no-till sorghum production in Nebraska.
- Implement research to predict P fixation capacity of soils across Nebraska and Ethiopia and assess effect of tillage systems on organic matter.
- Initiate data compilation to evaluate internal nutrient use efficiencies, and relate variations in grain yield and seed number to plant N concentration, uptake, and N harvest index.

Inadequate nutrient supply and water deficits are the primary production constraints addressed in this water and nutrient management research, as well as study of nutrient dynamics in the soil and in the crop.

Research Approach and Project Output

Nutrient and water management research in Ethiopia. The objectives are to obtain farmer and researcher assessment of tillage and implement options and to determine how tillage for water conservation interacts with nutrient supply and time of planting. Trials have been established in four semi-arid sorghum production locations in 2003 with varying elevation ranging 1300 to 1800 m. The locations include Welench'iti, Miesso, Sirinka and Mekelle at Abergele with trials on 3 to 6 farms per site for both April, at some locations, and June planting. In 2002, yield results were obtained at only one location, Abergele, due to drought conditions but farmer assessments were obtained from three locations. Main plot treatments vary according to location but generally include some variation of the following:

Traditional, e.g., tilled with *maresha*, broadcast sowing, and *shilishalo* for weed control.

Tie ridging using modified *maresha* (a test implement) with tie ridges made before planting. Plant in the furrow with a row planter (test implement).

In-furrow row planting with test implement but tie ridge at first weeding with the modified *maresha.*

Conservation tillage or reduced tillage. Plow 1-2 times. Apply Lasso Atrazine pre-emergence.

Farmers identified water deficits, low soil fertility, runoff associated with soil crusting and compaction, as well as *Striga*, as major constraints to sorghum production. Water loss to runoff in May and June is of major concern. Tie-ridging using a modified traditional plow *(maresha)* was seen as easy to use but not very good on stony soil. The draft requirements of the ridger were not too great for the oxen, even in May when oxen are often weakest. The oxen-drawn row planter was tested at Miesso and Wolenchiti where the cooperating farmers determined it to be appropriate for their needs as it was easy to use and gave good placement of seed and fertilizer. Farmers thought that tie-ridging and conservation tillage would be appropriate in their communities with conservation tillage preferred for stony or sandy soils and for those with inadequate access to draft power. Farmers emphasized that significant adoption will require farmer training in the use of the implements and the alternative tillage systems. The preliminary results suggest a need for further investigation of the *maresha* tie-ridger for fine texture soils that are not stony; for sandy and stony soils, the traditional *shilishalo* tillage or conservation tillage systems may be more appropriate. At Mekelle-Abergele in 2002, 6 trials were successfully implemented and grain and biomass yields were 142 and 88% more with fertilizer applied as compared to no fertilizer. There was no effect of tillage method, probably due to lack of heavy rainfall events.

P fixation of soils from Ethiopia and Uganda- Phosphorus sorption isotherms were determined for 30 soil samples collected in Ethiopia and Uganda to the 0-15 cm depth in November 2002. In Ethiopia, sampling was along transects from Debre Zeit east to Miesso and north to Mekelle. In Uganda, samples were collected in five districts of central and eastern Uganda. As termites have much influence on soil properties in Uganda, companion soil samples were also collected from and near termite mounds to evaluate effects on P holding capacity. P sorption maximum and P saturation index (PSI) were well correlated (Fig. 1). P sorption maximum increased moving south from entisol of northern Ethiopia to the more developed central and eastern vertic soils (Fig. 1). However, in the Abergelle region, red soil exhibited much lower P holding capacity than black soil located within few meters. Sand and clay contents of Uganda soils affect P sorption capacity. For sandy soils, soil from termite mounds had greater P sorption capacity than nearby soils while the opposite was true for clay loam soils.

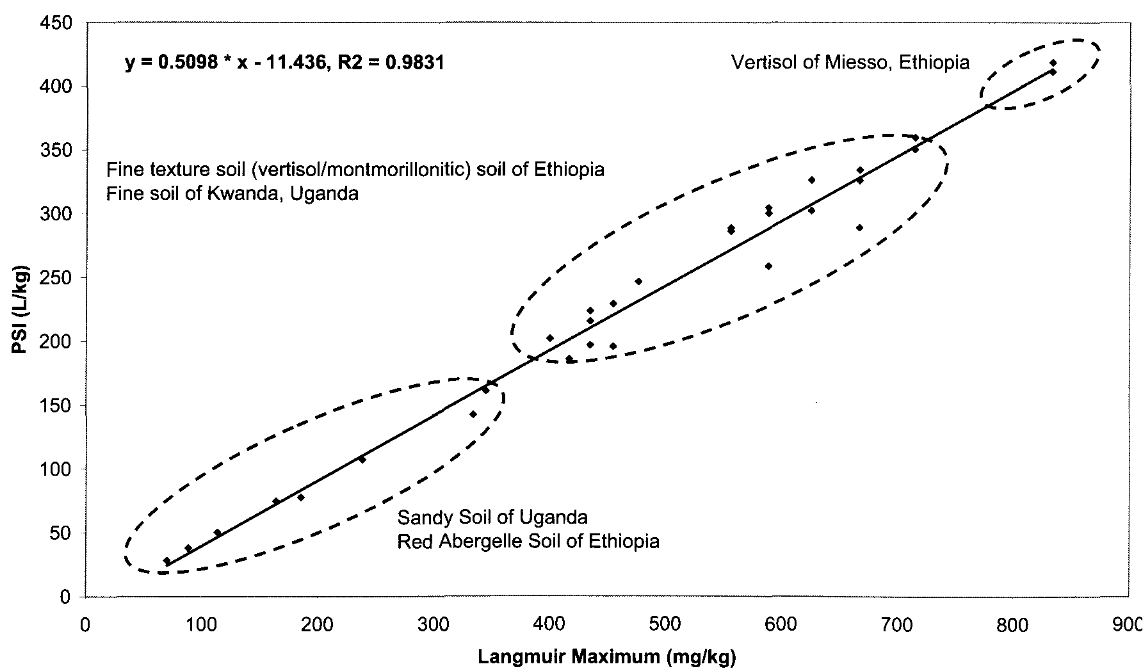

Fig. 1- P Saturation Index (PSI) and Langmuir Sorption Maximum

Table 1. Grain sorghum performance as affected by starter fertilizer treatments in 2002; means of 6 trials conducted under non-irrigated, no-till conditions in eastern Nebraska.

	Plants ha^{-1} 000	Early plant weight g $plant^{-1}$	Yield Mg ha^{-1}
No starter	86.8	5.65	6.20
22-22, 5x5	90.3	5.96	6.38
22-22, over the row	93.3	6.01	6.30
11-11, in-furrow	83.7	5.63	6.21
22-22-0-11, 5x5	91.2	6.14	6.06
22-22-0-11, over the row	90.5	5.54	6.14
11-11-0-6, in-furrow	86.3	6.31	6.08
11-11-0-6, in-furrow with ATS	87.6	5.89	6.17
LSD 0.10	6.02	0.412	0.29

Nutrient and water management research in Uganda. Research was been initiated with farmers in Kumi district in 2003. Farmers, together with research and extension staff, identified priority problems and research topics. On-farm research was conducted during the first season of 2003 but results are not yet available.

Starter fertilizer for no-till sorghum production in Nebraska. In 2002, 6 grain sorghum trials with 4 replications were conducted on farmers' fields across diverse topographic positions/soil types in Gage county of southeastern Nebraska. All sites had a history of continuous no-till and were non-irrigated. Soil pH ranged from 5.3 to 6.1. Soil organic matter was generally more than 3%. Bray-1 P ranged from low to very high. Potassium levels were high at all sites.

Three placement positions were compared: in the seed furrow (in-furrow), over the row, and 5 cm to the side of the row and 5 cm deep (5x5). Liquid starter fertilizer treatments (Table 1) were applied as N+P and N+P+S at the rates of 22 kg ha^{-1} each for N and P, and 11 kg ha^{-1} for S. Half rates were applied with in-furrow application. Ammonium sulfate was the main sulfur source but was compared to ammonium thio-sulfate (ATS) for in-furrow application.

The average density was 88,712 plants ha^{-1} (Table 1). Treatment effects did not have a significant effect but the mean density with in-furrow placement was 85,000 plants ha^{-1} compared to 91,390 for other placements. Early plant weight was greatest with 22-22-0-11 placed 5x5 and with 11-11-0-6 placed in the seed furrow. The average sorghum grain yield was 6.2 Mg ha^{-1} but yield was not affected by starter fertilizer treatment. Results for nutrient uptake are not yet available. Grain yield was not related to early plant growth but plots with more early growth tended to have more heads per acre at harvest time ($r = 0.49$).

Soybean N credit verified for grain sorghum in Nebraska. The UNL nitrogen recommendation for grain sorghum considers expected yield, soil organic matter, soil nitrate-N, and the effect of a previous legume crop. Recent results from on-station research indicate that the mean N benefit to grain sorghum following soybean is 90 kg N ha^{-1} while current recommendations allow 50 kg N ha^{-1}. This research was undertaken to verify a credit of 84 kg N ha^{-1} or to determine the conditions for when this credit is valid.

On-farm trials of four replications are being conducted in southeast Nebraska where the treatments are: 0 N; and the UNL recommendation giving 0, 50, and 84 kg ha^{-1} N credit for soybean. The results from 3 of 4 trials conducted in 2001 and 2002 give verification to the 84 kg N ha^{-1} credit (Table 2). The results of the Nagel trial indicate that 50 kg N ha^{-1} is a better

Table 2. Grain sorghum yield at various N fertilizer rates to verify a 84 kg (75 lb) N credit to sorghum following soybean in rotation.

	Fisser 2001	Nagel	Gronewald A 2002	Gronewald B	Mean
No N applied	4.39	3.91	4.74	6.59	4.90
84 kg N credit	5.66	4.02	5.09	6.22	5.25
50 kg N credit	5.36	5.32	5.17	6.53	5.60
No N credit	5.68	4.94	5.54	6.39	5.64
Sign.	*	*	0.066	0.71	*
LSD 0.05	1.07	1.07	0.61	0.77	0.57
Estimated N need before credits (lb/A)	112	140	78	95	

estimate of the credit. More information is needed to complete the verification.

Tillage and organic matter in Nebraska. Production of the sorghum-soybean rotation and the corn-soybean rotation in no-till systems is common in eastern Nebraska. Improved soil physical properties and increased soil organic matter (SOM) are commonly observed at the 0-5 cm depth with no-till as compared to tillage with little improvement below 5 cm. However, the increase in SOM generally slows or ceases after a few years of no-till. To increase no-till benefits, we hypothesized that occasional tillage of no-till, e.g. once in 15 years, may increase yield over time, improve surface soil to greater depth, and increase C sequestration. The effects of plow-disk tillage versus no-till, and occasional tillage of no-till, on SOM, particulate organic matter (POM), and wet aggregate stability were determined. Soil samples (0-5 cm) were collected from two long-term tillage trials and from a farmer's field where more than 25 years of continuous no-till was interrupted with a single season of disk tillage in 2001 in randomized strips across the field (the Occasional Tillage Trial). The occasional tillage trial was sampled one year after the tillage event. POM and POM:SOM were less with plow-disk tillage than with no-till (Table 3), but SOM was not significantly affected in the sorghum-soybean trial. These properties were not affected by the one-time tillage in the occasional tillage trial. Wet aggregate stability was less with plow-disk tillage than with no-till but not affected in the occasional tillage trial (Table 4).

The results show that occasional tillage can be conducted in no-till systems without soil degradation. Further research is being conducted on no-till production of sorghum and soybeans to determine if the hypothesized benefits of occasional tillage will be achieved.

Table 3. Effects of tillage on soil organic matter fractions.

	POM	SOM	POM:SOM
	Mg g^{-1}		%
	RMF-corn		
Plow-disk	4.1	36.3	11.4
No-till	14.4	48.0	30.0
LSD 0.05	1.93	3.08	2.62
	RMF-sorghum		
Plow-disk	3.9	34.4	11.4
No-till	8.8	39.5	22.2
LSD 0.05	3.02	5.86	4.59
	Occasional tillage		
Continuous no-till	9.2	33.4	27.6
No-till, disk, no-till	10.2	34.9	24.5
LSD 0.05	1.74	2.25	3.41

Table 4. Tillage effects on wet aggregate stability determined as the percent of aggregates retained following wet sieving.

	Aggregate size fractions, mm				
	2.0 – 8.0	4.0 – 8.0	2.0 – 4.0	1.0 – 2.0	0.50 – 1.0
	RMF-corn				
Plow	47.5	46.9	48.2	49.5	69.0
No-till	61.2	62.1	60.3	67.2	80.5
LSD 0.1	3.76	3.61	4.06	3.48	3.91
	RMF-sorghum				
Plow	43.0	44.2	41.9	45.4	64.8
No-till	50.6	50.8	50.4	55.1	73.4
LSD 0.1	5.66	5.64	6.47	8.81	5.55
	Occasional tillage				
No-till	68.1	71.9	64.4	66.3	83.3
No-till, disk, no-till	65.0	66.3	63.8	68.1	84.0
LSD 0.1	4.38	6.15	4.37	4.94	3.20

Networking Activities

During the INTSORMIL PI conference in November of 2002, we discussed the possibility of the compilation and publication of sorghum production database and atlas for use in regional policy formulation, research, and extension with John Lynam of the Rockfeller Foundation, Seyfu Ketema of ASARECA, and Anthony Obilana of ICRISAT-ECARSAM; collection of data in Ethiopia, Kenya and Uganda is being arranged. Dennis Friesien, CIMMYT-Nairobi and Dr. George Brhane of the Amhara regional development project have expressed interest to collaborate in an extension training program on tillage and water and nutrient management in 2004 and in subsequent extension activities. Dr. Wortmann participated in the First National Sorghum and Millet Research, Extension and Production workshop in Ethiopia, Nov. 12 to14, 2002.

Publications and Presentations

Farmer Assessment of Tillage Systems for Soil and Water Management in Sorghum Producing Areas of Ethiopia. By Worku B., Tewodros M., Zenbaba G., Neway M., Paulos T., and Jibril M., EARO-Nazret Research Center; Gebreyesus B. and Amare B., EARO-Mekelle Research Center; M. Mamo and C. Wortmann, University of Nebraska. Presented at the INTSORMIL PI conference, Addis Ababa, Ethiopia, Nov. 17-23, 2002.

Soil and Water Management for Improving Sorghum Production, by Charles Wortmann and Martha Mamo presented at the INTSORMIL PI conference, Addis Ababa, Ethiopia, Nov. 17-23, 2002.

Soil and Water Management for Improving Sorghum Production, by Charles Wortmann and Martha Mamo presented to the Agronomy and Horticulture Advisory Board, March 27, 2003.

Germplasm Enhancement and Conservation

Breeding Pearl Millet with Improved Performance and Stability

Final Report
Project ARS 204
Wayne W. Hanna
USDA-ARS

Principal Investigator

Wayne W. Hanna, USDA-ARS, P.O. Box 748, Tifton, GA 31793

Collaborating Scientists

Moussa Sonogo, Millet Breeder, Cinzana Agricultural Experiment Station, B.P. 214, Segou, Mali
Jada Gonda INRAN, Maradi, c/o Botorou Ouendeba, ICRISAT Sahelian Center, B.P 12404, Niamey, Niger
Roger Gates, USDA/ARS, Crop Genetics and Breeding, P.O. Box 748, Tifton, GA 31793
Jeff Wilson, USDA/ARS, Crop Genetics and Breeding, P.O. Box 748, Tifton, GA 31793
Steve Mason, University of Nebraska, Department of Agronomy, 229 Keim Hall, Lincoln, NE 68583-0748
Ignatius Angarawai, Millet Breeder, Lake Chad Research Institute, P.M.B. 1293, Maiduguri, Nigeria.
Amadou Fofana, Millet Breeder, CRZ BP 53, Kolda, Senegal.
F.P. Muuka, Millet Breeder, Soils and Crops Research, P.O. Box 910064, Mongu, Zambia.

Summary

This project was initiated in January, 2000. Population hybrids among West African landraces were made in 1999 and in the greenhouse during the 1999-2000 winter. Cooperators were identified in Niger, Mali, Senegal, Zambia and Nigeria for testing and evaluation of pearl millet population hybrids among landraces. Seeds were sent to all cooperators.

Population hybrids were crosses among West African landraces, but the hybrids did not out-yield the local genotypes, indicating a need to produce hybrids among locally adapted and desired types or at least where one parent is from this group. As in 2001, SOSAT-C88 was identified as a parent with good general combining ability that tended to produce the highest yielding grain hybrids. Significant variation existed among the population hybrids for grain yield. Only small differences for grain yields were observed for the various cycles of the population hybrids. Significant differences were observed for downy mildew resistance among the population hybrids. The population hybrids appear to have potential for improving grain yields in West Africa. Plans are to release a dwarf grain hybrid, TifGrain 102, developed in the Georgia program.

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.

U.S.

- 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

Landraces from West Africa were assembled and grown under quarantine. Landraces were intercrossed by collecting pollen from about 300 plants of one landrace, bulking the pollen and using the bulked pollen to pollinate 300 plants of another landrace. These crosses are cycle 1 and are referred to as population hybrids (Tables 1 and 2). The same procedure was used to produce cycles 2 and 3, except that the pollen collection and crossing were conducted on 300 random plants within each cycle1 population hybrid. An open-pollinated (random mating) population of cycle 1 was also grown in 2002 for the Exbornu x Ugandi(WA31) and Exbornu x Mansori (WA32) crosses. These population hybrids were evaluated for grain yield in Nigeria, Senegal, and Zambia in replicated trials. The hybrids were evaluated for forage production as part of a 9 x 9 lattice trial in Georgia.

Population hybrids with SOSAT-C88 as a parent tended to produce more grain and dry matter at almost all locations (Tables 1 and 2), but no hybrid significantly out yielded the best local cultivar. For example, hybrids from crosses with SoSat-C88 tended to be in the top grain producer group at all locations. WA25 and WA33 produce significantly more forage in Georgia than the best commercial hybrid. WA33 was also was the best dry matter producer in Zambia.

At most locations there were only small differences for grain or forage yields among the various cycles of the populations hybrids indicating that hybrid vigor could be maintained in these population hybrids.

Significant differences were recorded for downy mildew resistance among the population hybrids, both at a specific location and among locations. The least amount of variations and the lowest incidence of downy mildew was observed in Senegal. This variation could be due to different races of the disease in the various countries.

The population hybrids could make a contribution to improving grain yields of pearl millet in West Africa. However, it appears that crosses need to be made between specific types

Table 1. 2002 yields of population hybrids grown in Nigeria, Senegal,and Zambia.

		Nigeria				Zambia		Senegal	
		Downy Mildew		Grain/Plot		Grain/Plot	Stover/Plot	Downy Mildew	Grain Yield
		Loc#1	Loc#2	Loc#1	Loc#2				
				kg					kg ha^{-1}
Number	Pedigree								
WA 8	99-Ex-Borno Ugandi (C2)	2.7	4.0	0.68	1.15	0.806	1.118		
WA 9	Ex-Borno x Mansori (C2)	1.7	7.3	0.52	1.08	0.778	1.193		
WA10	Ex-Borno x Iniari (C2)	1.0	2.3	0.57	1.35	0.855	0.984		
WA11	Ex-Bornu x P3Kolo					0.884	1.103	1.6	1837
WA12	Ex-Borno x Ugandi	3.3	3.0	0.68	0.92	0.796	1.018		
WA13	Exbornu x Mansori					0.836	1.336		
WA14	Ex-Borno x Iniari	1.0	2.0	0.72	1.15	0.961	0.739		
WA15	P3Kolo x Ungandi					0.680	0.975		
WA16	P3Kolo x Mansori					0.863	0.720		
WA17	P3kolo x Iniari	1.3	3.3	0.93	1.27	0.572	0.809		
WA18	Ugandi x Mansori	1.0	1.0	0.48	0.83	0.816	0.705		
WA19	Ugandi x Iniari	1.7	6.0	0.50	1.07	0.689	0.990		
WA20	Iniari x Mansori	1.0	4.8	0.63	1.30	0.886	1.003		
WA21	2000-Ex-Borno SOSAT-C88	0.3	0.0	1.47	1.53	1.043	1.585	1.6	1915
WA22	Mansori x SOSAT-C88	0.3	2.3	1.10	1.60	1.234	1.331	2.4	1412
WA23	SOSAT-C88 x Ankountess	0.3	0.0	1.23	1.68	1.013	1.114	0.8	1719
WA24	SoSat-C88 x HKP-GMS					1.079	1.139		
WA25	SOSAT x GR-P1	1.0	0.0	0.93	1.32	1.125	1.331	0.8	1559
WA26	Ugandi x SoSat-C88	0.0	3.3	0.98	1.18	0.798	1.278	0.8	1759
WA27	Ex-Borno x UGandi (C2)	1.0	5.0	0.35	1.12	0.665	1.014	0.0	1620
WA28	ExBorno X Masori (C2)	1.3	5.0	1.13	0.93	0.655	1.074	0.8	1183
WA29	Ex-Borno x Ugandi (C3)	0.7	2.7	0.52	0.77	0.674	0.969	0.8	1475
WA30	Ex-Borno x Mansori(C3)	1.7	2.3	0.63	0.90	0.840	0.984	0.8	1305
WA31	Ex-Borno x Ugandi(C1-op)	2.0	0.0	0.45	1.10	0.875	1.083	0.8	1694
WA32	Ex-Borno x Mansori(C1-op)	0.7	3.3	0.57	1.53	0.998	2.024	1.6	1597
WA33	SoSat C88 x Gwagwa	0.0	0.0	1.72	1.55			2.3	1958
Check	Souna							7.1	1573
Check	SoSat-C88	0.0	0.0	1.12	1.45				
Check	Ex-Borno	0.7	0.0	1.12	1.55				
Check	Lubasi					0.938	1.524		
Check	Kuomboka					1.083	1.339		
Check	Kataba Local					0.723	1.860		
5% LSD		1.9	4.9	0.46	0.60	0.248	0.582	2.4	515

All WAs are cycle 1 population hybrids except as indicated:WA8, WA9, WA10, WA27 and WA28 are cycle 2. WA29 and WA30 are cycle 3. WA31 and WA32 are open-pollinated cycle 1. † = PPDS

Table 2. 2002 Forage yields and IVDMD of population hybrids grown in Georgia.

Number	Pedigree	Dry Matter Yields –kg ha^{-1}–	IVDMD %
WA 8	99-Ex-Borno Ugandi (C2)	12441	62
WA 9	Ex-Borno x Mansori (C2)	11864	63
WA10	Ex-Borno x Iniari (C2)	13838	59
WA12	Ex-Borno x Ugandi	12264	61
WA13	Exbornu x Mansori	13058	61
WA14	Ex-Borno x Iniari	13280	63
WA15	P3Kolo x Ungandi	12467	63
WA16	P3Kolo x Mansori	13079	63
WA17	P3kolo x Iniari	13339	64
WA18	Ugandi x Mansori	12502	64
WA19	Ugandi x Iniari	11829	62
WA20	Iniari x Mansori	12029	61
WA21	2000-Ex-Borno SOSAT-C88	14081	64
WA22	Mansori x SOSAT-C88	13726	64
WA23	SOSAT-C88 x Ankountess	15552	65
WA24	SoSat-C88 x HKP-GMS	14083	63
WA25	SOSAT x GR-P1	17097	64
WA26	Ugandi x SoSat-C88	14226	64
WA27	Ex-Borno x UGandi (C2	11534	64
WA28	ExBorno X Masori (C2)	11477	61
WA29	Ex-Borno x Ugandi (C3)	11339	62
WA30	Ex-Borno x Mansori(C3)	11251	62
WA31	Ex-Borno x Ugandi(C1-op)	12796	61
WA32	Ex-Borno x Mansori(C1-op)	14209	65
WA33	SoSat C88 x Gwagwa	17508	61
Check	Tifleaf 3	14377	63
5% LSD		1501	6

All WAs are cycle 1 population hybrids except as indicated:WA8, WA9, WA10, WA27 and WA28 are cycle 2. WA29 and WA30 are cycle 3. WA31 and WA32 are open-pollinated cycle 1.

(maturity; height; grain color and size; head length; etc) with local adaptation. Genotypes such as SOSAT-C88 with good general combing ability could be effectively used to enhance yield. Crosses between SOSAT-C88 and Souna3, Kuomboka, Toroniou C1 should be evaluated for grain production.

We have been working on a disease (mainly rust) resistant dwarf (1.5 m tall) pearl millet grain hybrid for about 9 years. Plans are to release an advanced hybrid, TifGrain 102, at the end of 2003. TifGrain 102 yields from 4300 to 5700 kg ha^{-1} for May and June plantings. Row widths of 35 to 52 cm appear to produce the most grain. The hybrid flowers in 45 days and grain can be combine harvested in 85 days.

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Breeding Pearl Millet for Improved Stability, Performance, and Pest Resistance

Project ARS 206
Jeffrey P. Wilson
USDA-ARS

Principal Investigator

Jeffrey P. Wilson, USDA-ARS Crop Genetics & Breeding Research Unit, University of Georgia, Tifton, GA 31793

Collaborating Scientists

Ignatius Angarawai, Lake Chad Research Institute, KM 6 Gamboru Ngala Rd., P.M.B. 1293, Maiduguri, Nigeria
Amadou Fofana, CRZ, Insitut Senegalais de Recherches Agricoles, BP 53, Kolda, Senegal
Jada Gonda, INRAN/CERRA Maradi, BP 240, Maradi, Niger
Steven K. Nutsugah, Savannah Agricultural Research Institute, P.O. Box 52, Tamale, Ghana
Moussa Sanogo, IER, Cinzana Agricultural Research Station, Bp 214, Ségou, Mali
Patricia Timper, USDA-ARS Crop Protection and Management Research Unit, University of Georgia, Tifton, GA 31793

Summary

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

In the first year of this project, progress toward meeting these objectives has been made. Project collaborators at multiple locations have been identified. These individuals have contributed cultivars and experimental germplasm for evaluating genotype x environment interactions in grain yield, quality, and disease and pest resistance. Collaborators have reached consensus on project objectives, methods and time-table to achieve these objectives. A replicated set of selected pearl millet germplasm was distributed among collaborators. Multilocation experiments have been established in Ghana, Mali, Niger, Nigeria, and Senegal. The germplasm is being assessed for characteristics that contribute directly or indirectly to stability of grain yield and quality.

In an effort to expand the diversity in the breeding populations being selected at collaborating locations, crosses have been made between several African cultivars and U.S. breeding lines to develop new germplasm in the A_1 and A_4 male sterile cytoplasms, and also with corresponding genes for fertility restoration. The introduced accessions are being evaluated for pests and diseases of importance to growers in the U.S. and in Africa. Sources of resistance to leaf blight, rust, and root knot nematode have been identified in the African pearl millets.

Objectives, Production and Utilization Constraints

Objectives

- Broaden diversity of pearl millet germplasm available to breeders and researchers.
- Identify sources of disease and pest resistance for pearl millet improvement.
- Identify characteristics associated with desirable pearl millet grain quality, and biotic and abiotic factors that affect grain quality.
- Develop and release pearl millet with high grain yield, resistance to multiple diseases, and improved grain quality.

Production and Utilization Constraints

Yield and stability of pearl millet grain and stover are affected by biotic and abiotic stresses, including diseases, nematodes, insects, and drought. The primary diseases and pests in the United States include rust (*Puccinia substriata* var. *indica*), leaf blight (*Pyricularia grisea*), grain molds (caused by several fungi), root knot nematodes (*Meloidogyne incognita* and *M. arenaria*), and chinch bug (*Blissus leucopterus leucopterus*). Primary diseases and pests in Africa include downy mildew (*Sclerospora graminicola*), and *Striga* (*Striga hermonthica*). Genetic resistance or tolerance is necessary to reduce yield losses and variability in grain and stover quality.

Developing the commercial potential of pearl millet will require that growers produce a consistent product to sell to processors. Stability of grain quality is also likely to be affected by both abiotic and biotic constraints. The impact of pearl millet genotype, diseases, and environmental constraints are not well-defined, in part because grain quality standards for pearl millet are poorly defined. Quality represents the combination of several factors, such as grain shape, color, and size, endosperm hardness, proximate composition, and the presence of grain molds, mycotoxins, and insects.

Research Approach and Project Output

Genotype and Environmental Effects on Pearl Millet Grain Quality

Research Methods

Multi-location evaluation of genotype x environment interactions affecting grain quality are needed to identify genotypes with inherently superior grain yield and quality, and the relative importance of diseases and other constraints on yield and quality. These studies were designed in part to define more clearly grain characteristics among genotypes, and the stability of expression over a range of production environments.

Samples of 86 pearl millet germplasms have been acquired. These were selected by colleagues on the basis of their high grain quality, their fertility restoration for specific cytoplasms, resistance to diseases or pests, agronomic traits, or commercial usefulness. From these, 40 germplasms were distributed to collaborators in Ghana, Mali, Niger, Nigeria, and Senegal for multi-location evaluation of stability of grain yield and quality traits. These studies were initiated this year, and research results are not yet available.

Disease and Pest Resistance in Pearl Millet

Research Methods

Use of pearl millet germplasm from African countries will broaden the genetic base of the breeding populations in U.S. programs, and is a likely source of important characteristics. Accessions acquired from collaborators were evaluated for resistance to foliar diseases and to root knot nematodes. Seedlings were evaluated in two replicated experiments in the greenhouse for resistance to pyricularia leaf spot and rust. In separate tests, plants were subjected to multiple inoculations to determine the frequency of plants with resistance (based on infection type) in these cultivars. Selected accessions were evaluated for resistance to the southern root-knot nematode in two replicated tests in the greenhouse. Pots containing five plants were inoculated with eggs of *Meloidogyne incognita*. After grain harvest, eggs were extracted from roots. Differential reproduction of the nematode on the different genotypes was determined.

Research Findings

The results of the foliar disease inoculations support what is already known about these pathosystems. In the presence of continued disease pressure, a reproductive advantage is associated with disease resistance. Pyricularia leaf spot is a chronic disease of pearl millet in West Africa, and there was relatively greater frequency of resistance to leaf spot than to rust, which occurs less often in the region. In spite of multiple inoculations, conditions for successful infection were less than optimal since the susceptible Tift 454 control expressed uncharacteristically high levels of apparent resistance to both diseases (Table 1). Potential sources of resistance to leaf spot include Ankoutess, DMR 36-1, and ¾ HK-B78. Sources of rust resistance were more limited, and 99-72 and Ugandi appear to be most promising.

All accessions were more resistant to the southern root knot nematode than was HGM 100 (Table 1). SoSank and SoSat C-88 appear to be most resistant. It can be hypothesized that SoSank has resistance genes from both SoSat C-88 and Ankoutess, since it supported numerically less nematode reproduction than either of these parental sources.

Networking Activities

Attended the American Phytopathological Society meeting, Milwaukee, WI July 27-31, 2002. Served as chair of the Collections and Germplasm Committee, member of the Office of International Programs Research Committee, and as senior editor of *Phytopathology*.

Participated in "Pearl Millet Research Planning Workshop for West and Central Africa: Facilitating the improvement of pearl millet in West Africa through conventional and molecular plant breeding, farmer participation, and comparative genomics strategies" at Bamako, Mali, October 9-12, 2002. Presented invited paper "Application of the Dynamic Multiline Population Strategy for Developing Stable Disease Resistance in Pearl Millet Hybrids: Issues in Pathosystem Dynamics". Contributed to prioritizing pearl millet development research needs for West and Central Africa, and identified potential collaboration between INTSORMIL CRSP project ARS-206 with representatives of National Agricultural Research programs and Non-Governmental Organizations.

Participated in and presented research results at the INTSORMIL CRSP PI conference "Increasing Profitability of Sorghum and Millets" held at Addis Ababa, Ethiopia, November 17-23, 2002. Contributed to developing 2006-2011 vision statements for West Africa (West) and West Africa (East) regional program working groups.

Attended "Molecular Breeding of Forage and Turf, 3rd International Symposium", Dallas, TX, May 18-20, 2003. Identified technology and methods applicable to improvement of pearl millet for use as forage or grain.

Contributed information for report "Sorghum and Pearl Millet Health Food and Industrial Products in Developed Countries" to be presented by J. Dahlberg and T. Snyder at the

Table 1. Pearl millet germplasm evaluated for disease and pest resistance in greenhouse trials.

Genotype	Pyricularia resistance (% plants)	Rust resistance (% plants)	*Meloidogyne incognita* (eggs/g root)
Ankoutess (Source 1)	62	31	...
Ankoutess (Source 2)	74	38	83 cde
DMR 15	44	22	...
DMR 36-1	68	35	...
DMR 68	60	30	...
DMR 72	63	32	...
Ex-Bornu	61	31	365 bcd
GCP V6	53	27	122 cde
GCT	56	28	69 cde
Gwagawa	64	39	160 cde
HKP-GMS (Source 1)	62	32	127 cde
HKP-GMS (Source 2)	59	30	115 cde
3/4 HK-B78	68	34	244 cd
Iniari	56	33	...
LCIC 9702	47	25	273 bc
Mansouri	44	28	625 b
P3Kollo	58	31	532 b
Sadoré local	59	31	135 cde
SoSank	58	29	38 e
SoSat C-88 (Source 1)	62	31	...
SoSat C-88 (Source 2)	63	31	62 de
Taram	61	31	90 cde
Ugandi	55	52	250 cd
Zatib (Source 2)	66	33	76 cde
Zatib (Source 3)	54	27	...
Zongo	52	27	165 cde
99-70	47	23	...
99-71	22	24	...
99-72	52	75	...
Tift 454	23	15	...
HGM 100	...	...	3554 a
lsd $_{(P=0.05)}$	20	33	...[z]

[z] Mean separation based on analysis of square-root transformed data

Expert Meeting on "Alternative Uses of Sorghum and Pearl Millet in Asia", July 1-4, 2003 at ICRISAT, Patancheru, India.

Served as member of Sorghum and Millet Crop Germplasm Committee.

Served on Advisory Committee for the University of Georgia's Office of International Agriculture.

Presented "Managing Diseases with Host Resistance: A Perspective from Breeding Pearl Millet" to the University of Georgia Plant Pathology Department, Athens, GA. November 5, 2002.

Hosted visit to Tifton, Georgia, by Dr. C.L.L. Gowda, Global Theme Leader, Crop Management and Utilization, and Dr. K.N. Rai, former Director, Germplasm Resources and Enhancement Program, ICRISAT, India. Discussed potential areas of ARS/INTSORMIL/ICRISAT collaborative research. August 1, 2002.

Hosted visit to Tifton, Georgia, by Dr. Ouendeba Botorou, Director, ROCAFREMI (West and Central African Millet Research Network), Niger. Discussed organizational objectives and collaborative research needs for pearl millet improvement for West Central Africa. Current resources and potential for integration of efforts among INTSORMIL, ICRISAT, and National Agricultural Research scientists were identified. August 11, 2002.

Hosted visit to Tifton, Georgia, by Walter de Milliano, African Cereals Specialist, African Center for Crop Improvement, University of Natal, Republic of South Africa. Discussed regional and global objectives and strategies for pearl millet improvement, and identified specific germplasm exchange opportunities between ARS and Southern Africa region programs. June 19-21, 2003.

Visited John Erpelding, Sorghum Curator, at the USDA-ARS Tropical Agriculture Research Station, Mayaguez, Puerto Rico. Discussed application of molecular genetic technology to germplasm conservation and breeding objectives in sorghum and pearl millet. March 28, 2003.

Experimental pearl millet germplasm developed in the U.S. was distributed to collaborators in Guatemala and El Salvador, and field supplies were provided to collaborators in Mali and Ghana.

Publications and Presentations

Journal Articles

Lynch, R.E., B. Guo, P. Timper, and J.P. Wilson. 2003. United States Department of Agriculture-Agricultural Research Service research on improving host-plant resistance to pests. Pest Management Science 59:718-727.

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Wilson, J.P. and R.N. Gates. 2002. The dynamic multiline population: An alternative approach to durable resistance? pg 65-69 in: Leslie, J.F. (Ed.) Sorghum and Millets Diseases. Iowa State Press, Ames, Iowa.

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Abstracts

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Hanna, W., I. Angarawai, A. Fofana, R. Gates, J. Gonda, S. Gupta, F. Muuka, B. Ouendeba, M. Sanogo, and J. Wilson. 2002. Performance of various cycles of population hybrids between West African pearl millet landraces. INTSORMIL PI Conference. November 18-20, 2002. Addis Ababa, Ethiopia.

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Z. Jurjevic, D.M. Wilson, J.P. Wilson, G.C. Rains, D.M. Geiser, N. Widstrom. *Fusarium* species on Georgia corn and pearl millet and its relation with fumonisin production. Phytopathology 93:S42.

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

Project PRF 207
Gebisa Ejeta
Purdue University

Principal Investigator

Dr. Gebisa Ejeta, Dept of Agronomy, Purdue University, West Lafayette, IN 47907

Collaborating Scientists

Dr. Aberra Deressa, Agronomist, EARO, Melkassa Research Station, Nazret, Ethiopia
Mr. Zenbaba Gutema, Sorghum Breeder, EARO, Melkassa Research Station, Nazret, Ethiopia.
Dr. Issoufou Kapran, Sorghum Breeder, INRAN, Niamey, Niger
Dr. Aboubacar Touré, Sorghum Breeder, IER, Bamako, Mali
Mr. C.K. Kamau, Sorghum Breeder, KARI, Kenya
Dr. Peter Esele, Plant Pathologist, NARO, Uganda
Dr. Hamis Sadaan, Sorghum Breeder, Department of Crops, Tanzania
Mr. Tesfamichael Abraha, Agronomist, DARE, Eritrea
Dr. Mitchell Tuinstra, Dept of Agronomy, Kansas State University, Manhattan, KS 66506
Dr. Darrell Rosenow, Texas A&M Univ Ag Experiment Station, Route 3, Lubbock, TX 79403
Dr. Kay Porter, Pioneer HiBred International, Plainview, TX 79072
Dr. Bruce Hamaker, Cereal Chemist, Dept of Food Science, Purdue University, West Lafayette, IN 47907
Dr. Peter Goldsbrough, Geneticist, Dept of Horticulture, Purdue University, West Lafayette, IN 47907
Dr. Layia Adeola, Animal Nutritionist, Dept of Animal Sciences, Purdue University, West Lafayette, IN 47907

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.

PRF207 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.

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 in-

creased levels of resistance to drought, cold, diseases, and improved grain quality characteristics.
- To assemble unique sorghum germplasm, and to encourage and facilitate free exchange of germplasm between U.S. and LDC scientists and institutions.
- To assess applicability of various statistical and DNA fingerprinting technologies for evaluating genomic similarity or for discerning genetic diversity of sorghum and millet germplasm pools.

Training, Networking, and Institutional Development

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

Research Approach

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 complementing 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, and several locations in Africa. Over the years, assistance in field evaluation of nurseries has also been provided by industry colleagues particularly at Pioneer HiBred and DeKalb Genetics

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

Project Output

Research Findings

Selection for Grain Yield in Sorghum Under Moisture Stress and Nutrient Stress Environments

Crop breeders in the semi-arid tropics often confront a combination of moisture and nutrient stress in their target production environments. Stability of performance under stress conditions is thus a desirable goal for crop improvement. To improve and stabilize crop production in stress environments, the genetic potential of the crop germplasm to available environmental stresses need to be adjusted. Strategies are available for improving performance in nutrient deficient and moisture deficit soils of the SAT. One of the approaches assumes that selection of plant genotypes under optimal nutrient and moisture supply may maximize genetic gain in low input production environments. Testing the usefulness of this approach will be important both in the stress-prone SAT as well as in temperate environments where stress is infrequent but farmers are often looking for ways to reduce production costs. In certain situations, the amount of genetic progress from selection for broad adaptation in both favorable and adverse production conditions diminishes as the intensity and frequency of stress increases in the unfavorable production environments. In others, the initial selection under limited nitrogen supply would not improve the probability of identifying crop genotypes with wide adaptation to both high and low fertility conditions. These conclusions were drawn from sorghum studies which were conducted in either moisture stress or limited soil fertility. However, crop breeders in the semi-arid tropics most frequently confront a combination of both moisture and nutrient stresses in their target production environments. Therefore, evaluating breeding materials under both limited moisture and nutrient supply may increase the chance for identifying lines which are adapted to one or both stress conditions.

The breeding procedure commonly practiced for handling segregating generations affects the rate of genetic progress that can be made under stress. Single plants selected from early segregating generations in nutrient deficient and moisture deficit soils may fail to maintain the same expression in subsequent

Table 1. Mean grain yield, days to flowering, and plant height of single-seed derived F6 lines, their parents, and inbred checks grown under high and low fertility as well as rainfed and irrigated conditions for two years.

Environment	Recombinant inbred lines Min	Max	Mean	Parent Mean	Check Mean
			Grain Yield (Mg/ha^{-1})		
Low Fertility	1.44	4.84	2.84a[1]	3.96a	2.67a
High Fertility	3.42	9.16	6.46b	7.72b	6.44b
Rainfed	1.08	2.94	1.94a	2.34a	1.96a
Irrigated	1.25	4.64	2.94b	3.23b	2.92b
			Plant Height (cm)		
Low Fertility	68	184	124a	106a	109a
High Fertility	65	194	126a	108a	113a
Rainfed	60	158	98a	87a	80a
Irrigated	64	192	123b	108b	102b
			Days to Flowering		
Low Fertility	68	92	76a	76a	76a
High Fertility	70	85	76a	75a	74a
Rainfed	58	69	64a	63a	62a
Irrigated	56	72	66b	66a	63a

[1] Means of the two fertility levels or moisture regimes followed by the same letter were not significantly different at p=0.05 level using t-test.

progeny testing because of the inherent lack of uniformity in the intensity of these stresses in the experimental field during selection as well as because of the resultant segregation from single plants. To minimize these problems, evaluation and selection for stress tolerance may be delayed until true breeding lines are developed. The use of the single seed descent breeding method which allows rapid attainment of homozygosity may, therefore, be suitable for developing recombinant inbred lines to be tested under an array of contrasting moisture and nutrient environments.

The objectives of this study were (1) to explore the extent of genetic variability among recombinant inbred lines of sorghum in high and low fertility as well as in irrigated and rainfed conditions and (2) to predict and measure the correlated responses of yield when selection is exercised in either one environment or a combination of contrasting environments.

Fifty-seven random RI lines of sorghum derived via single seed descent from the F_6 generation of a cross between K886 and CS3541 were used as experimental materials. K886 was an inbred line tolerant to pre-flowering drought stress. CS3541 was chosen for its susceptibility to pre-flowering drought stress and its good general combining ability and production of high yield potential hybrids under stress free conditions. The responses of these two sorghum inbred lines to limited nutrient supply was unknown. The 57 RI lines, the two parents, and three checks with tolerance to either pre- or post-flowering drought stress were grown under dryland, irrigated, low fertility, and high fertility conditions. The low fertility experiment was planted in the field which received no fertilizer for over 35 years. The high fertility experiment received 150 kg N, 40 kg P, and 50 kg K per hectare.

Mean yields of all RI lines, their parents, and checks in the low fertility environment were significantly smaller than those in high fertility environment. Low soil fertility reduced mean yields of all genotypes to 46% of the high fertility environment (Table 1). The overall mean yield of all genotypes in the rainfed environment was reduced to 69% of the irrigated environment. Grain yields under irrigation were unexpectedly low because of the limited irrigation water supply. The recombinant inbred lines, their parents, and checks did not differ significantly from one another for grain yield in each contrasting environment (data not shown). The low fertility environment did not differ from the high fertility environment for plant heights of the inbred lines, their parents, and checks. By contrast, plants from each group grew significantly taller in the irrigated environment than in the rainfed environment. The differences in mean days to flowering between high and low fertility and between rainfed and irrigated environments were not significant. Mean yield of the highest yielding RI line was more than twice as great as the mean yield of the lowest yielding recombinant inbred line in each test environment. In spite of such large differences in grain yield, the genetic variance in high fertility environment was not significant because of large year x line interaction.

The genetic variance for grain yield in each stress environment did not differ from the corresponding nonstress environment based on standard errors. Furthermore, line x year interaction for grain yield in each stress environment was either comparable to or significantly smaller than that in the corresponding nonstress environment (Table 2). Although the genetic variances for plant height and days to flowering in nonstress environments were slightly higher than those in the respective stress environments, the differences were not statis-

Table 2. Components of variance and heritability estimates for grain yield, plant height, days to flowering of recombinant inbred lines for contrasting test environments.

Environments	Gen. Var	GXE VAR	Heritability
		Grain Yield	
Low Fertility	0.18±0.08**	0.14±0.07**	0.60±0.26
High Fertility	0.04±0.10	0.51±0.13**	0.18±0.44
Rainfed	0.16±0.08*	0.21±0.08**	0.54±0.28
Irrigated	0.24±0.09**	0.18±0.09**	0.59±0.24
		Plant Height	
Low Fertility	0.83±0.19**	0.09±0.02**	0.96±0.22
High Fertility	0.86±0.19**	0.05±0.02**	0.97±0.21
Rainfed	0.71±0.17**	0.11±0.03**	0.93±0.22
Irrigated	0.89±0.19**	0.05±0.02**	0.97±0.21
		Days to Flowering	
Low Fertility	0.67±0.15**	0.04±0.02*	0.94±0.21
High Fertility	0.59±0.16**	0.24±0.06**	0.88±0.23
Rainfed	0.49±0.13**	0.13±0.05**	0.86±0.23
Irrigated	0.81±0.18**	0.07±0.03**	0.94±0.21

*, ** Significantly different from zero at p=0.05, and p=0.01 levels, respectively.

tically significant based on standard errors. Heritability estimates for each trait in each contrasting environment followed a similar trend as the genetic variance estimates (Table 2). Genetic correlation between low and high fertility environments for grain yield did not differ significantly from zero. Although the genetic correlation between grain yields in rainfed and irrigated environments was more than two times as large as its standard error, it was not very high either (r_g=0.66). Genetic correlation between grain yields in rainfed and low fertility environments was close to one. These results did suggest that yield responses of the RI lines in the two sets of contrasting environments, soil fertility and moisture regime, were controlled by different sets of alleles. By contrast, the performances of inbred lines under rainfed and low fertility environments were similar. Genetic correlations between contrasting environments for plant height and days to flowering were significant and high. Predicted gain from indirect selection for grain yield in each nonstress environment (high fertility and irrigated) was smaller than the predicted gain from direct selection in the corresponding stress environment (low fertility and rainfed), as indicated by the relative efficiency value of < 1.0. Indirect selection for grain yield under rainfed condition was found to be as efficient as direct selection under low soil fertility. Indirect selection for plant height and days to flowering in each nonstressful environment produced as large a response in the respective stress environment as direct selection in the stress environment itself.

Because year to year variation is inherently high in stress-prone production environments, a selection scheme that takes advantage of genotype by year interaction may prove useful. A rank summation index which assigned equal weights to the two years in each environment as well as in a combination of contrasting environments was used to evaluate the actual yield advances from indirect and direct selections (Table 3). Indirect selection in low fertility environment was less effective for improving grain yield under high fertility environment than direct selection in high fertility environment itself. In contrast, the yield advances under low fertility environment resulting from indirect selection in high fertility environment was nearly as high as the one from direct selection in low fertility environment. Selection based on the rank summation which included both low and high fertility environments increased yields significantly in these two contrasting environments. When the index involved rainfed and low fertility environments, yield increases of the selected lines was greater in low fertility environment than in high fertility environment. Selection in the rainfed environment improved yield significantly in both rainfed and irrigated environments. On the other hand, indirect selection in the irrigated environment failed to improve yield under rainfed condition. Indirect selection for increased yield based on the rank summation which involved both irrigated and rainfed environments or rainfed and low fertility conditions were nearly as good as the corresponding direct selections made in irrigated and rainfed environments (Table 3).

As sorghum is largely produced in nutrient deficient and moisture deficit soils in the semi-arid tropics, it is necessary to evaluate the genetic potential of breeding materials to withstand these two stresses. Although a limited number of recombinant inbred lines were included in our studies, large differences in grain yield among these lines were found in low fertility and rainfed environments. Thus, the cross segregated for genes controlling productivity in both nutrient deficient and moisture deficit soils. The variation in grain yield was not cor-

Table 3. Mean grain yield of the best 10 lines selected in a single environment or a combination of environments by using the rank summation index which was expressed as a percentage of the overall mean of all the random lines tested in each response environment.

Selection Environments	Response Environment Low Fertility	High Fertility
Low Fertility	135**	111
High Fertility	126**	125**
High + Low Fertility	130**	122**
Rainfed + Low Fertility	132**	113**
	Rainfed	Irrigated
Dryland	131**	124**
Irrigated	93	142**
Irrigated + Rainfed	126**	134**
Rainfed + Low Fertility	128**	129**

**Significantly higher than the overall mean of all the inbred lines (100%) at p=0.01 level using LSD.

related with the variation in plant height and days to flowering, indicating that it should be possible to identify high yielding lines specifically adapted to nutrient and moisture limited environments in different maturity and height backgrounds. One of the arguments for selecting in a favorable environment, even if improved performance is sought for a stress environment, is that the former permits greater genetic variance among lines with smaller year to year fluctuation in genotypic performance than does the latter. The genetic and line x year interaction variance estimates for grain yield in the high fertility and irrigated environments of our studies did not indicate such trends. In fact, genetic variances for grain yield in these two nonstressful conditions did not differ significantly from those in the corresponding stress conditions. The magnitude of line x year interaction for grain yield in each nonstress environment (high fertility or irrigated) was either comparable to or grater than that in the respective stress environment (low fertility or rainfed). Even if the genetic variance under nonstress condition was larger than the genetic variance under stress condition, the differences for grain yield observed in the absence of stress might be largely unrelated to the differences observed in the presence of severe stress. Variation in productivity of genotypes observed in the presence of drought stress may arise from differences in anatomical, morphological, and physiological features. Furthermore, variation in the yielding ability of genotypes in the presence of nutrient stress may be mediated by differences in nutrient uptake, partitioning of the nutrients into the grain, and nutrient use efficiency. Therefore, detecting differences among genotypes for responses to stress by means of such complex traits of adaptation will be difficult when stress is absent.

Indirect selection for increased yield under high fertility or irrigated environment was found to be less efficient than direct selection in the corresponding stress environment (low fertility or rainfed). However, selection in each nonstress environment based on the rank summation index scores identified lines which did well in the respective stress environment. Since the genetic correlation was an overall inverse measure of the genotype x environment interaction of the entire set of lines, some genotypes could interact very little with contrasting environments notwithstanding the presence of a low genetic correlation. Our results suggested that selection for yield in moisture and nutrient stress environments should be done directly in those environments. However, the development of separate breeding programs for moisture and nutrient stress environments will be difficult and expensive. A more realistic approach would be to screen breeding materials in plots which combine both drought and nutrient stress. The strong genetic correlation between rainfed and low fertility environments for yield and the common occurrence of inbred lines which were top-ranking in both rainfed and low fertility conditions in our studies provided an additional support to this approach. To achieve greater gain in performance in these two stress conditions, incorporating parents with good performance under low input levels in crosses will be needed. Because favorable growing seasons are occasionally encountered in sorghum production environments, alternating selection in moisture and nutrient stress with selection in favorable conditions may permit the identification of lines which are adapted to both stressful and nonstressful conditions.

Networking Activities

Research Investigator Exchange

We had visitors from India, Ethiopia, Burkina Faso, Italy, Mexico, and Brazil during 2002. Discussions were held on work in drought tolerance, mold resistance as well as marker assisted selection for many of the traits addressed in this project.

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 20 countries in 2002.

Publications

Refereed Papers

Cisse, N., and G. Ejeta. 2003. Genetic variation and relationships among seedling vigor traits in sorghum. Crop Sci. 43:824-828.

Grenier, C., P.J. Bramel, J.A. Dahlberg, A. El-Ahmadi, M. Mohammed, G.C. Peterson, D.T. Rosenow and G. Ejeta. 2003. Sorghums of the Sudan: Analysis of regional diversity and distribution. Genet. Res. And Crop Evol. 48: 1-12.

Mickelbart, M.V., G.Peel, R.J. Joly, D. Rhodes, G. Ejeta and P. Goldsbrough. 2003. Development and characterization of near-isogenic lines of sorghum segregating for glycinebetaine accumulation. Physiol. Plant. 118: 253-261.

Yang, W.J., P.J. Rich, J.D. Axtell, K.V.Wood, C.C.Bonham, G. Ejeta, M.V. Mickelbart and David Rhodes. 2003. Genotypic variation for glycinebetaine in sorghum. Crop Sci. 43:162-169.

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Menkir, A. and G. Ejeta. 2003. Selection for grain yield in sorghum under moisture stress and nutrient stress environments. Afric. Crop Science Journal (In Press).

Invited Presentations

Ejeta, G. 2002. Increasing crop yields through hybrids: Prospects for sorghum hybrids in Ethiopia. First National Workshop on Sorghum and Millets in Ethiopia, 11-14 November, Nazret, Ethiopia.

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

Project TAM 222
Darrell T. Rosenow
Texas A&M University

Principal Investigator

Darrell T. Rosenow, Sorghum Breeder, Texas A&M Univ Ag Experiment Station, Rt 3, Box 219, Lubbock, TX 79403

Collaborating Scientists

Dr. Aboubacar Touré, Sorghum Breeder, INTSORMIL Host Country Coordinator, IER, B.P. 438, Sotuba, Bamako, Mali
Dr. Medson Chisi, Sorghum Breeder, Golden Valley Research Station, GART, Box 54, Fringila, Zambia
Ing. René Clará, Sorghum Breeder, CENTA, San Andres, Apartado Postal 885, San Salvador, El Salvador
Ing. Rafael Obando, Sorghum Breeder, CNIA/INTA, Apartado 1247, Managua, Nicaragua
Dr. Ndiaga Cisse, Plant Breeder, ISRA-CNRA, B.P. 53, Bambey, Senegal
Dr. Ibrahim D.K. Atokple, Sorghum Breeder, SARI, P.O. Box 52, Tamale, Ghana
Dr. Neal McLaren, Plant Pathologist, ARC - Grain Crops Inst, P.B. X1251, Potchefstroom 2520, Republic of South Africa
Dr. G. C. Peterson, Sorghum Breeder, Texas A&M University Research and Extension Center, Lubbock, TX 79403
Dr. W.L. Rooney, Sorghum Breeder, Dept of Soil & Crop Sciences, Texas A&M University, College Station, TX 77843
Dr. L.W. Rooney, Cereal Chemist, Dept of Soil & Crop Sciences, Texas A&M University, College Station, TX 77843
Dr. R. D. Waniska, Cereal Chemist, Dept of Soil & Crop Sciences, Texas A&M University, College Station, TX 77843
Dr. G. N. Odvody, Plant Pathologist, Texas A&M University Ag Research & Extension Center, Corpus Christi, TX 78406
Dr. Gebisa Ejeta, Sorghum Breeder, Dept of Agronomy, Purdue University, West Lafayette, IN 47907
Dr. M.R. Tuinstra, Sorghum Breeder, Dept of Agronomy, Kansas State University, Manhattan, KS 66506
Dr. L.E. Claflin, Pathologist, Kansas State University, Manhattan, KS 66506

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 and evaluate new germplasm for use in the U.S. and host countries. Forty-nine new fully converted exotic lines and 71 partially converted lines from the cooperative TAMU-TAES/USDA-ARS Sorghum Conversion Program were submitted for release. Numerous advanced generation B and R lines developed in TAM 222 were identified as potential releases for distribution to private companies and U.S. and host country public programs as the project leader attempts to phase down the sorghum breeding project in preparation for retirement.

Data and characterization on the Mali Sorghum collection of indigenous sorghum cultivars was completed and entered into the USDA-ARS GRIN system. Several very unique and promising new Durra and Durra-Bicolor and Durra-Dochna type cultivars from the dry northern part of Mali were identified in the Collection, and hold promise in sorghum improvement in the drought prone areas of Africa and the U.S.A. B/R-line reaction and hybrid vigor of selected Malian and Sudanese cultivars was determined. Twenty-five sorghums from the Mali Collection were selected for entry into the Sorghum Conversion Program.

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

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

Flour made from the IER/INTSORMIL developed tan plant guinea cultivar, N'Tenimissa, was successfully used in Mali by a private bakery (GAM) to produce and market a new cookie, DeliKen, made with 20% sorghum flour being substituted for wheat flour. A private entrepreneur was successful in organizing the production of 13,800 kg of N'Tenimissa in 2001 and had initiated new markets in addition to the GAM bakery. He organized the production of an estimated 200 tons of N'Tenimissa grain in 2002 with numerous farmers, but company financial problems halted the 2002 project. It has been shown that new cultivars with improved grain quality traits can stimulate the development and commercialization of new sorghum-based products. Some of the new N'Tenimissa breeding progenies in Mali show good promise to be even superior to N'Tenimissa for production and grain quality. One of the new cultivars, 97-SB-F5DT-63, N'Tenimissa*Tiemarfing, has been released and called Wassa. Two other new tan-plant, true Guinea cultivars (N'Tenimissa*Tiemarfing) have been given names Zarra and Keninkedie, and will be increased and evaluated for value-added products and commercial utilization.

Collaborative INTSORMIL activities recently initiated in Senegal and Ghana are continuing in the areas of sorghum breeding, disease resistance, and *Striga*, as well as in entomology and agronomy research. MOUs are currently in place with both countries.

Objectives, Production and Utilization Constraints

Objectives

U.S.

- Develop and release 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.

Western Region/West Africa (Mali, Ghana, Senegal)

- 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 West Africa, and with acceptable levels of disease resistance. Characterize and describe the selected indigenous Mali and Sudan sorghum cultivars and evaluate for useful traits and breeding potential.
- Strengthen the collaboration with scientists in Ghana and Senegal including breeding, pathology, entomology, agronomy, and *Striga* research.

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, disease resistance, and germplasm base 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 over 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 nonguinea 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 the southern regions, late maturing, photoperiod sensitive sorghums are needed to assure grain maturity after the rainy season.

Much of West Africa, especially the more northern areas, are drought prone areas and drought tolerance is important. Foliar diseases such as anthracnose and sooty stripe are important in the central and southern parts and in certain areas of Southern Africa along with leaf blight. In 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 most areas including 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 and must be done on site in Central America.

There is a constant need in host countries and in 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. or worldwide lines or 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. 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), and 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 in the U.S. at the NSSL, 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

Breeding, selection, and screening for drought resistance continued, using major field screening nurseries at Lubbock, Halfway, Chillicothe, Corpus Christi and Beeville good pre-flowering stress occurred at Corpus Christi and Beeville. Extreme late season stress at Lubbock and Halfway resulted in excellent post-flowering stess and lodging ratings. The "stay-green" line, BTx642/B35, continues to be an excellent source of post-flowering drought resistance and lodging resistance in breeding progeny. Breeding derivatives of the parental line, BTX643(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 and hybrid evaluation continued on the above mentioned B lines which includes 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.

Approximately 30 A-B pairs and 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 potential 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 have been identified. See Table 1 for a listing of several breeding lines for potential release.

Table 1. Potential A/B Line and R-Line releases from Dr. D. Rosenow breeding project (TAM 222).

Designation/Pedigree		Unique Traits(s)
A/B HF14	(BTx643/B1*BTx635)-HF14	White, tan plant, head smut res
A/B HF8	(BTx643/B1*BTx635)-HF8	White, tan plant
A/B V57	(BTx643/B1*BTx635)-V57	White, tan plant
A/B V78	(BTx643/B1*BTx635)-V78	White, tan plant, head smut res
A/B V26	(B2-1*BTx635)-V26	White, tan plant, head smut res
A/B HF4(3d)	(BTx634*B4)-HF4	White, tan plant, head smut res
A/B HF25	(BTx635*B4)-HF25	White, tan plant, head smut res
A. L06 wxy	(B.BON34*B9502)-LD6 wx	White, tan plant, waxy endosperm
A. LD6 non	(B.BON34*B9502)-LD6 non	White, tan plant
A. BE7	(B.HF14*B001(B1*B9501))-HDOPBK-BE7	White, tan plant, head smut res
A. BE8	(B.HF14*B01(B1*B9501))-HDOPBK-BE8	White, tan plant, head smut res
A. BE1	(B.HF14*B.DLO357)-HDOPBK-BE1	White, tan plant, head smut res
A. TP25der	Tan Plant Population deriv.	White, tan plant, head smut res, wxy
--	(BTx623*QL3)*B.HF13)-HL14	White, tan plant, P3 D.mil res
--	(BTx623*QL3)*B.HF13)-HL15	White, tan plant, P3 D:mil res
A. 2-2(B)	(BTx625*B35)	Red, purple, SG, ldg res
A. 402	(BTx3042*(BTx625*B35))	Red, purple, SG, ldg res, hs res
A. 403	(BTx3042*(BTx625*B35))	Red, purple, SG, ldg res
A. 409	(B1*B9501)	Wh, purple, some ldg res
A. PDLT157	(B1*B9501)	Wh, purple, some ldg res
A. DLO357	(B1*B9501)	Red, purple, some SG, ldg res
A. DLT125	(B1*B9501)	Red, purple, some SG, ldg res
A. V10	(B1*B9501)-V10	Red, purple, some SG, ldg res
A. V60	(B1*B9501)-V60	Red, purple, some SG, ldg res
A. HF88	(B1*B9501)-HF88	Wh, purple, some SG, ldg res
A. LD2	(B35*B402)-LD2	Red, purple, SG, ldg res, HS res
A.HD9	(B35*B402)-HD9	Red, purple, SG, ldg res, HS res
A. V3	(B35*B9503)-V3	Lem Yel, purple, some SG, ldg res
A. HL?-HL2	(B1*B9501)-HD?-HL2	Wh, purple, some SG, ldg res, HS res
A. HL??-HL2	(B1*B9501)-HD??-HL2	Wh, purple, some SG, ldg res, HS res
Restorer Lines		
86EON361	(R5646*SC326-6)	W, Tn, Anth, Rust, LB res
87EON366	(TAM428*(Tx432*CS3541))	W, Tn
90EON328	(Sureno*BDM499)-HD5	W, Tn, Wthr Res, P3 D. Mil Res
98CD187	(87EON366*90EON328)-HF6	W, Tn, Wthr Res, P3 D. Mil Res
96CD635	(SRN39*90EON328)-HF4	W, Tn, P3 D.Mil Res
96CD677	(87EON366*90EON328)-HF3	W, Tn, P3 D.Mil Res
90EON343	(Tx2895*(SC170*MR4-4671))-BH7	Red, Tan, Wthr/GrMold Res
99GW092	(86EON361*90EON343)-HD12	Red, Tan, Wthr/GrMold Res
88BE2668	(Tx2783*(SC748*3C630))	Red, Pur, Ldg Res, Some Wthr Res
82BDM499	(SC173*SC414)	W, P, P3 D.Mil Res, Dt Res
86PL2120	(SC748*SC630)*SC414)	R, P, P3D.Mil Res
92BD1982-4	(PL2120*87EO366)-BD6	P. Tan, P3 D. Mil Res, Wthr Res
5EO509	(PL2120*BH8606)-BD19	Red, Pur, P3 D. Mil Res, Wthr Res
R4317	(SC170-6-17*MR4-4671)LEC	Red, Pur, Wthr Res
87BH8606	(Tx433*(SC748*SC630))	R, P, Wthr Res, Ldg Res
--	(86EO361*BE2668)-LL2	W, T, good hybrids
--	(Macia*BE2668)-HD9	R, T, good hybrids
--	(86EO361*Macia)-HD15	W, T, good hybrids
--	(Macia*Dorado)(Several)	W, T, Wide Adap
--	(M84-7*VG153))19178	W, T, Wthr Res
--	(Sureno*VG153)CC549	W, T, Wthr Res
--	(Sureno*87EO366)-CW3	W, T, Wthr Res

B9501 = (B7904*(SC748*SC630))
B9502 = BTx3042*(BTx625*B35))
B001 = (B1*B9501)
B9503 = (BTx623*(BTx625*B35))

Forty-nine new fully converted lines and 71 partially converted bulks from the cooperative TAMU-TAES/USDA-ARS sorghum conversion program have been submitted to USDA initiating release procedures.

Near isogenic lines (NILs) developed (BC6 of (B35*Tx7000)) to do fine mapping of stay green QTLs and to do functional genomics and stress physiology research in cooperation with scientists in Australia were evaluated for stay green in Texas and Australia. In another project, advanced backcross populations and hybrids were generated and evaluated to identify QTLs for yield and heterosis in exotic germplasm. One donor parent, Lian Tang Ai, a Chinese landrace cultivar appeared to enhance both grain yield and earliness in hybrids and could be useful in enhancing yield in hybrids.

Several new tan-plant N'Tenimissa derivative guinea type breeding lines looked promising in Mali in 2001, showing less stalk breakage, and better head bug resistance than N'Tenimissa. One line, 97-SB-F5DT-63, N'Tenimissa*Tiemarfing, has been released and is called Wassa. Two other germplasm, true Guinea cultivars (N'Tenimissa*Tiemarfing) were given names Zarra and Keninkedie and will be increased for use in value-added products. Also, some new, shorter N'Tenimissa derivative F_4 and F_5 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. A local private entrepreneur successfully organized the production of a large quantity of grain of N'Tenimissa in 2001 in the Bamako area and has initiated a new market for the flour. His efforts in 2002 were dashed due to financial and other problems in his company.

In Nicaragua, several of the breeding lines which have looked outstanding in the Southern Africa region, were evaluated and some performed very well (Table 2). The lines (Macia*Dorado)-LL6, (ICSV1089BF*Macia)-HF9, (Macia*Dorado)-LL2, (Macia*Dorado)-HD12, and (ICSV1089BF*Macia)-HF2 combine high yield and appropriate plant height, and maturity, and agronomic traits for potential use as new cultivars in Nicaragua. Also, the white, tan cultivar, Macia, introduced by Dr. Gary Odvody from Southern Africa region, has been selected in Nicaragua for release (Africana) (Table 3). Macia was one of several elite African sorghums sent to Central America in 1999 is an INTSORMIL nursery.

Table 2. Performance of advanced (generation white seeded), tan plant breeding lines for potential as cultivars, CNIA, Nicaragua, 2002.

Variety/ Pedigree	Seed Source	Grain Yield kg ha^{-1}	Days to Flower	Plant Height cm	Panicle Exsertion cm
Sureno	99L1048	7206	68	207	10
(Macia*Sureno)-HF19	01BD4966	6226	70	197	9
(Macia*Dorado)-LL6	01CA1749	5950	68	159	8
(ICSV1089BF*Macia)-HF9	01CA1792	5732	69	159	10
(Macia*Dorado)-LL2	01CA1728	5359	69	169	18
(Macia*Dorado)-HD12	01CA1532	5106	69	170	16
(ICSV1089BF*Macia)-HF2	01CA1776	5009	73	169	6
ISCV1089BF	00L2455	4687	75	227	8
(SRN39*09EON328)-HF4	00CA4295	4488	71	150	9
(Macia*Dorado)-LL7	01CA1764	4431	67	155	12
(CE151*MP531)-LD42	01BD5214	4118	64	147	9
(90EO328*CE151)-LD11	01CD3298	4042	68	144	12
(Macia*Dorado)-HD4	01CA1517	4038	69	161	7
(ICSV1089BE*Macia)-HF11	01CA1803	3787	69	157	11
(Macia*Dorado)-HD12	01CA1538	3723	67	166	12
98CD181/(87E0361*90E0328)-HF6	00L2330	3488	72	147	15
Dorado	99L1856	3343	70	155	12
Kuyuma	00L2567	2704	68	160	8
99GW092/(86E0361*90E0343)-HD12	00L2451	2262	72	140	20
(87E0366*90EON328)-HF14	00BD2485	2071	70	156	7
Test Mean		4158			

Table 3. Performance of selected released and experimental white seeded, tan plant cultivars, CNIA, Nicaragua, 2002.

Variety	Grain Yield kg/ha^{-1}	Days to Flower	Plant Height, cm	Panicle Exsertion, cm
Pinolero 1	6813	66	202	10
(TxP)S-6-P-1-11	6488	62	182	10
Macia (Africana)	6337	65	174	11
SOBERANO	6331	65	172	10
(TxP)S-6-P-1-7	6206	62	196	14
(TxP)S-6-P-1-12	6056	65	170	14
CENTA-RCV	5801	69	203	12
JOCORO	5202	68	162	8
Tortillero precoz	4658	56	162	11

Thirty-five selected diverse Malian indigenous sorghums, including some new unique Durras, Durra-Bicolor, Bicolor, and Durra Dochna from Northern Mali, along with 30 primarily Guinea-Caudatum sorghums from Southern Sudan were evaluated for B/R fertility reaction, hybrid vigor and presence of the dominant B1 gene (gives testa with U.S. females) in Mali and Puerto Rico (Table 4). Most Malian cultivars were restorers except for a few Guinea types, especially Margaritaferum types. Essentially all the Guinea-Caudatum derivative cultivars from Southern Sudan were strong restorers. The dominant B1 gene was absent in most Durra and Durra-Bicolor Malian lines, and some of these lines showed promising heterosis. There appeared to be rather good differences in hybrid vigor among lines, especially in Mali.

Table 4. F1 hybrid evaluation, fertility reaction and B1 gene evaluation of selected Malian and Sudanese cultivars from the Mali and Sudan Sorghum Collection, Mali (2002) and Puerto Rico (2002-2003 winter).

Cultivar[1/] Designation	Race/[2/] Working Group	Hybrid[3/] Agronomic Score Mali	Hybrid[3/] Agronomic Score P. Rico	Fertility[4/] Reaction	Testa[5/] (B1) Reaction
97ML10	B/B	2.6	3.0	R	P
97ML20	DB/DB	2.2	2.4	R	P
97ML37	DB/DB	2.1	2.2	PR	A
97ML45	GB/GB	2.2	2.2	PR	A
97ML223	D/D	1.9	2.2	R	A
97ML268	D/D (Dif. Gad)	1.9	2.2	R	A
97ML477	D/D (Not Gad)	1.9	2.3	R	A
97ML508	D/D (Not Gad)	2.0	--	R	P (ss)
97ML518	C/CD	2.0	2.2	R	A
97ML737	G/G	2.1	2.4	PB	P (ss)
97ML754	DB/DB	2.3	2.1	R	A
97ML846	G/G	2.3	2.4	R	P
97ML961*	C/Consp (Enda)	--	2.1	B-BP	P
97ML987	G/G 9CSM388)	--	2.2	R	P
97ML1010	G/Consp	2.3	2.3	R	A
97ML1067	D/D	1.9	2.2	R	A
97ML1100	D/D (Lak Gad ty)	2.1	2.1	R	A
97ML1122	C/C Nig	2.4	2.0	R	P
97ML1211	D/D (Erect Hd)	1.9	2.1	R	A
97ML1296	G/G (Sequetana)	2.2	2.4	R	P
97ML1587	D/D (Erect)	2.0	2.2	PR	A
97ML1635	G/GK	2.2	2.5	PB	P
97ML1788	B/BD	2.1	2.2	R	A
97ML1803	DB/DDoc	2.0	2.3	PR	A
97ML1807*	B/BD	2.1	2.2	PR	A
97ML1832	D/D (Erect)	2.1	2.1	PB	A
97ML1869	D/DB	2.1	2.0	R	A
97ML2255	G/G	2.2	2.3	R	PB
97ML2335	G/G	2.3	2.4	P	PB
97ML2369	G/Marg	2.5	2.6	B	P
97ML2447	G/Marg	2.5	2.6	B	P
CSM63E	G/G	2.0	2.5	R	P
Lakahiri	D/D	2.1	2.3	R	A
Gadiaba	D/D	--	--	R	A
Bagoba	D/D	2.1	2.2	R	A
CSM63	G/G	2.3	--	P	P
CSM228	G/Marg	2.5	2.6	BP	P
CSM219	G/G	2.2	2.4	R	P
N'Tenimissa	G/G	2.1	2.3	B	A
GH/84-3/5 (Nigeria)	D/D	2.0	2.1	R	A
SU842	G/GC	2.2	2.2	R	P
SU1844	GC/GC	2.0	2.0	R	P
SU1855	CG/CG	2.3	2.2	PR	P
SU1890*	CN/CN	2.4	2.2	R	P
SU1894	CN/NG	2.1	2.3	R	P
SU1898	G/CG	2.1	2.2	R	P
SU1900	C/CK Kaura	2.2	2.2	PR	P
SU1903	C/CG	2.1	2.1	PR	P
SU1909	CG/CG	2.1	2.2	R	P

Table 4 cont'd. F1 hybrid evaluation, fertility reaction and B1 gene evaluation of selected Malian and Sudanese cultivars from the Mali and Sudan Sorghum Collection, Mali (2002 and Puerto Rico (2002-2003 winter).

Cultivar[1/] Designation	Race/[2/] Working Group	Hybrid[3/] Agronomic Score Mali	Hybrid[3/] Agronomic Score P. Rico	Fertility[4/] Reaction	Testa[5/] (B1) Reaction
SU1913	CC/CG	2.3	2.3	BP-PR	P
SU1916	G/Consp	2.0	2.4	R	P
SU1926	CC/NG	2.1	2.5	R	P
SU1929	CG/CG	2.1	2.4	PR	P
SU1930	CB/GN	1.9	2.4	R	P
SU1934	CG/CG	2.0	2.3	PR	A
SU1936*	CG/GN	2.0	2.2	R	P
SU1944	CG/GN	2.4	2.2	P-PR	P
SU1948	CG/GN	2.4	2.1	P-PR	A?
SU1954*	CG/GN	2.1	2.2	R	Seg
SU1970	CG/CG	2.0	2.2	R	Seg
SU1972	CG/CG	2.1	2.2	R	Seg
SU1975	CG/CG	2.1	2.4	R	P
SU1977*	CG/GN	2.1	2.2	R	P
SU2057	CG/CG	2.2	2.1	R	P
SU2070	CG/CG	2.1	2.3	R	P
SU2092*	CG/CG	2.1	2.1	R	P
SU2104	GC/GC	2.0	2.2	R	P
IS12661C(SC170)	C/ZZ	1.8	1.9	R	A
SU1765	C/ZZ	1.8	1.9	R	A

1/ All hybrids made with ATx3042 unless designated with *, ATx 3197, 97ML= 1997 Mali Collection plot numbers; SU= 1991 Sudan and 1993 St. Croix plot numbers.

2/ B = Bicolor, G = Guinea, D = Durra, C = Caudatum, k = Kafir, Consp = Conspicuum, Doc - Dochna;, Marg = Margaritaferum, Nig - Nigericans, N - Nigricans, ZZ - Zerazera

3/ Agronomic score; 1 = very good to 5 = very poor. Primary criteria was grain yield.

4/ B = no seed, PB = 5-10%, P = 20= 50%, PR = 50-80%, R = 80% and greater.

5/ Presence (P) or absence (A) of testa in F1 hybrid. P = Dominant B1 gene present in male parent. ss = recessive spreader in male

Networking Activities

Workshops/Conferences

Participated in the biennial Grain Sorghum Research and Utilization Conference and SICNA Meeting, Feb. 16-18, 2003, Albuquerque, New Mexico and presented a paper.

Participated in the INTSORMIL PI Conference November 17-23, 2002, Addis Ababa, Ethiopia, chaired a session, presented a paper, and went on the pre- and post-conference tours, and served on the Planning committee for the PI Conference.

Participated in the Kansas/Nebraska sorghum Field Day and Workshop, September 18-19, 2002 at Manhattan, Kansas, and the photo-insensitive GRIN Collection Growout at Colwich, KS September 20.

Research Investigator Exchanges

Interacted with numerous Host Country and U.S. INTSORMIL scientists and discussed and planned future research plans and activities at the INTSORMIL PI Conference in Ethiopia, November 17-23, 2002.

Participated in the Sorghum Germplasm Committee meetings at Colwich, KS, Sept. 20, 2002 and at the SICNA meetings in Albuquerque, NM, Feb. 16, 2003, and discussed germplasm and other sorghum research.

Traveled to Mali, November 8-14, 2002 to evaluate INTSORMIL/IER collaborative research at Sotuba and Cinzana, and discuss and plan future activities with Malian scientists.

Traveled to Ethiopia, November 15-24, 2002 for the INTSORMIL PI Conference and discussed and planned future research with numerous Host County and U.S. scientists especially as related to West Africa, but also with scientists from East Africa, Southern Africa, and Central America.

Participated in the INTSORMIL TC Meeting, May 11-13, 2003 at Kansas City and interacted with several INTSORMIL scientists.

Coordinated the training of Mr. Niaba Teme, former sorghum breeding technician with IER, Mali who completed his M.S. degree in December, 2002 at Texas Tech University, cooperative with Texas A&M, and is now working on his Ph.D.

Interacted with several private seed company scientists at the SICNA Meetings, at the Sorghum Advisory Committee Growouts at Tampico, Mexico, March 5-7, 203, and at the sorghum Field Day at Lubbock/Halfway, September, 2002 where future possible releases from Rosenow's sorghum breeding program were viewed and discussed.

Hosted several international and U.S. visitors at Lubbock where they toured sorghum plots and discussed sorghum breeding and germplasm research. Visiting scientists included: Neil Muller - Pacific Seeds Breeder, Queensland, Australia, Sept. 15-16, 2002; two lady India Sorghum Breeders, Sept. 23-24, 2002; Issoufou Kapran (Niger, sorghum breeder), Sept. 23-25, 2002; Bob Henzell, Australian sorghum breeder, Sept. 28-October 4, 2002; John and Janet Taylor, South Africa quality/utilization scientists, Oct. 21-22, 2002; and John Mullet, Robert and Patricia Klein, Texas A&M Molecular Biologists, May 30, 2002.

Germplasm and Research Information Exchange

Germplasm Conservation and Use

Continued the coordination of the work with the Mali Sorghum Collection with the completion of the data and characterization and entry into the USDA/ARS GRIN system. The Collection was evaluated, characterization completed, and a tentative working collection identified in cooperation with Drs. Aboubacar Touré, Jeff Dahlberg, and John Erpelding, and Mr. Niaba Teme. After the seed sent to Experiment Georgia has been processed, seed of the entire collection will be sent to NSSL at Ft. Collins, Colorado 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-ARS for entry into the GRIN system.

Nineteen new sorghum breeding lines from IER, Mali were introduced into the U.S. and evaluated in Puerto Rico and seed increased.. These included some Durras from northern Mali and white-seeded, tan-plant, good food quality guinea derivative and non-guinea types. Selected indigenous sorghums from the Mali working Collection (35) and the Sudan Working Collection (30) were evaluated for B/R reaction and hybrid vigor in Mali and Puerto Rico.

The 4,000+ photoperiod insensitive entries from the GRIN Sorghum Collection were grown at Halfway, Texas in 2002 for observation and evaluation by interested sorghum workers. Notes were also taken on a duplicate planting at Colwick, Kansas.

Two sets of new fully converted exotic lines (27 and 22 items) from the cooperative TAMU-TAES/USDA-ARS Sorghum Conversion Program were selected for release and are being prepared for release along with 71 partially converted lines. Twenty-five Mali entries, including some new, diverse types from Northern Mali were selected for entry into the Sorghum Conversion Program.

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). Also, special drought trials and elite germplasm nurseries were assembled and distributed. Countries to which large numbers of germplasm items were distributed include Mali, Niger, Ghana, Senegal, Nigeria, Burkina Faso, Zimbabwe, Botswana, Zambia, South Africa, Ethiopia, Guatemala, El Salvador, Nicaragua, and Mexico.

Assistance Given

Joint evaluation of germplasm and nursery and test entry decisions was done collaboratively with national scientists. 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 Ghana, Senegal, and Mali, and other miscellaneous supplies for Mali.

Other Collaborators

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. Zenbaba Gutema, Sorghum Breeder, EARO, Nazareth, Ethiopia

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

Dr. Eva Weltzien Rattunde, Sorghum Breeder, ICRISAT, Bamako, Mali

Dr. Paul Marley, Pathologist, IAR, Ahmadu Bello University, Samaru, Zaria, Nigeria

Dr. Adama Neya, Pathologist, INERA, Farako-Ba Station, Bobo Dioulasso, Burkina-Faso

Dr. Mamaurou Diourte, Pathologist, IER, Sotuba Station, Bamako, Mali

Mr. Leo Mpofu, Sorghum Breeder, Plant Breeding Institute, c/o SADC/ICRISAT , Bulawayo, Zimbabwe.

Mr. Hector Deras, Sorghum Breeder, CENTA, San Andres, El Salvador

Dr. John Erpelding, Sorghum Curator, USDA/ARS, Tropical Agriculture Research Station, Mayaguez, Puerto Rico.

Dr. Jeff Dahlberg, Research Director, National Grain Sorghum Producers Association, Lubbock, TX.

Dr. Bob Henzell, Sorghum Breeder, QDPI, Warwick, QLD, Australia

Dr. Andrew Borrell, Physiologist, QDPI, Warwick, QLD, Australia.

Dr. Henry T. Nguyen, Molecular Biologist, University of Missouri, Columbus, MO

Dr. John Mullet, Molecular Biology, Department of Biochemistry, Texas A&M University, College Station, TX 77843.

Dr. Robert Wright, Molecular Biology, Department of Plant and Soil Sciences, Texas Tech University, Lubbock, TX 79409.

Dr. Paxton Peyton, Molecular Biology, USDA-ARS, Plant Stress Lab, Lubbock, TX 79409.

Dr. Robert Klein, Molecular Biology, USDA-ARS, College Station, TX 77843.

Dr. Patricia Klein, Molecular Biology, Crop Biotech Center, College Station, TX 77843.

Dr. William Payne, Plant Physiologist, Texas A&M Research Center, Amarillo, TX.

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

Project TAM 223
Gary C. Peterson
Texas A&M University

Principal Investigator

Gary C. Peterson, Professor, Sorghum Breeding & Genetics, Texas Agricultural Experiment Station, Lubbock, TX 79403

Collaborating Scientists

Dr. Medson Chisi, Sorghum Breeding, Golden Valley Research Station, Box 54, Fringila, Zambia
Dr. Neal McLaren, ARC-Grain Crops Institute, Private Bag X1251, Potchefstroom 2520, Republic of South Africa
Dr. J. van den Berg, Entomology, School of Environmental Sciences, Potchefstroom Univ, PB X6001, Potchefstroom 2520 South Africa
Dr. Hannalene du Plessis, Entomology, ARC - Grain Crops Inst, PB X1251, Potchefstroom 2520, Republic of South Africa
Ing. Rafael Obando, Sorghum Breeding, Instituto Nicaragense de Tecnolog, Edificio Mar, Apdo.1247, Managua, Nicaragua
Ing. René Clará, Sorghum Breeding, CENTA, Apartado Postal 885, San Salvador, El Salvador
Ms. Phoebe Ditshipi, Plant Pathology, Dept of Ag Research, Private Bag 0033, Gaborone, Botswana
Dr. David Munthali, Entomology, Botswana College of Agriculture, Private Bag 0027, Gaborone, Botswana
Dr. Aboubacar Touré, Sorghum Breeding, IER, Sotuba, B.P. 438, Bamako, Mali
Dr. Sidi B. Coulibaly, Sorghum Breeding, IER Sotuba, B.P. 438, Bamako, Mali (August 1998 - January 2003, Graduate Research Assistant, Texas A&M University Ag Research and Extension Center, Rt. 3, Box 219, Lubbock, TX)
Dr. Bonnie B. Pendleton, Entomology, Division of Agriculture, West Texas A&M University, Canyon, TX 79016
Dr. W.L. Rooney, Sorghum Breeding, Dept of Soil & Crop Sciences, Texas A&M Univ, College Station, TX 77843
Dr. Lloyd Rooney, Cereal Chemistry, Dept of Soil & Crop Sciences, Texas A&M Univ, College Station, TX 77843
Dr. D.T. Rosenow, Sorghum Breeding, Texas Ag Experiment Station, Rt 3 Box 219, Lubbock, TX 79403

Summary

Increase Yield and Promote Economic Growth

Research emphasis of this project has emphasized the breeding for resistance to insects component of the integrated Texas A&M University sorghum improvement program. Primary objectives are to identify, characterize and utilize the genetic diversity of grain sorghum to develop improved cultivars, germplasm, or parental lines resistant to selected biotic and abiotic stresses. Insect pests receiving emphasis are the sorghum midge (*Stenodiplosis sorghicola*), greenbug (*Schizaphis graminum*), and sugarcane aphid (*Melanaphis sacchari*). Segregating populations are also selected for resistance to economically important diseases including but not limited to: sorghum downy mildew (caused by *Peronosclerospora sorghi* [Westan and Uppal] Shaw), head smut (caused by (*Sphacelotheca reiliana* [Kuhn] Clinton), and anthracnose (caused by *Colletotrichum graminicola* [Cesati] Wilson). Other diseases for which resistant genotypes are selected include zonate leaf spot (caused by (*Gloeocercospora sorghi* [Bain and Edgerton]), bacterial leaf streak (caused by *Xanthomonas holcicola* [Elliot] Star and Burkholder), bacterial leaf stripe (caused by *Pseudomonas andropogoni* ([E.F. Smith] Stapp), and charcoal rot (caused by *Macrophomina phaseolina* ([Tassi] Goid). Project emphasis is shifting to include additional research on food type sorghums and drought resistance while maintaining a resistance to insects component.

Breeding and selection activities use primarily conventional methodology. Collaborative molecular biology research has mapped genes for resistance to greenbug biotypes and molecular markers have been used to concurrently select for greenbug resistance and stay-green (post-flowering drought tolerance). Numerous lines from different populations are being evaluated to identify superior lines resistant to greenbug biotype I with excellent stay-green and wide adaptation.

A primary research objective is to develop sorghum midge-resistant hybrid parental lines. 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 favorable traits including adaptation, disease resistance, etc. The best midge-resistant lines in hybrid combination produce

10-15% less grain yield than the best susceptible hybrids when sorghum midge are absent at anthesis. When sorghum midge are present at anthesis, or when planting occurs two weeks later than normal, resistant hybrids produce significantly more grain than susceptible hybrids. Research is on-going to select for improved grain yield potential. With a shift in project emphasis research on sorghum midge resistant hybrids will be decreased with new emphasis placed on sorghum midge resistant varieties for use in developing country production systems.

Increase Yield, Promote Economic Growth, Improve Nutrition

Experimental greenbug resistant lines with wide adaptation and resistance to several diseases are in advanced yield testing. Included is an array of plant and grain color combinations such as tan plant, white grain and tan plant, red grain. Tan plant red or white grain sorghum hybrids with multiple stress resistance and high yield potential may help increase utilization of sorghum in new or non-traditional uses. Multiple stress resistance, wide adaptation, diverse plant types will be used by private industry after release in hybrid development programs.

Improve Institutional Capacity

The principal investigator serves on the graduate committee of one M.S. student (from Mali), and two Ph.D. students (co-chair of Malian student at Texas Tech and U.S. student at Texas A&M University). The Malian M.S. student completed the degree in December 2002 and is now working on a Ph.D. degree at Texas Tech University. The principal investigator coordinated the short-term training of a Southern African breeding collaborator, and assisted in the short-term training of collaborators from Botswana, Zambia, and South Africa.

Objectives, Production and Utilization Constraints

Objectives

- Obtain and evaluate germplasm for resistance to arthropod pests and other stresses including selected diseases and drought.
- Develop and release high-yielding, agronomically improved sorghums resistant to selected insects and other biotic or abiotic stresses.
- Utilize molecular biology to increase understanding of plant traits for stress resistance.
- Develop and release high grain yield sorghums with multiple stress resistance and improved grain quality traits.

Constraints

Sorghum production and yield stability is constrained by biotic and abiotic stresses including insects, diseases and drought. Insects pose a risk in all sorghum production areas with damage depending on the insect and local environment. To reduce stress impact sorghum hybrids or cultivars with enhanced environmental fitness are required. Cultivars experience stress concurrently or sequentially and genetic resistance to multiple stresses reduces environmental risk and enhances productivity. This is especially important as production ecosystems change with the natural balance between cultivars and biotic stresses experiencing change.

Farmers use hybrids or cultivars with improved genetics for adaptation, stress resistance, and quality to meet the demands of increased food production in economically profitable, environmentally sustainable production systems. This requires a multi-disciplinary research program to integrate resistant genotypes into the management system. Varieties or hybrids with genetic resistance to stress 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 LDC research is supported through graduate education, germplasm exchange and evaluation, site visits, and research at nursery locations in Texas. Activity is conducted in three regional programs - Southern Africa, Central America, and West Africa (Mali). Project resources directed to Mali support a Ph.D. student. Southern Africa research is directed at incorporating resistance to sugarcane aphid into adapted cultivars. Additional selection criteria includes disease resistance, adaptation, and end-use traits. Research in Nicaragua and El Salvador supports research on sorghum midge (the most important biotic production constraint in Nicaragua), drought resistance, disease resistance, adaptation, and end-use traits. In the United States, sorghum midge and greenbug-resistant sources have been identified and used in developing elite resistant sorghums. Through collaborative ties with other projects genetic inheritance, resistance mechanisms, molecular mapping, and marker-assisted selection research has been 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 lines from the sorghum conversion program. New resistance sources are crossed to elite resistant germplasm, and to other germplasm with superior trait(s). Although a primary selection criteria is insect resistance, other significant selection criteria include wide adaptation, resistance to specific diseases, drought resistance, weathering resistance and improved end-use traits. Based on data analysis and phenotypic evaluation, crosses are made among elite lines to produce germplasm for subsequent evaluation. The goal is to combine resistance genes for multiple stresses into a single high grain yield genotype.

For insects important in LDCs 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/or greenhouses, and agronomic and yield data collected if possible. The populations are grown in the U.S. and selected for adaptation.

Research Findings

Sorghum Midge Resistance

Primary emphasis has been directed to identify new superior A- or R-lines. The lines should exhibit a high level of sorghum midge resistance, superior agronomic traits, and high grain yield potential. The research focus is changing to reduce efforts in hybrid development and increase efforts in development of sorghum midge resistant varieties for use in developing country production. In 2002, the midge line test (74 entries x three replications) was grown at three locations including Corpus Christi, TX to evaluate for resistance and Managua, Nicaragua for resistance and adaptation. Partial results are reported in Table 1. At Corpus Christi, sorghum midge population density at anthesis was low with test mean of 4.1 (rated on a scale of 1 = 0-10% damaged kernels, 2 = 11-21%, up to 9 = 80-100% damaged kernels.) Conclusions can be made for sorghum midge resistance under low to moderate population density only. Previous research indicates that genotypes resistant under low to moderate population density may not be resistant under high population density. Significant differences were not identified between any of the resistant or susceptible checks. The most resistant experimental entries were rated a 2 indicating damage of about 20%. Many entries were identified with excellent resistant under low to moderate population density. However, these entries may not be resistant under high or moderate population density. At the INTA station near Managua, Nicaragua, population density was low with a test mean of 2. The highest grain yield lines in Nicaragua exhibited a moderate resistance level in Texas. There was generally a positive relationship between sorghum midge resistance in Texas and Nicaragua with all but one entry expressing higher resistance in Nicaragua. Several entries were identified with good midge resistance in Texas and Nicaragua, and good grain yield in Nicaragua.

Grain yield potential of elite breeding lines in hybrid combination was evaluated at Corpus Christi. The midge hybrid test (43 entries x three replications) was evaluated in a late planting (about 4 weeks after farmer planted sorghum) date for sorghum in the Texas Coastal Bend. The growing season was characterized by little rain from planting through maturity.

Table 1. Sorghum midge damage rating and other agronomic traits for selected entries in the midge line test at Corpus Christi, TX and Managua, Nicaragua, 2002.

	Midge Damage Rating†			Days to 50% Anthesis	
Designation	Corpus Christi	Managua	Grain Yield	Corpus Christi	Managua
			-kg/ha-		
(85OG4300-5*Tx2782)-SM5-CM2-	6.3	1	6412	83	67
(PM12713*Tx2882)-CM3-CM2-	4.0	1	6162	75	70
(91CC515*MR114-90M11)-SM4-SM1-	6.7	1	4975	80	66
01MLT60/02BRON196(sib)/(Tx2880*(86EO361*(Tx2880*PI550607)))-PC1-PR10-LG2-CG2 -CM2-	2.7	2	4762	82	65
(PM13713*Tx2882)-SM8-CM1-	3.0	1	4426	77	70
(Tx2882*SRN39)-CM3-SM2-	3.7	2	4094	83	62
MB108B/P.G.	2.0	2	4024	80	67
(Tx2883*(Tx2864*(Tx436*(Tx2864*PI550607))))-PC2-SM1-SM2-CM1-CG2-BG1	2.3	2	3912	83	73
00MLT165/01MLT156/(PM12713*Tx2880)-CM5-CM3-	2.3	2	3872	82	67
B8PR1011	5.7	2	3744	79	64
(Tx2883*(Tx2737*(Tx436*(Tx2783*PI550607))))-PC1-SM1-SM1-CM1-SM1-CABK	3.3	3	3702	75	70
01MLT62/02BRON196(sib)/(Tx2880*(86EO361*(Tx2880*PI550607)))-PC1-PR10-LG2-CG3 -SM2-	6.3	1	3689	84	67
(91CC515*MR114-90M11)-SM15-CM2-	4.0	2	3680	78	67
BTx640	5.0	3	3592	80	64
(90EO343*94ML37/(6EO362*Tx2880))-SM4-SM1	4.3	3	3583	80	68
(MB120C-BM5-*MB108B/P.G.)-SM10-CM1-	3.7	1	3540	78	69
01MLT69/(Tx2880*(Tx2880*(Tx2864*(Tx436*(Tx2864*PI550607)))))-PR2-LG18-CG1-CG2-	3.0	3	3528	79	66
97ML9/(Tx2882*7EO366)/7BRON146	3.3	2	3500	83	68
9MLT181	3.7	1	3500	82	64
RTx430	3.0	3	3468	78	65
MEAN	4.1	2	3468		

† Rated on scale of 1 = 0-10% damaged kernels, 2 = 11-20% damaged kernels, up to 9 = 91-100% damaged kernels.

Partial results are shown in Table 2. Sorghum midge population density at anthesis was low to moderate with a test mean of 4.2, indicating about 40% grain loss due to sorghum midge damage. The standard resistant check is ATx2755*Tx2882 and the standard susceptible check is ATx2752*RTx430. Grain yield was low, test mean of 1265 kg ha^{-1}, due to the harsh environmental conditions at Corpus Christi. The six lowest grain yield entries, and 8 of the lowest 10, were susceptible hybrids. All produced significantly less grain than the resistant checks and most experimental entries. Results confirm previous observations that with a late planting date and sorghum midge present at anthesis most resistant hybrids will produce significantly more grain than susceptible hybrids. Seed size measured as gram weight per 100 kernels led to the conclusion that seed size of susceptible hybrids was generally smaller than resistant hybrids although the differences were usually not significant.

There is concern that it will not be possible to develop sorghum midge resistant hybrids for use in the United States. The primary constraint to wide-spread use of currently possibly available hybrids is the lower grain yield potential (averaging 10-15%) of resistant than susceptible hybrids in a normal planting. However, for production delayed at planting two weeks or more resistant hybrids will out-yield susceptibly hybrids without insecticide application. With increasing environmental concern regarding pesticide application a reduction in availability of insecticides to control sorghum midge could significantly increase interest in and potential use of resistant hybrids.

Greenbug Resistance

Selections to develop germplasm resistant to biotype I were made. The primary resistance sources 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 level of resistance is desired. 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.

Experimental germplasm has been selected for diversity of plant type, wide adaptation, foliar disease resistance, and increased grain yield potential. This germplasm will be useful as sources of improved traits for other breeding programs, and selected germplasm might have potential as varieties in specific production systems. Thirty entries were evaluated for grain yield potential as varieties in Managua, Nicaragua (partial results in Table 3). Several lines exhibited excellent grain yield

Table 2. Grain Yield and other agronomic traits of selected entries in the midge hybrid test at Corpus Christi, TX, 2002.

Hybrid	Class	Grain Yield	Midge Damage†	100 kernel weight	Plant Height	Panicle Exsertion
		-kg/ha^{-1}-		-g-	-cm-	-cm-
A8PR1011*Tx2767		2388	2.3	1.82	107	0
A0PR11*Tx2880		2383	2.0	1.86	92	1
A0PR13*Tx2882		2333	3.3	1.80	89	2
A9PR2143*Tx2880		2217	2.3	1.63	103	2
A8PR1011*MB108B		2193	3.0	1.60	131	2
A0PR13*Tx2880		1842	2.3	1.78	93	2
A8PR1015*Tx2880		1817	2.7	1.92	119	2
A9PR2147*Tx2882		1807	2.3	1.66	88	1
A8PR1011*9MLT176		1746	4.3	1.65	108	4
A8PR1013*9MLT181		1728	2.0	1.31	103	4
A8PR1011*9MLT181		1667	2.3	1.27	103	5
A8PR1011*Tx2882		1662	2.0	1.57	100	0
A8PR1011*9MLT180		1659	3.0	1.49	105	5
A8PR1011*Tx2880		1654	2.3	1.39	102	4
A9PR2145*Tx2882		1598	2.3	1.80	92	2
A8PR1011*9MLT157		1580	2.3	1.63	101	1
ATx2755*Tx2882	R-Ck	1568	2.7	1.86	88	1
ATx2755*MB108B	R-Ck	1469	5.3	1.73	110	3
ATx2752*RTx430	S-Ck	1393	6.7	2.42	93	0
ATx2755*Tx2880	R-Ck	1254	3.0	1.65	86	4
A1*Tx430	S-Ck	768	7.7	1.94	110	0
A35*Tx430	S-Ck	331	7.7	1.82	105	5
A807*Tx2783	S-Ck	281	9.0	1.56	112	2
MEAN		1265	4.2	1.71	101	2
LSD.05		456	1.1	0.16	9.5	2

† Rated on a scale of 1 = 0-10% damaged kernels, 2 = 11-20% damaged kernels, up to 9 = 91-100% damaged kernels.

Table 3. Grain yield and other agronomic traits in line evaluation at Managua, Nicaragua, 2002.

Designation	Grain Yield	Days to 50% Anthesis	Height	Exsertion	Panicle Length	Foliar Disease†	Adaptation†
	-kg/ha^{-1}-		-cm-	-cm-	-cm-		
6BRON167	5194	71	108	5	29	2.0	3.0
5BRON152	4901	70	117	4	35	1.5	2.0
6OBS124	4675	64	136	15	34	2.0	3.0
6OBS172	4530	73	136	8	37	2.0	2.0
5BRON135	4249	72	144	13	37	1.0	3.0
Tx430	4161	64	118	8	28	2.0	2.0
9BRON125	3981	65	116	6	38	2.0	2.5
B8PR1059	3827	70	113	5	29	2.0	2.5
GR134-90M50	3822	75	114	3	34	2.0	3.0
(GR127-90M37*GR107-90M18)	3525	69	132	19	33	2.0	3.0
GR107-90M17	3424	72	105	3	32	2.0	2.5
5BRON139	3207	74	123	2	33	1.0	2.0
B8PR1051	3049	70	116	0	34	2.0	2.5
7BRON187	3045	66	119	2	31	2.0	2.5
6BRON163	3021	72	125	10	32	2.0	3.0
5BRON156	3014	73	128	6	33	1.5	2.5
B8PR1053	2990	66	119	0	32	2.0	2.5
B8PR1057	2738	70	113	6	32	1.5	3.0
5BRON155	2606	66	132	20	31	1.5	3.0
BTx631	2389	72	140	7	37	1.5	3.0
5BRON154	2244	70	138	14	36	1.5	3.0
8BRON122	2218	70	117	12	30	1.5	3.0
BTx3042	1840	54	119	17	30	4.5	4.5
BTx635	1400	73	127	0	29	1.5	3.0
Tx436	1005	62	116	23	24	3.0	4.0

† Rated on a scale of 1 = no foliar disease present up to 5 = leaves killed by foliar disease.
† Rated on a scale of 1 = most acceptable with excellent grain yield potential up to 5 = not acceptable with poor grain yield potential.

potential, acceptable height, and outstanding foliar disease resistance. Several of the lines were evaluated in hybrid combination and evaluated against local commercial hybrids. The hybrids A8PR1057*6BRON167, A8PR1051*RTx430, A0PR1059*5BRON159, and A8PR1053*RTx430 produced grain yield of 6658, 6120, 5931 and 5875 kg ha^{-1} respectively with good agronomic (height, exsertion, panicle length, and uniformity) characteristics and acceptable foliar disease resistance. There were no significant differences between these hybrids and the local commercial hybrids CB8996, Ámbar and CB8976.

Sugarcane Aphid Resistance

The sugarcane aphid (*Melanaphis sacchari*) is an insect pest of sorghum throughout Southern Africa. Collaborative research is between TAM 223, the Botswana Department of Agricultural Research (DAR), and the South African Grain Crops Research Institute. Resistance sources including TAM428, CE151, WM#177, Sima (IS23250), SDSL89426, FGYQ336 have been crossed to locally adapted cultivars (include Segeolane, Marupantse, Macia, Town, SV1, and A964) and to elite lines from the Texas program to develop a range of populations. The segregating populations are planted at Corpus Christi, Beeville and Lubbock, Texas for evaluation and selection. Evaluation for sugarcane aphid resistance and adaptation to local environments is done at Potchefstroom, South Africa or Gaborone, Botswana.

Evaluation for sugarcane aphid resistance was done in two trials of 100 entries each. One trial was planted at the mid-altitude research station of the ARC-Grain Crops Institute in Potchefstroom and one at the sub-tropical, low-altitude station at Burgershall Research Station near Hazyview (partial results in Table 4). Aphid damage was evaluated when the majority of entries were in the milk stage. Severity of infestation was evaluated using a 1 to 5 scale, where 1 = no aphids present on plants, 2 = light infestation with aphids present on a few leaves (no dead leaves), 3 = moderate infestation with many aphids present of two to three leaves (one or two dead leaves may be present), 4 = high infestation with many aphids on nearly all leaves (many dead leaves) and 5 = majority of plants in plot dying. Plants with a rating of 1 or 2 were considered to be resistant, while a rating of 3 indicated an intermediate level of resistance. Plants with a rating of 4 or 5 were considered susceptible.

Sugarcane aphid infestation levels were similar at both locations. Results indicated that 22 and 15%, respectively for Potchefrstroom and Burgershall, of the entries rate 1 indicating none to little damage. Ratings of 2 were recorded for 27 and 24% of the entries at Potcherstroom and Burgershall, respectively. Ratings of 5 were recorded for 5 and 15% of the entries at Potcherstroom and Burgershall respectively died as a result of aphid infestation.

The following experimental entries had no aphids on any plants at both locations: (Segaolane*WM#322)-LG2-LG2-BG1-BG1, (EPSON2-40/E#15SADC*TAM428)-LG3-BG1-BG1, (CE151*TAM428)-LG1-BGBK-CCBK, (6OB128/(Tx2862*6EO361)*CE151)-LG19-CCBK-CCBK, (CE151*TAM428)-CG1-BGBK-CCBK, (Macia*TAM428)-LL9, (CE151*TAM428)-LG2-CG1-BG1, (6BRON161/

Table 4. Mean damage ratings in the sugarcane aphid test at Potchefstroom and Burgershall, South Africa, 2003.

	Sugarcane aphid damage†		
Designation	Average	Potcherstroom	Burgershall
PRGC/E#222879	1.0	1.0	1.0
PRGC/E#69414	1.0	1.0	1.0
(Macia*TAM428)-LL9	1.0	1.0	1.0
(CE151*TAM428)-LG2-CG1-BG1	1.0	1.0	1.0
WM#177	1.3	1.5	1.0
PRGC/E#222878	1.3	1.0	1.5
(6OB128/(Tx2862*6EO361)*CE151)-LG19-CCBK-CCBK	1.3	1.0	1.5
(CE151*TAM428)-LG1-BGBK-CCBK	1.3	1.0	1.5
(A964*FGYQ336)-LG4-LG2-BG1-BG3	1.3	1.5	1.0
FGYQ336	1.5	1.5	1.5
(CE151*TAM428)-CG1-BGBK-CCBK	1.5	1.5	1.5
(6OBS124/94CE81-3/GR134B-LG56-*WM#177)-LG1-LG1-BG3-BGBK	1.5	1.5	1.5
(6BRON161/(7EO366*Tx2783)-HG54-*CE151)-CG4-BG1-BG1	1.5	1.0	2.0
(EPSON2-40/E#15-SADC*TAM428)-LG3-BG1-BG1	1.5	1.5	1.5
WM#322	1.8	2.0	1.5
Ent.62/SADC	1.8	1.0	2.5
(EPSON2-40/E#15/SADC*A964)-CG3-BGBK-CCBK	1.8	2.0	1.5
(6BRON126/(87BH8606-14*GR107-90M46)*EPSON2-40/E#15/SADC)-LG2-LG1-BGBK-CCBK	1.8	2.5	1.0
(5BRON131/((80C2241*GR108-90M30)-HG46)*WM#177)-LG1-BGBK-CCBK	1.8	1.0	2.5
(SV1*Sima/IS23250)-LG15-CG1-BG2-BGBK	1.8	1.0	2.5
(6BRON126/5BRON154/(87BH8606-14*GR107-90M46)*EPSON2-40/E#14/SADC)-LG3-CG1-BG1	1.8	1.5	2.0
(CE151*TAM428)-CG1-BG1-BG3	1.8	1.0	2.5
(Segeolane*WM#322)-LG2-LG2-BG1-LG1	1.8	1.5	2.0
(6BRON161/(7EO366*Tx2783)*CE151)-LG5-CG2-BG1-BG2	1.8	1.5	2.0
Sima (IS23250)	2.0	1.5	2.5
CE151	2.0	1.0	3.0
(6OB124/(GR134B-LG56)*WM#177)-LG7-CG2-BGBK-CCBK	2.0	1.5	2.5
(6OB128/(Tx2862*6EO361)*CE151)-LG4-CG1-BGBK-CCBK	2.0	1.5	2.5
(6BRON161/(7EO366*Tx2783)*CE151)-LG2-CG3-BG2-BGBK	2.0	1.5	2.5
(EPSON2-40/E#15-SADC*TAM428)-CG1-BG1-BG2	2.0	2.5	1.5
(Macia*TAM428)-LL2	2.3	1.5	3.0
(SDSL89426*6OB124/GR134B-)-LG5-CCBK-CCBK	2.3	2.0	2.5
(6BRON126/(87BH8606-14*GR107-90M46)*EPSON2-40/E#15/SADC)-LG3-CG1-BGBK-CCBK	2.3	2.5	2.0
(6OB128/(Tx2862*6EO361)*CE151)-LG25-CG1-BGBK-CCBK	2.3	2.0	2.5
(CE151*TAM428)-LG15-LG1-BG1-BGBK	2.3	2.0	2.5
(CE151*TAM428)-LG20-LG1-LG2-CG2	2.3	2.0	2.5
(6OB128/(Tx2862*6EO361)*CE151)-LG16-CG1-LGBK-LG2	2.3	2.0	2.5
(EPSON2-40/E#15/SADC*((BRON154/87BH8606-1*GR107-90M46)*EPSON2-40/E#15/SADC))-CG5-LG1-BG1	2.3	2.0	2.5
FGYQ353	2.5	2.0	3.0
(EPSON2-40/E#15/SADC*TAM428)-CG1-BGBK-CCBK	2.5	2.0	3.0
(6OBS128/94CE88-3/(Tx2862*6EO361)*EPSON2-40/E#15/SADC)-LG15-CG2-BG2-BGBK	2.5	3.0	2.0
(6OB124/94CE81-3/GR134B-LG56-*WM#177)-CG3-BG1-BGBK	2.5	2.0	3.0
(SDSL89426*6OB124/94CE81-3/GR134B-LG56-)LG5-CG1-BG2-BG1	2.5	2.0	3.0
(6OB128/(Tx2862*6EO361)*CE151)-LG25-CG1-BG2-BG2	2.5	2.5	2.5
(6BRON161/(7EO366*Tx2783)*CE151)-LG4-CG2-BG2-BG1	2.5	2.0	3.0
(6BRON161/(7EO366*Tx2783)-HG54-*EPSON2-40/E#15/SADC)-LG1-BG2-BG2	2.5	3.0	2.0
SDSL89426	2.8	3.0	2.5
GR128-92M12	2.8	2.0	3.5
(Tx430*Sima/IS23250)-LG5-CCBK-CCBK	2.8	2.0	3.5
(6OB128/(Tx2862*6EO361)*CE151)-LG27-LG1-BGBK-CCBK	2.8	2.0	3.5
(BRON161/(7EO366*Tx2783)*EPSON2-40/E#15/SADC)-LG5-CC2-BG1-BGBK	2.8	3.0	2.5
(5BRON131/(80C2241*GR108-90M30)*SDSL9426)-LG6-LG1-BG1-BG2	2.8	2.5	3.0
(6BRON126/5BRON154/(87BH8606-14*GR107-90M46)*EPSON2-40/E#14/SADC)-LG2-LG1-BG2	2.8	3.0	2.5
(6BRON161/(7EO366*Tx2783)-HG54-*CE151)-CG3-BG2-BG2	2.8	3.0	2.5
(6BRON161/(7EO366*Tx2783)-HG54-*CE151)-LG1-BG3-BG2	2.8	3.0	2.5
(6BRON161/(7EO366*Tx2783)*EPSON2-40/E#15/SADC)-LG4-CG1-BG1-LG2	2.8	3.0	2.5

((7EO366*Tx2783)-JG54*CE151)-CG4-BG1-BG1, (CE151*TAM428)-LG2-CG1-BG1,(6OB128/(Tx2862*6EO361)*CE151)-LG25-CG1-BGBK-CCBK, (6OB124/94CE81-3/GR134B-LG56*WM#177)-LG1-LG1-BG3, and (A964*FGYQ336)-LG4-LG2-BG1-BG3. Additionally, the following checks had no aphids on any plants: PRGC/E#22879, PRGC/E#222878, PRGC/E#69414, WM#177, and WM#322.

Greenbug Resistance/Stay-Green Study

Marker-assisted selection research for greenbug resistance and stay-green (post-flowering drought tolerance) was completed. This is a collaborative research activity between TAM 223, TAM 222, and the molecular biology laboratory of Dr. Henry Nguyen (formerly at Texas Tech University and currently at the University of Missouri). Dr. Sidi Bekaye Coulibaly (Mali) completed Ph.D. research to compare the efficiency of marker-assisted selection versus traditional selection methodology and returned to Mali in February 2003.

Grain yield is a complex trait that is influenced by genetic and environmental factors. Severe losses can be caused by drought, a common stress in most sorghum growing regions. Ninety-eight recombinant inbred line populations (RILs) of *Sorghum bicolor* L. Moench were derived from a cross between

Table 4 -cont'd. Mean damage ratings in the sugarcane aphid test at Potchefstroom and Burgershall, South Africa, 2003.

	Sugarcane aphid damage†		
Designation	Average	Potcherstroom	Burgershall
(6BRON126/5BRON154/(87BH8606-14*GR107-90M46)-HG10-*EPSON2-40/E#15/SADC)-CG2-BG2-BG2	2.8	3.5	2.0
TAM428	3.0	3.5	2.5
(CE151*BDM499)-LD17-BE2	3.0	2.5	3.5
(6OB128/(Tx2862*6EO361)*CE151)-LG3-LG1-BGBK-CCBK	3.0	2.5	3.5
(5BRON139/((6EO361*GR107der)-LG7)*CE151)-LG2-BGBK-CCBK	3.0	2.5	3.5
(6BRON161/((7EO366*Tx2783)-HG54)*CE151)-CG3-BGBK-CCBK	3.0	3.0	3.0
(6BRON161/(7EO366*Tx2783)*EPSON2040/E#15/SADC)-CG2-BG2-BGBK	3.0	3.0	3.0
(6OBS129/94CE89-2/(Tx2862*6EO361)-LG30-*WM#177)-CG1-BG1-BG2	3.0	3.0	3.0
(CE151*(6BRON119/(6EO361*GR107der)-CE151))-CG5-BG1-BG2	3.0	2.0	4.0
Kuyuma	4.5	4.0	5.0
Macia	4.8	4.5	5.0
Segaolane	5.0	5.0	5.0
MEAN	2.8	2.6	3.0
LSD.05	0.9	1.0	1.3

† Rated on a scale of 1 = no aphids present on plants, 2 = light infestation with aphids present on a few leaves (no dead leaves), 3 = moderate infestation with many aphids present on two to three leaves (one or two dead leaves may be present), 4 = high infestation with many aphids on nearly all leaves (many dead leaves), 5 = majority of plants in plot dying.

B35 (BTx642), a post-flowering drought resistant but pre-flowering drought susceptible line, and Tx7000, a post-flowering drought susceptible but pre-flowering drought resistant line. Two hundred and seventy four restriction fragment length polymorphic (RFLP) markers covering the sorghum genome were used to identify the main-effect and the epistatic QTLs.

Highly significant ($P<0.05$) differences were detected between the parents (B35 and Tx7000) and among the RILs for grain yield, drought susceptibility index, grain yield loss percentage, and grain yield geometric mean. Low drought susceptibility index did not always indicate higher grain yield but generally indicated lower grain yield loss percentage.

The MAPMAKER/QTL analysis detected 11 main-effect QTLs for grain yield under water stress and non-stress conditions in Lubbock and Halfway with many (7) on linkage groups A and F. Under stress conditions during 1994 in Halfway, 3 main-effect QTLs collectively explained 48.2% of the phenotypic variation in grain yield. Linkage group A contained a QTL (*Gya.2*) strongly associated (21.0%) with sorghum grain yield under one stress environment. Among the QTLs identified under non-stress environments, 1 QTL (*Gyf.2*) located on linkage group F was consistent across locations.

The performance of BC_2 to BC_4 backcross generations from the introgression of stay-green into greenbug resistant lines was evaluated in 217 backcross lines from 9 populations along with 15 parental lines used as checks. None of the progenies or parental lines were as resistant as the resistant check B35. Among all populations, only four lines were classified as post-flowering drought resistant. The populations generally produced more grain yield than the parental lines. Most progenies were resistant to biotype E greenbug but were only slightly resistant to susceptible to biotype I. In general, progenies or parental lines with a combination of multiple QTLs were resistant to moderately resistant to both greenbug biotypes E and I. Results indicated that QTL9 was more linked to resistance to both greenbug biotypes than QTL2, which was found linked to biotype E.

The performance of backcross generations derived from the introgression of stay-green quantitative trait loci into elite lines of sorghum was evaluated in 150 BC_2 to BC_4 progenies from 5 populations developed from elite released and unreleased lines along with 15 parental lines used as checks. Results indicated that only one line would be classified as post-flowering drought resistant as the resistant check B35. This progeny might has escaped post-flowering drought stress because of its earliness. Stay-green QTL analysis did not show any relationship with the phenotypic ratings in the field. Although some progenies were carrying stay-green QTLs, they were considered as post-flowering drought susceptible based on the reaction under field conditions of late season moisture stress.

Networking Activities

Workshops and Meetings

Participated in the 2003 Sorghum Industry Conference and Biennial Grain Sorghum Research and Utilization Conference, 16-18 February 2003, Albuquerque, NM.

Research Investigator Exchanges

Interacted with private seed company scientists and Texas Grain Sorghum Association representatives on several occasions as part of the Texas Agricultural Experiment Station (TAES) Sorghum Advisory Committee.

Interacted with sorghum farmers and Texas Grain Sorghum Association representatives on several occasions as TAES PROFIT (Productive Rotations On Farms In Texas) coordinator.

Zambia and Zimbabwe - 1-12 October 2002. In Zambia met with Ministry of Agriculture, Department of Agricultural Research scientists to discuss national and regional sorghum and pearl millet research. Evaluated winter nursery sorghum research plots near Nanga. Planned increase of sorghum variety for eventual distribution in drought stricken areas of Southern Africa. In Zimbabwe met with Department of Research and Specialist Service scientist to discuss regional sorghum breeding activity at ICRISAT Center, Matopos. Participated in meeting of the SMINET (Sorghum and Millet Improvement Network) Steering Committee at ICRISAT Center, Matopos.

Ethiopia - 13-25 November 2002. Participated in INTSORMIL Principal Investigators Conference and pre-/post-conference tours in Ethiopia. Delivered presentations on "Overview of INTSORMIL Southern Africa Program" and "INTSORMIL and Sorghum/Pearl Millet Research in the United States". Met with INTSORMIL collaborators to plan additional research and to discuss the next INTSORMIL grant extension proposal.

Participated in Sorghum Germplasm Committee meeting, 20 September 2002, Colwich, KS. Evaluated grow-out of the insensitive sorghum collection. Interacted with private scientists on issues related to germplasm.

Participated in INTSORMIL Technical Committee meeting 15-16 February 2003, Albuquerque, NM.

Participated in Sorghum Germplasm Committee meeting 16 February 2003, Albuquerque, NM. Interacted with private scientists and USDA scientists and administrators on issues related to germplasm.

Participated in INTSORMIL Technical Committee meeting 12-13 May 2003, Kansas City, MO.

Participated in INTSORMIL Board of Directors meeting 18-19 May 2003, Kansas City, MO.

Coordinated short-term training program of Mr. Leo Mpofu (Southern Africa region) in plant breeding at Texas A&M University, July-August 2002.

Coordinated travel of Dr. Neal McLaren (South Africa), Mr. Godwin Kaula (Zambia), and Ms. Phoebe Ditshipi to U.S., June 16-30, 2003.

Germplasm and Research Information Exchange

Germplasm Conservation Use

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

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

Served on M.S. committee of N. Teme (Mali), and co-chair of Ph.D. committee for S.B. Coulibaly (Mali) and R. Gorena (U.S.). Met with Dr. John Taylor during his visit to the United States to discuss sorghum breeding for improved quality and INTSORMIL Southern Africa activity, October, 2002. Coordinated short-term visit and training program of Dr. Neal McLaren (South Africa), Mr. Godwin Kaula (Zambia), and Ms. Phoebe Ditshipi (Botswana), June, 2003.

Other Collaborators

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

Mr. Leo Mpofu, Department of Research and Specialist Service, Matopos Research Station, P.O. K5137, Bulawayo, Zimbabwe

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

Dr. G.N. Odvody, Plant Pathology, Texas Agricultural Experiment Station, Texas A&M University Agricultural Research and Extension Center, Route 2 Box 589, Corpus Christi, TX 78406-9704

Dr. John Byrd, USDA-ARS, Plant Science and Water Conservation Research Lab., 1301 N. Western Road, Stillwater, OK 74075

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

Publications and Presentations

Abstracts

Rosenow, D.T., N. Teme, C.A. Woodfin, G.N. Odvody, and G.C. Peterson. 2003. Relationship of stay-green with charcoal rot and lodging in sorghum. Pp.475-476. *In* Proc. of Global 2000: Sorghum and Pearl Millet Diseases III. Guanajuato, Mexico, Sep. 23-30, 2000. Iowa State Press, Ames, IA.

Presentations

Peterson, G.C., B.B. Pendleton, and G.L. Teetes. 2003. PROFIT - Productive Rotations On Farms In Texas: A New Paradigm for Sorghum Research and Information Delivery. Pp.365-370. *In* Proc. of Global 2000: Sorghum and Pearl Millet Diseases III. Guanajuato, Mexico, Sep. 23-30, 2000. Iowa State Press, Ames, IA.

Refereed Journal

Machado, S., E.D. Bynum, Jr., T.L. Archer, J. Bordovsky, K. Bronson, D.M. Nesmith, D.T. Rosenow, and G.C. Peterson. 2002. Spatial and temporal variability of sorghum grain yield: site-specific interactions of soil, water, pests, and diseases. J. of Precision Agriculture 3:389-406.

Dissertations and Thesis

Coulibaly, S.B. 2002. Evaluation of backcross progenies and recombinant inbred line populations of sorghum (Sorghum bicolor (L.) Moench). Ph.D. dissertation. Texas Tech University, Lubbock, TX.

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

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

Collaborating Scientists

Mr. Kaka Saley, Cereal Scientist; Moustapha Moussa, Cereal Technologist; Dr. Adam Aboubacar, Cereal Technologist; Ms. Ramatou Seydou, Chemist; Dr. Issoufou Kapran, Sorghum Breeder; INRAN B.P. 429, Niamey, Niger
Ms. Senayit Yetneberk, Cereal Scientist, IAR, Nazret Research Station, Box 436, Nazret, Ethiopia
Ms. Betty Bugusu, Cereal Scientist, KARI, Katumani National Dryland Farming Research Ctr, Box 340, Machakos, Kenya
Mr. Ababacar N'Doye, ITA, BP 2765, Route de Peres Maristes Hann, Dakar, Senegal
Mr. Iro Nkama, Univ of Maiduguri, Dept of Food Science & Technology, PMB 1069, Maiduguri 600001, Nigeria
Dr. Arun Chandrashekar, Cereal Chemist, CFTRI, Department of Food Microbiology, Mysore 570013, India
Dr. D.S. Murty, Mahyco Research Foundation, Hyderabad, India
Dr. Gebisa Ejeta, Sorghum Breeder; Dr. Layi Adeola, Poultry Nutritionist; Ms. Chia-Ping Huang, Cereal Chemist; Ms. Debra Sherman, Microscopist; Dr. Moustapha Benmoussa, Plant Molecular Biologist, Purdue Univ, West Lafayette, IN
Dr. Brian Larkins, Plant Molecular Biologist, Univ of Arizona, Tucson, AZ
Dr. Tae Wae Moon, Food Chemist, Seoul National University, Seoul, Korea

Summary

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

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

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

must be developed are being actively pursued by a number of groups. In Burkina Faso, a collaboration will begin in the upcoming year.

Objectives, Production and Utilization Constraints

Objectives

- Determine the relationships between the physical, structural, and chemical components of grains and food and nutritional aspects to improve 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 likely to be lost. In addition, breeding grains that have superior quality traits will more probably give rise to processed food products that can be successfully and competitively marketed. This is especially true for sorghum that is perceived by some to have comparably poor quality characteristics to other major cereals. 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

As described in previous annual reports, PRF 212 and INRAN/Niger Food Technology Laboratory set up a cereal processing unit at INRAN to conduct research, demonstration, and testing of sorghum and millet processed products. A central goal of the project has been to optimize the processing system and products, to generate information for entrepreneurial startups, and to work with interested individuals in the private sector. Products produced by the unit include high quality flours and grits, and agglomerated products including fine couscous (or *dambou*), medium couscous, and the coarse particle-size product *degue*. 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 Dr. Jacques 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 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. Currently, a regional project funded through IFAD is providing support for a local entrepreneur to start up a similar processing unit with technical support from INRAN.

Market Testing of Packaged Flour and Couscous Products

Following an in-home consumer test of processed sorghum couscous that was reported last year, a market test was conducted to determine consumer attitudes toward pricing and package appearance. Products were made from irrigation-produced NAD-1 hybrid sorghum grain. Couscous (450 kg) and high quality, decorticated flour (265 kg) were packaged in 500 g bags with labels and placed in three market segments – open market, small shops, and supermarkets. A questionnaire at the place of sale was given. The results for the packaging were that consumers, in general, wanted more detailed nutritional and preparation information. Also, it was suggested that the package should better protect the product; indicating a need for thicker plastic bagging or box. Indication of product shelf-life was also lacking. Regarding the price, consumers found that 500 CFA/500 g bag was somewhat high. Accordingly, the consumers suggested price between 200 and 500/bag, which averaged 347 CFA/bag. It was suggested that larger quantities of couscous could be sold at discounted prices. Overall, consumers were highly enthusiastic about the products.

Sorghum NAD-1 flour and couscous was sold at the three market levels at 250 CFA/kg and 350 CFA/500 g, respectively. Products were sold out in 12 days. Sixty percent of couscous sales were from the larger supermarkets, indicating that potential buyers of couscous come from medium- to high-income consumers. Demand for NAD-1 couscous and flour products continues to grow. Further investigation is needed to determine ways to reduce production costs. Currently, contracting with farmers in the Maradi region is being used as a source of high quality sorghum and millet grains for processing into couscous and flour using the INRAN Cereal Processing Unit.

Initial Studies on Sorghum Foods Staling Properties

Sorghum porridges and other foods, such as injera and rotis, have fundamental properties that differ somewhat from like foods made from other cereal grains. Often sorghum porridges are characterized to be comparably thick pastes (this may be desirable) that form rather stiff gels that, depending on variety used, often do not have good keeping quality. Flat breads made from sorghum, such as kisra, injera, and roti may be of high quality, but tend to go stale rather quickly when stored. We are interested in the fundamental nature of sorghum grain components that makes sorghum grain flour behave as it does, and accordingly how these traits can be manipulated through genetics or processing.

Our initial hypothesis suggests that these undesirable properties (related to staling) could be attributed to sorghum starch fine structure; specifically the gross molecular architecture and length of linear chains of the amylopectin molecule. The first phase of this project is to determine and quantify differences in the rate of retrogradation among three sorghum varieties using isolated rice and corn starches for comparison. Compression, differential scanning calorimetry, and dynamic oscillatory rheometry tests will be performed on aged starch gels to compare rates of retrogradation. In addition to isolated starches, several sorghum, corn, and rice flours will be compared on a dry weight starch basis using the above tests to determine the effects of non-starch components on retrogradation rates. Initial tests performed on isolated starches indicate that a maize variety and the sorghum variety Mota retrograde faster than sorghum varieties SC 283-14 and P851171. Isolated rice starch appears to have the slowest rate of retrogradation of the four isolated starches. Starch structural studies are in progress.

Sorghum with High Protein Digestibility

Grain Quality

Studies to improve grain quality (hardness) of the high protein digestibility/high lysine sorghum mutant were reinitiated this project year with the hiring of a post-doctoral research associate (T. Tesso, sorghum breeder) to work with Dr. Ejeta and Hamaker. This continues work on nutritional quality improvement relating specifically to the high protein digestibility/high lysine sorghum mutant. As described before, this mutant 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. The protein body mutation apparently causes overexpression of certain cytoplasmic proteins that concurrently result in elevated lysine content. Our main challenge at this point is to convert a modified, though only slightly vitreous kernel background of the recent mutant lines to a hard, vitreous kernel phenotype with a consistency of panicle grains and stability of trait for release. Importantly, it was shown in the 2001 INTSORMIL report that a vitreous normal-appearing kernel with mutant high digestibility protein bodies is possible, however consistency within the panicle was lacking and stability of this combination is still uncertain. Yet, the potential for such a conversion has been demonstrated. In India, Drs. Murty and Chandrashekar have made progress on the grain quality question through the collaborative project (finished in 2001) funded by Mahyco Research Foundation. Similar results show improved quality mutant grain from crosses made with elite Indian germplasm. However similarly, consistency and stability are uncertain.

In screening of F_5 lines produced from crosses of modified mutant lines with highly vitreous parents, a few lines were found with well modified kernel type and seemingly good consistency within panicles. These modified endosperm types have been previously described as containing a vitreous (hard) endosperm section originating out of the interior of the kernel rather than the typical phenotype where vitreous endosperm is found at the kernel periphery radiating toward the center. In the lines chosen, the vitreous endosperm section accounted for approximately 50% or more of total area and opaque endosperm appeared encircling it with only a thin region at the kernel periphery. In further analysis by transmission electron microscopy, it was found that the best line did contain the mutation as visualized by the characteristic abnormally shaped protein bodies. These lines have been planted in diverse locations to assess stability of the endosperm texture.

Swine Digestibility and Feed Value Study

A swine study was initiated to assess digestibility and feed value of the high protein digestibility/high lysine sorghum mutant.

Sorghum Starch Digestibility

Cooked sorghum porridges and some other foods are known to have lower starch, as well as protein, digestibility compared to other like cereal foods. In our previous work, low protein digestibility in cooked porridge was attributed to formation of disulfide cross-links during cooking. Other studies in our laboratory conducted to determine the factors causing low starch digestibility in cooked sorghum showed that the major non-starch flour components, including protein, lipids and dietary fiber, contribute to the low starch digestibility, but protein, the second largest flour component after starch, was shown to have the single largest effect. Accordingly, the high protein digestibility mutant described above was shown to significantly increase in starch digestibility when pretreated with protease (pepsin) before being digested with alpha-amylase. Overall, a correlation of 0.97 was observed between starch digestibility and protein digestibility of sorghum cultivars when protease treatment preceded amylase digestion. This was potentially valuable information, as high digestibility sorghums could have a useful impact in weaning foods and other foods where high availability of macronutrients is critical. Such sorghums could find a place in diets of the marginally malnourished who do not meet UN-set requirements for protein and energy intake.

Our more recent research emphasis on the slowly digesting starch characteristic of cooked sorghum foods has been to better understand this phenomenon at the mechanistic level so that the trait can be more effectively manipulated. While there is good reason to increase starch digestibility, or energy availability, there is also a compelling reason to decrease starch digestion rate (or lower glycemic index) for the health problem of diabetes, and perhaps obesity and cardiovascular disease.

The role of protein component in low starch digestibility of cooked sorghum porridges

Three possible ways through which the protein in the flour system may contribute to low starch digestibility were investigated. They included: 1) presence of proteinaceous amylase inhibitors, 2) limitation of degree of starch gelatinization (gelatinization increases digestibility), and 3) restriction of starch accessibility by hydrolysis enzymes (protein acting as a barrier).

1. Most conventional enzyme inhibitors are protein in nature. Alpha-amylase inhibitory activity has been detected in many cereals such as rice, maize, and sorghum. The potential antinutritional effects of these inhibitors on humans are of significant importance especially for the inhibitors that are stable to heat and acid. Our results showed a decrease in a-amylase activity of 2-25% among the sorghum cultivars and 10% in the maize control. No decrease in a-amylase activity was detected in rice, indicating the absence of inhibitors. In the buffer extracts, the inhibitor activity ranged from 11-25% for sorghum, 12% for maize, and none in rice. Cooking substantially decreased and in some cases eliminated the inhibitory activity in the extracts except for the normal cultivar IS 10644, suggesting that the inhibitors were heat labile and not a significant factor in starch digestibility of cooked sorghum foods.

2. Starch granules are found embedded within a protein matrix that contains protein bodies in the vitreous endosperm. The endosperm structure of the grain thus may affect degree of starch gelatinization with a lower degree of gelatinization in vitreous endosperm compared to floury. Consequently, restriction of starch gelatinization could reduce its digestibility. Results on gelatinization parameters measured using differential scanning calorimetry showed that the low starch digestibility observed in sorghum is not due to limited starch gelatinization or to crystallinity of the native starch.

3. Confocal laser scanning microscopy was used to elucidate the microstructural interactions between starch and protein that may cause low starch digestibility. The protein component was labeled with 3-(4-carboxybenzoyl) quinoline-2-carboxaldehyde (CBCQA), a dye which fluoresces only after reaction with primary amines in proteins.

Figure 1 shows reconstructed three dimensional images of the microstructure of raw wild-type sorghum, the high protein digestibility sorghum mutant, maize, and rice flour samples. The bright areas correspond to the fluorescence of CBCQA stained proteins. By contrast, the dark areas reflect the location of the non-fluorescent starch granules as determined by the non-confocal transmitted light images (figures not shown). Within the bright areas, particularly in the sorghum samples, tiny dark spheres that are presumed to be protein bodies can be seen. In general, the two sorghum and maize flour samples exhibited similar microstructure in which most of the starch granules appeared to be surrounded and or linked by the protein. However, the starch granules in the wild-type sorghum were tightly packed and characterized by polygonal shape, while those of maize and mutant sorghum appeared more loosely packed and more spherical. The wild-type sorghum also appeared to have a higher concentration of protein bodies embedded in the protein matrix than the mutant sorghum and maize. In the raw rice sample, most of the starch granules appeared completely embedded in the protein. This could be attributed to the fact that rice starch granules are smaller in size compared to maize or sorghum.

Confocal micrographs revealed that cooking drastically changed the protein microstructure of samples (Figure 2). Sorghum proteins formed two types of structures: extended web-like and rigid sheet-like structures (Figure 2A and 2B). Maize proteins formed large aggregates and a few extended web-like structures that seemed to collapse on releasing starch (Figure 2C). The rice proteins also formed aggregates that seemed to expose or release gelatinized starch for digestion (Figure 2D). Reconstructed three-dimensional images of double-labeled cooked sorghum porridge showed entrapment of gelatinized starch in the protein structures (not shown). These results indicate that encapsulation of starch within the sheet-like and web-like structures may cause reduced starch accessibility to digestive enzymes, hence the observed low starch digestibility observed in sorghum porridges.

In conclusion, it was observed the alpha-amylase inhibitors present in the cereals samples are heat labile thus are not a major concern in cooked porridges. Sorghum protein forms resilient web-like and sheet-like structures that encapsulate starch resulting in reduced accessibility of starch by enzyme. Maize and rice protein form aggregates and collapsed web-like structures that allow release of gelatinized starch. Protein component does not seem to affect the degree gelatinization of starch granules.

Starch Digestibility in Raw Grain

Sorghum grain typically is considered to have somewhat lower feed efficiency compared to other feed grains attributed mainly to a comparably lower starch digestibility. In low tannin and tannin-free cultivars, lower values have been associated with the dense protein matrix in the grain and accordingly less access of digestive amylases to the starch. High protein digestibility sorghums have shown some promise in increasing starch digestibility levels, however, our data is not conclusive on this matter. Another possible approach to increase starch

Figure 1. **Confocal micrographs of reconstructed three dimensional images of raw flours showing protein (bright areas). A, B, C, and D represent wild-type sorghum, high protein digestibility sorghum mutant, maize, and rice, respectively. Bar size 25μm.**

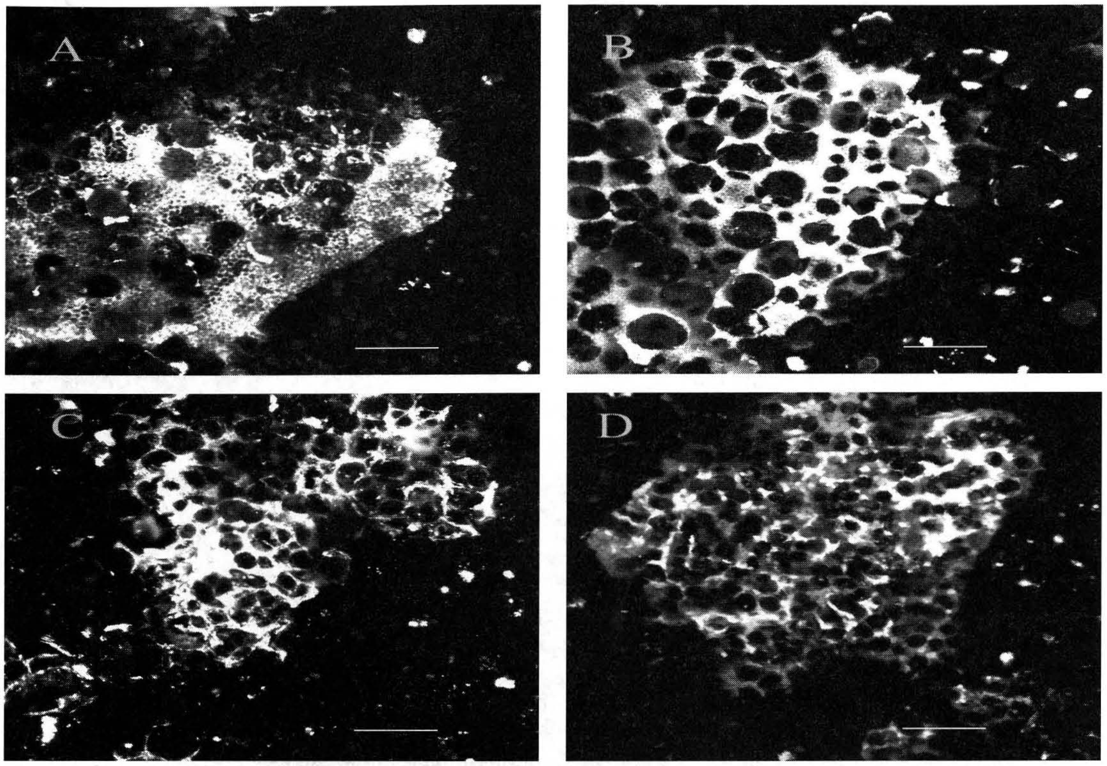
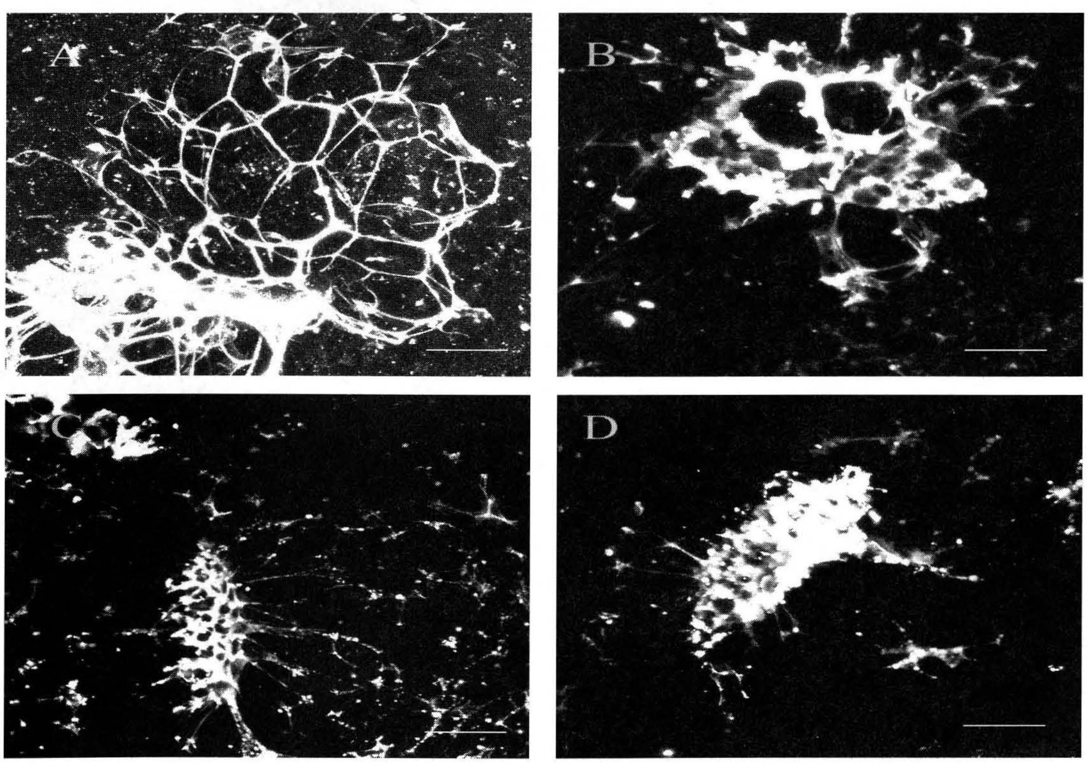


Figure 2. **Confocal micrographs of reconstructed three dimensional images of cooked porridges showing protein (bright areas). A, B, C, and D represent wild-type sorghum, high protein digestibility sorghum mutant, maize, and rice, respectively. Bar size 25μm.**



digestibility of sorghum in animal feed is to examine starch granule and molecular structures and their relationship to digestibility.

Investigation of the Structures of Cereal Starches Attacked by Alpha-amylase

Starch is composed of two major molecular species – amylose and amylopectin, the former mostly linear in shape and smaller in size, and the latter highly branched and very large. Wild-type cereals usually have starch with approximately 20-25% amylose by weight and the remaining amylopectin. Waxy grain has essentially no amylose, and heterowaxy contains ¼ waxy kernels giving a lower than normal amount of amylose. Starches used were from wild-type sorghum, heterowaxy sorghum, maize, waxy maize, and rice. Isolated starch samples were digested with alpha-amylase for 1, 3, and 6 hr. The rates of a-amylase digestion were in the order of waxy maize > heterowaxy sorghum > rice > normal maize > normal sorghum (Figure 3). Percent digestion after six hours was 84% for waxy maize, 71% for heterowaxy sorghum and rice, 53% for normal maize, and 52% for normal sorghum.

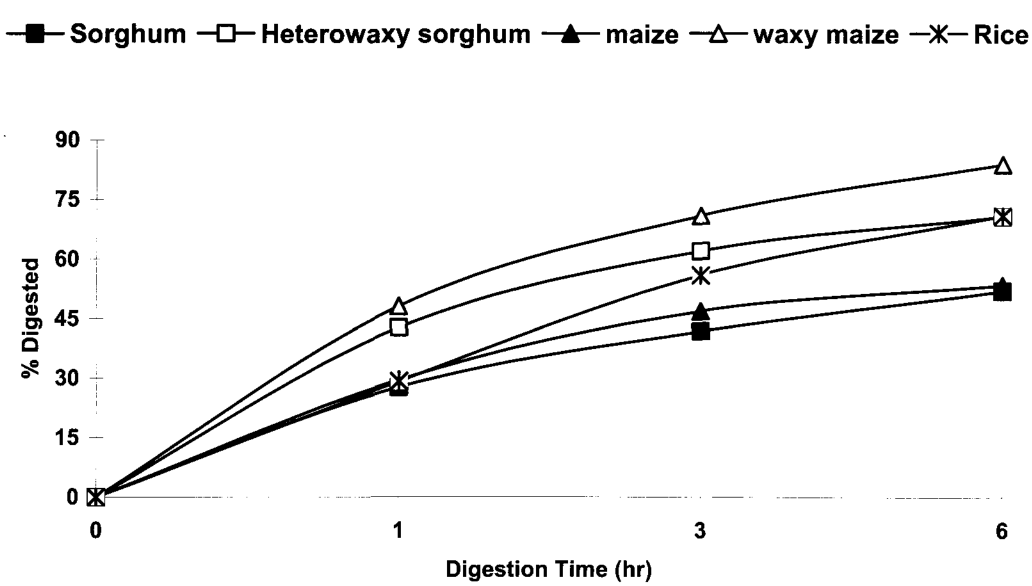
Our working hypothesis as to the structural basis of these digestibility differences is that the length of the shorter chains of amylopectin determines degree of crystallinity of starch granules that in turn impacts digestion rate. Therefore, longer degree of polymerization of the short chains that is consistent among molecules would lead to higher crystallinity and lower digestion rate. Native and digested starch samples were debranched to linear chains with isoamylase and fractionated on a size-exclusion chromatography column. Except for waxy maize, three distinct fractions representing linear chains were obtained. Fraction I (FrI) contained amylose and long linear chains of amylopectin. Fraction II (FrII) and III (FrIII) represented the intermediate and short chains of amylopectin. The chromatographic profiles showed a shift towards shorter chains for FrIII in the order of waxy maize > heterowaxy sorghum > rice > normal maize > normal sorghum. One hour digestion resulted in a significant decrease in the proportion of FrIII and a shift towards longer linear chains indicating that the shortest chains of amylopectin are among the first structure component of amylopectin to be digested. There was also a significant drop in the proportion of FrI in the first hour of digestion, possibly indicating that amylose is being digested faster. Taken as a whole, this data suggest that sorghum has lower isolated starch digestibility than the other cereals tested due to amylopectin structure that should lead to a higher degree of crystallinity.

Networking Activities

Dr. Hamaker traveled to Addis Ababa, Ethiopia in November, 2002 to attend the INTSORMIL All-PI Conference and made two presentations – 1) summary of the West Africa (Eastern Region) program, and 2) an overview of work done and potential for changing sorghum and millet nutritional quality. In the week prior to the conference, he attended the Ethiopian Agricultural Research Organization annual conference in Nazret and presented INTSORMIL work related to attempts to commercialize sorghum and millet products in West Africa, specifically agglomerated products such as couscous.

In January 2003, Dr. Hamaker traveled to Dakar, Senegal and met with Dr. Rooney, Ababacar N'Doye, and Ouendeba

Figure 3. Digestion rates of α-amylase treated native starches.



Botorou to develop a concept paper on commercialization of millet and sorghum products, and the supply chain management that is necessary to achieve high quality, competitive products. Ouendeba Botorou organized this activity to complement a previous paper developed by Dr. Sanders and team on farmer contracts and marketing.

In February 2003, Dr. Hamaker attended a symposium in Seoul, Korea at Seoul National University and gave a presentation on slowly digesting starch with coverage of our work on sorghum starch digestibility.

In April 2003, a paper by Dr. Hamaker was presented *in absentia* at the Afripro Conference in Pretoria, South Africa on the role of sorghum proteins in the quality of sorghum foods.

Publications and Presentations

Abstracts

B.A. Bugusu and B. R. Hamaker. Effect of non-starch components of sorghum flour on in vitro starch digestibility of cooked porridges, American Association of Cereal Chemists annual meeting, Montreal, October.

B.P. Suhendra and B.R. Hamaker. Relationship of protein to starch digestibility of sorghum grain for animal feed use, American Association of Cereal Chemists annual meeting, Montreal, October.

M. Maladen and B.R. Hamaker. Stability and potential application of a three-component complex, American Association of Cereal Chemists annual meeting, Montreal, October.

X.Z. Han, J.N. BeMiller, and B.R. Hamaker. Detection of proteins in starch granule channels, American Association of Cereal Chemists annual meeting, Montreal, October.

J.T. Manful, R. D. Coker, and B. R. Hamaker. Effect of artisanal rice parboiling methods on milling yield and starch characteristics, American Association of Cereal Chemists annual meeting, Montreal, October.

B.R. Hamaker. Overview of INTSORMIL West Africa (East) Program, INTSORMIL International Principal Investigators Conference, Addis Ababa, Ethiopia, November.

B.R. Hamaker. Improving sorghum and millet nutrition for food and feed. INTSORMIL International Principal Investigators Conference, Addis Ababa, Ethiopia, November.

Journal Articles

Aboubacar, A., Axtell, J.D., Nduulu, L., and Hamaker, B.R. 2003. A turbidity assay for rapid and efficient identification of high protein digestibility sorghum lines. *Cereal Chem.* 80:40-44.

Zhang, G. and Hamaker, B.R. 2003. A three component interaction among starch, protein, and free fatty acids revealed by pasting profiles. *J. Agric. Food Chem.* 51:2797-2800.

Zhang, G., Maladen, M.D., and Hamaker, B.R. 2003. Detection of a novel three component complex consisting of starch, protein, and free fatty acids. *J. Agric. Food Chem.* 51:2801-2805.

Duodu, K.G., Taylor, J.R.N., Belton, P.S., and Hamaker, B.R. 2003. Factors affecting sorghum protein digestibility. *J. Cereal Sci.* 38:117-131.

L.F. Dowling, C. Arndt, and B.R. Hamaker. 2002. Economic viability of high digestibility sorghum as feed for market broilers, *Agronomy J.* 94:1050-1058.

Dissertations and Theses

Suhendra, B.P. 2002. Factors that influence the digestibility of starch in raw sorghum grain. M.S.

Prado, B. 2002. Characteristics of branched water-soluble glucans from ball-milled starch and commercial maltodextrins and their effect on pasting behavior in starch systems. M.S.

Food and Nutritional Quality of Sorghum and Millet

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

Principal Investigator

Lloyd W. Rooney, Professor, Food Science & Agronomy, Cereal Quality Lab, Soil & Crop Sciences Dept, Texas A&M University, College Station, Texas 77843

Cooperator: Ralph D. Waniska, Professor, Food Science, Cereal Quality Lab, Texas A&M University, College Station, Texas 77843

Collaborating Scientists

Ms. A.B. Berthe, Food Technologist &Dr. A. Touré, Sorghum Breeder: IER, Bamako, Republic of Mali
Drs. D.T. Rosenow & G. Peterson, Texas A&M Univ, Ag Research & Ext Ctr, Lubbock, Texas 79403
Dr. W.L. Rooney, Soil & Crop Sciences Dept, Texas A&M Univ, College Station, Texas 77843
Drs. Mitch Tuinstra, Dept of Agronomy & Joe Hancock, Dept of Animal Sciences, Kansas State Univ, Manhattan, KS 66506
Dr. Sergio Serna-Saldivar, Professor/Head, Food Science, ITESM, Monterrey, Mexico
Professor John R.N. Taylor, Head, Food Technology Dept, University of Pretoria, Pretoria 0002, South Africa
Ms. Fidelia Herrera & Ing. René Clará, CENTA, Km 33.5,Carretera a Santa Ana, San Andres, La Libertad, El Salvador

Summary

In Mali, an entrepreneur successfully produced N'Tenemissa, a white tan sorghum under identity-preserved (IP) marketing procedures. The grain produced excellent food products because it was photosensitive and was not discolored by insects and molds. Additional improved tan plant photosensitive local varieties are in the pipeline.

New more efficient higher yielding white tan varieties are nearing release from the IER breeding program. The photosensitive types escape significant weathering/molding that adversely affects earlier insensitive white tans. These value-enhanced sorghums provide improved grain quality for IP marketing of sorghums.

Value-enhanced white food sorghums developed in part by this project were promoted by the U.S. Grains Council in Japan and other countries for food processing, and have been used by the Japanese food industry to market snacks and several other products.

Extrusion of whole kernel and ground whole kernel sorghums produce extrudates with excellent properties for use in whole grain healthy snacks and ready-to-eat breakfast cereals. Our graduate students demonstrated prototype products called Bongos, winning first place in the National American Association of Cereal Chemists product development competition. The extruder is a low-cost, short-barrel friction type that could be used by small companies in targeted countries, i.e., Central America.

Several mills in the U.S. are producing sorghum flour for niche markets. The operations are small but produce sorghum flour and other products that have been made into foods for Celiac-Sprue patients.

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. Special sorghum brans and their extracts have excellent antioxidant properties in various food systems.

Several parental sorghum lines released from our program are used in commercial food hybrids. New commercial sorghum hybrids with tan plant white pericarp color were released by commercial hybrid seed companies. ATx635 hybrids have outstanding milling and food properties. Red tan plant hybrid sorghums have excellent milling properties compared to red purple plant sorghums.

Antifungal proteins are related to grain mold resistance in sorghum. An improved faster assay for antifungal protein detection was developed. Sorghums that retain higher levels of antifungal proteins, when exposed to warm, humid environments and mold attack, have the highest resistance to molds.

Near infrared (NIR) equipment was calibrated for starch, protein and moisture for whole kernels of sorghum. The nondestructive method was successfully used for whole grain analysis of sorghums.

A single kernel hardness tester was used successfully for hardness, kernel size and kernel weight. They are efficient methods for evaluation of grain quality; however, the hardness data was not significantly correlated with TADD hardness obtained by abrasive principles.

Two Ph.D. and two M.S. students completed their degrees.

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

The major constraint to development of profitable sorghum and millet foods remains the lack of a consistent supply of good quality grain at affordable prices. Until a source of IP good quality grain can be produced, sorghum and millet products will be of inferior quality. Systems for marketing IP grains as value-added products for urban consumers are critically important. These systems start with the seed or even before the seed and must be profitable for all parties through to the consumer. Slowly the concept of supply chain management is being adapted by National Research Leaders.

This project relates quality to measurable characteristics that can be used to select sorghum and millets 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.

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

The acquisition of good quality grain for value-added processing is absolutely essential to produce acceptable food products from sorghum and millet. That is why we have pushed hard for new improved varieties with good processing quality even if grain yield is not significantly increased. In most cases, systems to produce the new varieties and deliver the grain to processors are lacking and are difficult to put in place. More people are beginning to understand the need to develop supply chain management schemes to secure grain for processing. Many small entrepreneurs demanding improved quality grain appear willing to pay more because grain quality is critically important for their continued success and expansion of markets.

Significant Accomplishment

Applications of Technology in Mali

Work in Mali continues to demonstrate the value of new white, tan-plant photosensitive sorghum varieties in food systems. During the past few years, progress to develop an effective IP production scheme to produce sorghum of good quality for processing into value-added flour and meal was demonstrated. The General Foods Company of Mali produced consumer-acceptable cookies containing the white food sorghum. However, the price of wheat flour decreased because of a government decision to subsidize it, which caused the company to discontinue use of sorghum. This change meant the entrepreneur who obtained the IP food sorghum did not have a market for his grain. However, he was able to process the white food-sorghums into rice-like products that he sold for a profit. Thus, the IP concept has been proven sound by Malian personnel. New value-enhanced food sorghums from the Malian sorghum breeding program will likely improve productivity and profitability. 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 for all participants along the value chain. The long-term sustainability is still to be determined.

Another positive development is that farmers growing the white tan sorghums prefer the porridge made from these 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. This project has interacted with the Malian program for more than 20 years. We hope that significantly faster progress will continue now that Malian business people are involved.

New Markets for Food Sorghums

Several extruded salty snacks and milled products based on IP U.S. white food sorghums continue to be sold by Japanese food companies. South Korea and other countries are interested in using white food sorghums. Utilization of sorghum in these highly developed countries will help our efforts to convince food companies in other countries that sorghum is a good food ingredient. Similar findings in Mali, Central America, Mexico and other countries of West Africa demonstrate that sorghum of good quality is necessary for value-added products. The products are acceptable and purchased by consumers provided convenience, good taste, appearance and consistent quality is available at competitive prices. In South Africa, significant quantities of Mabella meal are consumed even though the price is significantly higher than mealy meal (maize) because a 14% value-added tax is assessed to sorghum processed products. Botswana is an example where maize consumption is decreasing while sorghum consumption is increasing even though red or brown sorghum must be imported from South Africa.

Applications in Honduras and El Salvador

Our research on sorghum has been applied in Honduras and El Salvador. The variety Sureno, and others with white tan plant color are used in Central America for tortillas, rosquillos, and rosquetes. In El Salvador, sorghum flours from white tan plant varieties are used in small bakeries to produce pan dulce, muffins, bread, rosquetes, 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. The opportunities exist to stimulate use of white food sorghums in Central America since a source of grain is available, but technologies that can be used to decorticate sorghum and mill it into flour or meal are required along with production of a consistent supply of IP grain.

Sorghum Phenols and Catechins as Antioxidants

Specialty sorghums and their products were analyzed for antioxidant potential using three methods; oxygen radical absorbance capacity (ORAC), 2,2-azinobis (3-ethyl-benzothiaziline-6-sulfonic acid) (ABTS), and 2,2-diphenyl-1-picrylhydrazyl (DPPH). The sorghums were also analyzed for total phenol contents (Table 1, Figure 1, 2). The brown and black sorghum brans had the highest levels of antioxidant activity along with the most total phenols. The catechin levels were highest for the brown sorghums. Since the phenols are concentrated in the outer layers of the sorghum kernel, the bran obtained by abrasive decortication or roller milling has 3-4 times the antioxidant activity of the whole grains.

The three methods for measuring antioxidants were compared to determine if a less expensive and more convenient method could be used for analysis of antioxidant activity. The ABTS and DPPH methods correlated highly with ORAC (R2 = 0.98). The ABTS method was the most suitable for sorghums; it had a cost advantage over ORAC and was more consistent

Table 1. Phenol contents and antioxidant properties of sorghum and sorghum products measured by three methods.

Sample	ORAC[a]	ABTS[a]	DPPH[a]	Phenol[b]
White grain	22	6	6	3
White grain extrudate	26	7	6	3
White bran	64	28	21	6
Red grain	140	53	28	7
Red bran	710	230	71	20
Black 2001 grain	219	57	41	6
Black 2001 extrudate	94	37	32	5
Black 2001 bran	1,008	250	184	26
Bread (30% Black 1999 bran)	92	45	28	5
Cookie (50% Black 1999 bran)	170	90	51	9
Hi Tannin (brown) grain	453	108	118	13
Hi Tannin grain extrudate	286	90	74	6
Hi Tannin bran	2,400	512	495	55
Sumac (brown) grain	868	226	202	23
Sumac bran	3,124	768	716	66
Bread (30% Sumac bran)	254	108	78	8
Cookie (50% Sumac bran)	324	130	106	14
CV	6.8	3.5	5.3	6.0

*a*mmol TE/g DM basis

*b*mg GAE/g DM basis (Folin-Ciocalteu method)

*Based on highest value reported by Moyer et al (2003)[a] from among 29 varieties.

[a]Moyer, RA; Hummer, KE; Finn, CE; Frei, B; Wrolstad, RE. 2002. Anthocyanins, phenolics, and antioxidant capacity in diverse small fruits: *Vaccinium, Rubus,* and *Ribes*. J Agric Food Chem. 50:519-525.

Fig. 1. Antioxidant (ORAC) levels in different sorghum brans compared to wheat bran and fruits (dry basis)

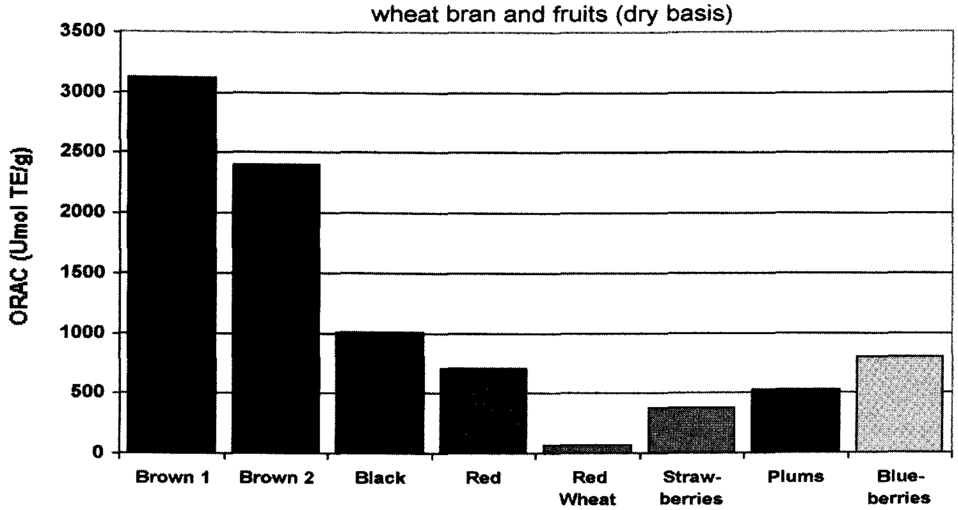
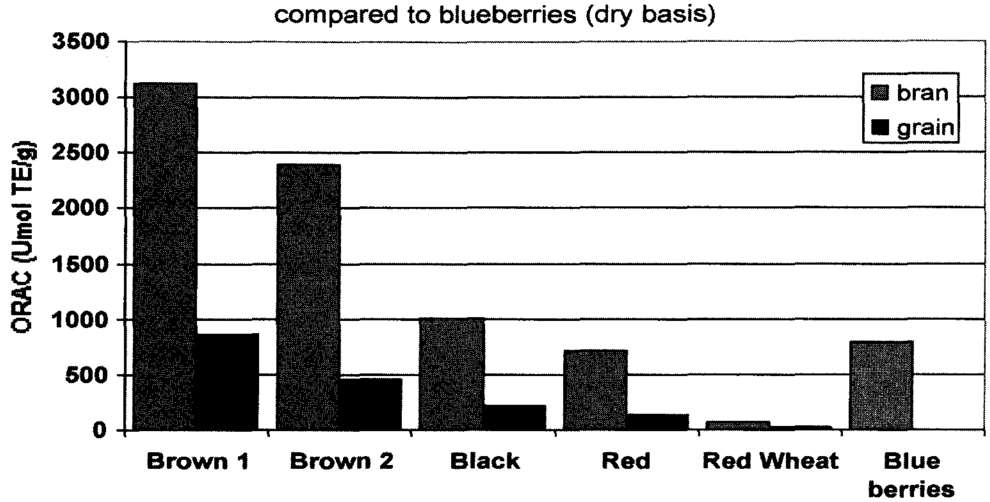


Fig. 2. Antioxidant (ORAC) values of sorghum grain and bran compared to blueberries (dry basis)



across samples than DPPH. Actually the total phenol contents of the sorghums were correlated highly with their antioxidant activity (R2 = 0.96 to 0.98). Thus, it is possible to predict antioxidant levels in sorghum by using total phenol analysis with confirmative tests using ABTS or the ORAC methods when more nutritionally relevant data is required. Trials with animals and humans are needed.

The bran is high in dietary fiber, phytates and natural brown or black pigments that impart attractive colors 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 by a commercial bakery.

Ms. Crystal Rudiger completed her M.S thesis and developed a bread mix containing brown or black. sorghum bran with flax seed, gluten, barley and wheat flour. The bread made there from has excellent flavor, texture and outstanding levels of dietary fiber, antioxidants, ligans and omega 3 fatty acids with a natural brown color. Black sorghum bran in breads resulted in appearance, texture, color and specific volume (cm3/g) similar to commercial specialty or dark rye breads.

The HPLC analysis of procyanidins (condensed tannins) indicated that tannin or brown sorghums had a large number of oligomers that comprised the condensed tannins. The processing of tannin sorghums using extrusion significantly reduced the polymer size of the procyanidins. The increased percentages of oligomers with less than 10 units may positively affect the biological significance of the antioxidants. The type of processing is important since similar changes did not occur when the brans were mixed into cookie and breads. The potential to produce healthy foods from sorghum is quite high.

Ms. Linda Dykes, Ph.D. student, continues to characterize sorghum phenols and tannins using HPLC and other techniques. Dr. J. Awika, Kenya, completed his Ph.D. degree on antioxidants in sorghum and is currently a research associate continuing research on sorghum and wheat quality here in our laboratory. Our laboratory is collaborating with Dr. Prior's group at

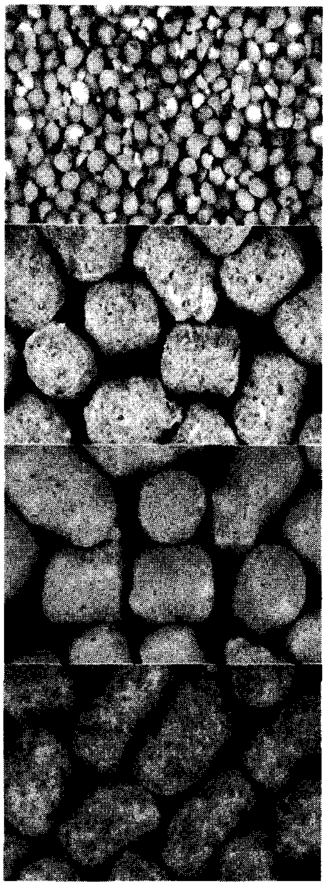


Figure 3. Bongos sorghum snack, in order from top, decorticated grain, extrudates without seasoning, and extrudates with cheese and nacho seasoning.

the USDA Nutrition Lab in Little Rock, Arkansas to explore the relationship of processing of sorghum brans and its affect on health.

Extrusion

It is possible to produce expanded sorghums directly from whole ground undecorticated white or brown sorghum grains using low-cost friction extruders. More research will be done to demonstrate the utility of sorghums of various kinds in low-cost extrusion of snacks. These smaller extruders are used in areas where infrastructure does not permit use of more costly sophisticated extruders and processes. Low-cost friction extruders can be used to produce an array of products. Thus, the ability to produce snacks directly from whole clean grain is a distinct advantage for sorghum. Extrudates of 100% whole brown or tannin sorghums would have excellent nutritional properties. More work is needed to document their properties.

The evaluation of sorghum as an ingredient in extrusion of snacks and breakfast foods was initiated to compare their properties with corn and rice. This information is of interest to potential users of sorghum around the world. Rice produces extrudates with white, bland flavor and excellent crispness. The goal of these experiments is to test the extrudate properties of sorghum directly against corn and rice ingredients. The white food sorghums have a bland flavor, light color and produce acceptable food products of various kinds.

White sorghum samples prepared by combining 4 decortication levels (0, 10, 20 and 30%) and three particle sizes were extruded in a Maddox single screw friction-type extruder. A commercial yellow cornmeal and polished rice were extruded as controls. The extrusion conditions were held constant for all samples. The expansion ratio, bulk density, color and texture of the extrudates were significantly affected by both particle size and decortication level. As the decortication level increased, the extrudates were whiter, more expanded, less dense, more crisp and more thoroughly cooked. The extrudates made from coarse particle size materials had the most desirable characteristics compared to the other particle sizes used. Some sorghum products had a higher expansion ratio than both rice and corn, and had similar bulk density and texture characteristics. With increasing decortication level, whiter, more expanded, stronger and crispier, bland flavored extrudates were produced. The decortication level and particle size can be used to vary expansion ratio, crispiness and bulk density.

Three graduate students in our laboratory produced "BONGOS", a whole grain sorghum extruded snack, which won first place in the National American Association of Cereal Chemists Product Development Competition (Figure 3). The product was made from whole grain white food sorghum via a short barrel friction type extruder followed by baking the extrudates and seasoning with different flavors. The whole grain products are healthy with a very acceptable texture that is firmer than the usual extrudates made from milled rice, maize and sorghum. Moreover, the shelf life is excellent and the product looks and tastes great. This illustrates the functionality of sorghum for use in extrusion and as a food ingredient.

The Japanese are interested in sorghum because it has a bland flavor, light color, can carry mild flavors and seasonings similar to rice, has good extrusion properties similar to rice, and is potentially less expensive. Participants in our Snack Foods short course from Central America are interested in using sorghum but finding a consistent supply of good quality grain is a significant problem.

Sorghum Flour in Specialty Products

Sorghum flour (SF) can be substituted for 100% of the wheat flour in a variety of products that are used in gluten free diets for Celiac-Sprue patients who are intolerant of wheat and other cool weather cereals. Sorghum flour produces acceptable baked products with additives to substitute for its lack of gluten. Various prepared mixes, flours and other products containing sorghum have been introduced into specialty markets recently. The National Sorghum Producers Association is promoting sorghum as a healthy food ingredient and it has ethnic appeal to many immigrants.

Sorghum Starch, Malting and Brewing Studies

Dr. Serna-Saldivar, ITESM, Monterrey, Mexico, is continuing to collaborate on sorghum research, especially with students working on sorghum for brewing, industrial films and as a source of antioxidants. His group has conducted significant research on wet milling of sorghum and evaluated its use as brewing adjuncts. Dr. Serna has provided assistance to our project in El Salvador and Nicaragua by presenting a summary of his research activities on sorghum to Central American scientists at a planning workshop in Nicaragua.

Central American Use of Sorghum

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 have 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. 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. As we work to enhance utilization at the entrepreneur level, the combination of cereals and legumes to produce value-added foods is critically important.

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 a cost effective substitute or diluent for rice in many households. Success could lead to significant economic activity.

Tan Plant Food-type Hybrid Performance and Quality Trials

Attributes of sorghums that produce light colored meals, flour and grits with bland flavors were evaluated under different environments in uniform yield trials with 40 entries. This work was in collaboration with Dr. Tuinstra and W. Rooney, who conducted the evaluation trials. Red and white sorghum varieties grown at locations in Texas, Kansas and Nebraska from 1999-2002 were evaluated for hardness using a SKHT (single kernel hardness tester), decortication properties using TADD (tangential abrasive dehulling device), TKW (thousand kernel weight), color (L, a, b), test weight, density, proximate composition and relative mold damage. Mean quality data for some of the most relevant hybrids are presented in Table 2.

Environment and hybrids significantly affected composition, physical and processing properties. White tan sorghum (WT) hybrids were harder, more dense and lighter in color than white purple (WP) hybrids or red hybrids (Figure 4). WP hybrids were more adversely affected by weathering and molds than WT hybrids. All of the ATx635 hybrids had significantly improved physical properties and higher milling yields than the other white hybrids. This grain also has a thin pericarp that is particularly suited to whole grain extrusion.

White sorghums had better milling performance than red hybrids. A significant correlation (r=0.69, n=105) was found between SKHT and TADD hardness values, suggesting SKHT could be used to predict decortication properties. Efforts by breeders, agronomists and food technologists have produced tan white food-type sorghums with significantly improved food quality attributes.

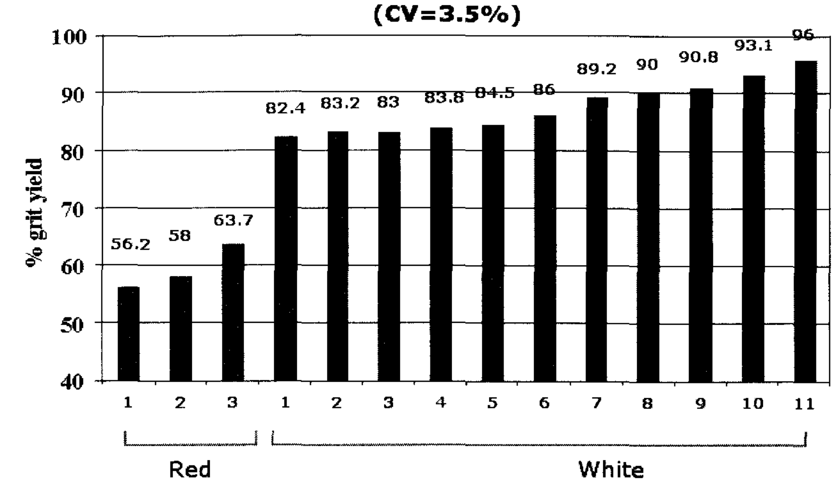
The red tan hybrid sorghums could be grown in areas where molds and weathering are serious problems, such as in the coastal bend of Texas, in areas where the Kharif sorghums are grown in India and in many African countries where the sorghums mature during moist conditions. The problem of molding and staining is decreased with tan plant sorghums that have straw colored glumes. For example, the Kharif sorghums of India become black with mold damage and sell for 50-60% discount. This is rapidly reducing the sorghum production in India. The red tans might be useful for decortication and pro-

Table 2. Physical and composition attributes of selected sorghum hybrids grown over four years at four locations in Texas, Kansas, and Nebraska.

Pedigree	Type	Hardness Index	Decortication Yield (%)	Grain L Value	Grit L Value	TKW (g)	Diameter (mm)	Density (g/cc)	Protein (%)	Fat (%)
ATx635*RTx436	WT	94.9 a	85.8 a	63.1 a	68.2 a	23.2	1.97	1.396 a	11.0	3.8
ATxArg-1*RTx436	WT	91.5 a	82.7 ab	62.6 ab	69.6 a	22.6	1.83	1.389 ab	10.8	3.6
888Y	WT	90.3 ab	86.4 a	59.5 c	67.8 ab	25.8	1.92	1.396 a	11.2	3.9
ATx378*RTx430	RP	83.4 bc	75.9 cd	47.7 d	65.3 b	30.0	2.22	1.376 cd	11.5	3.8
ATx623*RTx430	WP	83.0 c	74.9 cd	59.5 c	68.2 a	29.0	2.17	1.373 cd	10.0	3.5
ATx631*RTx436	WT	79.9 cd	79.1 bc	63.8 a	69.6 a	25.6	2.07	1.381 bc	11.1	3.9
ATx631*RTx2903	RT	74.1 de	72.3 d	46.8 d	69.9 a	24.3	2.03	1.369 d	12.5	4.0
AOK11*RTx2741	WP	70.6 e	70.7 d	60.4 bc	68.2 a	25.9	1.97	1.368 d	9.5	3.5
LSD (a=0.05)		7.2	5.9	2.3	2.4	4.0	0.22	0.011	1.3	0.3

Means with same letters not significantly different

Fig. 4: Decorticated Grain Yield of red and white sorghums adjusted to an L value of 67 (CV=3.5%)



duce better food and poultry feed than the white sorghums currently being grown. The Kharif hybrids sell for significantly less money than the rabbi or dry, post rainy season sorghum called maldandi. Similar problems occur in much of Africa except the Sudan, Ethiopia and others where sorghum matures in the very dry season.

Yield, Agronomics and Quality Attributes of Commercial White Tan Food Sorghum Hybrids

Samples of commercial sorghums exported from the Gulf Coast (11) and value-enhanced white food sorghums grown on farmers' fields (21) were analyzed for composition, physical and milling properties for each of three crop years. The white food grains had higher test weight, increased true density, reduced floaters and significantly higher yields of decorticated grain than the commercial export sorghum samples for each of the three years. The protein content of the food sorghums was significantly higher than that of the commercial sorghum samples. These data were used by the United States Grains Council to provide information on the new food sorghums available. Partial support for the analysis was provided.

Improved Methods of Analysis

NIR equipment to analyze for protein, moisture and starch in whole grains was calibrated. The use of NIR to analyze for starch, protein and moisture is successful but continuous improvements in the calibrations are needed. A large number of samples were analyzed with good repeatability. Numerous factors like color, cracked and broken kernels, glume content and degree of molding appear to affect the analytical values obtained.

A single kernel characterization system used for wheat kernel hardness was modified slightly for sorghum hardness, diameter and moisture measurements. This must be confirmed with a larger set of samples. At this time the abrasive milling procedure appears to be necessary to assess hardness, especially if one wants to compare yields vs. color of the decorticated grain.

Role of Antifungal Proteins (AFP) in Minimizing Grain Molding of Sorghum

Drs. Waniska and Bejosano have evaluated the role of AFP for several years. The results of the 3-year study (2000-2002) were analyzed and summarized in a manuscript submitted for publication entitled "Antifungal proteins in commercial hybrids and elite sorghums" by F.P. Bejosano, R.D. Waniska, and W.L. Rooney. The report consolidates the findings on the commercial hybrids and public parental lines grown in College Station in 2000, 2001 and 2002 that were selected for the study. Previous studies evaluated small numbers of sorghum genotypes. In this study a larger (98 lines in 2000 and 2001; 42 in 2002) and more diverse collection was evaluated to determine if previous findings apply when sorghums are grown in normal agronomic practices and typical environments.

The sorghum growing environments in 2000 and 2001 did not result in sufficient mold damage to correlate AFP content with grain mold resistance. However, the sorghum growing environments in 2002 resulted in significant mold damage. The environment in 2002 caused significant fungal deterioration of grain. The variation in mold infection among the genotypes increased as the grains reached combine harvest maturity. Consequently, significant changes in AFP content from physiological to combine harvest maturity were observed. Genotypes, which lost more AFP at combine harvest maturity, had significantly greater mold damage. Thus, we were able to demonstrate that sorghums with higher levels and increased retention of AFP had significantly reduced grain molding.

Grain mold is considered a complex disease, which is influenced by interaction of qualitatively and quantitatively inherited traits. Although other caryopsis traits are known to contribute to grain mold resistance specifically tannins, harder endosperm, and red pericarp color, these studies have shown that presence of AFP is a major factor. Hence, sorghums can be classified as mold resistant or susceptible based on their AFP content and retention when they are exposed to environmental conditions that promote mold infection.

The AFP content is reduced by increased mold pressure during maturation. Mold resistant sorghums retain more AFPs than susceptible ones when grown under conditions causing mold damage. Both white and red sorghums had the same response. Thus, it is possible to analyze for AFP content to determine resistance only under conditions where high levels of molding occurs. Under this situation, the sorghum breeders can make selections subjectively as to relative mold resistance among the lines. AFP cannot be used on mature, dry grain to predict mold resistance.

Work to complete the studies continues but additional studies are required, especially those that follow AFP levels in mold resistant lines from one generation to the next. Once this is wrapped up the work will be complete. New efforts to understand the role of certain phenols in the bright red cultivars with resistance will be initiated applying recent new analytical techniques for their separation.

Networking Activities

Southern Africa

The PI, Dr. Lloyd Rooney, made 3 trips to Africa and one trip to ICRISAT India to present information on management of the grain supply chain to improve sorghum and millet food products. Graduate students in the Food Science Department at University of Pretoria are from many African countries. Many participate in the Regional Master of Science program, which consists of joint programs between CSIR and University of Pretoria. Thus, INTSORMIL's interaction with the University of Pretoria informs many future African food industry leaders of the potential role of sorghum and millets as food and industrial ingredients. INTSORMIL is providing significant assistance to the region by involvement in these key programs.

Dr. Leda Hugo, Mozambique, completed her Ph.D. with Dr. Taylor at the University of Pretoria on the use of malted and fermented sorghum in composite breads. She is currently a professor at University of Eduardo Mondlane University teaching in the food science program and conducting research on post harvest grain processing. Her process to ferment sorghum flour prior to baking has significant potential for commercialization.

Ms. S. Yetneberk from Ethiopia has continued her Ph.D. program at University of Pretoria under Dr. John Taylor. She has made excellent progress to determine major factors affecting the quality of injera from sorghum cultivars grown in Ethiopia. She found significant differences among sorghum cultivars in injera quality. Also the addition of emulsifying agents appears to improve quality and prolong shelf life of injera from sorghum. Some hard white cultivars have acceptable injera quality. She is nearly through with her dissertation and works as part of the Ethiopian National Sorghum Improvement Program.

Mr. Steve Barrion, M.S. candidate, University of Pretoria, is working on milling of pearl millet from Namibia. Commercial milled products from a major millet variety were produced and analyzed for components and physical properties. He made plans to obtain several commercial varieties of pearl millets from Namibia for analysis, especially of the phenols. This project should provide useful information relative to commercial milling of pearl millet compared to traditional milling.

Ms. Nomsua, Bulawayo, Zimbabwe, is working on a Ph.D. in food science at the University of Pretoria, involving antioxidants from sorghum. She teaches food science courses at the National University of Zimbabwe in Bulawayo. She is just starting her program with Dr. Taylor's group. She will probably come to our laboratory to work with phenol and antioxidant analyses in 2004.

Dr. Lloyd Rooney participated in the AFRIPRO conference that was held in April 2003 in Pretoria to assess the current status of research in Africa on sorghum proteins and related subjects. The European Economic Community has sponsored work in several African and European Universities and Research Centers. The conference brought together a critical mass of African and European scientists. INTSORMIL must maintain and develop a continuing dialog with these scientists since our interests are complementary. Many of the African scientists participating were trained as part of our INTSORMIL program. They have been exercising leadership in some of these projects. Dr. Rooney presented information on the importance of supply chain management for securing a consistent supply of grain for processing into value-added products for urban consumers. Professor Taylor, University of Pretoria, is funded by both groups and facilitates interactions quite well. These projects are synergistic and complementary.

Honduras, Salvador, Mexico and South America

René Clará, Sorghum Breeder, El Salvador and sorghum breeders from Nicaragua spent time in the Cereal Quality Lab, TAMU. Dr. Rooney traveled to Managua, Nicaragua to develop collaborative research plans. The information obtained in Japan applies quite well to the situation in Salvador and elsewhere in Central America. A small Central American 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.

Dr. 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 PhD and subsequent post doctorate experience in our laboratory was partially funded from INTSORMIL.

We currently have three graduate students from Mexico partially funded on TAM 226. We are able to leverage our INTSORMIL funds by using additional research funds from private industry and other agencies to conduct joint research activities. The practical short course on snack foods provides opportunities to conduct proprietary research projects for participants. These short courses generate funds that are used to partially support graduate students.

Dr. Javier Bueso, Honduras, completed his Ph.D. He was partially supported by INTSORMIL and worked on sorghum but his dissertation was on staling of tortillas since his last year was funded by a Tom Slick Graduate Fellowship from Texas A&M University. Our current level of funding did not permit him to work only on sorghum.

We are actively recruiting a graduate student from El Salvador and Nicaragua to develop skilled personnel for those programs in Central America where food science related to crop improvement programs are unavailable or scarce. Travel to El Salvador and Nicaragua is scheduled for late July 2003.

Mali and West Africa

Dr. A. Touré, IER, Mali, and his associates have made progress in utilization and breeding research to develop IP production and use of the new white tan plant photosensitive sorghum varieties for value-added production. It is clear that many scientists and others understand that acquisition of good quality sorghum and millet grains for processing is necessary to produce profitable, competitive food products for urban markets. This is a continuous painstakingly slow process but progress is occurring. This same concept has been demonstrated in Niger and other places where poor quality grain produced unacceptable products that consumers will not buy.

Dr. Rooney participated in an intensive short-term mission to Dakar, Senegal in January 2003 to evaluate utilization of millet as processed foods. The progress in Dakar is spectacular and gives a positive indication of what can be done. The long term efforts of Institute of Technology Alimentaire (ITA) in Dakar has led to a large number of small businesses that process millet couscous of various kinds, flour, meal and more sophisticated products like yogurt containing 30% millet and a snack made by extrusion puffing using locally produced materials. The products were of excellent quality overall; processors realize they need improved quality and consistency of grain and are willing to pay more for it. The organization of farmers to produce higher quality grain and supply chain management and sharing in profits by all parties are the next steps toward more efficiency. These developments are the results of long-term efforts on the part of numerous international agencies that assisted ITA and other organizations to lay the groundwork for these entrepreneurs. The time is ripe to develop a supply chain to provide value-enhanced grain for increased profits for all participants from seed producers through to the consumer. A supply chain for improved quality grain will make delivery and adoption of new cultivars much easier and will permit processors to expand production to meet market demands that appear to exist.

North America

Several papers were presented at the annual American Association of Cereal Chemists Conference, Montreal, Canada. Dr. Rooney presented sorghum quality/ utilization discussions to Texas Sorghum Producers Board Members and panels and U.S. Grains Council sponsored trade teams. A special seminar at TAMU was developed for a Japanese trade delegation interested in white sorghum for food processing. Mr. David Acosta, one of our graduate students, won first prize for the best paper at the National Sorghum Producers Association Conference. He presented his research on extrusion of sorghum to produce snacks.

Three of our graduate students won first place for Bongo's at the National AACC Conference Product Development Competition.

Visitors and collaborators from Southern Africa, Australia, Mali, Niger, Botswana, Honduras, Guatemala, El Salvador, Korea, Japan, Venezuela, Colombia, and China were presented information.

Practical Snack Foods Short Course

Our laboratory conducts an annual short course on practical snack foods production for private industry in which sorghum utilization is part of the program. A book on Snack Food Processing co-edited by Dr. Rooney contains information on food sorghum. Participants from all over the world enrolled in the short course, including several from Central America and Mexico. This short course produces a profit, which is used to partially support our research activities, another example of leveraging of resources.

Sorghum Market Development Activities

The U.S. Grains Council 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 were presented at U.S. Grain Council sponsored value-enhanced market development work shops in the United States and Japan. At the request of the U.S. Grains Council, we presented a one day workshop on white food sorghum quality and processing properties to several Japanese food processors in our laboratory where we discussed value-enhanced sorghums for food processing.

Training, Education and Human Resource Development

Monterrey Institute of Technology: our collaboration with Dr. Serna-Saldivar, Head, Food Science Dept., ITESM, Monterey, Mexico has led to completion of six M.S. degrees. These young scientists have positions in the Mexican food industry, which transfers the technology directly to industry.

Drs. J. Awika from Kenya and J. Bueso from Honduras completed Ph.D. degrees. Two M.S. thesis were completed. Two graduate students from Mexico and two from the U.S. currently work on INTSORMIL related research in our laboratory, with partial financial support while several others are supported from non INTSORMIL funds. Inflation has significantly reduced the number of graduate students that can be supported.

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Host Country Program Enhancement

Central America (El Salvador, Nicaragua)

Stephen C. Mason
University of Nebraska

Coordinators

Ing. René Clará Valencia, Plant Breeder, CENTA, Apdo. Postal 885, San Salvador, El Salvador [Central America Regional Host Coordinator]
Ing. Rafael Obando Solis, Agronomist, CNIA/INTA, Apdo. 1247, Managua, Nicaragua [Nicaragua Country Coordinator]
Ing. Mario Enesto Parada Jaco, Entomologist, CENTA, Apdo. Postal 885, San Salvador, El Salvador [El Salvador Country Coordinator]
Dr. Stephen C. Mason, 229 Keim Hall, Dept. of Agronomy, University of Nebraska, Lincoln, NE [Central America Regional Coordinator]

Collaborating Scientists

Mr. Francisco Vargas, Agronomist, ANPROSOR, Nicaraguan Grain Sorghum Producers Association, Managua, Nicaragua
Mr. Sergio Pichardo Guido, Plant Pathologist, UNA, Managua, Nicaragua
Ms. Yanet Guitiérez Gaitán, Plant Pathologist, UNA, Managua, Nicaragua
Ms. Martha Zamora, Entomologist, UNA, Managua, Nicaraqua
Ing. Reina Flor Guzmán de Serrano, Plant Pathologist, CENTA, San Andrés, El Salvador
Ing. Carlos Armando Borja Melara, Plant Pathologist, CENTA, San Andrés, El Salvador
Ing. Carmen Gutiérrez D., Entomologist, INTA, Managua, Nicaragua
Ing. Hector Deras F., Plant Breeder, CENTA, San Andrés, El Salvador
Ing. Salvador Zeledón, Plant Breeder, CENTA, San Andrés, El Salvador
Ing. José Wilfredo CastaZeda, Agronomist, CENTA, San Andrés, El Salvador
Ing. Max Hernández, Agronomist, CENTA, San Andrés, El Salvador
Ing. Quirino Argueta Portillo, Agronomist, CENTA, San Andrés, El Salvador
Ing. Orlando Téllez Obregón, Soil & Water Scientist, Posoltega, INTA, Nicaragua
Mr. Leonardo García Centeno, Agronomist, UNA, Managua, Nicaragua
Ing. Fidelia Herrara de Paz, Food Scientist, CENTA, San Andrés, El Salvador
Dr. Henry Pitre, Dept. of Entomology and Plant Pathology, Mississippi State University, Mississippi State, MS
Dr. Lloyd Rooney, Cereal Quality Laboratory, Dept. of Soil & Crop Sciences, Texas A & M University, College Station, TX
Dr. Gary Peterson, Texas A & M University Agricultural Research and Extension Center, Rt. 3 Box 219, Lubbock, TX
Dr. Larry Claflin, Dept. of Plant Pathology, Kansas State University, Manhattan, KS
Dr. W.L. Rooney, Dept. of Soil and Crop Sciences, Texas A & M University, College Station, TX
Dr. Darrell T. Rosenow, Texas A & M University Agricultural Research and Extension Center, Rt. 3 Box 219, Lubbock, TX
Dr. John Sanders, Dept. of Agricultural Economics, Purdue University, West Lafayette, IN
Dr. Sergio O. Serna-Saldivar, Instituto Tecnologico y de Estudios Superiores, Monterrey, Mexico

Collaborative Program

Vision Statement

The following vision statement was developed during the past year. "INTSORMIL collaboration will support national research programs' efforts to develop dynamic, competent institutional research programs which contribute to productivity, economic growth, natural resource conservation and improved diets for grain sorghum producers, processors and consumers. Scientists in the region will work as regional, multi-institutional, multi-disciplinary teams collaborating with extension services, NGOs, international research centers, PCCMCA, the private sector and scientists from U.S. land grant universities to increase productivity, profitability, economic growth, conservation of natural resources, and food security for producers, processors and consumers of sorghum".

Institutions

Active INTSORMIL collaboration in Central America is occurring primarily among the following institutions: Centro

Nacional de Technología de Agropecuaria y Forestal (CENTA), El Salvador; Instituto Nicaragüense de Tecnología Agropecuaria (INTA), Nicaragua; Universidad Nacional Agraria (UNA), Managua, Nicaragua; Kansas State University, Mississippi State University, Texas A&M University; and the University of Nebraska. In addition, INTSORMIL has a current MOU with the Universidad Nacional Autónoma de Nicaragua (UNAN), Leon, Nicaragua, and maintains ties with the Escuela Agrícola Panamericana (EAP), Honduras based upon past collaboration. During early 2003 contacts were initiated by the Dirección de Ciencia y Tecnología Agropecuaria (DICTA) in Honduras, and it is hoped to sign a Memorandum of Understanding and initiate collaborative research with DICTA late in 2003.

Organization and Management

In 1999, INTSORMIL shifted program emphasis in Central America to El Salvador and Nicaragua. Scientists from collaborating institutions met and developed a research plan for the 2000 -2001 years with collaborative projects in plant breeding, utilization, plant protection (entomology and plant pathology), and agronomy. On February 27-28, 2002 scientists met to present two-year research results and develop priorities for collaborative research for 2002-2006. In Oct 2002, the research directors of collaborating institutions met to develop a regional training plan for sorghum research programs.

Financial Inputs

Primary financial support for the program is from the INTSORMIL Central America Regional Program budget, which was $105,000 during the past year.The four collaborative research projects (plant breeding, utilization, plant protection, and agronomy) were budgeted at $8,000 to $21,000 each based upon output in 2001-2002 and activities proposed for 2002 - 2003, with the balance maintained at the INTSORMIL Management Entity to cover regional expenses. These regional expenses included expenses associated with the Central America Research Directors meeting, equipment purchases and administrative travel.

Collaboration

INTSORMIL's Central America program has collaboration with many non-governmental organizations mainly in validation of new sorghum varieties on-farm, and formal collaboration with national extension services, and it has served as a catalyst for Central American grain sorghum research and technology transfer. Collaborative relationships have been established with a number of universities in El Salvador and Nicaragua, and undergraduate students often complete thesis research on INTSORMIL-supported experiments. In addition, René Clará Valencia coordinated the regional grain sorghum yield trials conducted by the PCCMCA, and provided technical assistance for seed production to the private seed company Productoras de Semillas in Guatemala. A strong collaborative relationship has been developed between INTSORMIL's regional sorghum research program and ANPROSOR, the Nicaraguan grain sorghum producers association, which has assisted in identifying research priorities and has collaborated with a number of research studies since 2002. Regional scientists have formal collaboration with the CIRAD-CIAT project on participatory plant breeding for sorghum (and upland rice), and ICRISAT provides germplasm for breeding use as requested.

Sorghum Production/Utilization Constraints

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 maicillos criollos produce low yields, they are planted on approximately 67% of the grain sorghum area in Central America.

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 both maicillos criollos and other sorghum varieties is essential to obtain economical yield increases. To date, increased grain sorghum production, yield and area are due primarily to utilization of improved cultivars (hybrids and varieties) other than maicillos criollos.

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 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.

Research Accomplishments and Planning

Sorghum Research Reporting and Planning Workshop

The workshop was held on February 27 - 28, 2002 and attended by thirty-six participants sponsored by INTSORMIL, five sponsored by INTA, and several administrators from INTA, UNA and ANPROSOR. INTSORMIL helped support a special issue of the scientific journal *La Calera* Vol 3 (February 2003) which included published articles based upon 11 of the reports, and two other reports were published in *La Calera* Vol 2.

Programa Cooperativo Centroamericano para el Mejoramiento de Cultivos y Animales (PCCMCA) [Cooperative Central American Program for Crop and Animal Improvement] Annual Meeting

Regional coordinators and 6 collaborating scientists participated in this annual meeting April 28 - May 2, 2003. Thirteen out of 15 oral papers on grain sorghum were presented by INTSORMIL collaborators, and the meeting provided a forum for broadening contacts with programs in other countries and with the private sector. In addition, it was useful for regional planning of the 2003 growing season research and technology transfer plans.

Research Directors Meeting

A regional research directors meeting was held Oct. 3, 2002 in Managua, Nicaragua with the goal to prioritize degree education and short-term training needs of sorghum research programs in Central America. Degree training priorities were in the areas of food science and plant breeding. In addition, plant pathology was a high priority in Nicaragua and entomology in El Salvador. Much effort has been made to identify potential candidates for graduate study, and one has started a Ph.D. program in plant pathology at Mississippi State. In addition, a student for a Ph.D. program in entomology at Mississippi State will start English language training in August 2003 with a goal of enrollment in a Ph.D. program in Jan. 2004.

The research directors determined a short-term training priority list of experimental design, statistical data analysis and scientific communication as the highest priority, and the Universidad Nacional Agraria (UNA) in Nicaragua is planning such a course in late 2003. Other short-term training needs identified were plant breeding, and utilization of sorghum for forage. CENTA has agreed to prepare training in these two areas for 2003 and 2004.

Meeting with CENTA Board of Directors

At the request of CENTA, the Regional Coordinators met with the CENTA Board of Directors on April 28. Presentations on INTSORMIL programs worldwide and in Central America were made, followed by discussion of present activities and future opportunities. The CENTA Board of Directors suggested that INTSORMIL increase contacts with snack food companies and with the Ministry of Economics micro-enterprise efforts, and that board members would assist with efforts to obtain USAID Mission funds to increase degree education and degree training efforts.

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 (for relay intercropping systems with sorghum planted into the existing maize crop) or insensitive varieties for grain production or dual use as grain and forage. Photoperiod-insensitive lines may also serve as parents for hybrids. During 2002-2003, the Nicaraguan program took regional leadership for the hybrid development program, while El Salvador took regional leadership for the photoperiod sensitive variety program. 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. Collaborative ties have been made with Dr. Gille Trouché, CIRAD-CIAT project, with focus on a participatory sorghum breeding program in Nicaragua.

Research Results

Regional PCCMCA trials were conducted for four sorghum hybrids from Christiniani Burkard, Sefloarca and Prosemillas, a common check hybrid and a local check hybrid at 6 locations in El Salvador, Guatemala and Nicaragua. No hybrid differences in grain yield, plant height or days to flowering were found.

Plant breeding programs in El Salvador and Nicaragua are evaluating photoperiod sensitive sorghum varieties (maicillos criollos and millón) for relay intercropping systems with maize, and in some cases, with dry beans. In El Salvador the varieties 85-SCP-805 and ES-790 produced yields approximately 25% higher than the mean in both 2001 and 2002 (Table 1) and have been shown to have high nitrogen use efficiencies (see project report UNL 213). They have been selected for on-farm validation testing in 2003. Future research will emphasize transfer of the varieties 85-SCP-805, 86-EO-226 and ES-790 to hillside farmers in relay intercropping systems with maize, and evaluate the new potential varieties EIME 119, EIME 178 and PRE-EIME 112 on-farm in relay intercropping with maize. In Nicaragua, selection for improved photoperiod-sensitive varieties started in 1998. In 2002, two evaluation trials were conducted at high-yield and low-yield locations in the Las Segovias re-

Table 1. Yield of best photoperiod-insensitive and photoperiod-sensitive grain sorghum varieties, and check varieties tested in El Salvador, 2001 and 2002.

Photoperiod-Insensitive			Photoperiod-Sensitive		
Variety	2001	2002	Variety	2001†	2002
	T/ha				
Soberano (Check)	5.86ab	5.41a	EIME 119	5.14ab	4.09a
ICSV LM-89513	5.72ab	5.21a	85-SCP-805	5.90a	4.06a
ICSV LM- 90520	5.86ab	5.18a	ES-790	5.85a	4.03ab
ICSV LM- 90538	7.86a	5.13ab	PRE-EIME 178		3.62abc
ICSR-939	5.69ab	4.99ab	86-EO-226	4.80abc	3.60abc
RCV (Check)	5.63ab	4.84ab	PRE-EIME 112	4.29abc	3.42abc
ICSV LM-89537	5.67ab	4.82ab	PRE-EIME 169	3.42 bc	3.37abc
ICSV LM-93076	5.69ab	4.79ab	PRE-EIME 163		3.32abc
ICSV LM-93077	6.25ab	4.73ab	PRE-EIME 182		3.28abc
ICSV LM-93075	5.53ab	4.47ab	PRE-EIME 180	3.10 c	3.26abc
ICSV LM-92512	5.71ab	4.41ab	EIME 113		3.03abc
ICSV LM-89544	6.31ab	4.40 b	Local Check	5.36a	2.73 bc
Mean	5.27	4.86		4.32	3.00
C.V. (%)	20.8	7.3		17.1	18.6

† Lack of values in 2001 indicate that this variety is a new selection from the nursery, and was not included in the evaluation in 2001.

gion with 13 or 17 photoperiod sensitive varieties. The varieties PREEIME 119 and PREEIME 117 with yields greater than 3100 kg ha^{-1} in one trial and PREEIME 217 with yields greater than 5000 kg ha^{-1} in another appear to be most promising. Based upon previous years' results, the varieties ES-790, 86-EO-226 and EIME 113 are in validation trials on-farm in 2003. In both countries, there is a population-based improvement effort to utilize the broad base of photoperiod-sensitive germplasm present in Central America.

Evaluations of photoperiod-insensitive varieties continues in both countries. In El Salvador, none of the best potential varieties produced a superior yield in 2001 or 2002 compared to the best local check variety (Table 1). Therefore, future efforts will bring in new genetic material with greater potential to increase grain yield. In addition, more emphasis will be given to kernel size and weight, kernels per panicle, and tolerance to foliar diseases. In Nicaragua, several evaluation trials for white and red grain were conducted to select lines for potential release as varieties. Also, a nursery of African lines forwarded by Texas A & M University has been evaluated. At present, the variety INTA-CNIA is being released for high-yield environments, and the varieties INTA-Trinidad and INTA-Ligera for low rainfall zones. Recently the white grain varieties Macía (locally called 'Africana'), CENTA-RCV (El Salvador) and (TXP)-12, and the red grain varieties (SR17)-10-2-2-2, (SR-16)-10-1-1-3 and (SR-6)-1-5-1-1 have been selected for on-farm validation trials.

Forage hybrid research using inbred lines from ICRISAT and Texas A & M University continued with both yield and quality evaluation of hybrids (Table 2). The lower-forage- yielding lines tended to have higher forage quality, but the best hybrids listed in Table 2 were selected based upon yield and quality. These hybrids will be tested on-farm to obtain animal response data, and the inbred lines will be increased in preparation for release in 2004 or 2005.

SureZo was developed with INTSORMIL collaboration in Honduras. In El Salvador, SureZo has been named CENTA

Table 2. Yield and quality of best forage sorghum hybrids tested in El Salvador in 2002.

Hybrid	Yield (Green Weight)†	Total Digestible Nutrients	Net Energy (Lactation)	Acid Detergent Fiber (ADF)	Neutral Detergent Fiber (NDF)	Protein in NDF
	T/ha	%	Mcal/kg	%	%	%
ICSA 275 * TX-2784	195.5	59.3	1.29	62.0	37.0	5.1
ICSA 613 * TX-2784	193.8	59.1	1.29	65.4	37.3	5.2
ICSA 541 * TX-2784	181.2	58.9	1.28	63.3	37.5	4.4
ICSA 264 * TX-2784	190.3	55.4	1.16	64.5	42.0	3.9
ICSA 264 * TX-2785	176.3	60.0	1.32	60.1	36.1	4.8
ICSA 606 * TX-2784	176.7	59.3	1.29	64.0	37.0	4.5
HF-895 (Check)	150.3	55.7	1.30	60.2	41.6	5.3

† Dry weight was approximately 23% of the green weight.

Table 3. Summary of validation trials for CENTA S-3 (Sureño) for silage production at the milk to early dough growth stage in El Salvador, mean of 19 trials in 2002.

Variety	Days to Cutting	Plant Height	Yield Green Biomass	Yield Dry Matter	Lipid	Carbohydrates	Protein
		cm	-------------- T/ha ----- ----------		------------- % -------------------		
CENTA S-3	74	234	50.7	37.4	2.3	81.1	10.1
CENTA S-2 (Check)	84	257	41.0	30.5	1.6	80.3	9.9

S-3 and was validated against the best available sorghum variety for silage production. Validation tests indicated that CENTA S-3 has 10% greater yield and better nutritional value than CENTA S-2 (Table 3). Cattle producers are asking for seed of CENTA S-3, and private industry has initiated production of 25 metric tons of seed to plant 1400 ha of this sorghum variety in 2004.

In Nicaragua, research on developing grain sorghum hybrids was initiated. Sorghum hybrids originating from CENTA (El Salvador) and Texas A & M University were evaluated. The inbred lines used to produce these hybrids will be evaluated, and seed will be increased in 2003. In addition, male-sterile lines were evaluated for yield, adaptation and potential for use in producing hybrids. The CENTA hybrids ICSA613*99CA2519, ICSA613*86-EO-361, and ICSA613*96CD635 were the best, producing yields of 7.0 to 7.6 T/ha grain yield, while the Texas hybrids A8PR1057*6BRON167, A8PR1051*TX430, A0PR59*5BRON159, and A0PR1053*TX430 produced acceptable yields between 5.9 and 6.5 T/ha. The inbred lines ICSA-613, 86-EO-361, 99CA2519, 96CD635, 99CA2519, A8PR1057, A8PR1051, A0PR59, A0PR1053, 6BRON167, 5BRON159 and Tx430 are being evaluated in 2003. The male-sterile inbred lines ICS-275, ICS-333, ICS-361, ICS-541 and TX-629 were selected as being well adapted to Nicaraguan growing conditions, and seed is being increased in 2003.

Entomology and Plant Pathology Research

Research Methods

Farmer surveys and evaluation of the All Disease and Insect Nursery (ADIN) were used in El Salvador and Nicaragua in 2000 and 2001 to identify the pests more commonly occurring in grain sorghum fields to help guide future research. M.S. thesis research on sorghum midge was conducted in Nicaragua and published in *Tropical Agriculture*, *La Calera* and in an extension bulletin. Alternate methods for control of sorghum midge and leaf-footed bugs on sorghum panicles was conducted in 2002. In El Salvador, studies were conducted on economic thresholds of fall armyworm infestation during the whorl stage, timing of spraying for control of sorghum midge, and the ADIN and producer fields were evaluated for the most commonly occurring insects. Plant pathologists used fungicide applications in their research to determine economic yield losses from fungal diseases. Two meetings organized by UNA, INTA, CIRAD-CIAT and ANPROSOR were held in May 2003 with 70 farmers from the Pacific Region of Nicaragua to learn about the main sorghum production constraints in Nicaragua.

Research Results

Producer surveys and evaluation of ADIN in 2001-2003 found that most prevalent diseases were anthracnose and gray spot (*Cercospora)* in Nicaragua, and rust *(Puccinia* species) in El Salvador, and the most prevalent insect pests were fall armyworm *(Spodoptera* species) and midge in both countries. The pink scavenger caterpillar was observed to infest sorghum panicles in 2002. Insecticide treatments were found to be more effective than barrier crops for midge control in sorghum, while biological treatments produced inconclusive results which merit further study. Infestation with fall armyworm from 0 to 80% during the whorl growth stage had no effect on sorghum yield in both 2001 and 2002, indicating that sorghum plants can recuperate from early season damage. Timing of insecticide spraying between 10 and 50% flowering and no insecticide application produced similar yield indicating that natural infestation was not at an economic threshold.

Evaluation of ADIN studies in Nicaragua confirmed anthracnose and gray spot to be the major diseases in Nicaragua, and differences among sorghum lines on susceptibility to these two diseases varied. The lines BTX-378, 96GCPO, B143 and LG-35 were very susceptible while R9113, 98PR1057, 90EON343 and 91BE7414 had less than 10% infestation. In El Salvador, application of the fungicide Cycosin and elemental sulfur during vegetative growth had no effect on reducing incidence of fungal pathogens. Application during grain fill reduced incidence of *Gloeocercospora*, *Collectotrichum*, *Helminthosporium* and *Puccinia*, but had no effect on grain yield. Six sorghum varieties were evaluated for susceptibility to rust which showed large differences, with 'punta de lanza' and 'sapo' (photoperiod sensitive varieties) having less than 15% incidence and the sorghum line 88B943 having over 75% incidence.

In Nicaragua, farmer meetings identified felt needs for training in integrated pest management of grain sorghum, especially with diseases, and agronomic management. In addition, fertilizer management (particularly rates and application timing), weed control and additional utilization options beyond being a poultry feed. They indicated a need for a simple grain sorghum production manual. Many of the farmers offerred their farms to be used for research studies.

Grain Utilization (Quality) Research

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 Agrícola Panamericana in Honduras. In recent years the research has broadened to include grain sorghum flour substitution in yeast and sweet breads in El Salvador. This research has included market surveys, and research on specific grain quality/food utilization issues by CENTA, with undergraduate students from the Escuela Agrícola Panamericana, or graduate students at Texas A & M University or the Instituto Tecnologico y de Estudios Superiores, Monterrey, Mexico. In 2002, CENTA established collaboration with the Universidad José Matías Delgado in El Salvador, and conducted research on decortification of sorghum grain, development of new sweet bread recipes, and determination of shelf life of sweet breads made with whole sorghum grain.

Research Results

Research in El Salvador during the past 20 years has developed the technology for incorporating sorghum flour from white, food-grade sorghum cultivars for use in French and sweet bread for urban areas. The research also developed use of 100% sorghum flour for sweet bread, cold drinks (horchatas, refrescos); hot drinks (atoles); and popped sorghum (alboroto). Five tests were conducted with rice millers to decorticate sorghum grain, all being unsuccessful. Several new sweet bread recipes were developed all using 20 to 25% whole sorghum grain flour. Twelve products were evaluated for shelf life, with pastelito de leche and pastelito de piZa being 7 days; queiquito, guaracha and pegadito being 25 days; semita alta, pelona, canasta, gusano and picuda being 30 days: and semita pacha, novia and pichardine being 35 days.

Agronomy Research

Research Methods

Agronomic research was conducted in 2000-2002 to evaluate nitrogen use efficiency of grain sorghum photoperiod-sensitive and -insensitive genotypes and to determine optimal nitrogen fertilizer rate recommendations. Four to six grain sorghum varieties were grown at 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. Fertilizer use efficiency and utilization nitrogen use efficiencies were calculated from these data. Nitrogen rate by plant population studies were conducted with broomcorn at six locations in Nicaragua.

Research Results (See Project UNL-213 Report for More Detailed Information)

In Central America, nitrogen application increased sorghum grain yields quadratically for both photoperiod-sensitive and -insensitive varieties. Little difference in nitrogen use efficiency (NUE) was found among the photoperiod-insensitive varieties tested, indicating that broader screening of germplasm in Central America sorghum breeding programs will be needed to identify and develop high nitrogen use efficient photoperiod-insensitive sorghum varieties. Nitrogen application of 90 to 115 kg ha^{-1} was necessary to optimize grain yields. In El Salvador, the photoperiod-sensitive varieties SCP-805 and ES-790 for relay intercropping with maize were found to be high yielding and to have high NUE and % N Fertilizer Recovery. Grain yields were optimized with 47 kg ha^{-1} N application. Validation trials are underway on-farm in collaboration with non-governmental agencies to promote the use of the variety 85-SCP-805 with moderate application of nitrogen fertilizer.

Broomcorn yields were not influenced by changes in plant population, but were influenced by nitrogen rate which varied across locations. On average, broomcorn yield increased linearly to nitrogen application with a 16% increase in yield for each 30 kg ha^{-1} nitrogen applied.

Mutual Research Benefits

Many constraints to sorghum production 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 effects of some of these constraints. The maicillos criollos are a unique type of grain sorghum and can potentially contribute useful food quality traits to U.S. germplasm. Several maillos criollos 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. INTSORMIL's collaborative research in entomology and plant pathology research includes pests that affect grain sorghum both in Central America and in the U.S., such as sorghum midge, fall armyworm, gray spot and ergot. Economic development of Central American countries will increase food security in the region, and potentially increase U.S. exports to the region.

Institution Building

Equipment and Other Support

INTSORMIL has provided pass-through funding and supplies for pathology laboratories in El Salvador and Nicaragua.

Three chlorophyll meters were purchased to facilitate agronomy research on N fertilizer management and nitrogen use efficiency.

Training and Education

Mr. Javier Bueso (Honduras), Assistant Professor, Escuela Agricola Panamericano (Honduras) , completed a Ph.D degree in Food Science at Texas A&M University, and Rafael Mateo (Honduras) is pursuing a Ph.D. in plant breeding at Texas A&M University. Johnson Zeledón (Nicaragua) is pursuing a Ph.D. degree in entomology at Mississippi State University, and Segio Pichardo Guido has just started a Ph.D. program in plant pathology at Mississippi State University. Candidates for INTSORMIL-supported graduate degree programs in the United States are being chosen to meet regional priorities, and assistance with English language study is being provided. Short-term training on experimental design, data analysis and scientific communication is planned for 2003-2004. Jesus Narro (Mexico), Sergio Picahrdo Guido and Yanet Gutiérrez (Nicaragua) attended the Fuscarium Workshop sponsored by Kansas State University in June 2003. Martha Perez Valdivia, Marion Suarez, Vicente Reyes and Augusto Romero received B.S. degrees at UNA in Nicaragua with thesis research conducted on INTSORMIL collaborative agronomy experiments.

Networking

Institutions/Organizations

INTSORMIL support has contributed to increased collaboration among CENTA, INTA and UNA during the past four years. In El Salvador, increased collaboration with the non-governmental organizations ESBESA, ESBESA-Ramírez Consultores, MAG/AVES, FUNPROCOOP, PRODAP (Proyecto de Desarrollo Rural en la Región Paracentral), and FUNDESYRAM (Fundación Para E Desarrollo Socio-Económico y Restauración Ambiental) primarily with validation testing of sorghum varieties to be released. A collaborative relationship has also been established with the Universidad José Matías Delgado. In Nicaragua, increased collaboration with the CIRAD-CIAT Watershed Project at San Dionisio has been strengthened, especially collaboration with Dr. Gilles Trouché, sorghum breeder. Also collaboration with the universities of Campesina (UNICAM), Centroamericana (CSA) and Católica del Tropico Seco de Estelí (UCATSE), and with the non-governmental organizations ADRA-Ocotal, CARITAS-Matagalpa and CARE-Estelí have been developed. National programs have strong linkages to private seed companies, and are developing closer ties with feed and food utilization companies. Particularly noteworthy is providing technical assistance to the seed company Productora de Semilla in Guatemala. Close working ties with the Asociacíon SalvadoreZa de Panifacadores (ASPAN) in El Salvador continues. Improved networking with INTSORMIL universities and Instituto Tecnologico y de Estudios Superiores, Monterrey, Mexico is desired through graduate education and collaborative research efforts. INTSORMIL is actively working to promote strengthed collaborative linkages.

Travel

INTSORMIL sponsored the Central America Research Directors meeting 3 October, 2002 in Managua, Nicaragua with representation from INTA, UNA, CENTA and INTSORMIL.

Nine scientists and two research directors attended the INTSORMIL Principal Investigators Conference in Addis Ababa, Ethiopia in November 2002. Several research planning meetings were held with U.S. and Central American scientists during the meeting.

Regional coordinators and 6 collaborating scientists attended the PCCMCA meeting April 27 - May 2, 2003 in La Ceiba, Honduras. Thirteen sorghum research papers were presented by INTSORMIL collaborators.

Dr. Larry Claflin visited INTSORMIL scientists conducting collaborative research in El Salvador and Nicaragua in Dec., 2002.

Regional coordinator René Clará visited Nicaragua several times to coordinate activities and assist with the INTA plant breeding program. He also visited Productora de Semillas in Guatemala to provide assistance on sorghum seed production.

Dr. Stephen Mason, Regional Coordinator, made trips to El Salvador and Nicaragua in September-October 2002 and to El Salvador and Honduras April-May, 2003.

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

Gebisa Ejeta
Purdue University

Coordinators

Gebisa Ejeta, Regional Coordinator, Purdue University, Department of Agronomy, West Lafayette, IN 47907
Katy Ibrahim, Administrative Assistant, International Programs in Agriculture, Purdue University, West Lafayette, IN 47907
Zenbaba Gutema, Ethiopia Country Coordinator, EARO, PO Box 2003, Addis Ababa, Ethiopia
C. K. Kamau, Kenya Country Coordinator, Katumani National Dryland Farming Research Ctr, Box 340, Machakos, Kenya
Semere Amlesom, Eritrea Country Coordinator, Division of Ag Research & Ext Services, Box 10438, Asmara, Eritrea
Peter Esele, Uganda Country Coordinator, Serere Ag & Animal Production Research Institute, Serere, PO, Soroti, Uganda

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 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 Understanding (MOU) have been signed with NARS in Ethiopia, Eritrea, Kenya, Tanzania and Uganda. With these MOUs, 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 part of 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 program, 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 consultation 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

Ethiopia

Agronomy – Kidane Georgis, EARO; Charles ortmann/ Martha Mammo, INTSORMIL

Striga Management – Fasil Redda, EARO, MOA; Gebisa Ejeta, INTSORMIL

Entomology – Tsedeke Abate, EARO; Henry Pitre, INTSORMIL

Agricultural Economics – Yeshi Chiche, EARO; John Sanders, INTSORMIL

Sorghum Utilization – Senait Yetneberk, EARO; Bruce Hamaker and Gebisa Ejeta, INTSORMIL.

Research Extension - 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

Striga – C. Mburu, KARI; Gebisa Ejeta, INTSORMIL

Uganda

Sorghum and Millet Pathology – Peter Esele, NARO; Gebisa Ejeta, INTSORMIL

Sorghum Agronomy - Joseph Oryokot, NARO; Charles Wortmann, INTSORMIL

Eritrea

Sorghum Breeding – Tesfamichael Abraha, DARHRD; Gebisa Ejeta, INTSORMIL.

Millet Breeding – Neguse Abraha, DARHRD

Entomology – Asmelash Woldai, DARHRD; Henry Pitre, INTSORMIL

Striga Management – Goitom Ghobezai, DARHRD; Gebisa Ejeta, INTSORMIL

Sorghum/Millet Constraints Researched

Sorghum and millet are important crops in all of the countries in the Horn of Africa, (Table 1) ranking first or second in cultivated area among the major cereal crops of the region. Sudan and Ethiopia are the indisputable centers of origin for sorghum and are major centers of genetic diversity for both crops. In addition, a wealth of improved sorghum and millet germplasm has been made available in both of these countries as a result of association with INTSORMIL and ICRISAT. Collaborative research between Sudan and INTSORMIL has also resulted in research and production technologies that can be shared by other members of the Horn of Africa.

According to the sorghum and millet scientists in the Horn of Africa region, "the major sorghum and millet production and utilization constraints (Table 2) are generally common to all countries.

These constraints include lack of improved germplasm, drought, *Striga*, insects and diseases (anthracnose, leaf blight, grain molds, smuts, ergot 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

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	1000	280	1000	280
Kenya	120	745	90	85	682	58
Sudan	4684	785		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 & Marketing	X	X	X	X	X

production. Breeding efforts currently in use to incorporate drought tolerance traits to genotypes with high yield potential are limited by lack of a field screening procedure and lack of knowledge of sources of appropriate germplasm with useful traits. The lack of absolute definition of good food quality parameters and good screening methods for food quality to some extent also limit the utilization of high yielding sorghum and millet varieties. Very little research has also gone in developing germplasm with resistance to the major insect pests and diseases. *Striga*, a major parasitic weed of sorghum and millet, constitutes a major constraint to the production of these crops. There is very little sorghum and millet germplasm with resistance to *Striga* and the mechanisms that render resistance to *Striga* are not well understood. Knowledge about inheritance of many of these traits is also lacking. In many of these areas, the crop/bush fallow system of production has traditionally been used to provide enough nutrients and possibly some moisture for a period of crop years (5-10 years fallow/2-4 years cropping). In some areas, other crops are often grown in an intercropping system with millet and sorghum to maximize production. Over the last 2-3 decades, rainfall in the Horn of Africa region has declined, thus reducing the soil recovery rate during fallow. Fallow periods have also decreased due to higher human and animal pressure on plant cover, resulting in further reduction of sorghum and millet yields in the region. Research on all of these aspects is needed to improve sorghum and millet production and utilization in the Horn of Africa.

Research Progress

Ethiopia

Sorghum (*Sorghum bicolor*) is the third most important cereal crop in Ethiopia both in its production and area coverage following teff and maize. It is grown in 12 of the 18 major agro-ecological zones of the country that are currently recognized. Especially it is a very important crop in the lowland arid and semi-arid areas of the country where drought has been recurrent and thus crop failures are common. About one million hectares are devoted to sorghum production each year and 1.2 million tons are produced. The national average yield is 1.2 tons per hectare. However, research results indicate that 3-6 tons per hectare can be produced based on the growing environment. The major reasons for the low national average yield is attributed to drought, *Striga*, soil fertility decline, birds, diseases and insect pests. To tackle at least some of these constraints INTSORMIL CRSP collaborative research was initiated six years ago and significant advances have been made. Highlights of the research activities of the 2002/2003 cropping season are given here.

Research Highlight

During 2002/2003 cropping season three ongoing research activities vis-B-vis hybrid sorghum variety development, *Striga* resistant sorghum variety development and long cycle sorghum variety development were undertaken. In addition, new collaborative research in areas of agronomy, particularly soil and water conservation and extension of integrated *Striga* control technologies were initiated.

Hybrid/Variety development

Two sets of hybrid trials advanced from the previous season and one initial sorghum hybrid trial were tested for yield and other desirable characteristics at Melkassa, Kobo and Mieso. The trial conducted at Mieso was not successful due to an extended dry spell that occurred after planting. The ad-

Table 3. Mean grain yield (t/ha), days to 50% flowering and plant height (cm) of 16 hybrids included in 2001 Elite Sorghum Hybrid Trial (ESHT) at Melkassa (MS) and Kobbo (KB)

Identification	Grain yield g/ha			Days to Flowering			Plant height cm		
	MS	KB	Mean	MS	KB	Mean	MS	KB	Mean
ICSA – 15 x ICSR – 14	5.8	6.3	6.1	71	80	75	179	172	176
ICSA – 21 x ICSR – 50	5.8	6.2	6.0	71	79	75	178	145	161
P-9518A x KCTENT # 17 DTN	5.3	6.0	5.7	66	76	71	168	168	168
ICSA 34 x ICSR – 14	5.3	6.0	5.7	69	79	74	170	165	168
ICSA – 15 x 34443 – 2 – OP	5.0	6.4	5.7	70	79	74	234	214	224
p-9513 A x KCTENT # 17DTN	5.5	5.4	5.5	68	79	73	173	161	167
P-9501 A x ICSR - 14	5.2	5.7	5.5	69	78	73	173	148	160
P-9513 A x 90MW 5344	4.9	5.6	5.3	68	76	72	184	166	175
P-9534 Ax KCTENT # 17DTN	5.4	4.9	5.2	69	77	73	183	168	175
P 9501 A x ICSR - 16	5.4	5.0	5.2	69	76	73	174	155	164
ICSA – 34 x ICSR - 161	5.0	5.4	5.2	69	77	73	158	143	150
ICSA – 15 x ICSR - 161	4.2	5.5	4.9	72	78	75	181	151	166
ICSA – 21 x ICSR – 161	4.6	5.1	4.9	70	78	74	174	153	163
P-9534 A x ICSR 16	4.9	4.7	4.8	70	76	73	170	155	163
M – 90950 A x MR 747	4.5	4.3	4.4	73	84	78	183	162	172
Meko	3.5	3.2	3.4	68	78	73	169	148	159
Mean	5.0	5.4		69	78		178	161	
LSD (0.05)	0.9	1.2		2	6		11	20	
CV%	12	15		1	3		4	9	

vanced sorghum hybrid trial (ASHT) comprised 25 hybrids and a standard check. From the data summarized for Melkassa and Kobo 21 of the tested hybrids yielded over the check variety and the yield range obtained across location ranged from 3.1-5.6 tons per hectare. Sixteen genotypes including one standard check were included in the second set of experiments, of the elite sorghum hybrid trial (ESHT), The results indicate that all the hybrids performed significantly better than the check variety. Across the two testing sites, the mean yield performance of the hybrids ranged from 3.4 – 6.1 tons per hectare (Table 3). In addition 291 hybrids were introduced from Purdue University for evaluation under Melkassa conditions (Table 3). From these introduced materials 14 hybrids (6 from Experimental hybrid-1, 5 from experimental hybrid-2, and 3 from elite sorghum hybrid) were found to be agronomically promising. Again 4 A & B lines were selected for our subsequent hybrid crossing program during the off-season. To undertake further testing the R-lines from Purdue University for the selected hybrids are needed.

Moreover two hybrids were identified for on-farm verification from the hybrids that have been evaluated in multi-location testing for a number of years. These hybrids have excellent agronomic potential for production under dryland conditions in Ethiopia. Currently the hybrids are being evaluated for seed production under the natural pollination.

Striga Resistant Sorghum Variety Development

Evaluation and selection of *Striga* cross segregants: out of 1530 total population/families/lines we evaluated 668 were

Table 4. Mean Grain yield (t/ha), days to 50% flowering, plant height (cm) and mean *Striga* count of 12 varieties included in *Striga* Resistant Sorghum National Variety Trial (SRSNVT) at Zema (ZM), Abergele (AB), Sirinka (SR) and Shiraro (SH) in 2001 crop season.

	Grain yield					Days to flowering					Plant height					Striga Count			
Identification	ZM	AB	SR	SH	Mean	ZM	AB	SR	SH	Mean	ZM	AB	SR	SH	Mean	ZM	SR	SH	Mean
M-36121 x Tigray Coll. (Red)	1.2	2.1	2.2	3.0	2.1	79	68	65	79	71	140	146	147	138	142.4	92	9	1	34
(148 x E-35-1)-4 x CS 3541 derive 5-4-2-1 x SRN-39	1.0	1.7	1.9	3.1	1.9	83	65	67	83	74	139	118	136	131	130.9	17	2	1	7
(148 x E-35-1)-4 x CS 3541 derive 5-4-2-1 x SRN-39	1.2	1.3	2.2	3.0	1.9	82	74	65	83	76	142	122	134	127	131.1	24	3	1	9
M-36121 x Tigray Coll.	1.2	1.6	2.3	2.5	1.9	84	74	68	84	78	141	146	170	140	149.0	24	6	1	10
(148 x E-35-1)-4 x CS 3541 derive 5-4-2-1 x P-9403	0.8	2.2	2.2	2.1	1.8	80	67	61	78	71	136	127	130	136	132.0	23	4	2	10
(148 x E-35-1)-4 x CS 3541 derive 5-4-2-1 x P-9401	0.6	1.4	2.2	2.4	1.7	80	63	67	81	73	127	112	121	121	120.0	10	5	1	5
(148 x E-35-1)-4 x CS 3541 derive 5-4-2-1 x P-9401	0.6	1.4	1.8	2.9	1.7	80	72	66	80	75	162	141	154	146	150.6	40	4	1	15
P_9403 (Abshir)	0.8	1.9	1.6	2.4	1.7	77	63	60	77	70	140	129	129	129	131.6	40	6	1	16
Local Check	0.6	1.4	2.1	2.6	1.7	98	67	67	84	79	209	117	155	162	185.6	25	8	9	14
P-9401 (Gubye)	0.8	1.4	1.6	2.2	1.5	78	63	60	77	70	131	113	120	125	122.0	18	8	1	9
(148 x E-35-1)-4 x CS 3541 derive 5-4-2-1 x P-9408	0.6	1.6	1.5	1.9	1.4	70	61	68	75	69	137	138	149	145	141.7	15	2	0	6
(148 x E-35-1)-4 x CS 3541 derive 5-4-2-1 x SRN-39	0.4	1.2	1.5	1.9	1.3	89	72	69	84	79	134	102	122	110	116.8	18	5	0	8
Mean	0.8	1.6	1.9	2.5		82	67	65	81		145	126	139	142					
LSD	0.5	0.8	0.7	0.7		3	8	3	2		12	13	40	12					
CV%	44	33	23	18		3	8	3	2		6	7	21	6					

crosses for *Striga* resistance. Two hundred seventy seven of them were advanced for the next evaluation.

Evaluation of *Striga* resistant varieties: Twenty one *Striga* resistant varieties locally crossed and advanced from lines originally introduced from Purdue University were organized in two sets of experiments (one national and one prenational variety trials) and evaluated for *Striga hermontica* resistance at Sheraro, Abergele, Zema and Sirinka. In the national variety trial a total of 12 entries with local and standard checks were tested across four locations and a yield range of 1.3 to 2.1 tons per hectare (Table 4) recorded out of which five entries outyielded the standard and local checks. The preliminary variety trial consisted of 12 entries and a standard and a local check (Table 5). Lower grain yield were recorded at Zema (Gojam) due to poor agronomic management. This resulted in lower mean yield over the testing locations. Moreover, the lower *Striga* count observed in the local check may be explained due to infestation variation in the plot. But this year the *Striga* count was generally low for unknown reasons.

Long Cycle Sorghum Variety Development

The objectives of this activity were previously described. In this group two sets of long maturing drought tolerant sorghum cultivars were conducted for the lowland moisture stressed areas of the country in the 2002 cropping season. The trial conducted at Mieso was not successful due to an extended dry spell that occurred after planting. The preliminary variety trial consisting of 21 cultivars with yield range of 2.6 to 5.7 tons per hectare (Table 6) and out of which two of the cultivars overyielded the check. In a similar trend two cultivars scored higher grain yield over the check among 24 cultivars of the national variety trial. The yield range of the national variety trial extended from 1.9 to 5.3 tons per hectare at Melkassa (Table 7). Most of the cultivars in both sets of experiments grew taller

Table 5. Mean grain yield (t/ha^{-1}), days to 50% flowering and plant height (cm) of 14 varieties included in *Striga*

	Grain yield					Days to flowering					Plant height					Striga Count			
Identification	SH	ZM	SR	AB	Mean	SH	ZM	SR	AB	Mean	SH	ZM	SR	AB	Mean	SH	ZM	SR	Mean
(Farmida x SRN – 39) F12 96/97 PR-289	18	8	19	6	13	61	82	84	68	74	132	119	100	98	112	5	1	1	3
(SRN – 39 x P 954063) F14 96/97 PR – 279	17	5	16	8	12	57	78	83	65	71	137	134	113	119	126	2	1	1	1
(SRN – 39 x P 954063) F14 96/97 PR - 254	16	6	18	7	12	55	79	81	64	70	116	131	108	112	117	6	2	4	4
(SRN – 39 x P 954063) F14 96/97 PR – 279	15	9	12	7	11	49	74	77	61	65	126	133	113	87	115	7	2	3	4
(SRN – 39 x P 954063) F14 96/97 PR – 269	15	8	14	6	11	51	75	78	65	67	134	119	103	110	117	3	1	5	3
(Farmida x SRN – 39) F12 96/97 PR-269	15	4	13	7	10	52	83	80	60	69	120	126	106	112	116	4	1	2	2
1988 PP 37 SELFED 59 96/97 PR – 389	16	6	10	7	10	50	81	84	71	75	120	122	105	109	114	5	1	2	3
(SRN – 39 x P 954063) F14 96/97 PR – 284	15	7	10	7	10	58	74	77	60	65	133	132	115	115	124	5	0	3	3
(SRN – 39 x P 954063) F14 96/97 PR – 284	16	8	10	8	10	50	78	77	62	67	132	136	115	124	127	15	0	3	6
(N 13 x SRN – 39) F 14 96/97 PR – 329	15	6	15	4	10		77	81	65	70	111	121	102	100	109	19	2	6	9
Local Check	16	8	12	5	10	65	105	88	68	82	263	215	206	107	198	11	1	10	7
(N 13 x SRN – 39) F 14 96/97 PR – 314	10	6	9	7	8	49	76	80	64	67	135	129	103	117	121	2	0	0	1
(SRN – 39 x P 954063) F14 96/97 PR - 369	15	6	9	4	8	63	82	83	69	73	105	117	94	87	101	4	0	8	4
P-9401	17	3	10	4	8	58	81	80	68	71	123	122	107	96	112	4	0	4	3
Mean	15	6	13	6		55	80	81	65		135	133	113	107		7			
LSD (0.05)	3	5	4	3		2	7	2	7		6	13	8	29					
Cv%	19	43	21	32		2	5	2	6		3	6	4	17					

Resistant Sorghum preliminary Variety Trial (SRSPVT) at Shirero (SH) Zema (ZM)Sirnka (SR) Abergele (AB) in 2001 cropping season

Table 6. Mean grain yield (t/ha) days to flowering and plant height (cm) of 21 varieties included in long cycle sorghum preliminary variety trial (LCSPVT) at Melkassa in the 2001 growing season

Entry #	Identification	Grain yield	Days to 50% flowering	Plant height
1	Acc. # 206089	4.9	99	303
2	Acc. # 206089	3.9	109	353
3	Acc. # 69265 -1	5.6	112	348
4	Acc. # 69265 -1	4.7	102	365
5	Acc. # 212644 -1	3.4	97	335
7	Acc. # 217367	3.3	109	335
8	Acc. # 213361	3.9	105	323
9	Acc. # 206189 – 1	5.7	107	350
10	Acc. # 206189 - 2	4.9	108	363
12	Acc. # 213370	3.5	86	273
13	Acc. # 212644-2	2.7	98	305
14	Jemoye	3.7	98	285
15	Boruoda	4.0	104	378
16	Short muyera	3.8	112	335
18	Unbred Acc. # 3498	2.6	97	293
19	Wagree red	4.9	117	385
20	Wagree White	2.9	107	368
21	Local check	4.9	102	245
	Mean	3.9	103	327
	LSD (0.05)	1.6	5	50
	CV%	20	2	7

than the checks. They produced higher stover yields with quality seed that is preferred by most small-scale farmers

New Collaborative Research Activities Initiated During 2002

Agronomy/Soil and Water Conservation

The objectives of this research activity are:

- To assess the utility and effectiveness of tie-ridge and row planting implements with farmers on their farms and under farmers' management;
- Compare tillage alternatives for yields under farmers' conditions;
- Determine the importance and the interaction of fertilizers with water management and
- Determine the role of sowing date (late maturing variety sown in April and early maturing variety sown in June) on the above three objectives.
- The activities were planned for Miesso, Wolenchiti and Mekelle. As there has been exceptionally late onset of rains, trials designed especially for long maturing cultivars could not be established. However, at Wolenchiti the trial was established using short maturing varieties under a small rains regime.

Summary and Conclusions

- Promising hybrids have been identified for on-farm evaluations
- Some long maturing sorghum varieties for dryland areas of Ethiopia were identified for on farm verification
- Some promising *Striga* resistant varieties were selected to give more options to farmers
- The newly initiated research projects gave additional promotion for INTSORMIL/EARO collaboration.

Eritrea

Sorghum

The general objectives of the sorghum improvement program in Eritrea are as follows:

- To enhance and develop more adaptive, disease, and pest resistant, improved sorghum varieties, populations and hybrids suitable for the farmers' community
- To identify and use a range of landrace germplasm for developing new varieties derived from crosses.
- To develop capacity to produce, distribute and maintain breeder/foundation seed of open pollinated varieties, hybrids, and hybrid parents.
- To develop human capacity by training sorghum scientists and technicians in-country (on the job) and abroad.

The two activities reported here include:

a) Crop evaluation in 2002 season at the research locations in Goluj, Shambuko and Hagaz
b) Seed production at Goluj and Shambuko

Table 7. Mean Grain yield (t/ha), days to 50% flowering and plant height (cm) of 24 varieties included in long cycle sorghum national variety trial (LCSNVT) at Melkassa in the 2001 cropping season

Entry #	Identification	Grain yield	Days to 50% flowering	Plant height
1	Killitie	3.2	96	279
2	Mishinga Adi	3.1	97	279
3	Abdellota	2.3	100	354
4	Abolla	3.1	99	330
5	Degalite (red)	1.9	107	340
6	Brmash	3.2	81	179
7	Degatite yellowish	3.1	106	361
8	ETS – 0738	2.8	117	379
9	ETS 3502	2.9	99	288
10	90 BK 4241	2.5	91	238
11	ETS 0601	2.8	105	340
12	ETS 789	3.4	105	314
13	Goronjo # 1	2.9	92	256
14	Merahabette Coll. # 9	3.9	109	260
15	Merahabette Coll. # 10	5.3	109	288
16	Merahabette Coll. # 4	1.9	93	301
17	Merahabette Coll. # 11	2.3	92	223
18	Merabette Coll. 8	1.9	88	303
19	Abay Gorje Coll. #	3.3	105	314
20	Abiy Gorje coll. #	2.6	102	326
21	Wollo Coll. # 1	2.9	100	314
22	Wollo Tenglle # 1	3.9	109	260
23	Woldia Coll # 1	5.0	107	310
24	Local Check	4.0	103	230
	Mean	3.1	100	298
	LSD (0.05)	1.4	4	33
	CV %	32	3	8

The sorghum research program was conducted for only the second time in Goluj. In the year 2001 all the trials and seed multiplication were highly affected by *Striga* and shatter cane, consequently yield and yield components were below the expected range. Rainfall of the year 2001 was good enough for the completion of the growing season for sorghum. However, the year 2002 was different with very low rainfall and thus all seed multiplication and trials suffered from moisture stress. The majority of the cultivars involved in the trial and seed multiplication failed to head.

At Hagaz research station (the main station for pearl millet program), though there was moisture stress, some promising varieties of sorghum were able to head and gave reasonable yields.

The seed multiplication at Shambuko research station was also much better than the Goluj station resulting in higher average yield of sorghum of breeder and foundation seeds. The amount of rainfall obtained at Shambuko Station was better than Goluj Research Station.

In general, 2001 and 2002 gave the sorghum researchers a good opportunity to give more emphasis to sorghum varieties that can tolerate moisture stress and *Striga* infestations in the country, specially in Gash-Barka region.

Crop Evaluation in 2002 Season at the Research Locations in Goluj and Hagaz

Ten improved sorghum varieties with known drought and heat tolerance were introduced from SADC/ICRISAT SMIP in Bulawayo in 2001 for adaptive testing at Hagaz. A local check variety was added. The trial was planted in a randomized complete block design with three replications, each plot with four rows of four meters length and spaced 0.75cm apart. The results of this trial are presented in Table 8 given below.

The 2002 season, with its severe drought (worst in 10 years), provided an excellent selection opportunity for the best heat and drought tolerant entries. Out of the 11 test entries, 6 were selected for further evaluation. Thus the 6 varieties are agronomically superior and with reasonable yield during such drought season. Varieties Town and IS 898 gave the highest yield. IESV 99069 was also agronomically superior with relatively good yield, though not as high a yielder. IS 898 (42 days) and IS 106 (50 days) were among the earliest varieties tested. With these results the following action plan was put in place:

Table 8. Mean Performance of sorghum for heat + drought, Hagaz, 2002

Entry No.	Varieties	Days to 50% Flowering (days)	Plant Height (cm)	Grain yield (Qt ha^{-1})	Agronomic Score (1-5)
1.	Mahube	54.0	107	6.4	1.3
2.	Town	58.0	197.7	10.2	2.5
3.	IS 898	42.0	140.7	10.0	1.8
4.	IS 3679	56.0	109.3	6.8	2.8
5.	IS 155	67.0	-	-	4.0
6.	SC 701-14 E	62.0	113.0	3.8	2.8
7.	F6 YQ 212	59.0	92.7	5.1	2.5
8.	IESV 99069	59.0	127.3	9.0	1.2
9.	IS 106	50.0	163.3	9.3	2.5
10.	IS 9615	-	-	-	5.0
11.	Wedi-Susa	56.0	93.7	5.7	2.8
	Grand Mean	56.4	127.2	7.4	
	LSD	2.2	16.4	7.5	
	CV %	0.3	5.2	29.2	
	F Prob (5%)	***	***	NS	

- Increase seed of the 6 selections in the off-season at Hagaz
- Repeat the trial in 2003 with the 6 selected introductions and 2 local checks (Wedi-susa and Embulbul) to confirm performance.
- Put the 6 selections with 1 local in On Farm Trial (3-6 farmers) in 2003, for farmers' involvement in the selection process and their verification.
- Cross the 6 selections with Wedi-Susa, Embulbul (already initiated in the breeding nursery) and other available landraces in Anseba and North Red Sea Zones to develop new, productive, heat/drought tolerant landrace-derived varieties.

Sorghum Landrace Evaluations

Thirty-four landraces, all collected from the lowland of Eritrea, were planted during the 2002 cropping season at Goluj, a new *Striga*-free site. The following 10 varieties showed better performance: Hugurtay, Wedi-aker short, Wedi-aker tall (late), Bazenay (loose head, yellow seed), Habarat (white twin seed chimro with black glumes and early), Chimro (yellow twin seed), Korkora (similar to wedi-aker tall, bold grain with white chalky seed), Grun keih (tall compact with small head and late), Estif (looks like wedi-aker tall with white chalky seed) and Sandashima (similar with Bazenay type and yellow seed). The ten selected landraces would be used in crossing block with released and pre-released varieties, to generate new/further landrace derived lines and varieties for drought condition and preferred by farmers.

Seed Production Efforts at Goluj and Shambuko:

In 2001, in-country seed production by the DARHRD only succeeded in pure grain rather than seed due to extensive damage by *Striga* and contamination by shattercane, at Goluj. In 2002, greater success was recorded in national efforts to produce their own seed:

Breeder/Foundation seed multiplication at Goluj

- Gedam el Hamam
- Planted in 0.16 hectare
- The field was very pure stand but failed to head due to severe drought

PP 290 (Shambuko)

- Planted in about 0.4 hectare
- Late planted after the trials
- Well spaced and excellent management

- Only 40 kilo grams of pure seed obtained due to severe drought

P 9401, P9405, P9406 and P9407 (Purdue *Striga* resistant varieties)
- Each planted in about 0.5 hectare
- Well managed, fertilizers both DAP and Urea applied at the right time and a tied-ridger was used to conserve moisture. However, due to the severe moisture stress, all entries faced terminal drought stress, when the crop started to flower and failed to set seed. However, varieties P 9401and P9405 were most adapted to drought condition in addition to their *Striga* tolerance and they were able to harvest half a quintal of each variety.

Foundation seed production at Shambuko
- One released variety (ICSV 210/Bushka) and two pre-released varieties (Gedam Hamam and Macia) from the national sorghum improvement program were planted at Shambuko Research station. A Farmer's field day was conducted before the varieties were harvested. Farmers preferred Macia for its bold seed and Bushka for its high yield. Both varieties were well accepted for their white color seed.

Sorghum varieties in the foundation seed fields were:

Gedam Hamam
- Excellent management planted on 3.0 hectare
- Highly affected by drought
- About 8.4 quintal of foundation and 2.1 quintal of breeder seed were produced.

Macia
- Fairly good field though drought affected; planted on about 2.7 hectare
- A total 9.1 quintal of foundation seed were produced.

ICSV 210/Bushka/
- a good well-managed field, planted in about 5.6 hectare
- about 27.3 quintals of pure foundation was obtained.

Pearl Millet Breeding

Pearl millet (Pennistum glaucum) has protogynous nature of flowering and is grown mainly for grain in the tropical and sub-tropical areas of Africa and in the Indian sub-continent. It is an indispensable food for millions inhabiting the semi-arid and arid tropics and is more important in the diet of the poor (Harinarayana, 1987).

Pearl millet is the second largest food crop in Eritrea, grown mainly by small farmers in the low- lands and mid-lands. Landraces currently grown by the farmers contain the traits that farmers have selected for over centuries, and thus represent a very valuable resource for the breeding program. However, because of the cross-pollinated nature of the crop, such desirable traits may not exist in a high frequency in landrace populations and may be accompanied by various undesirable traits, such as susceptibility to downy mildew.

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 (Singh et al., 1993). Downy mildew is widely distributed in Eritrea and occurs in epidemic form on farmer landraces, making it the major millet disease in Eritrea. Surveys conducted in 1999 and 2000 showed high levels of downy mildew incidence ranging from 30% to as high as 70% in farmers' fields.

The Eritrean pearl millet breeding program which started its research and breeding activities in early 2000, seeks to produce adapted, disease resistant pearl millet varieties, acceptable to farmers, that will help to increase and stabilize millet productivity in Eritrea. In this effort, local landraces and exotic cultivars were tested for their disease resistance and yield capabilities. Crosses were made between the exotic and local landraces to increase disease resistance and productivity of the landraces. Thus, twenty five population crosses were made and evaluated involving five landraces and five introduced materials at Hagaz in the rainy season of 2000. Out of these, four population crosses were identified and further random mating carried out.

In the rainy season of 2002, the third random mated bulks of these four population crosses were tested on-farm with the farmer's local cultivar as control for their adaptability, disease resistance, yield potential and to assess the farmers' perception of the positive and negative aspects of the new crosses.

The on-farm trials were conducted at 15 sites in Zoba Anseba (5 in sub-Zoba Hagaz, 4 in sub-zoba Hamelmalo, 3 in sub-zoba Keren and 2 in sub-Zoba Elabered) and 10 sites in Gash Barka (2 sites in each of Mogollo, Gogne, Barentu, Shambiko and Agordat sub-zobas). Plot size was 50 meters square (5m x 10m) and the plots were laid side by side. Extension personnel from the Ministry of Agriculture from these sub-zobas were entrusted with the responsibility of identifying farmers and conducting the trials.

Hagaz Research site is located at an altitude of 850 m.a.s.l. with minimum and maximum temperatures of about 12 c and 42 c respectively. The average rainfall ranges from 300 – 400 mm/annum. The site has a typical arid and semi-arid climatic conditions which is conducive for pearl millet research work. During the growing period (July 1- September 10, 2002), a total of 252mm in 23 rainy days were recorded and the minimum and maximum temperature was 10 and 42 c (applied to all trials). Two hand weeding and cultivation were also done. Analysis of variance was computed using Gen-stat 5 soft ware in all the trials.

Research Objectives

- Identify the best Eritrean landraces for reselection and for use as parents in the breeding program
- Produce reselected versions of three landraces, with higher yield potential, better downy
- mildew resistance and better uniformity.
- Identify a set of adapted introduced varieties for use as parents in the breeding program
- Select crosses for making experimental varieties beginning in 2001
- Evaluate best top-cross hybrids, improved landraces, selected exotic varieties, new population crosses, new experimental varieties
- Evaluate best experimental varieties as on-station and on-farm trials
- Assure adequate stocks of breeder seed of ICMV 221 and one new promising variety (Tokroray x ICMV 221)

Six selected landraces were collected from farmers' fields in 2001 and 2 landraces from 1999. They were sown on 4m x 0.75m x 8 rows after basal application of DAP at a rate of 100 kg ha^{-2}. Thinning and transplanting were done after 2 weeks and was top-dressed using urea 3 weeks after planting at a rate of 100kg ha^{-2}. The crop was irrigated every 4-5 days till maturity and the total irrigation was 15. At heading time, selfing bags were put and pollination by hand was done within the landraces (half-sibbing). The materials used are indicated Table 9 below.

The pollinated panicles were harvested and threshed after drying. Seed of 0.5 – 1.5kg was obtained from each landraces. By half-sibbing activity, the original seed of the 8 landraces was produced. These materials were evaluated in replicated form in the rainy season of the same year.

To develop top-cross hybrids of pearl millet, two landraces of Tosho and Mebred (4m x 0.75m x 20 rows each) and 5 A-lines (sterile lines from ICRISAT) were sown on 4m x 0.75m x 5 rows each after basal application of DAP at a rate of 100 kg ha^{-2}. Thinning and transplanting were done after 2 weeks and was top-dressed using urea 3 weeks after planting at a rate of 100kg ha^{-2}. The crop was irrigated every 4-5 days till maturity and the total irrigation was 15. At heading time, selfing bags were put and pollination by hand was done between the landraces and the A-lines. The A-lines used in the crossing programme are indicated below:

ICMA 89111 x Tosho
ICMA 95333 x Tosho
ICMA 97333 x Tosho
ICMA 91222 x Tosho
ICMA 97111 x Tosho
ICMA 89111 x Mebred
ICMA 95333 x Mebred
ICMA 97333 x Mebred
ICMA 91222 x Mebred
ICMA 97111 x Mebred

Harvesting of 10 crossed panicles were done and bulk seed was made. The 10 top-cross hybrids were developed and tested for their performance in the rainy season of the same year. Seed ranging from 2-3kg was produced.

Five of the A-lines ranging from 1-5 were crossed with Tosho and Mebred. Synchronization of flowering between the A-lines and the landraces was good. From this activity, 10 topcross hybrids were developed. These topcross hybrids are half variety and half hybrid, so it is not pure hybrid. Because of this character, they have the potential to resist disease like downy mildew. Moreover, they are expected to be more productive than local landraces in most cases.

To develop new population crosses, two landraces of Tosho and Mebred (4m x 0.75m x 20 rows each) and 4 exotic varieties were sown on 4m x 0.75m x 5 rows each after basal application of DAP at a rate of 100 kg ha^{-2}. Thinning and transplanting were done after 2 weeks and was top-dressed using urea 3 weeks after planting at a rate of 100kg ha^{-2}. The crop was irrigated every 4-5 days till maturity and the total irrigation was 15. At heading time, selfing bags were put and pollination by hand was done between the landraces and the exotic materials. The exotic materials used in the crossing program are indicated below:

IAC ISC TCP 1
MC SRC
SUDAN POP 1
SOS AT C88

After controlled pollination was accomplished , the following population crosses were developed.

Tosho x IAC ISC TCP 1
Tosho x MC SRC
Tosho x SUDAN POP 1
Tosho x SOS AT C88
Mebred x IAC ISC TCP 1
Mebred x MC SRC
Mebred x SUDAN POP 1
Mebred x SOS AT C88

Table 9. Landraces used for seed increase, off-season, 2002.

Entry No.	Entry Name	Remark
1	Ashera	
2	Libana	Yellow seed
3	Jengeren	
4	Mogollo 2	High tillering
5	Bultug Megareh	
6	Hirkuk	
7	Tokroray	
8	Gudmay	

The two improved landraces were used as females and the 4 exotic varieties were used as male parents. The pollination approach to collect for example bulk pollen from the male parents and dusted on the female parents. This activity resulted in the developing 8 new population crosses. These population crosses are expected to have better panicles, resistance to downy mildew and adaptation than the parents. These will be evaluated in the rainy season of 2002 in replicated form.

Preliminary Evaluation of New Landraces

Experimental materials used were 6 with 1 variety as standard check. The experimental design used was RCBD with 3 replications. They were planted with spacing of 4m x 0.75m x 4 rows. Observations were recorded on the central 2 rows of each plots for the following characters: days to 75% flowering, plant height, plant count, head count, panicle count, panicle yield, panicle size, 100 seed weight and grain yield.

To maintain soil fertility, 100kg ha^{-2} DAP before planting and 100 kg ha^{-2} of urea were applied 3 weeks after planting. Thinning and transplanting were done 2 weeks after planting. It was cultivated once and hand weeded twice. The materials used are listed below:

Ashera
Libana
Jengeren
Mogollo 2
Megareh
Hirkuk
Kona

The analysis of variance (Table 10) for days to 75% flowering and plant height showed highly significant difference ($P < 0.001$) indicating that plants reach 75% flowering date at different times and they also differ in plant heights. However, there was no significant difference for grain yield ($P = 0.401$) and agronomic score ($P = 0.009$) between the landraces.

Comparisons between the 7 landraces were made. When days to 75% flowering is considered, the earliest variety was Kona (check) and the latest were Libana and Megareh. The landrace Mogollo 2 was also similar to Kona with respect to earliness. When the grain yield, is considered, landraces Ashera and Libana performed well and attained more than the grand mean. This will be confirmed in the rainy season of 2003.

Preliminary Evaluation of Improved Landraces

To identify productive landraces which will be used in future breeding programs.

The experimental materials used were 5 with 1 variety as standard check. The experimental design used was RCBD with 3 replications. They were planted with spacing of 4m x 0.75m x 4 rows. Observations were recorded on the central 2 rows of each plots for the following characters: days to 75% flowering, plant height, plant count, head count, panicle count, panicle yield, panicle size, 100 seed weight and grain yield.

Table 10. Result of Preliminary Yield Trial of New Landraces, Rainy Season, 2002.

Ent. No.	Entry Name	Flower Day (75%)	Plant ht (cm)	Grain yld Qt/ha	Agro score Rank	Remark
1	Ashera	52	221.3	15.1	5	***
2	Libana	55	220.0	14.4	5	***
3	Jengeren	54	220.7	13.3	6	
4	Mogollo 2	46	182.3	12.8	6	
5	Megareh	55	224.7	9.5	6	
6	Hirkuk	54	226.7	12.5	5	
7	Kona (check)	44	195.7	17.2	6	***
	Grand Mean	52	213.0	13.5	5.7	
	LSD	2.3	15.8	9.9	0.67	
	Se	0.7	7.3	3.7	0.24	
	CV (%)	1.4	4.2	27.1	4.1	
	F. Prob (5%)	***	***	NS	NS	

To maintain soil fertility, 100kg ha^{-2} DAP before planting and 100 kg ha^{-2} of urea were applied 3 weeks after planting. Thinning and transplanting were done 2 weeks after planting. It was cultivated once and hand-weeded twice. The materials used are listed below:

Mebred
Tosho
Zibedi
Tokroray
Bultug Keren
Kona (check)

The analysis of variance (Table 11) showed significant difference for all traits indicating that there was genetic influence for the respected trait.

Comparisons between the 7 genotypes were made. When days to 75% flowering is considered, the earliest varieties were Kona (check) and Tosho, and the latest was Bultug Keren. Mebred was the tallest and Kona was the shortest which is inversely related with the trait days to 75% flowering date. When the grain yield was considered, Kona (21.6 qt/ha), Tosho (21.2 qt/ha) and Mebred (17.4 qt/ha) attained more or less the same grain yield/ha. Therefore, the 3 landraces could be considered

Table 11. Result of Preliminary Yield Trial of Improved Landraces, Rainy Season,2002.

Ent. No.	Entry Name	Flower Day (75%)	Plant ht (cm)	Grain yld Qt/ha	Agro.score Rank	Remark
1	Mebred	53	227.7	17.4	6	**
2	Tosho	48	210.0	21.2	5	***
3	Zibedi	54	216.7	13.5	6	
4	Tokroray	52	192.3	10.4	7	
5	Bultug Keren	55	208.7	5.1	7	
6	Kona (check)	44	177.7	21.6	6	***
	Grand Mean	51	205.5	14.9	6	
	LSD	3.5	21.8	7.7	0.9	
	Se	0.7	6.3	3.5	0.4	
	%)					
	b (5%)					

as potential genotypes. This trial will be repeated in the rainy season of 2003 for confirmation.

Advanced Yield Trials on Exotic Pearl Millet Varieties

The experimental varieties used were 27 + 4 (checks) which were selected from the previous experiment. The experimental design used was RCBD with 3 replications. Spacing was 4m x 0.75m x 4 rows. At the time of planting basal application of DAP at a rate of 100 kg ha^{-2} was applied and after 2 weeks thinning and transplanting were done. Top-dressing at a rate of 100kg ha^{-2} urea was given 3 weeks after planting.

Observations were taken on the central two rows for days to 75% flowering, plant height, plant count, head count, head yield, ear length and grain yield. The materials used in this trial are listed below:

ICMP 95490
ICMP 97754
ICMP 98107
EERC CO
IAC ISC TCP 4
IAC ISC TCP 6
Sudan pop II
EC 89 CO x MC 88 CO
EC 89 CO x GB 8735
EC 89 CO x ICMV 90311
EC 89 CO x INIRIARI comp
MC 89 CO x AIMP 92901
MC 89 CO x RCB IC 912
AIMP 92901 x SDMV 96063
RCB IC 912 x GB 8735
RCB IC x ICMV 90311
SDMV 96051 x INIARI Comp
SDMV 96063 x SDMV 95017
SDMV 96063 x GB 8735
SDMV 96063 x GUERIARI-1
SDMV 96063 x ICMV 90311
SDMV 95017 x GUERIARI-1
SDMV 95017 x ICMV 90311
GB 8735 x GUERIARI-1
GB 8735 x ICMV 90311
GB 8735 x INIARI Comp
GUERINIARI-1 x ICMV 90311
Tokroray var.
B/keren var
Tosho var
B/mebred var

In the analysis of variance (Table 12) for days to 75% flowering day ($P < 0.001$) and grain yield ($P < 0.001$), genotypes showed highly significant difference between them indicating that genetic variation have influenced the maturity date and grain yield. Moreover, there was significant difference between genotypes for the trait plant height ($P = 0.044$).

The variety EERC CO was the earliest to flower. However, it was the shortest in plant height that resulted in less biomass and the least in agronomic performance. This variety can be used as source of early gene in the future breeding programme. Bultug Keren was the latest to mature and the least in grain yield. This landrace selected by farmers in the year 1999 but it was not performing well as compared to other landraces because it was late maturing.

When the trait grain yield was considered, the cross EC 18 CO x RCB IC 912 attained the highest grain yield. Among the landraces used as local checks, Tosho and Bultug Mebred were not inferior than exotic varieties with respect to their grain yield and agronomic performance.

The exotic varieties listed from 1-7 (except EERC CO) did not show any significant difference among them. These varieties were supposed to show better performance. This could be due to soil factor because the soil was very depleted and was easily affected by the current drought condition. This experiment will be repeated in the coming rainy season.

Seed Multiplication

Hagaz

In the previous two years' trials, the population cross Tokroray x Kona was selected as most promising population. It was planned to produce foundation seed of this variety. Two ha were sown, the selected harvesting process was done and about 500 kg of foundation seed was produced.

Shambiko

In Shambiko Research Station, the variety Kona (ICMV 221) was sown on 3 ha for foundation seed multiplication. At the end of the season, about 800 kg of foundation seed was produced.

Golij

In Golij Research Station, the population Tokroray x Kona was sown on 3 ha for foundation seed production. In spite of the bad the season, about 1,600 kg of foundation seed was produced. In addition to this, 300 panicles were selected and harvested for breeder seed multiplication.

Zoba Anseba (Hamelmalo and Hagaz sub-zobas)

In collaboration with Zoba Anseba, certified seed production of Kona variety was undertaken in Sub-Zobas Hagaz and Hamelmalo. Farmers were given contracts to produce certified seed and they were obliged to sell the seed to the Ministry of Agriculture at market price plus 25% premium price. The total hectarage was about 70 ha and the average yield was 1500 kg ha^{-1} in Sub-Zoba Hagaz and 800 kg ha^{-1} in Sub-Zoba Hamelmalo.

Table 12. Result of Advanced Yield Trial Exotic Pearl Millet Varieties, Rainy Season, 2002.

Ent. No.	Entry Name	Flower Day (75%)	Plant ht (cm)	Grain yld Qt/ha	Agro Score Rank	Remark
1	ICMP 95490	50	175.0	10.5	6	
2	ICMP 97754	48	176.0	9.5	6	
3	ICMP 98107	47	165.7	12.0	6	**
4	EERC CO	41	148.7	9.4	7	
5	IAC ISC TCP 4	49	167.0	10.5	6	
6	IAC ISC TCP6	50	185.0	10.4	6	
7	Sudan Pop II	48	175.0	10.8	6	
8	EC 89 CO x MC 88 CO	44	175.0	15.3	6	***
9	EC 89 CO x GB 8735	43	158.3	11.1	6	
10	EC 89 CO x ICMV 90311	47	176.7	11.8	6	
11	EC 89 CO x INIRIARI comp	45	161.0	11.0	6	
12	EC 88 CO x AIMP 92901	46	167.7	15.6	6	***
13	EC 88 CO x RCB IC 912	45	171.5	16.5	6	***
14	AIMP 92901 x SDMV 96063	47	170.7	14.2	6	*
15	RCB IC 912 x GB 8735	45	169.3	10.8	6	
16	RCB IC 912 x ICMV 90311	49	173.9	10.8	7	
17	SDMV 96051 x INIARI comp	45	166.0	12.5	5	
18	SDMV 96063 x SDMV 95017	47	168.5	14.9	6	*
19	SDMV 96063 x GB 8735	48	172.4	11.2	6	
20	SDMV 96063 x GUERIARI-1	48	17.3	11.0	6	
21	SDMV 96063 x ICMV 90311	51	165.9	5.0	6	
22	SDMV 95017 x GUERIARI-1	47	171.0	12.4	6	
23	SDMV 95017 x ICMV 90311	49	171.0	10.4	7	
24	GM 8735 x GUERIARI-1	47	169.0	12.5	6	
25	GB 8735 x ICMV 90311	49	183.0	11.6	6	
26	GB 8735 x INIARI Comp	45	173.3	12.2	6	
27	GUERINIARI-1 x ICMV 90311	50	175.7	8.6	7	
28	Tokroray Var	50	151.0	7.7	7	
29	B/Keren Var	64	142.0	2.0	7	
30	Tosho var	49	177.3	11.5	6	
31	B/Mebred Var	55	194.0	8.8	6	
	Grand Mean	48	171.1	11.0	6	
	LSD	3.1	22.3	4.6	1.0	
	Se	1.3	3.9	1.6	0.3	
	CV (%)	2.7	2.3	14.8	5.5	
	F. Prob (5%)	***	*	***	NS	

Table 13. On-farm Trial Results (qt/ha), Rainy Season, 2002.

ZOBA	SUB-ZOBA	SITE	VARIETIES					
			VAR.1	VAR.2	VAR.3	VAR.4	VAR.5	REMARK
Anseba	Keren	Megareh	0	0	0	0	0	no data
		Ona	11.1	11.5	17.1	13.7	13.6	
		Hashela	30.1	32.7	32.4	24	29.6	
	Habero	Fiza	0	0	0	0	0	no data
	Elabered	Omer	4.8	9.5	8	5.6	5	
		Kodi	7.3	2.5	5.7	6.4	3.4	
	Hemelmalo	Hamelmalo	15.6	15.4	12.2	16.9	12.6	
		Gizgiza	2.7	1.5	2.4	1	2.3	
		Libana	8.7	5.9	6.7	11.6	5.8	
		Beyan	20.6	22.4	22.2	18.6	16.3	
	Hagaz	Ashera	26.2	18.7	27.6	19.2	18.4	
		Glass	4	3.9	1.7	3.9	4.1	
		Badob	23.6	22.8	25.7	13	14	
		Awanjeli	2.6	2	4.3	1.5	1.8	
		Adi-Fekay	0	0	0	0	0	no data
Gash-Barka	Akordat	Engerne 1	0	0	0	0	0	no data
		Engerne 2	0	0	0	0	0	no data
	Mogollo	Mogollo 1	0	0	0	0	0	no data
		Mogollo 2	9.8	4.8	5.6	1.5	0.6	
	Barentu	Koita	11.2	15.7	17.3	7.3	21.4	
		Sosona	5.2	4.5	10.7	4.7	6	
	Gogni	Dassie	29.8	20.4	19.3	12.1	11	
		Ekunem	40.9	42.5	42.4	44.9	33.8	
	Shambiko	Asemeina	14.5	16.3	21.2	20.6	19.1	
		Binbina	1.3	1	1.5	0.8	0.9	
MEAN			14.6	13.7	15.3	12.3	11.9	

The highest yield was attained by variety 3 and followed by variety 1. The local check attained the lo west yield. In Zoba Anseba, 3 trials (from 15 trials) and in Zoba Gash Barka 3 trials (from 10 trials) failed due to uneven rainfall distribution.

Table 14. New Varieties Demonstration Results in Zoba Debub, 2002 Rainy Season.

			VARIETIES (qt/ha)						
Zoba	Sub-zoba	Site	VAR.1	VAR.2	VAR.3	VAR.4	VAR.5	VAR.6	REMARK
Debub	Adi-quala	Endagergish1	2.7	1.4	3.8	2.2	3.3	2.9	
		Endagergish2	16.7	12.4	16.2	12.4	21	11.7	
	Tsorena	Kude Anak	4.1	3	2.5	3.3	6.3	2.9	
MEAN			7.8	5.6	7.5	6.0	10.2	5.8	

On-Farm Trial

The on-farm trials were conducted at 15 sites in Zoba Anseba (5 in sub-zoba Hagaz, 4 in sub-zoba Hamelmalo, 3 in sub-zoba Keren and 2 in sub-Zoba Elabered) and 10 sites in Gash Barka (2 sites in each of Mogollo, Gogne, Barentu, Shambiko and Agordat sub-zobas). Moreover, on-farm demonstration was also conducted in Zoba Debub (2 in Sub-Zoba Adiquala and 1 in Sub-Zoba Tsorona).

- To test the new varieties in different agro-ecological zones.
- To demonstrate new pearl millet varieties in Zoba Debeb.

The experimental materials for Zoba Anseba and Gash Barka were 4 + 1 local check and for Zoba Debub were 6. Plot size was 50 meters square (5m x 10m) and the plots were laid side by side. Extension personnel from the Ministry of Agriculture from these sub-zobas were entrusted with the responsibility of identifying farmers and conducting the trials. General observation on disease prevalence and maturity date was taken visually and grain yield was estimated.

The highest yield was attained by variety 3 and followed by variety 1. The local check attained the lowest yield. In Zoba Anseba, 3 trials (from 15 trials) and in Zoba Gash Barka 3 trials (from 10 trials) failed due to uneven rainfall distribution.

Due to uneven rainfall distribution, some crop failure was observed (Table 13). Though variety 1 was second in grain yield, it has best agronomic performance specifically for maturity date. This is an important trait that can help the plant escape drought. During field day, farmers proposed this variety as the best and acceptable one with respect to its overall agronomic performance. The research team and some extension workers also agree to this proposal.

As indicated in the above Table 14, variety 5 (Kona) attained the highest yield and variety 2 was the least. Kona variety was the earliest to mature and escaped the prevailing drought. The drought observed affected most crops. However, pearl millet tolerated the drought and attained reasonable grain yield.

During the field day held in farm Endagergis 2, KONA was selected as the best of the 6 varieties. Therefore, it has been agreed to introduce this variety for the coming rainy season, 2003.

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

Gary C. Peterson
Texas A&M University

Coordinators

Dr. Medson Chisi, SMIP Steering Committee Member and Sorghum Breeder, Ministry of Agriculture, Crops and Soils Research, Golden Valley Research Trust, Chilanga, Zambia

Dr. Gary C. Peterson, INTSORMIL Coordinator for SADC Region and Sorghum Breeder, Texas A&M University Ag Research and Extension Center, Rt. 3, Box 219, Lubbock, TX

Collaborators

Mr. S.A. Ipinge, Pearl Millet Breeder, Ministry of Agriculture, Water and Rural Development, Tsumeb, Namibia

Mr. F. Muuka, Pearl Millet Breeder, Ministry of Agriculture, Kaoma Research Station, P.O. Box 940084, Kaoma, Zambia

Mr. M. Mogorosi, Pearl Millet Breeder, Principal Agricultural Research Officer, Ministry of Agriculture, Maun, Botswana

Dr. J. Wilson, Pearl Millet Breeder, USDA-ARS, P.O. Box 748, Tifton, GA

Mr. G. M. Kaula, Plant Pathologist, PB 7, Mt. Makulu Research Station, Chilanga, Zambia

Ms. P. Ditshipi, Plant Pathologist, Dept of Agricultural Research, Private Bag 0033, Gaborone, Botswana

Ms. E. Mtisi, Plant Pathologist, Plant Protection Research Institute, RSS Box 8108 Causeway, Harare, Zimbabwe

Dr. N. McLaren, Plant Pathologist, ARC-Grain Crops Institute, Private Bag X1251, Potchefstroom 2520, South Africa

Dr. W. Marasas, Pathologist, Program on Mycotoxins & Experimental Carcinogenesis, Medical Research Council, P.O. Box 19070, Tygerberg 7505, South Africa

Dr. J. Leslie, Plant Pathologist, Dept of Plant Pathology, Kansas State University, 4002 Throckmorton Plant Sciences Center, Manhattan, KS

Dr. J. Taylor, Cereal Quality, Department of Food Science, University of Pretoria, Pretoria 0002, South Africa

Dr. Janice Dewars, Research Scientist, CSIR, Pretoria, South Africa

Dr. L. Rooney, Cereal Quality, Dept of Soil and Crop Sciences, Texas A&M University, College Station, TX

Dr. H. Du Plessis, Entomologist, ARC-Grain Crops Institute, PB X1251, Potchefstroom 2520, South Africa

Dr. J. van den Berg, Entomologist, School of Environmental Sciences, Potchefstroom University, PB X6001, Potchefstroom 2520 South Africa

Dr. David Munthali, Entomology, Botswana College of Agriculture, PB 0027, Gaborone, Botswana

Dr. Bonnie B. Pendleton, Entomologist, Division of Agriculture, West Texas A&M University, Canyon, TX

Mr. Stephen Chite, Sorghum Breeder, Dept of Agricultural Research, Private Bag 0033, Gaborone, Botswana

Mr. L. Mpofu, Sorghum Breeder, Dept of Research & Specialist Service, Matopos Research Station, P.O. K5137, Bulawayo, Zimbabwe

Dr. W. Rooney, Sorghum Breeder, Dept of Soil & Crop Sciences, Texas A&M University, College Station, TX

Dr. Darrell Rosenow, Sorghum Breeder, Texas A&M University Ag Research and Extension Center, Rt. 3, Box 219, Lubbock, TX

Collaborative Program

Organization, Management, Implementation and Financial Inputs

The INTSORMIL Southern Africa regional program involves five projects:

Pearl Millet Breeding: Development of pearl millet cultivars for dryland production, commercialization and industrial development in Southern Africa

Pathology: Disease management research, identification and use of resistance

Food Quality: Food Quality

Entomology: Genetic resistance to sugarcane aphid and integrated pest management in Botswana and South Africa

Sorghum Breeding: Development of improved sorghum varieties and hybrids for Southern Africa

Through a Memorandum of Agreement with SADC/ ICRISAT/SMIP the regional program is fully integrated with regionally planned sorghum and pearl millet research. This allows INTSORMIL funds to be disbursed to 14 collaborating NARS scientists in 5 countries. The scientists represent 9 research agencies. The SMINET regional coordinator at the ICRISAT SMIP Center at Matopos, Zimbabwe is also involved. Activities in each project are planned annually in conjunction with NARS collaborators and the Work Plans are reviewed at the SMIP Technololgy Transfer Program (SMINET) Steering Committee Meeting to ensure they continue to fit in the profile of work needed for 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 SMINET at Matopos, Zimbabwe to ensure complementarity with existing regional sorghum and pearl millet programs. Pearl millet breeding is conducted with the Ministry of Agriculture, Water and Rural Development, Tsumeb, Namibia; the Ministry of Agriculture, Botswana; and the Ministry of Agriculture, Kaoma Research Station, Kaoma, Zambia. Plant pathology research is with the Agriculture Research Corporation (ARC) Summer Grain Crops Institute, Potchefstroom, South Africa (SA); Crops and Soil Research, Mt. Makulu Research Station, Chilanga, Zambia; Department of Agricultural Research, Gaborone, Botswana. and the Medical Research Council, Tygerberg, SA. Grain quality research is located in South Africa with the University of Pretoria and the ARC. The CSIR has strong interactions with the private sector in the region which will assist in transfer of information to help private entrepreneurs. Entomology research is with the ARC Summer Grains Crop Institute, Potchefstroom, SA and the Botswana College of Agriculture, Gaborone, Botswana. Sorghum breeding is conducted with the Golden Valley Research Trust, Zambia, and the Botswana Department of Agricultural Research. Activity in Zimbabwe with the Department of Research and Special Services and the Plant Protection Research Institute is restricted to evaluation is nurseries sent to the country.

The Planning Process

Research projects in breeding, pathology, entomology, and food quality are based on on-going linkages. 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 activity will continue to be developed as part of SMINET to ensure full integration with other regional sorghum and pearl millet research and development projects. Phase IV (initiated October, 1999) of the SMIP program to ICRISAT/ Matopos focuses entirely on technology transfer. Since ICRISAT has no core funded scientists in the SADC region, INTSORMIL's participation in regional crops research is regarded as essential by SMINET and collaborating countries. With the formal end of SMIP activities in December 2003 INTSORMIL will need to provide additional leadership to regional sorghum and pearl millet research and technology transfer. INTSORMIL will collaborate with any ICRISAT regional activity as appropriate and mutually beneficial, and will continue to develop linkages with other agencies and organizations to strengthen regional research and technology transfer.

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 structures. Genetic improvement and better disease or insect management 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 need to be improved since sorghum varieties with the required quality to meet commercial consumer requirements frequently have inconsistent production. 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 preservation for production, marketing, and processing.

New varieties and hybrids with increased grain yield potential, improved environmental adaptation, increased resistance to abiotic (drought tolerance) or biotic (disease and insect) stress, improved end-use traits, and other desirable traits are in development by national programs. Exotic sorghums and pearl millets are continually introduced into the SADC region as sources of needed traits. Identification of regionally adapted sorghum or pearl millet cultivars or hybrids with stable grain yield and multiple stress resistance will assist the NARS teams in developing lines, varieties, and hybrids for the diverse environments and production systems in each country and in similar SADC environments.

Constraints Addressed by Project Objectives

Pearl Millet Breeding: Develop topcross grain and forage hybrids adapted to low rainfall regimes in Southern Africa suitable for commercialization and stimulating industrial development, test prototype cultivars in commercial and industrial ventures, develop appropriate populations for sustaining the program. Important traits are yield, early maturity, and grain size.

Pathology: Identify adapted, agronomically desirable sources of resistance to major foliar pathogens and charcoal rot, including drought tolerance and resistance to sugarcane aphid where feasible. Determine vulnerability in recently released sorghums and the need for better sources of resistance. Determine mycotoxin production capabilities of new *Fusarium* species, and the presence of *Fusarium* mycotoxins in grain-molded grain.

Food Quality: Determine the physical, chemical and processing properties of local and improved sorghum and millets. Improve the quality of food products by modification of processes to reduce or eliminate anti-nutritional components. Summarize existing information on quality and utilization and transfer the information on utilization quality to potential users.

Entomology: Reduce yield losses by identifying, evaluating, and incorporating sugarcane aphid resistance into sorghum varieties and hybrids adapted to Southern African agricultural systems. Assess the response of sorghum varieties and segregating populations to other insect pests as appropriate. Develop integrated pest management strategies for sorghum insect pests in Southern Africa.

Sorghum Breeding: Develop high grain yield sorghum varieties and hybrids with improved quality traits for food, forage and feed and adaptation to drought prone areas in Zambia and Botswana. Enhance disease and pest resistance with improved germplasm or elite lines. Assist with seed production and distribution systems at a community level.

Research Progress

The Southern Africa regional research program composed of the five projects previously listed is directed to a goal of developing the technology for increased production and use of sorghum and pearl millet. Component projects conduct research which is specific to the project goals but has implications to research in other disciplines. Projects interact in development of new technology and the interaction is increasing as additional opportunities and funding becomes available. Collaboration currently exists between breeding and plant protection (pathology and entomology) and between food quality and breeding. New collaboration encompassing all projects to examine the potential for white seed, tan plant hybrids was established during this year. Results will be reported in the next Annual Report.

Tests and nurseries from the U.S. are distributed each year to collaborating programs tests and nurseries based on request. Multi-location evaluation of identical test and nurseries establishes the base-line data for performance response of introduced germplasm throughout the region. New useful germplasm suitable for direct use or use as parental lines in a breeding program are identified. Disease pathogen and insect pest distribution can be established as well as identification of resistance sources. Regional research is conducted under rain-fed conditions with little if any supplemental irrigation. Thus reporting of results in frequently contingent on timely and sufficient rainfall to produce the environment necessary for evaluation and conclusions based on the data collected.

Research reported is divided into the component research projects. Where tests or nurseries have been evaluated in separate location data is discussed by location and listed in common table.

Pearl Millet Breeding

In Zambia, research continued on the development of hybrids, backcrossing and collaborative testing of population hybrids. Activities included testing replicated trials, production and evaluation of hybrids, formation of the fourth backcrosses of A4, and maintenance of A- and B-lines. Research was conducted at the Longe TAS. In the hybrid development program one hundred sixty eight (168) experimental pearl millet hybrids formed in 2001 from exotic seed parents (A_1, A_4, A_5 cytoplasmic male steriles, inbred and maintainer lines, and open pollinated varieties) with nine Zambia genotypes as pollinators were evaluated. The hybrids exhibited a substantial range for grain yield (0.1925 - 1.8075 kg ha^{-1}) and within the test produced an overall mean a mean of 0.9586 kg ha^{-1}. One hundred six hybrids produced more grain yield than their corresponding pollinator parents. Increased height and susceptibility to ergot (*Claviceps fusiformis* Lov.) was observed in some hybrids. In the backcrossing program forty-five BC3's backcrosses made in 2001 were evaluated with their corresponding recurrent parents. Thirty-five backcrosses were superior in grain yield to their corresponding recurrent parents. The results contrast when compared with results from the second backcross when only a few hybrids exhibited heterosis.

In Namibia, research continued for three major objectives: development of top-cross hybrids by breeding A4 restorer versions of the best Namibian varieties for use with the selected A4 seed parents, development and testing of prototype hybrids using SMIP A4 seed parents, and identification of the best A4F1 male sterile seed parents. Research in the 2002-03 growing season was hindered by the drought conditions. Previous research has resulted in the development of early maturing varieties which increased the national grain yield average from 200 kg ha^{-1} to 400 kg ha^{-1}. Wide-spread adoption of hybrids should contribute to higher yields. Introductions, primarily from SADC/ICRISAT SMIP and the University of Nebraska, are used in the hybrid breeding program using the Maria Kaherero Composite (MKC) to produce A4 and R4 seed parents. The A4 and R4 genes have been incorporated into MKC and are used as sources from which to transfer useful genes. During the 2002/03 growing season 40 crosses were made to produce hybrids for evaluation in the 2003/04 cropping season. Research to identify a prolific F1 female parent continued. New hybrid

Table 1. Evaluation of the 2002 All Disease and Insect Nursery (ADIN) for disease reaction and selected traits at Mt. Makulu (Zambia), Panmure and Henderson (Zimbabwe), and Cedara (South Africa), 2002-2003.

	Mt. Makulu			Panmure			Henderson		Cedara			
Designation	Zonate†	Leaf spot†	Anthracnose†	Anthracnose†	Days to 50% anthesis	Desirability‡	Days to 50% anthesis	Leaf Blight†	Lodging %	Leaf Blight†	Grain Mold†	Desirability‡
(87EO366*90EO328)-HF6-ED1-	1.0	2.0	3									
97BRON179	1.0	1.0	3.0	1.5	71	2.5			0	3	3	2
BTx623	1.0	1.5	1.0						34.2	4	3.5	1.5
86EO361	1.0	1.0	2.5	1	72	1			2.8	0.5	0.5	4
Tx2911	1.0	1.0	2.0						0	2.5	2.5	3.5
B.DL6(wxy)	1.0	2.0	1.0	1	71	1.5			0	2.5	3	2
Tx436	1.0	1.5	1.0	1	74	2.5			0	0	2.5	4
90GCPOBS143	1.0	1.0	1.0	1	91	3	76	1.5	0	0	0	4.5
BTx2924	1.0	2.0	1.0	1.5	73	2			0	4	1	2.5
GR108-90M24	1.5	1.0	1.0	1.5	178	1			0	3.5	4	2
Tx430	2.0	1.0	1.0	1	71	1.5	75	1.5	0	0.5	2	4
SC326-6	1.0	1.0	1.0	1	89	3.5	84	1	9.3	0.5	4	3.5
96CD635	1.0	1.5	1.0						11.7	2.5	3	4
00CA4654	1.0	1.0	1.5	1	78	1			14.9	3	3	4
B8PR1013	1.0	2.5	1.0	1.5	72	2			6.3	4	4	2.5
91BE7414	1.0	2.0	1.5				73	1.5	0	0.5	3	5
BTx635	1.0	1.0	1	1.5	74	2	78	1:5	0	2.5	3.5	4
LG70	1.5	1.0	1.0	1	71	1			3.5	4	2	2
Tegemeo	1.0	1.0	1.0	1	78	2.5			7.2	3.5	0.5	2
90EON343	1.0	1.0	1.5						0	2.5	0	3
BTx378	1.0	1.0	1.5	1	71	2.5	76	1.5	0	0	3.5	2.5
BTx2923	1.0	1.5	1.0	1	72	2.5			0	3	3.5	2
B8PR1051	1.0	1.0	1.0	1	74	2			0	0	1	3
Tx2783	1.0	2.5	1.0	1	79	3			0	3	2	3.5
SC630-11E(II)	1.0	2.5	1.0	1.5	70	2	81	1	8.6	0	1	2
B.HF14	1.0	1.0	1.0	1.5	70	1			0	0.5	3	5
SC414-12E	1.0	1.0	1.0	1	69	1.5			0	0	3	3.5
MB108B	1.0	1.0	1	1.5	78	2			2	0.5	4	3.5
BTx2925	1.0	1.0	1.0	1.5	76	3			0	0	1	3.5
RTx2918	1.0	1.0	1.5	1	69	1.5	72	1	0	0	2	4
01BD4487	1.0	3.5	1.0	1	92	3			0	0	1	4.5
LG35	1.0	1.0	1.0	1.5	78	2	71	1.5	0	0	0	2
Sureno	1.0	2.0	1.0	1	78	2	72	1.5	14.1	0	0	2
88BE2668	1.0	3.5	1.0	1	76	1			0	0.5	2	2
9BRON125	1.0	1.0	1.0	1	76	3	73	1.5	0	0	1.5	3

genetics along with improved management practices is critical to increasing yield.

In Botswana, local land-races have poor yield (about 200 kg ha^{-1}) and late maturity. A regional pearl-millet variety yield trial consisting of thirty-six varieties was conducted at Francistown (Northeast Botswana) and Matsaudi (Northwest Botswana). The trial at Matsaudi failed due to destruction by elephants. At Francistown rainfall was significantly below normal, very erratic, and very late. Grain yield ranged from 39 kg $ha^{-1}$to 963 kg ha^{-1}. The farmers local check averaged 195 kg ha^{-1}. The top three varieties - SDMV-89007 (963 kg ha^{-1}), PMV-2 (679 kg ha^{-1}), and PMV-3 (660kg ha^{-1}) - have been previously released in Botswana and Zimbabwe. Results of the study indicate there is a need to develop early maturity drought tolerant varieties and to gradually introduce hybrids in order to improve grain yields.

Pathology

Research on diseases affecting sorghum and pearl millet is conducted throughout Southern Africa. The pathology program has active research programs in Zambia, Botswana, and South Africa. Nurseries are available to a collaborator in Zimbabwe. Field pathology research is supported by Texas A&M University through planting standard replicated nurseries or tests such as the ADIN (All Disease and Insect Nursery), GWT (Grain Weathering Test), and the ARGN (Anthracnose Resistance

Table 1. (Continued) Evaluation of the 2002 All Disease and Insect Nursery (ADIN) for disease reaction and selected traits at Mt. Makulu (Zambia), Panmure and Henderson (Zimbabwe), and Cedara (South Africa), 2002-2003.

98BRON122	1.0	2.5	1.0	1	72	1.5	75	1.5	0	0	2	3
Tx2880	1.0	4.0	1.0						0	3	4	2
96CD677	1.0	1.0	2.0						0	1.5	2.5	3
96GCP124	1.0	3.0	1.0	1	78	3			0	1.5	1	2
RTx2914	1.0	4.0	1.0						0	2	0.5	2
92BD1982-4	1.0	1.5	1.0	1	90	2.5			0	2.5	0.5	4
Tx7078	1.0	2.5	1.0	1	69	3.5			0	0.5	3	2.5
96GCP0BS172	1.0	1.0	5.0						6	4	0	4
R.9529	1.0	1.5	2.5	1.5	70	2			11.3	1.5	4	2
RTx2917	1.0	3.5	1.0	1	71	3.5			0	0	0	4
95BRON155	1.0	2.0	1.0	1	76	1.5	74	1.5	0	0.5	4	4
SRN39	1.0	1.0	3.5	1	73	2			0	0.5	3	3
BTx642	1.0	3.0	1.0	1	70	3			0	1	4.5	4
99GWO92	1.0	2.0	1.0	1	78	1.5			21.1	2.5	1.5	3
96GCPOB160	1.0	2.0	1.0	1	71	2			0	0	2	2
BTx2928/B9311	1.0	4.0	1.0						0	0.5	4	2
RTx2919/R.9603	1.0	2.0	1.0	1.5	70	2.5			0	0	3.5	4
TAM428	1.0	2.0	1.0	1	76	1	84	1	0	0.5	4.5	2
90EON328	1.0	1.0	1.0	1.5	76	1			16.4	0	0.5	3
Malisor 84-7	1.0	1.0	1.0	1	74	2			2.4	0	1.5	2
B8PR1059	1.0	1.0	1.0	1	70	1.5			0	0	2	4
B8PR1045	2.0	1.0	1.0	1	79	1.5			8.8	0	3	2
RTx2912	1.0	1.0	1.0	1	87	1			0	0.5	4	5
RTx2916	1.0	1.5	3.5	1	84	2.5			0	0.5	2	2
BTx631	1.0	1.0	1.0	1	90	3.5			0	1.5	4	4

† Rated on a scale of 1 = no disease present to 5 = plant death.
‡ Rated on a scale of 1 = most desirable to 5 = least desirable.

Germplasm Nursery). The replicated tests are usually planted at more than one location and data compiled to study germplasm environmental response and pathogen distribution. Fusarium research is conducted South Africa Medical Research Council and collaborates with Kansas State University.

The ADIN was planted at Mt. Makulu (Zambia), Cedara and Potchefstroom (South Africa), and Panmure and Henderson (Zimbabwe). The nursery was also planted at Sebele (Botswana) but failed due to drought. Reaction was recorded for anthracnose (caused by *Colletotrichum sublineloum*) at Mt. Makulu and Panmure, leaf spot (*Cercospora*) and zonate (*Gloeocercospora*) at Mt. Makulu, leaf blight (*Exserohilum turcicum*) at Henderson, Zimbabwe and Cedara, South Africa, and grain mold (*Fusarium* and *Curvularia*) at Cedara. In South Africa, dry and hot conditions throughout the local sorghum production areas and at trial sites caused disease severities to not be sufficiently high for reliable evaluation of germplasm, particularly for resistance to ergot. Ergot evaluation in new cultivar releases and the National Cultivar Trial is essential to ensure that no cold sensitive genotypes and hence cultivars that may become predisposed to cold induced sterility, are released into the commercial market. The current poor season of evaluation therefore has significant repercussions for the local seed industry and the release of new commercial hybrids.

Results of the ADIN disease evaluations are shown in Table 1. At Henderson disease development was slow early in the growing season with leaf blight the major disease problem. Diseases appearing in low incidence were ladder spot (caused by *Cercospora fusimaculans*), downy mildew (caused by *Peronosclerospora sorghi*) and ergot (caused by *Claviceps africana*). Three disease ratings (at 60, 84 (anthesis), and 105 (soft dough) after planting) were recorded. At Panmure the onset of disease was late and the rate of development was slow. Only two ratings were recorded at 74 (anthesis) and 98 (soft dough) days after planting. Unlike previous years, anthracnose was the major disease followed by leaf blight although disease levels were low. In the ADIN, 49 of 60 entries appeared to tolerant to anthracnose. However, this may be due to the low level of anthracnose present. Only three lines: 98CD187 (rated at 3), Tx2911 (4.5), and 96GCPOB172 (3.5) exhibited susceptibility. Eight lines were rated an average of 2. There was good correspondence between anthracnose ratings recorded at Mt. Makulu and Panmure. Leaf blight scores at Panmure were low with most lines (52 of 60) expressing no or very little disease with a rating of 1 to 1.5. Six lines scored a rating of 2. Fifteen lines expressed good tolerance to both leaf blight and anthracnose. In the ADIN 15 lines were identified with tolerance to leaf blight. At Mt. Makulu, major pathogens present were those that cause anthracnose, zonate and leaf spots. Leaf

Table 2. Evaluation of the 2002 Anthracnose Resistance Germplasm Nursery (ARGN) of Disease Reaction and other selection traits at Mansa, Zambia and Henderson, Zimbabwe, 2003-2003.

	Mansa				Henderson	
Designation	Zonate†	Anthracnose†	Sooty Stripe†	Desirability‡	Days to 50% Anthesis§	Leaf Blight†
86EON 361	1.5	2.0	3.0	2.5		
86EON 362	1.5	1.5	3.5	2.5	75	1.5
86EON374	2.0	1.5	2.5	4.0	73	1
82BOM499	3.5	1.0	1.5	4.0		
86EON 361sel/87BH8341	1.5	2.0	3.5	2.5		
86EON362sel/87L3570	1.5	1.5	3.5	2.5	74	1
IS 3574C/SC239	2.5	1.0	2.0	4.0		
IS3462C/SC701	4.0	1.0	2.0	4.0	65	1
R6956	2.5	1.0	2.0	4.0	69	1
Sureno	1.5	3.0	1.5	2.0	72	1.5
TAM 428	1.5	4.0	2.5	3.5		
BTx378	3.0	1.0	1.5	4.5	73	1.5
IS 12637C/SC146	1.5	1.0	2.5	2.5	74	1
SC326-6	2.5	1.0	2.0	2.5	75	1
IS2508C/SC414	3.0	1.0	1.0	3.5		
IS3552der/SC748-5	2.5	1.0	2.0	4.0	72	1.5
91CC371	2.5	1.0	2.5	3.5	71	1
91CC673	2.5	1.5	1.5	4.0	67	1
90C356	2.0	1.0	3.0	3.0	80	1
91CC362	1.5	1.0	3.0	4.0	85	1.5
86EON361sel/87BH8351	2.0	2.0	2.5	2.5	72	1.5
86EON362sel/87L3452	2.0	1.0	3.5	1.5	74	1
R8509	2.0	1.0	3.0	3.0		
R8601	3.0	3.0	4.0	4.5		
RTx430	4.0	4.0	3.5	4.5	83	1
87EON109/RTx2912	2.0	1.5	2.5	3.5	77	1
SRN39	3.0	1.0	2.0	2.5		
B8610	1.5	2.0	2.5	3.0		
BTx638	1.5	1.0	3.5	2.0		
BTx631	2.5	2.5	2.5	2.5		
R8511	2.0	1.0	2.0	4.0	81	1.5
R9603/RTx2912	1.5	1.5	3.5	3.0	85	1
91B2978	2.0	1.0	3.0	3.0	79	1
R9019	2.5	3.5	2.0	3.5		
R9120/BTx2917	3.5	3.0	3.5	4.0	75	1.5
R9317/RTx2918	2.0	1.5	3.0	4.0		
R9204	2.5	2.5	2.0	3.5		
RTx2907	2.5	1.5	2.0	3.5		
88B928	3.0	4.5	3.5	4.5		
R9519	2	4.0	2.0	2.5		
R9618	2.0	3.0	3.0	4.0	74	1.5
Macia	2.0	3.5	2.0	3.0		

† Rated on a scale of 1 = no damage to 5 = plant death.
‡ Rated on a scale of 1 = most desirable to 5 = least desirable.
§ Days from planting to when panicles are in 50% bloom.

spot was the most damaging disease and more prevalent that either anthracnose or zonate. In South Africa, 19 remained free of leaf blight (Exserohilum turcicum) while 34 entries had ratings of less than 1 on a 1-5 scale. Eleven entries, of which six were brown/red seeded, had grain mold ratings of less than 1.

The Anthracnose Resistance Germplasm Nursery (ARGN) was planted at Mansa, Zambia and Henderson, Zimbabwe (Table 2). Mansa generally has a high level of disease caused by anthracnose and incidence of the disease was higher when compared to other seasons. Significant differences between entries were identified with the lines 90C356, 99CC362, SRN 39, R8511,BTx638 and SC326-6 exhibiting good resistance to anthracnose. Disease caused by sooty stripe (caused by *Ramulispora sorghi*) and zonate (caused by *Gloeocercospora sorghi*) were observed at a higher level of severity than anthracnose. The agronomic desirability rating indicate poor adaptation of most lines to the location conditions. Additionally, most materials matured very early and were affected by grain molds

Table 3. Evaluation of the 2002 Southern African Breeding Nursery (SABN) for disease resistance and adaptation at Cedara, South Africa and for sugarcane aphid resistance at Potchefstroom, South Africa, 2002-2003.

Designation	Lodging -%-	Grain mold†	Leaf blight‡	Desirability§	Sugarcane Aphid Damage¶
Macia	28.6	1.5	1.5	2.0	1.0
CE151-262-A1	42.4	1.5	2.0	0.0	
TAM428	27.0	4.0	2.0	0.0	
(Macia*TAM428)-LL3-CA3-BE1-CA3	62.3	4.5	3.0	0.0	
(Macia*TAM428)-LL12	76.2	4.0	3.0	0.0	4.0
(90E0328*CE151)-BD39	0.0	3.0	2.5	3.0	
((TAM428*SV1)*CE151)-LA3	35.0	2.0	1.0	1.0	
(CE151*Macia)-LD3	0.0	4.0	1.5	3.0	
(CE151*Macia)-LD5-BE4	0.0	2.0	2.0	2.0	4.0
(CE151*Macia)-LD14	3.0	4.0	4.0	2.0	
(CE151*Macia)-LD5-BE1	0.0	3.5	2.0	2.0	3.5
(CE151*MP531)-LD11	11.2	1.0	2.5	2.0	3.5
(CE151*Macia)-BE22	5.7	3.0	1.0	2.0	4.0
(87E0366*TAM428)-HF2	0.0	4.0	2.5	2.0	1.0
((TAM428*SV1)*CE151)-LA2	0.0	2.0	3.5	3.0	4.0
(90E0328*CE151)-LA36	0.0	2.0	2.5	5.0	
(90E0328*CE151)-LA49	0.0	1.5	4.0	3.0	
(90E0328*CE151)-LD11-BD4	0.0	3.5	1.0	3.0	1.5
(90E0328*CE151)-LD11-BD6	0.0	2.0	4.0	2.0	
(90E0328*CE151)-LD13	0.0	3.0	0.5	2.0	2.5
(CE151*MP531)-LD42	0.0	1.0	1.5	2.0	
(CE151*Macia)-BE14	0.0	1.0	4.0	2.0	
(CE151*Macia)-BE21	0.0	2.0	3.0	3.5	1.5
(CE151*MP531)-LD42	0.0	2.5	3.5	4.0	1.0
RCV (El Salvador Variety)	0.0	1.5	2.5	3.0	
Pinolero 1 (Nicaragua Variety)	0.0	2.0	3.5	2.0	1.0
INTA F5 108 (TorYPin.1) (Nicaragua)	24.8	2.5	0.5	4.0	
(87E0366*TAM428)-HF4	0.0	3.0	0.5	1.0	3.0
(87E0366*TAM428)-HF15	0.0	3.0	0.0	2.0	3.0
(TAM428*SV1)-HD40	0.0	2.5	1.0	3.0	
(Macia*TAM428)-LL7	3.6	0.5	1.0	4.0	
(Macia*TAM428)-LL9	9.1	2.0	1.0	3.0	
(Macia*TAM428)-LL3-CA3-BE1-CA5	18.5	4.0	2.0	2.0	
(Macia*TAM428)-LL14	5.0	3.0	2.0	0.5	1.5
(CE151*MP531)-LD47	14.9	0.5	1.5	3.0	
(CE151*MP531)-LD27	38.6	2.5	1.0	4.0	3.0
(90E0328*CE151)-LD6	42.1	2.5	1.0	0.0	4.0
(90E0328*CE151)-LD11-BD4	16.3	1.0	0.5	1.5	
(90E0328*CE151)-LA37	8.2	4.0	1.5	1.0	3.5
(Sureno*CE151)-BE25-BE3	77.7	3.0	3.5	1.0	
((87E0366*WSV387)-HD19*CE151)-BD15	0.4	1.5	4.0	3.0	4.0
((87EO366*WSV387)-HD19*CE151)-BD18	0.0	2.0	4.0	3.0	4.0
Macia	21.3	2.0	2.0	3.5	
(87E0366*TAM428)-HF4	39.1	1.0	1.0	4.0	
(CE151*MP531)-LD27	0.0	1.5	2.0	1.0	
(Macia*TAM428)-LL9	9.8	3.0	3.5	2.5	1.0
(CE151*Macia)-BE14	14.8	3.5	2.0	2.0	4.0
(Macia*TAM428)-LL12	31.4	3.0	2.0	1.5	
Macia	38.4	2.0	1.5	0.0	3.0
(90E0328*CE151)-LD11-BD4	22.6	2.0	1.0	0.0	
(90E0328*CE151)-LD11-BD4	43.9	3.0	2.5	2.0	

due to the rains. At Henderson, 23 lines were identified with tolerance to leaf blight with a rating of 1 or 1.5.

The Southern Africa Breeding Nursery (SABN) was planted at Cedara and Potchefstroom for general disease screening and adaptation to local conditions (Table 3). Three entries remained free of leaf blight (*Exserohilum turcicum),* while 17 entries respectively had ratings of less than 1 on a 1-5 scale. Most entries were highly susceptible to grain molds and only 2 had ratings less than 1. Root rot was also severe with the incidence of root lodging exceeding 70 % in some entries. Although rust, anthracnose and ergot occurred on some entries, disease severities were not sufficient for conclusive evaluations.

Table 3 (continued). Evaluation of the 2002 Southern African Breeding Nursery (SABN) for disease resistance and adaptation at Cedara, South Africa and for sugarcane aphid resistance at Potchefstroom, South Africa, 2002-2003.

(CE151*Macia)-LD5-BE1	0.0	3.0	0.5	2.5	
(Macia*TAM428)-LL3-CA3-BE1-CA3	0.0	4.0	2.0	2.0	3.5
(CE151*MP531)-LD42	6.8	3.0	3.0	2.0	2.0
(Macia*TAM428)-LL3-CA3-BEI-CAS	9.1	4.0	4.0	2.5	
(90E0328*CE151)-LAA37	44.2	1.0	2.5	2.0	
87E0366*TAM428)-HF15	72.6	2.0	2.0	3.0	
(90E0328*CE151)-LD11-BD6	93.4	3.0	2.0	2.0	4.0
(CE751*Macia)-LD5-BE4	43.8	3.0	2.0	1.5	
TAM428	19.7	2.0	2.0	2.0	1.5
(Macia*TAM428)-LL14	0.0	4.0	0.0	2.0	
(Sureno*CE151)-BE25-BE3	0.0	4.0	2.0	2.0	3.0
(TAM428*SV1)-HD40	0.0	3.0	1.5	2.0	1.0
(90E0328*CE151)-LA49	0.0	4.0	1.5	2.0	3.0
(CE151"MP531)-LD71	26.3	4.0	2.0	2.0	
((TAM428*SV1)*CE151)-LA3	0.0	2.5	1.5	2.0	2.5
CE751-262-A1	0.0	3.0	0.5	2.0	
((TAM428*SV7)*CE151)-LA2	0.0	1.0	1.0	3.0	
RCV (El Salvador Variety)	0.0	2.5	1.0	3.0	2.5
(90E0328*CE151)-LD6	0.0	3.5	1.5	3.5	
INTA F5 108 (Tort*Pin.1) (Nicaragua)	29.8	1.5	0.0	4.0	2.0
(Macia*TAM428)-LL7	0.0	2.0	0.5	1.5	1.0
(90E0328*CE151)-LA36	4.7	2.5	0.5	1.0	3.0
(CE151*Macia)-LD14	81.1	4.0	3.5	2.0	2.5
(90E0328*CE151)-BD39	0.0	4.0	2.5	3.0	1.5
Pinolero 1 (Nicaragua Variety)	0.0	2.0	1.0	2.0	
(CE151*MP531)-LD47	29.5	3.5	1.0	2.5	2.5
(CE151*Macia)-BE21	26.5	3.5	0.5	3.0	
(87E0358*TAM428)-HF2	19.3	3.0	1.5	2.0	
Macia	0.0	3.0	1.0	3.0	
(90E0328*CE151)-LD13	37.7	4.0	1.5	2.0	
(CE151*Macia)-LD3	0.0	3.0	1.5	2.5	
((87E0366*WSV387)-HD79*CE151)-BD75	0.0	4.0	0.5	3.0	
(CE151*MP531)-LD42	0.0	3.0	0.5	3.0	
((87E0386*WSV387)-HD19*CE751)-BD18	39.2	3.5	1.0	2.0	
(CE151*Macia)-BE22	29.2	2.0	0.5	3.0	

† Rated on a scale of 1 = no grain mold present to 5 = 100% of grain infected with grain mold.
‡ Rated on a scale of 1 = no disease present to 5 = plant death.
§ Rated on a scale of 1 = most desirable to 5 = least desirable.
¶ Rated on a scale of 1 = no aphids present on plants, 2 = light infestation with aphids present on a few leaves (no dead leaves), 3 = moderate infestation with many aphids present on two to three leaves (one or two dead leaves may be present), 4 = high infestation with many aphids on nearly all leaves (many dead leaves) and 5 = majority of plants in plot dying.

In South Africa, 55 entries from the ADIN, SABN and Sugarcane Aphid Test were selected during 2001-02 for further evaluation and possible inclusion in local sorghum nurseries and use in developing agriculture production systems. Thirteen entries were retained after the current season for sources of resistance to leaf blight, grain mold, anthracnose as well as adapted white grain types. To these, 10 from the 2002-03 ADIN and 7 from the SABN will be added for further local evaluation.

At the University of the Free State, student collaboration continued with studies on grain molds. Grain from trials planted at Cedara, Bethlehem and Potchefstroom were evaluated for frequency of grain mold pathogens, germination, milling and malt quality and toxins. *Alternaria alternata* was the most common isolate and was isolated from 74 % of grains. This was followed by *Fusarium* spp. *Curvularia* spp. and *Phoma sorghina*. Identification of isolates is still in progress as well as a study to determine the population diversity of primary species. The relationship between grain mold rating and Abrasive Hardness Index was quantified and indicated a sharp decline in milling quality with increased grain mold severity rating (r=0.91**). Similarly, reduced germination induced by grain mold pathogens reduced diastatic power of malt. Fumonisin, aflotoxin, DON, moniliformin and zearalone analyses were negative indicating that these toxins did not occur at significant levels in the field. Studies are, however, continuing on isolates of individual organisms to determine the health hazard potential of grain-borne fungi and the weather conditions required to induce toxin production at significant levels. Embryo blight caused by grain pathogens was quantified and germination reductions of up to 72 % were recorded. Resistance to grain and embryo infection was related to phenol content of the tissues including glume proanthocyanidins, seed flavanols, apigeninidins and/or luteolinidins. Glume proanthocyanidins were significantly correlated with grain ergosterol content, which was used as an indicator or grain colonization (r=-0.83** and r=-0.87** in the greenhouse and field respectively).

In the 2002 Annual Report, *Fusarium* and mycotoxin analyses of sorghum and millet samples from Mali were reported. Further studies were undertaken on *Fusarium* isolates from sorghum sample 16 that contained the highest levels of fumonisins (1025 ng/g) but no moniliformin and pearl millet sample 4 that contained fumonisins (70 ng/g) as well as the highest level of moniliformin (524 ng/g) found in the Mali samples. The *Fusarium* isolates were identified morphologically or placed in morphological groups and analysed chemically by HPLC for fumonisins FB_1, FB_2 and FB_3. The 27 *Fusarium* strains from Pearl Millet Sample 4 isolated at PROMEC were separated into three morphological groups as follows:

F. andiyazi-like:	7 strains
F. nygamai-like:	8 strains
F. pseudonygamai-like:	12 strains

Five strains from each group were analysed for fumonisins. All 15 *Fusarium* isolates from Pearl Millet sample 4 that contained fumonisins FB_1, FB_2 and FB_3 produced FB_1. The *F. andiyazi*-like isolates produced the highest levels of FB_1, 4/5 produced FB_2 and 3/5 produced FB_3. The *F. nygamai*-like and *F. pseudonygamai*-like isolates produced much lower levels of FB_1, only 2/5 *F. nygamai*-like isolates produced FB_2 and none produced FB_3. Cultures of the 15 strains have been sent to Dr. Leslie for molecular charaterization. We received 54 *Fusarium* strains that were isolated from Sorghum Sample 16 from Dr. Leslie and identified them as follows:

F. andiyazi-like (Long chains, swollen cells in carnation leaves):	31
F. nygamai-like (Short chains, chlamydospores in aerial mycelium):	11
Others:	12

Fifteen of these strains (10 *F. andiyazi*-like and 5 *F. nygamai*-like) were selected to be analysed for fumonisins at PROMEC and for molecular characterization by Dr. Leslie.

Grain Quality

Graduate students in the Food Science Department at University of Pretoria are from many African countries. Many participate in the Regional Master of Science program, which consists of joint programs between CSIR and University of Pretoria. Thus, INTSORMIL's interaction with the University of Pretoria informs many future African food industry leaders of the potential role of sorghum and millets as food and industrial ingredients. INTSORMIL is providing significant assistance to the region by involvement in these key programs.

Dr. Lloyd Rooney participated in the AFRIPRO conference that was held in April 2003 in Pretoria to assess the current status of research in Africa on sorghum proteins and related subjects. The European Economic Community has sponsored work in several African and European Universities and Research Centers. The conference brought together a critical mass of African and European scientists. INTSORMIL must maintain and develop a continuing dialog with these scientists since our interests are complementary. Many of the African scientists participating were trained as part of our INTSORMIL program. They have been exercising leadership in some of these projects. Dr. Rooney presented information on the importance of supply chain management for securing a consistent supply of grain for processing into value-added products for urban consumers. Professor Taylor, University of Pretoria, is funded by both groups and facilitates interactions quite well. These projects are synergistic and complementary.

Injera is an Ethiopian flat bread made from cereals, with tef preferred for the best quality injera. However, because sorghum is less expensive in Ethiopia, there is great interest in improving the quality of sorghum for injera. A standardized laboratory method to produce and evaluate the characteristics of injera was developed by Ms. S. Yetneberk, a Ph.D. student working with Prof. Taylor at the University of Pretoria. Several experiments were conducted to determine the factors that affect injera quality from tef and sorghum. To determine the effect of cultivar, injera was prepared from 12 Ethiopian sorghum cultivars of varying kernel characteristics; one cultivar of white tef of good injera quality was used as a reference. Injera quality was evaluated using a trained panel and objective measurements of texture, color and other properties were made. The descriptive sensory analysis of fresh injera was analyzed using principal component analysis (PCA) In addition, the keeping quality of injera during storage was measured with a texture analyzer using a three-point bending method.

The sorghum cultivars varied in injera making properties and keeping qualities during storage. A good injera remains soft and rollable during storage up to 3 days. For the 12 varieties significant differences were found. In general the softer texture grains gave the best injera. However, some harder white varieties gave excellent quality injera which is of significance since most sorghums for injera are soft. Hard endosperm types were eliminated from sorghum improvement programs but these findings suggest that harder types may be useful for injera. Both variety and environment affect the properties of the sorghum for use in injera as expected. Some of the sorghums with purple plant color produced injera with greater color when they matured under higher humidity which caused additional pigmentation from the black or purple glumes. Another part of the dissertation deals with the relation between composition of the sorghum flour and injera quality and acceptability. Once this is developed a good approach to selection for injera quality can be developed.

The incorporation of emulsifiers into the batter used to make sorghum injera improved its texture and gave more uniform size and distribution of the "fish eyes" on the surface of the injera which is critically important. This suggests that small amounts of monoglycerides could significantly improve injera made from blends of sorghum and other cereals. In practice, injera is often made from blends of sorghum, wheat, maize, tef and other flours. For example, farmers grow red sorghums and will blend them with other flours to make injera. Only in unusual circumstances do they use 100% red sorghum flour in injera.

Studies on the effect of conditioning and varieties on the roller milling efficiency and yields will be conducted to determine flour yields and quality. These small industrial roller mills developed and manufactured in South Africa could be useful in other parts of the world as well. They have good capacity and appear durable and efficient. Plans are to obtain one for the University of Pretoria to enable production of quantities of sorghum and millet flour of consistent quality for use in food product development and process modifications.

Entomology

Sugarcane aphid screenings of sorghum were done in two trials of 100 entries each. Trials were planted in South Africa at the mid-altitude research station of the ARC-Grain Crops Institute in Potchefstroom and at the sub-tropical, low-altitude station at Burgershall Research Station, near Hazyview, and at the Botswana College of Agriculture, Gaborone (Table 4). Aphid damage was evaluated when the majority of the hybrids were in the milk stage. Severity of infestation/damage was evaluated using a 1 to 5 scale, where 1 = no aphids present on plants, 2 = light infestation with aphids present on a few leaves (no dead leaves), 3 = moderate infestation with many aphids present on two to three leaves (one or two dead leaves may be present), 4 = high infestation with many aphids on nearly all leaves (many dead leaves) and 5 = majority of plants in plot dying. Plants with a rating of 1 or 2 were considered to be resistant, while a rating of 3 indicated an intermediate level of resistance. Plants with a rating of 4 and 5 were considered susceptible.

Sugarcane aphid infestation levels at the Burgershall station were similar to those at Potchefstroom. Results from both trials indicated that 22 and 15 %, respectively for Potchefstroom and Burgershall of the entries rated 1 on a scale of 1 to 4, indicating no to very light damage. Ratings of 2 were scored for 27 and 24 % of the entries at Potchefstroom and Burgershall respectively. Resistant breeding material was therefore identified from the field trials. Sugarcane aphid infestation levels at Burgershall were similar to that of Potchefstroom. This confirms that an earlier planting date at the former locality results in higher infestation levels, as was suggested in the 2001-02 report. Five and 15 % of the entries at Potchefstroom and Burgershall, respectively died as a result of aphid infestation.

Infestation levels at both sites were high, judging by the number of entries of which plants were rated 5 (dead or dying because of aphid feeding). Results indicated that 29 % of the entries rated below 2 (indicating none to light damage). The following entries had no aphids on any of the plants at both Burgershall and Potchefstroom:

(Segaolane *WM#322)-LG2-LG2-BG1-LG1
(EPSON –40/E#15-SADC*TAM428)-LG3-BG1-BG1
(CE151*TAM428)-LG1-BGBK-CCBK
(6OB128/(Tx2862* 6EO361)*CE151)-LG19-CCBK-CCBK
PRGC/E#22879
PRGC/E#222878
(CE151*TAM428)-CG1-BGBK-CCBK
(Macia*TAM428)-LL9
PRGC/E#69414
WM#177
(CE151*TAM428)-LG2-CG1-BG1
(6BRON161/((7E0366*Tx2783)-HG54*CE151)-CG4-BG1-BG1
(CE151*TAM428)-LG2-CG1-BG1
(6OB128/(Tx2862* 6EO361)*CE151)-LG25-CG1-BGBK-CCBK
(6OB124/94CE81-3/GR134B-LG56-*WM#177)-LG1-LG1-BG3
WM#322
(A964*FGYQ336)LG4-LG2-BG1-BG3

Resistance to sugarcane aphid was evaluated during the seedling stage under artificial aphid infestation in a glasshouse trial. A single row of each of 100 entries was planted in containers (0.5 m x 0.3 m x 0.1 m). Inter-row spacing in the containers was 6 cm, with 2 cm between seedlings. There were 15 seedlings per row and these were infested with aphids ten days after emergence (two-leaf stage, plants approximately 10 cm tall). Leaves of infested plants in the field were brought to the greenhouse and the aphids brushed onto the rows of seedlings. Approximately 250 aphids of different instars were brushed onto each row (approximately 16 aphids per seedling). However, the aphid infestation did not establish on plants. After three attempts at infesting seedlings with aphids collected from the field, the trial was terminated.

Table 4. Mean sugarcane aphid damage rating in the 2002 Sugarcane Aphid Test, Potchefstroom and Burgershall, South Africa and Gaborone, Botswana, 2002-2003.

	South Africa			Botswana		
PEDIGREE	Mean†	Potchefstroom	Burgershall	Sugarcane Aphid†	Stem Borers‡	Termite§
(CE151*TAM428)-CG1-BGBK-CCBK	1.5	1.5	1.5	1.2	4.0	16.7
(6BRON161/(7EO366*Tx2783)*EPSON2-40/E#15/SADC)-LG4-CG1-BG 1-LG2	2.8	3.0	2.5	1.5	4.3	68.8
(CE151*BDM499)-LD17-BE1	4.3	4.5	4.0	1.5	2.8	50.0
(EPSON2-40/E#15/SADC*TAM428)-CG1-BGBK-CCBK	2.5	2.0	3.0	1.5	5.0	68.8
(6OB128/(Tx2862*6EO361)*CE151)-LG25-CG1-BGBK-CCBK	2.3	2.0	2.5	1.5	4.0	65.0
(EPSON2-40/E#15-SADC*TAM428)-LG3-BG1-BG1	1.5	1.5	1.5	1.5	2.8	12.5
(6BRON126/5BRON154/(87BH8606-14*GR107-90M46)*EPSON2-40/E# 14/SADC)-LG2-LG1-BG2	2.8	3.0	2.5	1.5	5.0	63.3
(Town*EPSON2-40/E#15/SADC)-LG1-BGBK-CCBK	3.5	3.5	3.5	1.5	4.0	57.2
(5BRON139/((6EO361*GR107der)-LG7)*CE151)-LG2-BGBK-CCBK	3.0	2.5	3.5	1.8	4.8	25.0
(6BRON161/(7EO366*Tx2783)*CE151)-LG4-CG2-BG2-BG1	2.5	2.0	3.0	1.8	94.8	20.0
(5BRON131/(80C2241*GR108-90M30)*SDSL9426)-LG6-LG1-BG1-BG2	2.8	2.5	3.0	1.8	3.5	33.4
(6OBS124/94CE81-3/GR134B-LG56-*WM#177)-LG1-LG1-BG3-BGBK	1.5	1.5	1.5	1.8	4.8	50.0
(6BRON161/(7EO366*Tx2783)*CE151)-LG2-CG3-BG2-BGBK	2.0	1.5	2.5	1.8	5.0	79.1
((6BRON126/(87BH8606-14*GR107-90M46))*CE151)-LG2-CG1-BG2-B GBK	3.3	3.0	3.5	2.0	4.8	0.0
(CE151*(6BRON119/(6EO361*GR107der)-CE151))-CG5-BG1-BG2	3.0	2.0	4.0	2.0	4.8	81.3
(6OBS129/94CE89-2/(Tx2862*6EO361)-LG30-*WM#177)-CG1-BG1-BG 2	3.0	3.0	3.0	2.0	4.5	50.0
(6BRON161/(7EO366*Tx2783)-HG54-*CE151)-CG4-BG1-BG1	1.5	1.0	2.0	2.0	4.0	57.1
(6OB128/(Tx2862*6EO361)*CE151)-LG3-LG1-BGBK-CCBK	3.0	2.5	3.5	2.0	4.5	67.9
(Town*EPSON2-40/E#15/SADC)-LG12-CG3-BGBK-BGBK	4.3	3.5	5.0	2.0	5.0	50.0
(6BRON161/(7EO366*Tx2783)-HG54-*CE151)-LG1-BG3-BG2	2.8	3.0	2.5	2.0	4.0	47.2
(6OB128/(Tx2862*6EO361)*CE151)-LG27-LG1-BG1-BG1	3.5	2.5	4.5	2.0	4.5	56.3
97M13/(Tx2882*6EO374)/7BRON152	3.8	3.5	4.0	2.0	3.5	25.0
(6OB128/(Tx2862*6EO361)*CE151)-LG4-CG1-BG1-BG2	3.8	3.5	4.0	2.0	3.0	32.5
(6OB128/(Tx2862*6EO361)*CE151)-LG25-CG1-BG2-BG2	2.5	2.5	2.5	2.0	5.0	18.8
(6OB128/(Tx2862*6EO361)*CE151)-LG4-CG1-BGBK-CCBK	2.0	1.5	2.5	2.0	4.5	32.2
(CE151*TAM428)-LG2-CG1-BG1	1.0	1.0	1.0	2.2		
(6BRON126/(87BH8606-14*GR107-90M46)*EPSON2-40/E#15/SADC)-L G1-LG1-BGBK-CCBK	4.0	4.0	4.0	2.2	5.0	76.9
(CE151*A964)-CG1-BG2-BG3	3.3	3.0	3.5	2.2	4.8	51.3
Ent.62/SADC	1.8	1.0	2.5	2.2	4.8	25.0
(Segeolane*TAM428)-LG2-CG1-BG1-LG2	5.0	5.0	5.0	2.2	5.0	55.0
(6BRON161/(7EO366*Tx2783)-HG54-*CE151)-CG3-BG2-BG2	2.8	3.0	2.5	2.2	3.8	53.3
(SDSL89426*6OB124/GR134B-)-LG5-CCBK-CCBK	2.3	2.0	2.5	2.2	4.8	56.7
(A964*FGYQ336)-LG4-LG2-BG1-BG3	1.3	1.5	1.0	2.2	5.0	22.5
(6BRON126/5BRON154/(87BH8606-14*GR107-90M46)*EPSON2-40/E# 14/SADC)-LG3-CG1-BG1	1.8	1.5	2.0	2.2	4.5	40.0
(Tx430*Sima/IS23250)-LG5-CCBK-CCBK	2.8	2.0	3.5	2.2	5.0	61.1
(Town*EPSON2-40/E#15/SADC)-CG2-BGBK-CCBK	4.5	4.0	5.0	2.2	4.5	48.6
(Tx2882*SRN39)-CM3-SM2-SM2-SM2	4.5	4.0	5.0	2.2	4.5	27.3
(6OBS128/94CE88-3/(Tx2862*6EO361)*EPSON2-40/E#15/SADC)-LG15 -CG2-BG2-BGBK	2.5	3.0	2.0	2.2	5.0	70.8
FGYQ353	2.5	2.0	3.0	2.2	4.8	47.9
(EPSON2-40/E#15/SADC*A964)-CG3-BGBK-CCBK	1.8	2.0	1.5	2.3	5.0	66.7

Table 4 (continued). Mean sugarcane aphid damage rating in the 2002 Sugarcane Aphid Test, Potchefstroom and Burgershall, South Africa and Gaborone, Botswana, 2002-2003.

	South Africa			Botswana		
PEDIGREE	Mean†	Potchefstroom	Burgershall	Sugarcane Aphid†	Stem Borers‡	Termite§
(EPSON2-40/E#15/SADC*((BRON154/87BH8606-1*GR107-90M46)*EPSON2-40/E#15/SADC))-CG5-LG1-BG1	2.3	2.0	2.5	2.5	5.0	20.0
(6OB128/(Tx2862*6EO361)*CE151)-LG16-CG1-LGBK-LG2	2.3	2.0	2.5	2.5	5.0	67.6
FGYQ336	1.5	1.5	1.5	2.5	5.0	43.1
(Segeolane*FGYQ336)-LG3-CG1-BG1-LG2	5.0	5.0	5.0	2.5	5.0	67.8
(Town*EPSON2-40/E#15/SADC)-CG3-BGBK-CCBK	4.8	4.5	5.0	2.5	5.0	79.1
(6BRON161/(7EO366*Tx2783)-HG54-*EPSON2-40/E#15/SADC)-LG1-BG2-BG2	2.5	3.0	2.0	2.5	5.0	38.1
PRGC/E#69414	1.0	1.0	1.0	2.5	5.0	50.0
GR128-92M12	2.8	2.0	3.5	2.5	5.0	40.3
(CE151*TAM428)-LG15-LG1-BG1-BGBK	2.3	2.0	2.5	2.5	5.0	75.0
(6OB128/(Tx2862*6EO361)*CE151)-LG27-LG1-BGBK-CCBK	2.8	2.0	3.5	2.5	4.8	64.3
Kuyuma	4.5	4.0	5.0	2.5	5.0	34.1
PRGC/E#222878	1.3	1.0	1.5	2.5	5.0	83.3
((6BRON126/(87BH8606-14*GR107-90M46))*CE151)-LG7-LG1-BG2-BGBK	3.5	3.0	4.0	2.5	5.0	50.0
(Macia*TAM428)-LL2	2.3	1.5	3.0	2.5	4.0	50.0
(SV1*Sima/IS23250)-LG15-CG1-BG2-BGBK	1.8	1.0	2.5	2.5	5.0	41.4
(Macia*TAM428)-LL9	1.0	1.0	1.0	2.5	5.0	42.4
(6BRON161/((7EO366*Tx2783)-HG54)*CE151)-LG1-BGBK-CCBK	4.0	4.0	4.0	2.5	4.0	26.3
(Segaolane*FGYQ336)-CG5-BGBK-CCBK	3.3	3.5	3.0	2.5	5.0	55.0
(CE151*BDM499)-LD17-BE2	3.0	2.5	3.5	2.5	5.0	40.5
(6OB124/94CE81-3/GR134B-LG56*EPSON2-40/E#15/SADC)-CG4-BG1-BG3	4.5	4.0	5.0	2.5	5.0	40.2
WM#177	1.3	1.5	1.0	2.5	5.0	52.8
PRGC/E#222879	1.0	1.0	1.0	2.5	4.0	23.1
(Segaolane*WM#322)-CG1-BGBK-CCBK	3.3	3.0	3.5	2.5	4.8	50.0
(MR112B-92M2*Tx2880)-SM3-SM1-ML52-CMBK	4.0	4.0	4.0	2.5	4.5	50.0
(6BRON126/(87BH8606-14*GR107-90M46)*EPSON2-40/E#15/SADC)-LG3-CG1-BGBK-CCBK	2.3	2.5	2.0	2.8	2.8	40.0
(SDSL89426*6OB124/94CE81-3/GR134B-LG56-)LG5-CG1-BG2-BG1	2.5	2.0	3.0	2.8	4.0	12.5
(6BRON161/(7EO366*Tx2783)*EPSON2040/E#15/SADC)-CG2-BG2-BGBK	3.0	3.0	3.0	2.8	4.8	54.2
(6BRON126/5BRON154/(87BH8606-14*GR107-90M46)-HG10-*EPSON2-40/E#15/SADC)-CG2-BG2-BG1	3.8	3.5	4.0	2.8	4.5	45.7
(6BRON126/((87BH8606-14*GR107-90M46)-HG10)*CE151)-CG1-BGBK-CCBK	4.0	4.0	4.0	2.8	4.5	33.3
Sima (IS23250)	2.0	1.5	2.5	2.8	4.0	12.5
(CE151*TAM428)-LG20-LG1-LG2-CG2	2.3	2.0	2.5	2.8	4.0	47.9
(EPSON2-40/E#15-SADC*TAM428)-CG1-BG1-BG2	2.0	2.5	1.5	2.8	3.8	50.0
Macia	4.8	4.5	5.0	3.0	5.0	29.1
(6OB128/(Tx2862*6EO361)*CE151)-LG19-CCBK-CCBK	1.3	1.0	1.5	3.0	4.0	71.6
(6OB124/(GR134B-LG56)*WM#177)-LG7-CG2-BGBK-CCBK	2.0	1.5	2.5	3.0	3.8	28.1
(5BRON131/((80C2241*GR108-90M30)-HG46)*WM#177)-LG1-BGBK-CCBK	1.8	1.0	2.5	3.0	5.0	45.0
(6BRON161/(7EO366*Tx2783)*CE151)-LG5-CG2-BG1-BG2	1.8	1.5	2.0	3.0	4.8	25.4
WM#322	1.8	2.0	1.5	3.0	5.0	59.5

Table 4 (continued). Mean sugarcane aphid damage rating in the 2002 Sugarcane Aphid Test, Potchefstroom and Burgershall, South Africa and Gaborone, Botswana, 2002-2003.

	South Africa			Botswana		
PEDIGREE	Mean†	Potchefstroom	Burgershall	Sugarcane Aphid†	Stem Borers‡	Termite§
(6BRON126/5BRON154/(87BH8606-14*GR107-90M46)-HG10-*EPSON 2-40/E#15/SADC)-CG2-BG2-BG2	2.8	3.5	2.0	3.0	4.5	92.9
SDSL89426	2.8	3.0	2.5	3.2	5.0	52.8
(6BRON126/(87BH8606-14*GR107-90M46)*EPSON2-40/E#15/SADC)-LG2-LG1-BGBK-CCBK	1.8	2.5	1.0	3.2	4.8	65.6
(A964*FGYQ336)-LG13-LG1-BGBK-CCBK	4.3	4.0	4.5	3.2	3.5	14.7
(CE151*TAM428)-LG1-BGBK-CCBK	1.3	1.0	1.5	3.2	4.0	17.9
(96AD34/6BRON116/5BRON131/(80CC2241*GR108-90M30)-HG46*WM#177)-CG2-BG1-BG1	3.5	3.5	3.5	3.2	3.5	35.0
(EPSON2-40/E#15/SADC*6OBS124/94CE81-3/GR134B-LG56-)-LG1-CG1-BG1-BGBK	3.5	3.5	3.5	3.2		
Segaolane	5.0	5.0	5.0	3.2	5.0	58.0
(6BRON161/((7EO366*Tx2783)-HG54)*CE151)-CG3-BGBK-CCBK	3.0	3.0	3.0	3.2	4.0	6.2
(CE151*TAM428)-CG1-BG1-BG3	1.8	1.0	2.5	3.5	4.8	78.6
(6OB124/94CE81-3/GR134B-LG56-*WM#177)-CG3-BG1-BGBK	2.5	2.0	3.0	3.5	4.8	30.8
(Segeolane*WM#322)-LG2-LG2-BG1-LG1	1.8	1.5	2.0	3.5	4.0	50.0
(BRON161/(7EO366*Tx2783)*EPSON2-40/E#15/SADC)-LG5-CC2-BG1-BGBK	2.8	3.0	2.5	3.8	5.0	51.5
TAM428	3.0	3.5	2.5	3.8	4.5	0.0
(6OB128/((Tx2862*6EO361)-LG30)*CE151)-CG5-BGBK-CCBK	4.3	4.0	4.5	3.8	5.0	57.2
(Macia*TAM428)-HD1-	4.0	4.0	4.0	3.8	4.0	41.7
(Tx2883*(Tx2880*(GR108-90M24*(Tx2862*(Tx430*(Tx2862*PI550607))))))-PR2-CCBK-CCBK	3.3	3.5	3.0	3.8	4.0	53.6
((6BRON126/87BH8606-14*GR107-90M46)*CE151)-LG2-CG1-BG2-BG3	4.0	3.5	4.5	3.8	4.0	25.0
(6OB124/(GR134B-LG56)*EPSON2-40/E#15/SADC)-CG2-BGBK-CCBK	3.8	3.5	4.0	4.0	5.0	71.2
(Macia*(MR127*87EO366))-HM1-CA1	3.8	4.0	3.5	4.0	4.8	50.0
(87EO366*TAM428)-HF2	3.8	4.0	3.5	4.5	4.5	69.1
CE151	2.0	1.0	3.0	4.5	5.0	64.1
MEAN	2.8	2.6	3.0			
LSD.05	0.9	1.0	1.3			
CV	26.7	23.4	26.4			

† Rated on a scale of 1 = no aphids present on plants, 2 = light infestation with aphids present on a few leaves (no dead leaves), 3 = moderate infestation with many aphids present on two to three leaves (one or two dead leaves may be present), 4 = high infestation with many aphids on nearly all leaves (many dead leaves) and 5 = majority of plants in plot dying.
‡ Rated on a scale of 1 = no damage to 5 = all plants in plot dead.
§ Percent of plants in plot infested with termites.

In Botswana, 13 of the 100 sorghum lines had relative damage less than 2.0. Additionally 12 of the 100 lines had low sugarcane aphid infested plants (less than 25% infested) while 17 were more than 70% infested. The sorghum lines with less than 25% infested plants should be evaluated further to confirm their resistance against the sugarcane aphid while the which had more than 70% infested plants would not be suitable for use because they are highly susceptible to the sugarcane aphid.

The effect of stem borer attack on the 100 sorghum lines evaluated at the Botswana College of Agriculture. The proportion of sorghum plants with dead hearts varied from 0% to 85.7%. Nine lines were identified with damage less than 4.0 (rated on a 1 to 5 scale). There lines should be evaluated further to determine their resistance level to stem borer

The lines were also evaluated for effect of termites. Apart from attack by the sugarcane aphid and stem borers, many of the 100 sorghum lines evaluated at the Botswana College of Agriculture during the 2002-2003 cropping season were also seriously damaged by termites. Termites were found to attack vigorously growing as well as wilting sorghum plants. The incidence of infested plants ranged from 0% attacked plants to 92.9%. Seventeen lines had damage less than 25.0%, and seven lines were greater that 70.0%. Based on resistance to termite attack, the 17 least susceptible sorghum lines would be the most promising for use under the Botswana conditions while the seven highly susceptible lines would not be suitable for use. The promising lines should be evaluated further during the 2003-04 cropping season to confirm their tolerance to termite attack.

The South African Breeding Nursery was evaluated at Potchefstroom for damage caused by sugarcane aphid (Table 3). Thirty percent of the entries in this trial was rated resistant while 28 % was highly susceptible (rated 4 and higher). The following entries rated lower than 2, indicating zero to slight presence of aphids and damage symptoms:

CE151-262-A1
TAM428
(90EO328*CE151)-BD39
(CE151*Macia)-LD3
(87EO366*TAM428)-MF2
(90EO328*CE151)-LD11-BD4
(CE151*Macia)-BE21
(CE151*MP531)-LD42
Pinolero 1 (Nicaragua Variety)
(TAM 428*SV1)-HD40
(Macia*TAM428)-LL7
(Macia*TAM428)-LL9
(Macia*TAM428)-LL14

Sorghum Breeding

Collaborative sorghum breeding activities are conducted in Zambia, Botswana, and Zimbabwe. Activities in Zimbabwe are restricted to evaluating introduced germplasm. Drought in Botswana and Zimbabwe restricted gathering of reliable data.

In 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. In 2002-03 season the collaborative work with INTSORMIL involved the exchange of germplasm and trials in breeding. The SABN, Drought Line Test (DLT) and some R-lines were evaluated at Golden Valley and Lusitu. One of the main objectives of the program is to generate genetic variability through collections, introductions and hybridization. A total of eight trials were evaluated at the Golden Valley Agricultural Research Trust, Mansa and Lusitu. The emphasis of the program has now 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 maintain and increase seed of released varieties. Field days were organized at the Golden Valley Agricultural Research Trust and Mt. Makulu Research Station where small scale farmers and participants from the industry participated. Farmers were offered a chance to see some of the promising improved varieties and products. Interest was generated with the kind of products that can be made from sorghum and millet. Lack of availability of improved seed continues to be a major challenge and hindrance utilization of technology generated by the program.

The 2002-03 season was affected by lack of rainfall at the beginning of the season although the rains were more normal later in the season. However, most parts Zambia received little rain and the distribution was poor. Trials on forage, brewing, feed and food were evaluated at the Golden Valley Agricultural Research Trust. The trials had excellent stands and most trials had high mean yields and low CV%. In the Sorghum Advanced Variety trial significant differences were observed among the entries for all the traits. The entries were exceptionally tall and the trial mean grain yield was 6200 kg ha^{-1}. A number of new varieties performed well. Variety [Framida x SDS 3843] 16-2-2 had a mean grain yield of 7500 kg ha^{-1}. Other varieties that had high mean yields are ZSV-15 (6900 kg ha^{-1}), SDS 3047 (6800 kg ha^{-1}), [ICSV 112 x WSV387]20-3-4 (6900 kg ha^{-1}), and [Framida x SDS3845]F6-5 (6600 kg ha^{-1}). The checks Kuyuma and Sima had lower mean yields than the trial mean. Variety [Framida x SDS3843]16-2-2 will be pre-released in October 2003. The White Sorghum Hybrid Trial contained 16 entries and had a trail mead of 6300 kg ha^{-1}. Significant differences were observed among entries. Hybrid MMSH-1391 had a high mean yield of 7250 kg ha^{-1}. Other promising hybrids are MMSH-1401 (7011 kg ha^{-1}), MMSH-1382 (7169 kg ha^{-1}) and MMSH-707 (6856 kg ha^{-1}). The Brown Sorghum Hybrid Trial had a trial mean of 6471 kg ha^{-1}. Hybrid MMSH-625 had a mean grain yield of 7900 kg ha^{-1} followed by MMSH-1356 (7800 kg ha^{-1}), MMSH-1031 (7900 kg ha^{-1}) MMSH-1365 (6500 kg ha^{-1}). Hybrids MMSH-625 and 1356 will be pre-released in October 2003.

Visual selections were made in test crosses, introductions, F2 populations, F3, F4, F5, and F6 progenies. Seed of released varieties was maintained and increased. The material evaluated included 30 pairs of A & B lines; 145 lines for seed increases; 90 experimental crosses and 36 test crosses. Additional seed of ZSV-15 (1.5 tons), Sima (2 tons) and Kuyuma (1.3 tons) were increased in isolation fields. Selected materials will be evaluated further next season.

Issues of seed production and distribution have continued to be a major hindrance to increased production of sorghum. Seed of released varieties cannot be produced by seed companies citing low demand. A group representing commercial farmers in the southern province visited the program in February 2003 to discuss the Zambian sorghum seed situation. The farmers indicated willingness to embark on seed production themselves given the necessary support. NGO's such as PAM-SHAPES 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. Because of the drought experienced in most parts of the country in 2001-02 season very little seed was available for farmers the past season. This situation is likely to carry over in the next season because of the partial drought experienced in the sorghum producing areas. With the support of INTSORMIL seed of the released variety Kuyuma, was produced on about 6 hectares in Nanga. Although the seed crop was affected by drought, 15 tons has been produced and has already been bought by farmers. It is hoped that the program can participate in this activity in the coming season.

In Botswana, sixty-five advanced sorghum lines from INTSORMIL were evaluated at Sebele. Included in the trial were 36 pre- and post-flowering drought tolerant lines from USA and around the world, eight lines derived from Segaolane, and some of the best breeding lines from the USA, Zambia, and South Africa. The trial suffered from insufficient moisture at germination and/or emergence resulting in generally poor stand establishment. Seasonal rainfall was below normal and poorly distributed and this further compounded the experiment. Data was recorded for days to flowering for some of the entries. The trial will be repeated during 2003-04.

Mutuality of Benefits

Productivity and utilization of both sorghum and pearl millet will ultimately be improved both in SADC countries and the USA through joint research. Reciprocal germplasm flow is mutually beneficial. Basic research from the USA can often be adapted for use in developing countries where grain yield potential, adaptation, stress resistance, and grain quality need to be increased. U. S. pathologists and entomologists can become familiar with diseases and insects not yet present in the USA, or find new resistance sources 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 of vital interest to U.S. scientists. Nutritional components of food quality researched in collaborative projects have relevance to grain values for livestock feed.

Institution Building

Equipment and Supplies

One Hewlett Packard iPAQ Pocket PC was delivered to the Zimbabwe sorghum breeding program.

The process to order and deliver pollinating bags to sorghum or pearl millet breeding programs in Zambia and Namibia was initiated.

Training

Through a previous regional USAID program INTSORMIL provided long-term training to a large number of SADC sorghum and pearl millet scientists. Currently at least one regional scientist is selected each year for a short-term training assignment with a U.S. principal investigator.

Mr. Leo Mpofu, sorghum breeder, participated in a short-term training program in July-August 2002 with Dr. Bill Rooney (TAM 220C) and Dr. Gary Peterson (TAM 223).

Ms. Rachel Ngulube-Msikita (Zambia) completed her M.S. degree in Agronomy at the University of Nebraska in December, 2002.

Ms. S. Yetneberk from Ethiopia has continued her Ph.D. program at the University of Pretoria under Dr. John Taylor. Her research is to determine major factors affecting the quality of injera from sorghum cultivars grown in Ethiopia. Anticipation date is in the fall of 2003. She will return to the Ethiopian National Sorghum Program.

Mr. Steve Barrion, M.S. candidate, University of Pretoria, is working on milling of pearl millet from Namibia. Commercial milled products from a major millet variety were produced and analyzed for components and physical properties. Plans were made to obtain several commercial varieties of pearl millets from Namibia for analysis, especially of the phenols. This project should provide useful information relative to commercial milling of pearl millet compared to traditional milling.

Ms. Nomsua R. Dlamini, Lecturer, National University of Zimbabwe, Bulawayo, Zimbabwe, is beginning work on a Ph.D. in food science at the University of Pretoria with Dr. Taylor. Her research will study antioxidants from sorghum. The title of her dissertation project is: Effect of variety and processing on the antioxidant properties of African sorghum based foods. This research will provide useful information on the role of sorghum phenols in health foods. Samples are being acquired with research being done mainly at the Univ. of Pretoria.

Ms. Phoebe Ditshipi, plant pathologist from Botswana, prepared to begin Ph.D. research at the University of Free State, South Africa with Dr. Neal McLaren.

Ms. Phoebe Ditshipi, Mr. Godwin Kaula (Zambia), and Dr. Neal McLaren visited the Texas A&M University sorghum breeding program at Corpus Christi and participated in the Fusarium Workshop at Kansas State University in June, 2002.

Host Country and U.S. Scientist Visits

John Leslie visited South Africa in September-October 2002 discuss current and plan future collaborative research.

Gary Peterson visited Zambia and Zimbabwe in October, 2002. In Zambia, met with Ministry of Agriculture, Department of Agricultural Research scientists to discuss activity in sorghum breeding and plant pathology. Traveled to Nanga to evaluate the Zambian sorghum breeding program winter nursery and discuss plans for a winter nursery seed increase to provide high quality planting seed for Zambian farmers. In Zimbabwe, participate in the SMINET Steering Committee Meeting.

Regional collaborators participated in the INTSORMIL Principal Investigators Conference in Addis Ababa, Ethiopia in November, 2002. Participants included: Botswana - S. Chite, P. Ditshipi, and M. Mogorosi; Namibia - S.A. Ipinge, South Africa - W. Marasas, N. McLaren, J. Taylor, and J. van den Berg; Zambia - M. Chisi, G. Kaula, and F. Muuka; Zimbabwe - L. Mpofu, E. Mtisi, and M. Mgonja (SMINET). Other regional participants to the conference included Dr. L. Hugo (Mozambique).

Dr. Wally Marasas was an instructor at the Fusarium Workshop at Kansas State University in June, 2003.

Dr. Medson Chisi visited regional research programs in Botswana, Namibia, and South Africa to review research activities in April, 2003.

Dr. Lloyd Rooney participated in the AFRIPRO conference that was held in April 2003 in Pretoria to assess the current status of research in Africa on sorghum proteins and related subjects.

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 2001-2002 growing season (collaborative with TAM 222, TAM 223, and TAM 220C).

Networking

An efficient sorghum and millet research and technology transfer network exists in the SADC region conducted by the SMIP program and INTSORMIL's SADC collaborative research program is completely integrated on a regional basis. The Zimbabwe unrest and political situation has imposed significant restrictions and a reduction of activity in Zimbabwe. 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. INTSORMIL is initiating a plant pathology training program with the University of Free State, South Africa. 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.

Program Accomplishments

INTSORMIL is fully integrated into the SADC and SMIP sorghum and pearl millet regional research and technology transfer activities. INTSORMIL regional work plans are annually reviewed by the SMINET Steering Committee.

Factors influencing the incidence and control of sorghum ergot are now better understood, leading to better control the disease, especially in hybrid production fields. Fungicides for control of ergot have been evaluated and significant interactions between fungicide and application time identified.

New sorghum and pearl millet varieties and hybrids are ready for release or in final testing prior to release. A large number of sorghum germplasms 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.

Collaborators at the Department of Food Science, University of Pretoria presented the following short-courses to improve the food technology skills of professionals in the sorghum and millet food industry in Southern Africa. 1)Course in sorghum malting technology has been presented to six groups of 12 people over the past 8 years. 2)Short course in opaque (sorghum) beer brewing has been presented annually to a total of some 150 people from throughout southern Africa over the past 6 years. 3)Under the sponsorship of the FAO and the Namibian government a pearl millet processing technology training facility has been designed and is the process of being constructed in northern Namibia.

Research into improving sorghum processing technologies is being carried out for the sorghum food industry in South Africa through its industry body, the Sorghum Forum. With the support of the USAID RAPID Program, sorghum grain end-use quality standards and methods have been developed to facilitate grain trade in southern Africa. Technical assistance has been rendered to the Botswana Bureau of Standards to implement sorghum grain standards incorporating these concepts and methods, and to Tanzanian businesses in the setting up of a sorghum industry forum.

The Department of Food Science, University of Pretoria and CSIR Bio/Chemtek in South Africa are the official SADC (Southern African Development Community) center for post-graduate training in Food Science and Technology. Because of the economic importance of sorghum and millets to the Region, a high percentage of post-graduate training involves research into these grains. Currently 4 masters and 6 doctoral students from 8 African countries are being trained sorghum and millet food science and technology. INTSORMIL collaboration with the Dep. of Food Science provides additional mutually beneficial training and research opportunities.

West Africa – Eastern Region (Niger, Nigeria, Burkina Faso)

Bruce Hamaker
Purdue University

Coordinators

Issoufou Kapran, INRAN/INTSORMIL Coordinator, B.P. 429, Niamey, Niger
Bruce Hamaker, Regional Coordinator, Food Science Department, Purdue University, West Lafayette, IN 47907
Katy Ibrahim, Administrative Assistant, International Programs in Agriculture, Purdue University, West Lafayette, IN 47907

Collaborative Program

The INTSORMIL program in the eastern region of West Africa includes a long-standing collaborative research effort in Niger, and more recent and smaller programs in Burkina Faso and Nigeria. All are multidisciplinary efforts that focus on sorghum and millet improvement in the region, however Niger has the only full range of research activities spanning various production agriculture disciplines, utilization, and economics. Programs in Burkina Faso and Nigeria are positioned with breeding/agronomy and utilization projects to address market-driven issues. ICRISAT has been an institutional collaborator in the region, as well as the regional millet and sorghum networks of ROCEFREMI and ROCARS. The regional networks, however, are undergoing fundamental changes and, in this past year, ROCEFREMI has ceased to function, and although ROCARS has continued, it functions at a minimal level. There are currently discussions amongst regional donors and CORAF, the regional coordinating entity for agricultural research, regarding the future of the networks. INTSORMIL sees the networks as vital partner(s) in realizing a coordinated effort towards regional sorghum and millet research and engagement. At the programmatic level, INTSORMIL research plans are developed between host country PI's and US INTSORMIL collaborators. A first regional meeting was held in Niamey in March 2000 with the aim of sharing research results and strategizing to meet the needs of the region. In this last year, investigators met at the All-PI Conference in Addis Ababa in November 2002. A regional meeting, bringing together PI's from Eastern and Western regions programs in West Africa is planned for April 2004.

List of Disciplines and PI Collaborators

Genetic Enhancement – Sorghum and Millet

Sorghum: INRAN, Niger - I. Kapran; U.S. - M. Tuinstra, U.S. – G. Ejeta

IAR, Nigeria - P. Marley; U.S.– D. Rosenow

INERA, Burkina Faso – A. Neya; U.S. – D. Rosenow

Millet: INRAN, Niger – J. Gonda; U.S. – J. Wilson

Lake Chad Research Institute, Nigeria – I. Angarawai

Sustainable Plant Protection Systems

Entomology: INRAN, Niger - H. Kadi Kadi; U.S.– B. Pendleton

Plant Pathology: INRAN, Niger – A. Kollo (on leave to Texas A&M University/ARS)

INERA, Burkina Faso – Hamidou Traore

Sustainable Crop Production Systems

Agronomy: INRAN, Niger – S. Sirifi, N. Mamane; U.S. – S. Mason

INERA, Burkina Faso - J.B. Taonda; U.S. – S. Mason

Economics: INRAN, Niger – T. Abdoulaye; U.S. – J. Sanders

Utilization and Marketing

Cereal Processing: INRAN, Niger – K. Saley, M. Moussa; U.S. – B. Hamaker

University of Maiduguri, Nigeria – I. Nkama; PU – B. Hamaker

IRSAT, Burkina Faso – B. Bougouma

ITA, Senegal – A. N'Doye

Poultry: INRAN, Niger – S. Issa; U.S. – J. Hancock

Marketing: INRAN, Niger - A. Tahirou

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 the eastern Sahelian region of West Africa 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 to generate income at the farmer and entrepreneurial levels.

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 and millet 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 processing businesses. New projects in breeding and poultry nutrition aim to encourage poultry producers to use sorghum and millet for feed.

Institution Building

Expendable supplies for field and office uses were purchased for the programs, as well as laptop computers and software for some project areas. The major input for the 2002-2003 year was the support, through regional and ME budgets, of regional scientists to attend the All-PI conference in Addis Ababa in November. Fifteen PI's from Niger, Burkina Faso, and Nigeria attended the meeting.

Tahirou Abdoulaye, INRAN/Niger, continued post-doctoral studies with John Sanders at Purdue University on the potential and acceptance of using biotechnology approaches towards improving sorghum and millets in W. Africa, and further developing a millet and sorghum marketing project in the region. These two activities involved travel to Niger, Burkina Faso, Senegal, and Mali.

Nouri Maman, INRAN/Niger, obtained his Ph.D. in agronomy from University of Nebraska under the supervision of Dr. Steve Mason, and returned to Niger as an INRAN scientist.

Pale Siebou, INERA/Burkina Faso, graduated with his M.S. in Agronomy from University of Nebraska with Steve Mason, and returned to Burkina Faso to work as a scientist in INERA.

Hamidou Traore, INERA/Burkina Faso, completed a one year study fellowship on *Striga* at Purdue University with Drs. Gebisa Ejeta and Dale Hess, and returned to Burkina Faso as an INERA scientist.

Dr. Abdourahmane Kollo, INRAN/Niger, joined a regional research project in Chad on desertification as the pathologist, and is on leave from INRAN.

Dr. Issoufou Kapran, INRAN/INTSORMIL host country coordinator made one trip to the U.S. during FY2002/2003, and attended a Rockefeller Foundation sponsored meeting in Uganda with Gebisa Ejeta .

Research Progress

Niger

Sorghum Breeding and Seed Production
I. Kapran, INRAN; G. Ejeta, Purdue University; M. Tuinstra, Kansas State University

Objective

To identify highly productive and well-adapted, open-pollinated varieties and hybrids to be increased for commercial production

Hybrid Program

In addition to breeding for open pollinated varieties, a strong focus is placed on hybrid breeding. Hybrids synthesized at INRAN or coming from Purdue go through nurseries and the best will reach advanced testing. In the preliminary hybrid trial, a yield average of about 2 tons per ha was obtained, which was also the yield of checks NAD-1 and Mota Maradi (MM). The best 3 hybrids yielded, however, over 3 tons per ha each. The best hybrid was P9526AxST9007-5-3-1 which yielded around 3.6 tons per ha while being early maturing. It is a cross between two tan plant parents belonging to the same maturity group, which will ease seed production and provide improved grain quality for food uses. Such early hybrids have the potential for adaptation over a wide area in Niger.

In the 2002 advanced trial which is in its second year, the best hybrid was 223xMR732 (Table 1). Its yield average was 3.8 tons while NAD-1 yielded 3 tons and MM yielded 1.4 ton per ha. Hybrid 223AxMR732 is an excellent hybrid both for grain quality and yield. Preliminary demonstration trials in the area of Konni were attractive to farmers. We are currently working on best agronomic practices for seed production of this hybrid because the two parental lines do not flower simultaneously.

Table 1. Advanced sorghum hybrid yield trial, Kollo 2002.

Entry #	Entry pedigree/designation	Seedling vigor (1-5)	Stand (number of seedlings)	50% flowering (days)	Height (cm)	Grain yield (kg ha^{-1})
1	223AxMR732	1.17f	108a	63ef	132efg	3776a
2	AHF8xMACIA	2.83a	37e	66bcd	180c	2005d
3	P9503xMACIA	1.67def	83abc	63f	180c	2891bc
4	P9511AxMACIA	1.17f	107a	62f	207b	3421ab
5	P9513AxMACIA	1.17f	105a	65def	193bc	3349ab
6	NAD1	2.bcd	73bc	70ab	192c	2905bc
7	223B	2.33ab	66cd	71a	142def	1352ef
8	BHF8	2.50ab	44de	71a	123g	832f
9	P9503B	2.00bcd	69cd	66cde	128fg	1363ef
10	P9511B	1.33ef	91abc	63ef	148d	1017ef
11	P9513B	2.67a	44de	67bcd	127g	922ef
12	TX623B	1.33ef	98ab	66bcd	132efg	2592c
13	MR732	1.83cde	83abc	67bcd	128fg	2873bc
14	MACIA	1.67def	89abc	69abc	143de	3182b
15	MM	1.67def	86abc	56g	243a	1444de
	ANOVA(Entries)	**	**	**	**	**
	Entry grand means	1.82	79	66	160	2262

*, **, significant and highly significant at the 5% level of probability. Entry means were compared using $lsd_{0.05}$.

Seed Production

INTSORMIL has achieved the support to initiate and launch a seed unit at INRAN. Based on similarity of constraints for all major crops of Niger, the seed unit is focusing its efforts to produce foundation seeds for millet, sorghum, cowpeas, groundnuts, and maize. However, the only hybrids are with sorghum. A total of 31 varieties were used and nearly 40 tons of seed have been obtained. This is a value of about CFA 40 million (approx. $75,000). The seed unit invested 12 million in direct labor costs, but even after estimating other costs it appears that seed production is feasible and profitable under the conditions of Niger. The area of commercial seed production deserves emphasis if research efforts are to be realized in farmer's fields.

Sorghum/Millet Quality and Utilization

K. Saley, M. Moussa,
M. Oumarou (deceased), I. Kapran, INRAN;
B. Hamaker and A. Aboubacar, Purdue University

In Memoriam
M. Oumarou and A. Mariama

Primary Objective

To initiate processing and commercialization of value-added sorghum and millet products with particular emphasis on utilization of locally and regionally fabricated food processing equipments

Specific Objectives

- To optimize sorghum couscous and associated products.
- To complete the 1st and 2nd phase of the marketing study in order to learn about the acceptability and the market potential of the processed NAD1 couscous.
- To optimize the processing equipment
- To transfer of the technology to beneficiaries

Findings

Flour and couscous quality was evaluated in hybrid grain grown both in breeding station and farmer's fields. Flour color varied from yellow (irrigated grains) to red-pink (rainfall grains) in both locations. Yield of decorticated grains varied from 43% (rainfall) to 80% (irrigated grains) as determined by amount removed to obtain a white flour.

Flours were obtained and couscous processed for the second phase of a market study to test high quality sorghum processed products produced by the INRAN unit in the marketplace. The first phase of the study tested couscous acceptability at the household level, as well as pricing data was reported before. About 600 kg of couscous and 300 kg of flour was distributed in nine selected stores. A short questionnaire was administered by sales agents to consumers who purchased products in same sales stores. Information related to price, rate of sale, and packaging quality was collected from buyers. Table 2

Table 2. Yield of couscous and associated products (marketing study).

Quantity of NAD-1 grains used (kg)	Yield of bran	Yield of flour	Yield of couscous obtained on flour basis (%) 1-2 mm	Yield of by-products (%) > 2 mm
P1 = 100	41.84	58.16	87	≤ 13
P2 = 100	44	56	88	≤ 12
P3 = 100	45.13	54.87	74	≤ 26
P4 = 100	43.75	56.25	78	≤ 22
P5 = 100	36.3	63.72	89	≤ 11
P6 = 100	35.72	64.28	87	≤ 13
P7 = 100	38.99	61.010	85	≤ 15
P8 = 100	39	61.0	85	≤ 15
P9 = 100	39.33	60.66	91	≤ 18
P10 = 100	40.81	59.18	82	≤ 15.4

Table 3. Microbiological analysis of NAD1 sorghum couscous and flour (marketing study).

Couscous samples	Parameters determined Aerobic bacterias mesophile	E. Coli /g	Moulds-yeast/g
	2000		
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
	2001		
Couscous (irrigated grains NAD-1)	9.10^4	Absent	**Absent**
Couscous (rainfall grains NAD-1)	$6,1.10^4$	Absent	Absent
	2002		
Flour Lossa	$\mathbf{29.10^3}$	**Absent**	**Absent**
Flour NAMARO	$\mathbf{92.10^3}$	**Absent**	**Absent**
Couscous LOSSA	$\mathbf{57.10^3}$	**Absent**	**Absent**
Couscous NAMARO	$\mathbf{204.10^3}$	**Absent**	**Absent**
Cooked Couscous Lossa	$\mathbf{138.10^3}$	**Absent**	**Absent**
Cooked Couscous Namaro	$\mathbf{74.10^3}$	**Absent**	**Absent**
Who-FAO range	$\mathbf{\leq 10^6}$	$\mathbf{\leq 10}$	$\mathbf{\leq 10^4}$

gives the yield of couscous obtained after processing NAD1 hybrid sorghum grains for this study. Yield varied from 74-91% for couscous ranging in particle size from 1-2 mm and 11-18% for the associated products with particle size greater than 2 mm.

Table 3 shows that values for microbiological counts on E. coli, aerobic bacteria mesophile, yeast, and molds for sorghum couscous processed for the market test were well within WHO-FAO acceptable ranges.

In 2001, 450 kg of couscous was packed in 500 g packages and placed in three market segments: open markets, central markets, and sales stores in town. Consumers reactions to price, packaging and rate of sale were monitored.

- According to consumer's responses, the informative and protective functions of the package should be improved to prevent breakage and damage. Also, they requested that information be added about the nutritive value and the shelf- life of the product.

- Price responsiveness: consumer suggested price/packaging type range from:

  200 –500 F CFA with an average cost of 347 F/500 g; 300 – 900 F CFA with an average cost of 531 F/ 1 kg, 1,500 – 2,750 CFA with an average cost of 1,852 CFA/ 5 kg, while the price of 500 g of couscous was fixed at 500 F CFA during the study.

- Sales realized in the supermarket represented about 60% of the total sales, indicating that the majority of buyers will be consumers with comparably high income.

In 2002, a second market test was conducted on 165 kg of couscous and 265 kg of sorghum flour in order to confirm consumer reaction to a new proposed price of 350 CFA/500g of the couscous and 250 CFA/1 kg of the flour. In 2003, a third market test was conducted on 150 kg of couscous and 100 kg of flour to satisfy demand for repurchase of the products by buyers. Price in this last study was fixed at 500 CFA/500 g in the supermarket and product quickly sold with repurchase suggesting that the high end market segment will pay somewhat higher prices.

Workshops/Promotional Exhibitions/Sales

Couscous and flour processing was exhibited at:

- INRAN/ICRISAT annual workshop, September 2002
- National Agricultural Trade Fare, N'Konni, Niger, March 2003
- Worker's Day, May 2003

Training

- A team of private processors was trained to process sorghum and millet products at the pilot unit in the cereal lab at INRAN April 2 to May 2, 2002.

Entomology

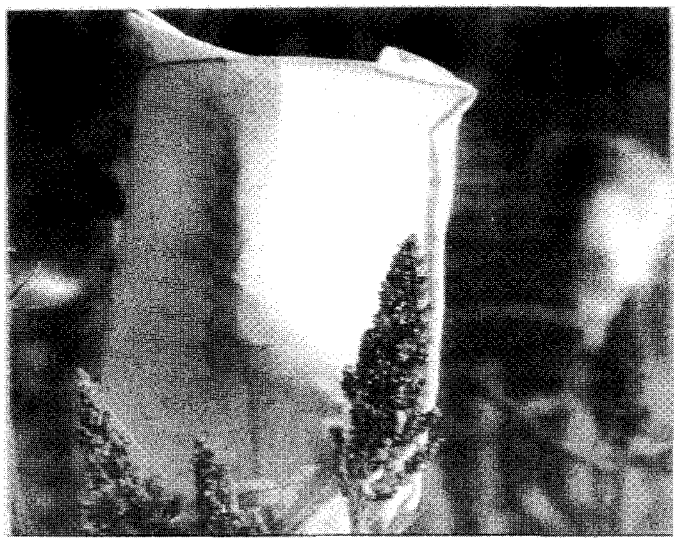
H. Kadi Kadi and I. Kapran, INRAN;
B. Pendleton, West Texas A&M University

Sorghum Midge

Primary Objective

- To determine the sorghum lines or varieties that are resistant to sorghum midge under field conditions

Figure 1. Head cage technique to study resistance to sorghum midge.



Specific Objectives

- To determine the periods of maximum midge density on each sorghum lines or varieties tested
- To identify sorghum lines with stable resistance against sorghum midge
- To develop and release promising varieties to farmers
- To develop new sorghum lines that have higher performance

The sorghum midge is most encountered insect pest in Niger on sorghum causing damage to the flowering panicles. The midge is found in all the areas of sandy or clay soils where the sorghum crop and its related species are grown. The sorghum midge is most damaging to late maturing varieties with a long vegetative phase. Such varieties suffer non-formation of up to more than half their seeds.

Field experiments were conducted at Maradi located in the East-Central part of Niger (15° 26° North and 8°33° East). The mean annual rainfall in that location is between 400 and 500 mm. A head-cage technique was used to screen sorghum lines for resistance to sorghum midge under field conditions. Caging sorghum midge with sorghum panicles is an important method for avoiding escape, and permits screening for midge resistance under uniform insect pressure. The head-cage technique was developed and standardized at ICRISAT (Fig. 1). Cages consist of a cylindrical wire frame made of 1.5-mm diameter galvanized iron wire. The loop attached to the top ring rests around the tip of panicle, and the extensions of the vertical bars at the lower ring are tied around the peduncle with a piece of G.I wire, or electric wiring clips. These prevent the cage from slipping when disturbed by wind or other external factors.

Based on the results, sorghum lines 99 SSD F9-18, 99 SSD F9-21, 99 SSD F9-33, 99 SSD F9-35 and ICSV 745 were identified as resistant to midge. These lines had the lowest (10-20%) grain loss even though some of these lines had high damaged spikelets. Based on three years of screening, we can confirm that the lines 99 SSD F9-21, 99 SSD F9-33, 99 SSD F9-35 and ICSV 745 are resistant to sorghum midge.

The process of developing new sorghum lines resistant to midge started in 2000 (sorghum breeding and entomology). Crosses of two resistant varieties (ICSV 745 and ICSV 88032) were made with 4 local and improved varieties (MOTA MARADI, MR 732, ATX 623 and IRAT 204). The most promising populations will be advanced to F4 generation during the 2002-03 cropping season.

Millet Head Miner

Objective

To assess the abundance and causes of mortality of millet head miner (*Heliocheilus albipunctella* de Joannis) under field conditions so that natural enemies-host interactions can be understood

Specific objectives will be to: 1) verify methodology for sampling and manipulating millet head miner populations and millet head miner natural enemies on millet, and 2) conduct cage exclusion studies on natural enemies attacking millet head miner on millet.

These studies are in the initial phase. Data analysis will focus on estimates of parameters (stage-specific survivorship, reproductive and death rates, etc.). Attention will be focused on life stages with significantly lower survivorship and on factors (natural enemies) that cause this low rate. Sample variances will be calculated for all data obtained on millet head miner. This will permit better development of the sampling methodology and understand damage levels of millet head miner.

Agronomic Studies for Producing Hybrid Sorghum Seed
S. Sirifi, I. Kapran, INRAN;
S. Mason, University of Nebraska, Lincoln

Pearl Millet Microdose Study

During the 2001 and 2002 cropping seasons, a study on microdosing of pearl millet was conducted on-station and on-farm. Sites were the Kalapate station and in some surrounding villages; a region characterized by average rainfall of 400-500 mm and poor sandy soil. Planting occurred in June and the usual field work – weeding, thinning, and harvest – was done one time each season. Crops were harvested in September 2001 and October 2002 at physiological maturity. Central rows were only harvested for stover and grain weight measurements. Average rainfall for the two seasons was 577.3 mm in 25 days and 609.0 in 32 days in 2001 and 2002, respectively. The rainy season lasted four months in 2001 and six months in 2002. Production of grain was influenced by diseases, pest, and soil conditions.

Results of an across year analysis showed good interaction between treatment and year for grain and stover yield in the on-station trial and for grain yield only in the on-farm trial. In the former, highest grain yield (1340.6 kg ha^{-1}) was obtained with microdose treatment of + 20 units/ha P + 30 units/ha N treatment 2002 season (T7*Season 2), while, in on-farm trials, the greatest grain yield was 869.3 kg ha^{-1} for microdose treatment of + 20 units/ha P (T3) in 2002. In general, grain production was better in 2002 than in 2001 for all treatments and season interactions. Nitrogen (N) and phosphorus (P) contents were determined for stover produced in the 2001 experiment. Stover N and P concentration and uptake were very low and were not different among treatments for the on-farm and on-station trials. N concentrations varied from 0.50% for T4 (microdose + 40 units/ha P) and T5 (microdose + 30 units/ha N) to 0.75% for T1 (check) in the on-station experiment. P concentration in the same experiment varied from 0.137% for T1 (check) to 0.29% for T7 (microdose + 20 units/ha + 30 units/ha N). In the on-farm experiment, stover N and P concentrations were about the same levels as those obtained in the on-station study (0.50 to 0.60% for N and 0.15 to 0.315% for P).

Hybrid Sorghum Seed Production

Experiments were conducted at the Lossa research station during 2001 and 2002 cropping seasons on density and fertilization effect in production of hybrid sorghum seed. Four N (urea) levels under four planting densities were used in seed production of two hybrid sorghums – NAD1 and F1 223. The objective of the study was to determine seed yield potential at different density and nitrogen levels in the production of these two hybrids. Split plot design was used with hybrid parent lines as main plot and density, and nitrogen level combinations as subplots. Treatments for density were 15,625; 20,833, 31,250, and 62,500 plants/ha, while N rates were 0, 50, 100, and 150 kg ha^{-1} of urea. Each trial was composed of three replications.

Analysis of variance was performed only on data from the 2001 season trials. Seed production failed in the 2002 season for NAD1 and F1 223 trials because of early flowering of the female line compared to that of the male parent. Late planting, drought, pest diseases, and insufficiency of supplemental irrigation were also factors which contributed to the failure of the crop. Results of the 2001 trial showed significant interactions between density and N rates for grain and stover yield of NAD1 and for grain yield only for F1 223. For NAD1, maximum seed yield (452.1 kg ha^{-1}) was obtained with density level of 31,250 plants/ha and nitrogen rate of 200 kg ha^{-1} of urea. For the hybrid sorghum F1 223, on the other hand, the greatest seed yield was produced with density level of 31,250 plants/ha and N rate of 200 kg ha^{-1} of urea. The treatment combination of 31,250 plants/ha density + 200 kg ha^{-1} urea N level seemed to be the best combination for sorghum hybrid seed production in the Lossa station 2001 trial. Sorghum hybrid seed production in this experiment was still low, but can be further increased greatly by improving growing conditions such as period of planting, availability of soil moisture by accurate supplemental irrigation, and crop protection against pests and diseases.

Nigeria

Pearl Millet Breeding

Multilocational Evaluation of Pearl Millet Male-Sterile Based Hybrids
I.I. Angarawai, W. B. Ndahi, Z.G.S. Turaki and I. E. Ezeaku, LCRI

Pearl millet is a staple cereal for over 40% of the Northern Nigerian populace especially in areas with 300 – 700 mm annual rainfall. This zone is also characterized by high pressure on land for infrastructural development competing with agricultural land. Thus the quest for high yield, early maturing and good food quality millet varieties that give high return per minimum input per unit area cannot be over-emphasized. Results from previous variety evaluation indicated that agronomic practices can but only help in expressing cultivars' genetic potential. Thus, the hybrid development project was conceived to exploit the heterotic potential, which forms the objective of this trial.

During the 2002 season, eight hybrids from 2001 season selections along with 2 checks were retained and evaluated in RCBD with 3 replications to confirm the previous results across five states in millet growing zones of Nigeria. Results of combined analysis indicated two hybrids, LCIC MH99-10 and LCIC MH99 – 25, to perform better with yield advantage of about 20% higher than farmer's local varieties. Yield potential ranged from 2.3 – 5.0 t ha^{-1} in favour of the hybrids. These hybrids based on their 2001 performance were advanced to on-farm trials in 2002 season. Results from farmer's trial revealed that LCICMH99-10 has a good dehulling quality, better 'fura' processing, and is moderately resistant to downy mildew.

Report for its official registration and release to farmers in Northern Nigeria is currently being prepared for submission to National Genetic Resource and Biotechnology Centre Moor Plantation, Ibadan, Nigeria for the 2004 meeting.

Evaluation of Top-cross Pearl Millet Hybrids
I.I. Angarawai, W. Hanna and W. B. Ndahi

During 2002 season, 23 top-cross hybrid lines, selection from 2001 season, were obtained from Tifton Experimental Station Georgia, U.S. and evaluated at two locations - Maiduguri and Gashua in Nigeria. The objective was to identify their adaptability, stability and resistance to downy mildew and *Striga*, grain yield, and food quality characteristics. Similar results with respect to yield compared to 2001 evaluation were observed in which hybrid lines with SOSAT-C88 as female parent gave higher grain yields (2 – 3 t ha^{-1}) with less than 5% downy mildew infestation. As a good general combiner for grain yield, conversion of SOSAT-C88 into male-sterile lines with A4 cytoplasm reached an advanced stage (BC4).

Millet Utilization
I. Nkama, S. Modu, M. Badau, A. Jato, University of Maiduguri; I. Angarawai, C. Uga, LCRI; B. Hamaker, Purdue University

Physical, Chemical, Rheological, Nutritional, and Sensory Aspects of Sorghum and Millet

The major sorghum and millet production and utilization constraints in Nigeria include, lack of improved varieties and lack of adoption of new production and utilization technologies for farmers and processors. An important use of sorghum and millet for food in Nigeria is in the preparation of tuwo, kunu, ogi, ndaleyi, masa, sinasin, and dakuwa. Grain and flour properties that contribute to the production of acceptable food products need to be defined. Also improvement of traditional food products and revolutionary change of sorghum and millet to new shelf stable foods and industrial products is needed to encourage increased production of grain. Sorghum has faired better than millet in Nigeria because additional industrial uses are now available in areas of beer brewing, malt drinks, biscuits, and animal feeds.

Eleven multi-location pearl millet hybrid lines and one farmer's local grown by Lake Chad Research Institute (LCRI), Maiduguri, Nigeria were evaluated for their physical, chemical and sensory attributes. There were variations in 1000 kernel weight (8.9 – 10.96g), 1000 kernel volume (5.5 – 9.85ml); density (1.05 – 1.63 g/ml), and germination percentage (85.5 – 97.0%). Also proximate composition varied considerably with the exception of crude fibre. Protein ranged from 10.6 – 13.8 %, fat 4.1 – 6.8%, ash 1.3 – 1.8%, and crude fibre 2.0 – 2.4%. Protein, fat and ash contents of all the hybrids ranged within the normal values reported for pearl millet and also in comparison with the farmer's local. Preliminary studies on the acceptability of these hybrids for the preparation of kunun zaki, ogi, and couscous showed that all the hybrid lines can be used to produce acceptable products. These hybrids can be considered as good materials for food processing. However, further studies will still be required as the hybrids are to be advanced for on-farm trials in the farmers' fields in the coming season.

Studies on Tuwon Tsari Flour

Tuwo is a thick porridge which is prepared from rice, maize, sorghum, or millet depending on taste, cost of grain, geographical location and availability of grain. Tuwo is common staple food item for about 57 million people living in Northern Nigeria. Tuwon tsari is a variation of normal tuwo prepared specifically from pearl millet. During its preparation the grain is dehulled, steeped in acid water prepared from lime juice or tamarind fruit pulp extract or kadal (steep water from previous fermentation) for 2 to 3 days, sun-dried and ground into flour. The process of fermentation removes the colored pigment. The flour is cooked into a thick gruel before serving.

During decortication and production of tsari flour from 4 different pearl millet cultivars (Ex Borno, GB 8735, SOSAT - C88, and Zango), we observed that protein content decreased on average by 24% (10.11 to 7.63%), fat by 24.3% (5.30 to 4.1%) and ash by 70.6% (1.58 to 0.46%). There was no significant difference in the amount of protein recovered among the 4 cultivars, but recovery in fat and ash were significantly different among the cultivars. In vitro carbohydrate digestibility of the native grain was low (23.4%). On processing, this increased to 71.5% (average). The in vitro protein digestibility also increased on average from 47.9% in the native grain to 54.8% in the tsari flour. Phytic acid content of the pearl millet samples decreased by 72% (average) in the tsari flours, this resulted in the increase in mineral availability in all samples by 20% for calcium, 17% for copper and 30% for phosphorus.

All tsari flour samples (6% w/w) had similar hot paste viscosity (mean) 35,840 centipoises). The peak viscosity for all samples was similar, although tsari flour from Zango millet gave slightly lower peak viscosity (BU). Tsari flour samples had a fairly high set back value which indicates that the cultivars would give a good stiff porridge of the type that is normally consumed with fingers. Sensory evaluation studies revealed significant differences in color, flavor, taste, texture and overall acceptability of the tsari flour samples from the four cultivars. Tuwon tsari from Zango (a popular local millet grown in North West Nigeria) and SOSAT – C88 (improved cultivar released in 1999 by LCRI) received the highest scores. No sample was rated below average in all the attributes considered. The lowest average score was 6.6 on a nine point hedonic scale. Studies in the Department of Food Science and Technology Laboratory indicate that the tsari flour can also be used in the preparation of weaning foods, biscuits, couscous, dakuwa (snack food from millet – groundnut flour blend) and fura.

Dissertation and Theses

Sherif Modu (2003). Production, physicochemical and sensory characteristics of ogi from different pearl millet cultivars (pennisetum glaucum). PhD Thesis University of maiduguri (completed).

Cecilia O. Ajalla (2003). Production, physicochemical and sensory characteristics of tuwon tsari (fermented thick porridge) from different pearl millet varieties. M.Sc. thesis. University of Maiduguri (completed).

David I Gbenyi (2003). Studies on the physicochemical, nutritional and sensory properties of dakuwa from malted cereal – legume blends. M.Sc. thesis. University of Maiduguri. (completed).

Mamudu Badau a Ph.D. student at Tafawa Balewa University, Bauchi, Nigeria is at the final stages of his study on the malting characteristics of pearl millet cultivars and their food application.

Sorghum Trials

P. Marley, D.A. Aba, J.A.Y. Shebayan,
L. Bamaiyi, IAR; D. Rosenow, Texas A&M University

In the International Sorghum Anthracnose Virulence Nursery trial, nine lines including B.TX 398, IS 854, SC 283, IS 12467 R.TX 434, SC 326-6 (IS 3758), IS 18760, SC 414-12E (IS 2508) and IS 6959 were found to be resistant (average disease score of 1-3). Two of these lines, SC 326-6 (IS 3758) and SC 414-12E (IS 2508), have currently been selected alongside our materials (SK5912, KSV 8, NRL 3 and Yar'ruruka) for genetic mapping. Of 28 lines that could be evaluated, 9 lines were resistant to foliar anthracnose. All 28 lines were resistant to covered, loose, long, head smut and grain mould. Other foliar diseases especially grey leaf spot and leaf blight were not observed. Insect infestation could not be assessed due to low insect pressure. Nineteen of the lines were resistant to foliar anthracnose while three lines were susceptible.

Results of the *Striga* control nursery showed that lines 97-SB-F5-DT-63, 97- SB-F5-DT-64, MALISOR 92-1, SRN 39 and SAMSORG 41 (ICSV 111) supported low *Striga* infestation and also showed low number of stands infested with *Striga*. This indicates that the lines are resistant to *S. hermonthica*. Lines CMDT 45 and SAMSORG 14 (KSV 8) had high *Striga* infestation, but SAMSORG 14 gave the highest grain yield. This clearly either indicates resistance or a high level of tolerance.

In the Advanced Medium Maturing trial, days to flowering ranged from 72.5 for entry 8(97-SB-F5DT-38) to 85 for entry 26 (SURENO 99L-1048). This shows low variation for that character (CV 5.55%). Plant height ranged from 95cm for entry 3 (97-SB-F5DT-149) to 272.5cm for entry 13 (97-SB-F5DT-97). There seems to be a wider variation in this trait (CV 42.41%) than in the previous one. Grain weight ranged from 266.7 kg ha^{-1} for most of the entries to 1866.7 kg ha^{-1} for entries 21 and 25 (Samsorg 14 and ICSV 905). These are local varieties. Only entries 22, 23 and 24 (KL-2, makaho Da Wayo and Farar Dawa) gave yields above 1000 kg ha^{-1}. All the exotic materials performed below 700 kg ha^{-1}. There are still some promising materials if tested for another year to confirm their performance.

In the Advanced Late Maturing trial, days to 50% flowering ranged from 51 for entry 1(97-FA-FST-71-2) to 85 for entry 16 (Samsorg 17). There was low variation within these traits (CV 29.62%). Plant height ranged from 122.5 cm for entry 5(97-SB-FST-154). The entries seemed to differ much in height (CV. 36-46%). For grain yield, they ranged from 333.3 kg ha^{-1} for entries 5 and 7 (97-SB-F5DT-154 and 98-FA-FST-41) to 1133 kg ha^{-1} for entry 16 (Samsorg 17). Entry 16 is later than all other entries and gave the best yield. Entries 1, 8, 9, 10, 11 and 12 hold some promise in terms of yields.

It is expected that most of these trials will be established in the 2002 cropping season. Further, this collaborative program has started research and extension activities in the area of sorghum utilization. This involves the development of sorghum based food products and an improved charcoal–based oven for use in baking sorghum based products. This improved oven was developed in 2001 under the program and is currently under testing. This will be extended to rural women for enhancement of their income.

Burkina Faso
Mechanized Zai and Microdose Research

J.B. Taonda, INERA;
S. Mason, University of Nebraska, Lincoln

The traditional zai system composed of planting pearl millet seed in a small hole with a small amount of manure increases water infiltration on some soils and results in increased yield, but requires considerable land labor. Scientists at INERA have developed a mechanized zai using animal traction. The objective of this study was to determine the effectiveness of the mechanized zai to the traditional zai and a flat-planted control across six different soil types in Burkina Faso. The study was conducted on farms in three villages with each farm considered a replication. The soil types present on the farms was sandy,

sandy loam, sandy clay, clay, gravelly clay and gravel. Microdose studies showed notable improvement in millet yield.

Networking

Networks in West Africa for millet (ROCEFREMI) and sorghum (ROCARS) are currently in a state of transition with the former now not functioning and the latter scaled down. INTSORMIL supported representatives to attend a joint network planning meeting, and continues to support a renewal of the regional networks. Networking occurred with the Millet-Sorghum Initiative coordinated by Global 2000 involving contracting between farmers and processors, and farmer warrantage/contracting conducted by O. Botourou and J. Sanders. World Vision supports seed activities in the Maradi region of Niger.

Partners in the Niger sorghum hybrid seed production effort include the IFAD/INRAN technology transfer project, the IFAD/Tillabery project, and the WINROCK-ONFARM project.

West Africa - Western Region (Mali, Ghana, Senegal)

Darrell T. Rosenow
Texas A&M University

Regional Coordinators

Dr. Aboubacar Touré, Sorghum Breeder, Regional Coordinator, IER, Sotuba Research Station, B.P. 262, Bamako, Mali
Dr. Darrell T. Rosenow, Sorghum Breeder, U.S. Regional Coordinator, Texas A&M University, Texas Ag Experiment Station, Route 3, Box 219, Lubbock, TX
Dr. Ndiaga Cissé, Sorghum Breeder, Co-Country Coordinator, ISRA/CNRA, Bambey, Senegal
Dr. Demba Farba M'Baye, Pathologist, Co-Country Coordinator, ISRA/CRZ, Kolda, Senegal
Dr. Samuel Saaka Buah, Agronomy, Co-Country Coordinator, SARI, Wa Station, Ghana
Dr. Ibrahim D.K. Atokple, Sorghum Breeder, Co-Country Coordinator, SARI, Tamale, Ghana

Collaborating Scientists

Dr. Minamba Bagayoko, Agronomist, IER, Niono Center, Segou
Ms. Fatim Cisse, Cereal Scientist, IER, Sotuba Station, Bamako, Mali
Dr. Niamoye Yaro Diarisso, Entomologist, IER, Sotuba Station, Bamako, Mali
Dr. Mamadou Doumbia, Soil Scientist, IER, Sotuba Station, Bamako, Mali
Dr. Yocouba Doumbia, Entomologist, IER., Sotuba Station, Bamako, Mali
Dr. Mamourou Diourté, Pathologist, IER, Sotuba Station, Bamako, Mali
Dr. Mountaga Kayentao, *Striga* (Weed Science), Sotuba Station, Bamako, Mali
Mr. Mamadou N'Diaye, Entomologist, IER, Cinzana Station, Segou, Mali
Mr. Moussa Sanogo, Millet Breeder, IER, Cinzana Station, Segou, Mali
Mr. Abdoul Wahab Touré, Agronomist, IER, Sotuba Station, Bamako, Mali
Dr. Samba Traoré, Agronomist, IER, Cinzana Station, Segou, Mali
Mr. Amadou Fofana, Millet Breeder, ISRA/CRZ, Kolda, Senegal
Mr. Mamadou Balde, Entomologist, ISRA/CNRA, Bambey, Senegal
Mr. Djibril Badiane, Entomologist, ISRA/CRZ, Kolda, Senegal
Mr. Moctar Wade, Weed Scientist (Striga), ISRA/CNRA, Bambey, Senegal
Dr. Steven K. Nutsugah, Pathologist, SARI, Tamale, Ghana
Dr. Paul B. Tanzubil, Entomologist, SARI, Manga Station, Ghana
Mr. Luke N. Abatania, Economist, SARI, Wa Station, Ghana
Mr. David A. Afribeh, Millet Breeder, SARI, Manga Station, Ghana
Dr. Gebisa Ejeta, Sorghum Breeder/Striga, Purdue University, West Lafayette, IN 47907
Dr. John Leslie, Pathologist, Kansas State University, Manhattan, KS 66506
Dr. Clint Magill, Pathologist/Molecular Genetics, Texas A&M University, College Station 77843
Dr. Stephen Mason, Agronomist, University of Nebraska, Lincoln, NE 68583-0915
Dr. Bonnie Pendleton, Entomologist, West Texas A&M University, Canyon, TX 79016
Dr. Gary Peterson, Sorghum Breeder, Texas A&M University, Lubbock, TX 79403
Dr. Lloyd Rooney, Cereal Scientist, Texas A&M University, College Station, TX 77843
Dr. John Sanders, Economist, Purdue University, West Lafayettte, IN 47907
Dr. Jeffrey Wilson, Millet Breeder, Pathologist, USDA-ARS, University of Georgia, Tifton, GA

Collaborative Program

The initial INTSORMIL collaborative program in this area was established in Mali which has a large multidisciplinary research program. The program centers around Malian scientists and each Malian scientist develops research plans cooperatively with a U.S. 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, disease control strategies, and *Striga* control.

A new thrust to the program previously centered in Mali began in 2000-2001 with the initiation of collaborative INTSORMIL research in Ghana and Senegal. A MOU between INTSORMIL and ISRA (Institute of Agricultural Research) in Senegal was signed in early 2001. An existing MOU with SARI (Savanna Agricultural Research Institute) in Ghana which involved agronomic research between Dr. S.S. Buah and Dr. J.W. Maranville was utilized to include the new collaborative efforts in Ghana. In 2002 a new MOU was signed between INTSORMIL and ITA (Institut de Technologic Alimentaire) in Dakar, Senegal which deals with commercialization of grain in Senegal.

Collaborative research was initiated in the 2001 crop season in both countries in breeding, pathology, entomology, and *Striga*, and also in agronomy in Ghana, continuing some of the research initiated in collaboration with Dr. Maranville. Breeding, disease, insect, drought, and *Striga* trials were developed collaboratively with Malian and U.S. INTSORMIL scientists and grown in Ghana and Senegal as well as in Mali. Some of these were also offered to scientists in Niger, Burkina Faso, and Nigeria, and scientists there requested seed of specific nurseries according to their interests and needs. Also, an elite sorghum germplasm nursery from worldwide sources was sent to Ghana and Senegal to broaden the genetic base of their breeding program. The mechanism for developing collaborative research plans is evolving as new INTSORMIL PIs initiate their programs, and PIs are able to interact and/or travel to these new countries. The PI Conference in Ethiopia in November, 2002 served as the initial broad based planning conference for collaborative research efforts among Mali, Ghana, and Senegal as well as with the Eastern Region (Niger, Nigeria, and Burkina Faso) scientists.

Other Collaboration

Collaboration involving germplasm exchange, workshops, monitoring tours, and specific research projects continued with the regional networks ROCARS (WACSRN), and ROCAFREMI as well as with ICRISAT at Samanko outside Bamako, Mali. Unfortunately, ROCARFEMI ceased operation prior to the 2002 crop season, and ROCARS funding for the 2002 crop season was ended, effectively ceasing operation. There also was cooperation with NGOs such as World Vision, Winrock, AMEDD, FDS, and GRADECOM in evaluation of potential new cultivars as well as with the Soil Management CRSP and the SYNGENTA Foundation.

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 Syngenta Foundation and World Bank support the IER research program.

Sorghum/Millet Constraints Researched

Plant Production Constraints

Grain yield level and stability in sorghum and millet production is of major importance in all the countries. Drought is a serious constraint to production over much of the area. Diseases, insect infestations and *Striga* significantly affect both sorghum and millet production. Head bugs and associated grain molds adversely affect sorghum yield and grain quality of sorghum. Anthracnose is a very severe sorghum disease in the more humid areas and long smut is severe in the drier regions. Sooty stripe can be a severe leaf disease problem. *Striga* is a major constraint for both sorghum and millet. Downey mildew is a serious problem on pearl millet.

Land Production Constraints

Low soil fertility combined with the low yield and unstable yields of local cultivars affect sorghum and millet production. Major soil related constraints to production 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, industrial sorghum and millet based products, and enhanced use for animal feed are needed to encourage production.

Research Methods

The collaborative program in the Western Region of West Africa 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 effort to develop new food products from sorghum and millet is emphasized in Mali 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 in the area are presented in individual PI project reports in this publication. This Regional Annual Report will emphasize research done by IER in Mali, SARI in Ghana, and ISRA in Senegal.

Sorghum Breeding

The sorghum breeding program in IER in Mali is a large and diverse program. The program utilizes 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 previously developed ICRISAT 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 toward white-seeded, tan-plant genotypes. Breeding for the dry northern areas also involves crosses with local Durras and good yielding Bicolor derivatives 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 more southern, high rainfall sites of Farako (Sikasso), Finkolo, 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 2002 rainy season, 60 new crosses were made at Sotuba, and the F_1's grown during the 2002-03 off-season nursery to get F_2 seeds.

From the multilocation evaluation of 108 F_2 families in the 2002 rainy season, 491 single-plant selections were made at Samanko, 254 at Cinzana and 112 at Finkolo. These selections will be advanced by the pedigree method. We evaluated 778 F_3 progenies mostly derived from tan guinea cultivars. The F3 families were grown at Samanko, Cinzana, Finkolo and Bema and we selected, 203 single heads at Sotuba, 89 at Cinzana and 85 at Béma. The F_4 and F_5 generations were evaluated according to the maturity group. The early and medium F_4 progenies were evaluated at Kolombada, Béma and Cinzana. We selected 139 panicles at Béma, 64 panicles at Kolombada and 147 panicles at Cinzana. The late F_4 progenies were evaluated at Finkolo and Kita with 18 and 65 panicles selected, respectively, at Kita and Finkolo. In the early F_5's we selected 15 lines at Béma and 18 at Cinzana. The medium F_5 progenies were evaluated and we selected 43 lines (28 at Sotuba and 15 at Kolombada). A total of 19 lines were selected for F_5 progenies at Finkolo and Kita. The F_5 selections move to the off-season for seed increase for entry into Group I yield trials the following year.

Yield trials of improved varieties in 2002 were divided into three maturity groups, Early, Medium, and Late with three groups (GI, GII, GIII) within each maturity corresponding to the years in tests (I - first year, II - second year, III - third year). Evaluation was for maturity, yield, agronomic desirability, and food quality.

Advanced Early Variety Trials

We evaluated our three advanced elite early variety group trials (GI, GII and GIII) at two locations, Bema and Cinzana. In GI (first year evaluation) with 46 entries at Cinzana and at Bema there were significant differences among entries for grain yield, plant height and flowering date. At Bema the highest yielding varieties were 01-CZ-F5P-244 and 01-BE-F5P-288 with 2000 kg ha^{-1} while the yield of local check was 1555 kg ha^{-1}. At Cinzana the variety 01-CZ-F5P-244 and the local had the same yield. In GII (two year evaluation) at Cinzana and Bema with 26 entries there were no significant differences among lines for the three variables studied.

After three years of evaluation, of 18 entries at two locations (GIII), four lines 99-BE-F5P-66 (2246 kg ha^{-1}), 99-BE-F5P-67 with 2046 kg ha^{-1}, 99-BE-F5P-69 (2002 kg ha^{-1}) and 99-BE-F5P-95 (2006 kg ha^{-1}) were retained for grain yield and grain quality and will be in on-farm tests in 2003 (Table 1). The line, 99-BE-F5P-128-1, performed well and was selected by 31 out of 34 farmers. It also appeared to have some tolerance to *Striga* as well as excellent resistance to the head bug (*Eurystylus*).

Advanced Medium Variety Trials

In GI at Sotuba, the variety 01-SB-F5-DT-198 ranked first with 4028 kg/ha followed by 01-SB-F5-DT-221 (3694 kg/ha); 01-SB-F5-DT-23-1 (3528 kg ha^{-1}); 01-SB-F5-DT-203 (3333 kg ha^{-1}); 01-SB-F5-DT-243 (3278 kg ha^{-1}) with a grain yield of 3000 kg ha^{-1} for the local check. At Kolombada the average yield (869 kg ha^{-1}) was lower than at Sotuba with the highest yielding variety, 01-SB-F5-DT-22,1 producing 1972 kg ha^{-1} compared to 987 kg ha^{-1} for the local check.

In GII at Sotuba, among the 26 varieties tested, the highest yielding variety 00-SB-F5-DT-18 gave 4228 kg ha^{-1} against 3583 kg ha^{-1} for the local, with a test mean yield of 2687 kg ha^{-1}. At Kolombada, there was no significant difference among entries for grain yield.

Table 1. Mean performance data on selected improved breeding varieties from sorghum yield trials, Mali, 2000-2002.

Designation	Pedigree	Days to 50% flowering	Plant height (m)	Grain yield (kg/ha^{-1})
Early GIII - (3 years - 2 locations)				
99-BE-F5P-66*	(89-SK-F4-53-2*Naga White)	73	1.7	2246
99-BE-F5P-128-1	(N'Tenimissa*Seguetana-CZ)	75	3	2102
99-BE-F5P-67*	(ICSV1078*89-CZ-CS-F5-21AF)	75	1.8	2046
99-BE-F5P-95*	(E36-1*(N'Tenimissa)	77	1.9	2006
99-BE-F5P-69*	(ISCV1078*89-CZ-CS-F5-21AF)	69	2.3	2002
CSM-63E (check)	Improved Local	66	2.9	2112
Local (check)		71	3.2	1965
(Test Mean)		72	2.5	1905
Medium GIII - (3 years - 2 locations)				
99-SB-F5DT-170-2*	(N'Tenimissa*CSM388)	82	3	2293
99-SB-F5DT-170-1*	(N'Tenimissa*CSM388)	82	2.8	2263
99-SB-F5DT-198*	(N'Tenimissa*Seguentana CZ)	86	3.5	2243
CSM 388 (check)	Improved Local	90	3.6	1683
Local (check)		91	3.4	2315
(Test Mean)		86	3.2	1999

*Entries to be advanced to on-farm trials in 2003.

After three years of evaluation (GIII) at two locations, three varieties, 99-SB-F5DT-170-1, 99-SB-F5DT-170-2, and 99-SB-F5DT-198 were selected for on-farm testing (Table 1). These lines also gave the highest decortication yield, the hardest grain, and the best tô stability.

Advanced Late Variety Trials

In GI with 40 entries at Finkolo and at Kita there were no significant difference among entries for grain yield. The average yield at Finkolo was 2187 kg ha^{-1}.

On-Farm Trials

Six farmers were selected in each of two locations, Cinzana and Sirakorola, where fifteen early maturing new varieties were compared to the local check of the farmer. Each plot consisted of 500 m^2; rows were 0.75 m apart and 5 m long. Varieties were evaluated for maturity, yield, agronomic desirability, and food quality. The analysis showed significant differences among entries for grain yield. Two lines 98-CZ-F5P-84 and 98-CZ-F5P-31-1 showed higher grain yield than the local. while the line 98-CZ-F5P-74-1 had the same grain yield as the local check.

For medium maturity varieties, 6 farmers at Ouéléssébougou and Bancoumana evaluated 9 varieties compared to the local check. The analysis showed significant difference among entries for grain yield at Ouéléssébougou. The variety 98-SB-F5DT-82 and the local check ranked first with more than1400 kg ha^{-1} followed by 98-SB-F5DT-52 (1220 kg ha^{-1}) and 98-SB-F5DT-19-3 (1130 kg ha^{-1}). 98-SB-F5DT-52 was appreciated by farmers for its forage and grain qualities.

In another on-farm test of medium maturity varieties, 6 farmers at Ouéléssébougou and Bancoumana compared to the local check for two years. The results showed the 97-SB-F5DT-150 as the highest yielding variety with more than 1400 kg ha^{-1} against 1100 kg ha^{-1} for the local. In Table 2, the farmer's desirability ratings are presented.

For the late maturity on-farm trial, 6 farmers were selected at Kita and Finkolo to evaluate 4 varieties. The analysis showed significant difference among entries for grain yield at Ouéléssébougou. The analysis showed significant difference among entries for grain yield at Kita. Two (97-KI-F5-22 and 96-CZ-F4P-99) and the local check ranked first with more than1700 kg ha^{-1}.

Seed Multiplication

Listed below are some improved cultivars and new breeding lines for which seed was increased by the Mali IER sorghum breeding program in 2002.

Varieties	Localities	Area (ha)	Quantity (kg)
CSM-63 E	Béma	1/2	500
MALISOR-92-1	Béma	1/2	200
CSM-388	Kolombada	¼	100
N'TENIMISSA	Kolombada	¼	100
97-SB-F5DT-64	Kolombada	¼	100
CSM-388	Tamala and	½	400
Seguetana	Ouélessebougou	½	400
Wassa	Tamala and Ouélessebougou Kafara	¼	200
96-CZ-F4P-98	Kita	¼	200
96-CZ-F4P-99	Kita	¼	200
96-CZ-F4P-98	Kebila	¼	62
96-CZ-F4P-99	Kebila	¼	22
Sakoïka I	Kebila	¼	210

Table 2. Farmer's appreciation of medium maturity on-farm varieties[1/].

Variety	Plant vigor	Maturity	Yield appreciation	Grain quality	Tô quality	Couscous quality	Porridge quality
97-SB-F5DT-74-1	3	2	3	3	2	2	2
97-SB-F5DT-150	1	2	1	1	1	1	1
Tiemaring (check)	3	3	3	3	3	3	3

[1/] 1: excellent, 2: very good, 3: good, 4: average, 5: poor

Senegal

A backcross program to introduce earlier maturity into the varieties CE151-262, CE196-7-2-1, CE 145-66, and CE180-33 for use in the drought prone northern zone. Three sources of earliness in introductions from Russia were used. The four local varieties were also used in crosses with lines from the 2001 observation nurseries. Some of the lines selected from the germplasm nursery are: Ajabsido, MP531, Malisor 84-7, M92-1, S34, ICSV400, ICSV401, Sureno, Dorado, VG153, and ICSV1089BF. From a guinea derivative population selected by ICRISAT for short stature, 95 families at S1, S2, S3, and S5 were grown for observation at Bambey. From INTSORMIL collaborative drought nursery of 35 entries, severe stress was favorable for drought reaction and 14 lines were selected for future evaluation and use. Yield trials in 2002 at Bambey and Sinthiou were all lost due to severe moisture stress and poor stands. The trails at Bambey were with 25 lines selected from the 2001 INTSORMIL collaborative observation nurseries. At Sinthiou in the east, 13 Malian breeding lines were included in the trial.

Ghana

A nation-wide sorghum germplasm collection was embarked upon (October-December, 2002) as a result of duplications and lack of passport data for the sorghum accessions collection by ICRISAT in 1997. So far 187 accessions have been collected from the 4 districts of each of the Upper West, Upper East, and Northern regions. All accessions will undergo agro-morphological evaluation during the 2003 season, to be complemented by molecular markers to help assess the true genetic diversity present as well as determination of their nutritional and functional properties.

Some of the best Striga resistant lines from the 2001 INTSORMIL/West African Striga Trial are being utilized in the breeding program. The drought tolerance trials suffered from shoot fly attack at the seedling stage followed by midge at flowering making drought evaluations impossible.

Hybrid Sorghum - Mali

The coperative IER/ICRISAT hybrid research funded by the Rockefeller Foundation continued with the evaluation of breeding lines and local cultivars for restorer (B/R) reaction, the presence of the B1 gene, and sterilization of B-lines through backcrossing. Several new Malian guinea and guinea/caudatum intergrades were evaluated for their fertility reaction, B gene status, and heterosis potential in Mali, 2002, and Puerto Rico (winter '02-'03). Also evaluated were 35 selected Malian indigenous cultivars representing the diversity in the Mali Sorghum Collection and 30 selected mostly Guinea/Caudatum exotics from Southern Sudan for their potential use in hybrid breeding in the Guinea type sorghum zone of West Africa. See Table 4 in the Annual Report of TAM 222 in this publication for detailed data. Most Malian cultivars were restorers except for a few Guinea types, especially Margaritaferum types. Essentially all the Guinea-Caudatum derivative cultivars from Southern Sudan were strong restorers and were dominant B1 and B2. The dominant B1 gene was absent in most Durra and Durra-Bicolor Malian lines, and some of these lines showed promising heterosis. There appeared to be rather good differences in hybrid vigor among lines, especially as expressed in Mali.

Several elite Mali breeding lines introduced into the U.S. showed good B-line reaction, and were backcrossed for sterilization in Puerto Rico. They are agronomically good, white-seeded, tan-plant cultivars with recessive b1. Their designation and pedigrees are: 99CZ-F5-131 (N'Tenimissa*Segnetana CZ); 99EADT#36/98SB-F5DT-17((M84-7*Tiemarfing)*Tiemarfing); 99 EADT#52/98SB-F5DT-52 (N'Tenimissa*CSM388); and 99SB-F5DT-169 (N'Tenimissa*CSM388).

Millet Breeding

Mali

At Cinzana, seed multiplication of the variety Ankountess*SoSat was carried out. This variety was selected from the 2001 African land race hybrid trial distributed from the ARS millet breeding program at Tifton, GA. The variety showed tolerance to downy mildew, high yield potential, and slight earliness compared to the local check. The variety has been evaluated by farmers at 27 locations in the Segou, San, Tominian, and Koro areas. Other activities included the production of the BC3 of CivarexA49105 and TrombedieR4, and the off season hybrid production of CivarexA49105* TrombedieR4.

At N'Tarla, the first cycle of recombination of the Indiana 05 improved population was done. Harvested plants were selected for downy mildew tolerance, panicle compactness, grain hardness, number of fertile tillers, and similar maturity to the local day length sensitive variety. Also, seed multiplication of the varieties Sanioba and Sanioteli was carried out under isolation, producing 150 kg and 140 kg, respectively.

Senegal

In the Advanced Yield Trial at Bambey, 8 synthetics and 2 checks were evaluted, but very low and erratic rainfall

Table 3. Performances of the inter-population millet hybrids trial at Bambey, Senegal, 2002.

Entrees	Cycle	Days to flowering	Mildew incidence %	Plant height (cm)	Panicle length (cm)	Number panicles/ plant	1000 grain weight (g)	Grain yield (kg/ha^{-1})
WA 12 Ex-Bornu x Uganda	1	50 cd	1.6	199 abc	24.8 c	120 ab	8.9	1836
WA 21 Ex-Bornu x SoSat C88	1	52 abc	1.6	193 abc	27.7 bc	92 bc	9.2	1915
WA 22 Mansori x SoSat C88	1	52 abc	2.4	208 ab	30.1 bc	80 c	9.7	1412
WA 23 SoSat C88 x Ankoutess	1	53 ab	0.8	191 bc	25 c	81 c	9.3	1719
WA 25 SoSat C88 x GR-P1	1	53 ab	0.8	210 ab	35 b	72 c	8.9	1559
WA 26 Ugandi x SoSat C88	1	48 d	0.8	210 ab	28.4 bc	92 bc	6.9	1759
WA 27 Ex- Bornu x Ugandi	2	49 d	0	182 c	25.1 c	130 a	10.2	1620
WA 28 Ex-Bornu x Mansori	2	50 cd	0.8	180 c	27.3 bc	103 abc	8.5	1182
WA 29 Ex Bornu x Ugandi	3	49 d	0.8	183 c	26.9 bc	117 ab	9.2	1475
WA 30 Ex -Bornu x Mansori	3	51 bcd	0.8	186 c	26.9 bc	114 ab	8.5	1305
WA 31 Ex-Bornu x Ugandi	OP	48 d	0.8	192 abc	27.3 bc	120 ab	9.7	1694
WA 32 Ex-Bornu x Mansori	OP	50 cd	1.6	191 bc	26.8 bc	112 ab	9.5	1596
WA 33 SoSat C88 x Gwagwa	1	53 a	2.3	213 a	30.8 bc	80 c	9.7	1958
Souna 3 (check)	-	52 abc	7.1	200 abc	45.4 a	71 c	6.5	1573
Means	-	51	1.6	195	29.1	99	8.9	1615
Significance	-	HS	-	S	HS	HS	NS	NS
S.E	-	0.66	-	7.98	1.84	7.46	0.77	180
C.V(%)	-	2.6	-	8.2	12.7	15.1	17.2	22.3

Table 4. Performance of selected sorghum varieties in *Striga* infested field at SARI, Ghana, in 2001 and 2002 cropping seasons.

Variety	Days to flower	Height (cm)	*Striga* count 28days		*Striga* count 42 days		*Striga* count at harvest		Panicle weight (kg/ha^{-1})		Grain weight (kg/ha^{-1})	
			2001	2002	2001	2002	2001	2002	2001	2002	2001	2002
CMDT-38	86	171	0.00	-	1	8	8	46	1534	1531	568	1014
CMDT-39	88	203	1.00	-	2	11	9	179	1187	1823	578	1138
SEGUETANA	84	192	0.00	-	3	25	9	54	1084	1093	472	444
CMDT-45	85	207	2.00	-	7	57	32	163	1455	1911	711	1156
97-SB-F5DT-63	87	187	0.00	-	5	1	28	7	1768	816	895	429
97-SB-F5DT-64	86	209	0.00	-	1	1	6	40	3284	1484	2232	1013
N'TENIMISSA	87	223	2.00	-	12	20	48	86	1494	1272	474	714
97-SB-F5DT-65	83	193	0.00	-	0	27	3	60	1673	1413	690	653
MALISOR-92-1	76	159	0.00	-	4	32	13	42	1214	922	1011	642
MALISOR-84-1	76	165	0.00	-	0	34	2	66	1333	1461	627	1016
CE-151-202-A1	87	142	0.00	-	0	35	0	58	-*	460	-*	253
SRN 39	78	146	0.00	-	1	4	3	30	1218	1320	362	569
SAMSORG 41	77	149	0.00	-	1	15	18	47	-*	1069	-*	704
SAMSORG 14	89	167	1.00	-	10	8	45	225	2120	1613	733	742
KP33-2	89	102	0.00	-	7	-	14	-	-*	-	-*	-
IS 7777	89	177	1.00	-	7	-	39	-	1459	-	341	-
Grand Mean	84	175	0.31	-	3.48	20	17.0	79	1602	1206	707	692
CV(%)	2.0	2.0	21.0	-	51.8	60.7	26.4	107	73.2	47.1	56.5	52.1
LSD(0.05)	3	6	1.10	-	3.00	43	7.491	141	664	955	673.8	605

* These did not produce any harvestable heads and were not included in the analysis of those parameters.

resulted in poor stands. Grain yield varied between 178 and 1631 kg ha^{-1}, the best performers being ISMI9404, ISMI9501, and ISMI9506, with 1631, 1600, and 1409 kg ha^{-1} respectively compared to the check, IBMV 8402 with 1080 kg ha^{-1}. ISMI9404 had a good overall agronomic rating this season, with moderate panicle length and good exsertion.

In the Inter–Population Hybrid Trial, 14 entries were evaluated (Table 3). Grain yield varied from 1182 to 1958 kg ha^{-1} but were not significantly different.

Two new synthetics, ISMI9301 and ISMI9305, were planted in on-farm sites near Bambey, but were abandoned due to poor plant stand.

At Kolda, seed of the new introduced early variety GB8735 was increased. This variety matures in 65-70 days in the dry northern zone. The seed will be used to disseminate the variety.

Striga

Mali

At Sotuba, 45 early, 37 medium, and 38 late maturing breeding lines selected from the IER breeding program were evaluated for Striga in 2002. Infestation, however, was low with no significant differences among entries in all trials. At Cinzana, unusually high Striga infestations occurred in the Advanced Yield Trials and several new elite breeding lines showed good tolerance compared to the local checks, inlcuding the new IER cultivar, Wassa (97-SB-F5DT-63).

Other *Striga* trials at Cinzana showed excellent infestations and good differential among entries, however, no data is available for this report. Some of the trials were from Purdue University.

Senegal

A screen house test was conducted with lines from the West African regional *Striga* trial distributed in 2001. Pot infestation was made with *Striga* seeds collected from sorghum fields in 2000. The number of *Striga* plants emerged was zero (0) on CMDT-39, Seguetena, 97-SB-F5DT-63 (Wassa), 97-SB-F5DT-65, Malisor 92-1, CE-151-262, SRN-39, Samsorg 41; it was one (1) on CMDT-38, CMDT-45, 97-SB-F5DT-64, Samsorg 14 and KP33-2, two (2) on N'Tenimissa, Malisor 84-1, IS 7777; and 3 on the check F2-20. The low *Striga* plant emergence did not permit conclusive differentiation among test entries but did indicate that differences among entries likely exist. The same lines were included in field tests, but because of poor germination due to drought, the trial was abandoned.

Similarly, 11 advanced millet synthetics were screened against *Striga hermonthica*, in a screen house. The *Striga* seeds were harvested from millet fields near Bambey in 2002. The mean number of emerged *Striga* plants was 1.9 and the most infested were ISMI 8203 with 4 plants emerged followed by Souna 3, ISMI 9404, ISMI 9504 with 3 *Striga* plants emerged. GAM 8203 and ISMI 9301 remained free of the parasite. Screening tests against *Striga* on sorghum and millet need be conducted over several locations and years for an accurate evaluation and for evidence of the possible presence of different races.

Ghana

Remnant seed of the 2001 West African *Striga* trial was planted at the same site in 2002. Table 4 shows data for the two years. The 16 varieties showed varied but high level of *Striga* resistance/tolerance. Generally, the *Striga* infestations were much higher in 2002 than 2001. The late maturity of line, CE-151-202-A1 resulted in severe midge infestations in 2001 and the lowest yield (253 kg ha^{-1}) in 2002 in spite of its high resistance to *Striga* . The line 97-SB-F5DT-64 however, combined high yields (range of 1.0-2.2 t ha^{-1}) with low level *Striga* infestation. Other lines that exhibited consistent high level of *Striga* resistance with appreciable yields over the two years included CMDT-38, 97-SB-F5DT-63 (Wassa), MALISOR 92-1, SRN 39 and SAMSORG 41. SRN 39 was much earlier than the rest of the lines and consequently suffered much bird damage. SAMSORG 14 appeared to be the most susceptible of all the lines evaluated. Considering other traits like grain quality and plant height the farmers had expressed their interest in the cultivars, CMDT-38 and CMDT-39. The sorghum breeding program will also utilize some of these resistance lines as source materials.

Pathology

Mali

For anthracnose, 3 years of screening indicated that six Malian breeding lines screened with inoculation at Sotuba showed good resistance to the disease. These six were: 99-SB-F5DT-51; 99-SB-F5DT-188; 99-SB-F5DT-200; 00-KO-F5DT-80; 98-FA-EART-101; and F2-78. Additionally 3 entries from Texas A&M/INTSORMIL ADIN (All Disease and Insect Nursery) and from the Texas A&M/INTSORMIL GWT (Grain Weathering Test) also were very resistant to anthracnose. These included SC326-6, 92BD1982-4, and BTx378 from the ADIN and SC279-14E, (Malisor 84-7*VG153)/19178, and (VG153*(TAM428*SBIII)-23)-BE2 from the GWT.

Three years results indicate that covered smut (*Sproisorium sorghi*) incidence can be reduced dramatically by treating sorghum seeds with 20 g of (Diro + Nguo + Néré) powder per kg of seed, with a grain yield increase of 56%. This plant pesticide can be used to replace Apron Stars in the future.

Ghana

To identify sources of stable broad-spectrum resistance to sorghum diseases for use in the breeding program, two trials were evaluated in 2002, the WASDON (West African Sorghum Disease Observation Nursery), put together in Mali by IER, and the Texas A&M/INTSORMIL ADIN. Disease and agronomic data on the WASDON is presented in Table 5.

Four entries (SAMSORG 14, SARIASO-01, OUEDZOURE and FOULATIEBA) were infected by grey leaf spot with mean score of 4.0. Sorghum entry SARIASO-02 and Kadaga were attacked by bacterial leaf stripe (*Burkholderia andropogonis*) a quarantine pathogen with mean scores of 4.0 and 5.0, respectively.

The yield potential of the genotypes screened in the 2002 ADIN was higher and ranged up to 2,013 kg ha^{-1}. The field disease reaction of the genotypes was higher in incidence and

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Variety	Days to flower	Height (cm)	*Striga* count 28days		*Striga* count 42 days		*Striga* count at harvest		Panicle weight (kg/ha^{-1})		Grain weight (kg/ha^{-1})	
			2001	2002	2001	2002	2001	2002	2001	2002	2001	2002
CMDT-38	86	171	0.00	-	1	8	8	46	1534	1531	568	1014
CMDT-39	88	203	1.00	-	2	11	9	179	1187	1823	578	1138
SEGUETANA	84	192	0.00	-	3	25	9	54	1084	1093	472	444
CMDT-45	85	207	2.00	-	7	57	32	163	1455	1911	711	1156
97-SB-F5DT-63	87	187	0.00	-	5	1	28	7	1768	816	895	429
97-SB-F5DT-64	86	209	0.00	-	1	1	6	40	3284	1484	2232	1013
N'TENIMISSA	87	223	2.00	-	12	20	48	86	1494	1272	474	714
97-SB-F5DT-65	83	193	0.00	-	0	27	3	60	1673	1413	690	653
MALISOR-92-1	76	159	0.00	-	4	32	13	42	1214	922	1011	642
MALISOR-84-1	76	165	0.00	-	0	34	2	66	1333	1461	627	1016
CE-151-202-A1	87	142	0.00	-	0	35	0	58	-*	460	-*	253
SRN 39	78	146	0.00	-	1	4	3	30	1218	1320	362	569
SAMSORG 41	77	149	0.00	-	1	15	18	47	-*	1069	-*	704
SAMSORG 14	89	167	1.00	-	10	8	45	225	2120	1613	733	742
KP33-2	89	102	0.00	-	7	-	14	-	-*	-	-*	-
IS 7777	89	177	1.00	-	7	-	39	-	1459	-	341	-
Grand Mean	84	175	0.31	-	3.48	20	17.0	79	1602	1206	707	692
CV(%)	2.0	2.0	21.0	-	51.8	60.7	26.4	107	73.2	47.1	56.5	52.1
LSD(0.05)	3	6	1.10	-	3.00	43	7.491	141	664	955	673.8	605

* These did not produce any harvestable heads and were not included in the analysis of those parameters.

severity. A score of 5.0 was recorded for zonate leaf spot on entry R9188. Grey leaf spot was rather prevalent with eleven entries with high scores of 4.0-7.0. Eight entries did not show any sign of shoot fly infestation, 8BPR1013, 96GCPOB143, 8BPR1019, 87EO109, Tx2917/R9120, Tx436, and BTx 631, while five others had less than 10% incidence, 96CA5986, 00CA4654, B8PR1059, R9603, and R9618. The seven top yielding entries were 98CD187 (2013 kg/ha), 96CA5986 (1653 kg ha^{-1}), SC326-6 (1627 kg ha^{-1}), GR108-90M24 (1427 kg ha^{-1}), 95BRON151 (1400 kg ha^{-1}), Malisor 84-7 (1346 kg ha^{-1}), and 88B943 (1333 kg ha^{-1}). Five entries were selected for further evaluation based on their overall agronomic traits and disease/pest tolerance or resistance (88BE 2668, 96GCPOB 124, 94CW 5045, B9307 and Tx2783).

Entomology

Mali

At the Cinzana Station, the sorghum breeding lines in the Advanced Early Maturity Variety Trials (GI, GII, and GIII) were evaluated for resistance or tolerance to the major insect pests, green aphid, sorghum midge, and head bug (*Eurystylus*). Aphid and midge populations were low, with no significant difference among lines. However, head bug pressure was high with significant differences among entries for head bug damage. Head bug damage ratings were made on 5 panicles per plot at maturity, and damage to the grain scored on a 1-9 scale where 1 + <10% damage to 9 = > 80% damage. There were excellent differences among entries for head bug damage with lines in each test showing excellent resistance with data on those plus other selected entries presented in Table 6.

At Sotuba, three large preliminary head bug screening nurseries (93, 113, and 121 entries) and three advanced screening nurseries were evaluated for head bugs (*Eurystalus*) and grain mold. Dry conditions during and after grain maturity resulted in very little grain mold damage, except to a few entries with severe head bug damage. Natural head bug infestation was high and excellent for screening. At heading, 2 panicles were protected with cages and 2 by selfing bags. At the milk stage, 5 unprotected panicles were sampled to determine head bug infestation level. At harvest, visual ratings were made on head bug and grain mold damage to the grain, and a 200 seed weight taken on threshed grain to determine grain weight loss due to head bug damage. In the first preliminary trial, 5 entries plus

Table 5. Performance data and field reactions[1] of sorghum genotypes (WASDON) to different diseases at Nyankpala, Ghana, 2002.

Entries	Origin	Days to 50% flowering	Plant height (cm)	Grain yield (kg/ha)	Grey leaf spot	Zonate leaf spot	Bacterial leaf stripe
SAMSORG 14	IAR, Samaru	85	246	307	4.0	2.0	1.0
SAMSORG 40	"	87	191	813	2.0	1.0	1.0
SARIASO-01	INERA, Burkina	83	285	1,433	4.0	2.0	1.0
SARIASO-02	"	83	285	880	3.0	1.0	4.0
OUEDZOURE	"	85	346	1,267	4.0	1.0	1.0
SC326-6	Texas, USA	87	94	107	1.0	1.0	1.0
VG 153	"	85	205	1,200	2.0	1.0	1.0
SURENO	"	91	217	607	1.0	1.0	1.0
9GW092	"	93	159	613	2.0	1.0	3.0
90L19178	"	81	203	1,267	2.0	1.0	1.0
98-FA-EART-101	IER, Mali	90	215	787	1.0	1.0	1.0
98-SB-F5-DT-25	"	84	269	693	1.0	1.0	1.0
98-SB-F5-DT-59	"	77	294	933	1.0	1.0	1.0
98-SB-F5-DT-4	"	88	117	900	2.0	1.0	1.0
98-KO-F5-DT-39-2	"	73	333	987	2.0	1.0	1.0
98-KI-F5-T-45	"	83	280	387	2.0	1.0	1.0
98-F2-82	"	80	148	1,467	2.0	1.0	1.0
97-SB-F5-DT-154	"	89	146	387	1.0	1.0	1.0
97-SB-F5-DT-160	"	100	129	200	1.0	1.0	1.0
F2-78	"	79	141	1,533	1.0	1.0	1.0
97-SB-F5-DT-150	"	89	169	607	2.0	1.0	1.0
97-SB-F5-DT-151	"	93	153	947	1.0	1.0	1.0
FOULATIEBA	"	84	326	1,207	4.0	2.0	1.0
KADAGA	SARI, Ghana	76	211	393	3.0	3.0	5.0
A2267-2	ICRISAT, Mali	91	213	613	2.0	1.0	1.0
Mean[2] (25 entries)		83.8	215.0	821.4	2.0	1.2	1.4

[1] Based on rating scale 1-9: 1 = no disease; 2 = 1-5%; 3 = 6-10%; 4 = 11-20%; 5 = 21-30%; 6 = 31-40%; 7 = 41-50%; 8 = 51-75% and 9 = > 75% of leaf area of the plant or panicle parts damaged by the disease.

severity. A score of 5.0 was recorded for zonate leaf spot on entry R9188. Grey leaf spot was rather prevalent with eleven entries with high scores of 4.0-7.0. Eight entries did not show any sign of shoot fly infestation, 8BPR1013, 96GCPOB143, 8BPR1019, 87EO109, Tx2917/R9120, Tx436, and BTx 631, while five others had less than 10% incidence, 96CA5986, 00CA4654, B8PR1059, R9603, and R9618. The seven top yielding entries were 98CD187 (2013 kg/ha), 96CA5986 (1653 kg ha^{-1}), SC326-6 (1627 kg ha^{-1}), GR108-90M24 (1427 kg ha^{-1}), 95BRON151 (1400 kg ha^{-1}), Malisor 84-7 (1346 kg ha^{-1}), and 88B943 (1333 kg ha^{-1}). Five entries were selected for further evaluation based on their overall agronomic traits and disease/pest tolerance or resistance (88BE 2668, 96GCPOB 124, 94CW 5045, B9307 and Tx2783).

Entomology

Mali

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Table 6. Performance of selected entries for head bug damage and other traits from the Advanced Early Maturity Variety Yield Trials (GI, GII, and GIII), Cinzana, Mali, 2002.

Designation	Days to flower	Plant height (m)	Head bug[1] damage rating	Grain yield (kg ha^{-1})
Early GI				
01-CZ-F5P-5	81	2	1	933
01-CZ-F5P-46	87	2.1	1	997
01-CZ-F5P-50	83	3.7	1	749
01-CZ-F5P-123	77	1.9	1	1168
97-SB-F5DT-63 (Wassa)	79	3.4	1	1225
CSM63E	73	2.8	1	1587
Malisor 92-1	72	1.9	6	1206
Local check	76	3.2	1	1473
Early GII				
00-BE-F5P-1	78	2.8	1	900
00-BE-F5P-93	83	1.9	1	967
Malisor 92-1	71	1.9	7	1086
97-SB-F5DT-63 (Wassa)	79	3.6	2	1105
CDM63E	72	2.5	1	581
Local Check	75	2.6	1	810
Early GIII				
99-BE-F5P-66	73	1.6	6	1590
99-BE-F5P-67	74	1.9	6	1471
99-BE-F5P-69	74	2.1	6	905
99-BE-F5P-95	78	1.7	5	1029
99-BE-F5P-120	78	2.7	1	1186
99-BE-F5P-128-1	74	3	1	1710
99-BE-F5P-131-1	73	2.7	1	1348
99-BE-F5P-131-2	71	2.8	1	1243
99-BE-F5P-131-3	71	2.7	1	1233
Malisor 92-1	71	1.8	6	1324
CSM63E	71	2.3	1	1100
Wassa	79	3.1	1	1433
Local Check	73	2.5	1	1414

[1] Rating scale: 1 = < 10% damage to 9 = > 80% damage.

the check, Malisor 84-7, showed a high level of head bug and grain mold resistance. Data on the 5 resistant lines and other selected susceptible lines for comparison purposes is presented in Table 7. The selfing bags and cages worked equally well in protecting grain from head bug damage. Grain mold damage was minimal overall, but highest in entries with high head bug damage. Seed weight was severely reduced in head bug susceptible lines, but was similar or reduced only slightly for unprotected and protected on resistant entries. Head bug numbers (adults and larva) varied considerably among entries, and were generally higher on susceptible lines but not always. There was no head bug damage on any protected panicles.

In the second preliminary nursery, 17 entries plus Malisor 84-7 shoed excellent head bug resistance with ratings of 1.5 or less: 00-CZ-F5P-23; 00-CZ-F5P-34; 00-BE-F5P-163; 00-BE-F5P-171; 00-BE-F5P-95; 00-KO-F5DT-108; 00-KO-F5DT-149; 00-KO-F5DT-301; 00-SB-F4DT-435; 00-SB-F5DT-247; 00-SB-F5DT-5; 00-SB-F5DT-366; 00-KI-F5T-89; 00-KI-F5T-20; 00-KI-F5T-47; 00-KI-F5T-32-1; and 00-KI-F5T-543. In the third preliminary nursery, 8 lines showed head bug resistance with ratings of 1.2 or less: 01-CZ-F5P-24; 01-CZ-F5P-76; 01-SB-F5DT-45; 01-SB-F5DT-46; 01-SB-F5DT-231; 01-FI-F5T-35; 01-KI-F5T-38; and 01-KI-F57-80.

Table 7. Head bug and grain mold evaluation of selected entries from the first preliminary Entomology nursery, Sotuba, Mali, 2002.

	Natural infestation					Protected selfing Bag		Protected cage	
	Head bugs at flowering				200 Seed		200 Seed		200 Seed
Varieties	Adults / 5 pan	Larva / 5 pan	Head bug[1] rating	Mold[1] rating	weight (g)	Mold[1] rating	weight (g)	Mold[1] rating	weight (g)
99CZ-F5P-136-2	65	0	1.2	1	4.1	1.2	4.4	1	4.5
99CZ-F5P-131-2	128	149	1.2	1	4.3	1	4.4	1.2	4.6
99CD-F5P-67-2	34	52	1.2	1	3.5	1	5	1	3.6
99SB-F5DT-170-1	15	3	1.2	1.2	4.8	1	5.4	1	5.3
99SB-F5DT-49-2	49	40	1.2	1	4	1.2	4.8	1	4.5
99CZ-F5P-104-2	47	9	7.5	1.2	2.6	1.2	4.6	1	4.3
99-CZ-F5P-123-1	70	348	6.7	2.2	4.8	2	6.4	1.5	6.5
99CZ-F5P-12-2	118	217	8.5	3.2	3.9	1	4.9	1	4.7
99-BE-F5P-22	91	133	6	2	4.7	1.5	7.7	2.3	6.5
99-BE-F5P-122	227	632	6	1.7	4.7	1.7	7.9	1	6
99-SB-F5DT-196	49	318	6	1.5	3.3	1.2	4.1	1	3.9
99-FA-F5DT-60	35	15	9	1	2.7	1	4.9	1	4.6
99-CA-F5P-104-1	77	24	6.2	1	3.5	1	5	1	4.8
Malisor 84-7	86	96	1.2	1	3.4	1	3.8	1	4.6

[1] Rating scale: 1 = no damage to 9 = 90% damage.

In the three advanced screening nurseries at Sotuba, 9, 18, and 21 breeding lines were evaluated for head bug and grain

Table 8. Head bug resistant breeding lines from the three advanced screening nurseries using natural and artificial infestation, Sotuba, Mali, 2002.

	Natural infestation			Infested			Protected
Varieties	Adults at flower/ 5 pan	Head bug[1] rating	200 seed weight (g)	Head bug adults	Head bug[1] rating	200 seed weight (g)	200 seed weight (g)
95-EPRS-G-1032	105	1.5	3.8	83	1	4.6	4.7
95-EPRS-G-1055[2]	182	6.5	2.2	74	1.5	3.3	3.5
PA-F4[2]	77	7.2	3.5	701	5.2	4.8	6.3
97-SB-F5DT-65	36	1.1	4.9	85	1.4	5.2	5.6
97-SB-F5DT-72-2	27	1	4.5	90	1.2	4.8	4.9
97-SB-F5DT-82	49	1.7	4.2	93	1.2	4.7	4.7
CZ-F5P-37-3	39	1.1	4.3	113	1	3.9	4.4
97-SB-F5DT-64[2]	16	5.5	2.6	110	2.8	2.8	3.4
97-SB-F5DT-150[2]	18	4	3.1	94	1.6	3.8	4.5
Malisor 84-7	24	2.1	3.6	71	1.6	3.9	4.1
97-SB-F5DT-74-1	140	1	3.3	103	1	3.4	3.5
98-BE-F5P-14	16	1.6	4.1	93	1.1	4.4	4.5
98-BE-F5P-10[2]	31	4.1	2.7	107	1.9	3.2	3.6
KO-F5-39-2[2]	18	4.4	3.6	94	2.4	4.1	3.9

[1] Rating scale: 1 = no damage to 9 = 90% damage.
[2] These entries rated as head bug susceptible based on natural infestation.

mold damage using natural infestation and artificial infestation under cages and compared to protected panicles. Several IER breeding lines showed excellent head bug resistance with ratings of less than 2.0 (Table 8). Natural infestation consistently resulted in more severe head bug damage even though the adult and larva numbers were not consistently higher. Adults were generally higher in infested, but larvae were higher under natural. Resistance expressed through low head bug damage ratings on the grain, plus maintenance of grain weight compared to protected, and slightly less grain mold.

Another entomology trial of midge resistant lines from the USA was planted at Samanko and evaluated for midge, head bug, and grain mold. Three entries, O1LI9315, 00LI1331, and O1BG2330 showed little midge damages or grain mold, but were damaged by the head bug. Only one entry, 00LI1316, showed good tolerance to the midge, head bugs, and grain mold.

A trial to test the efficacy of local plant extracts for head bug control was conducted at Samanko in 2002. Treatments included neem tree leaves juice, *Calotropus precera* leaves juice, and the control with varieties Malisor 92-1, same tolerance, and S34, very susceptible to head bugs. Although the two leaf extract treatments reduced the head bugs somewhat, there was not significant differences among treatments. However, the Calotropus juice seemed to be more effective on head bugs than the neem tree juice.

Senegal

The effect of chemicals and botanicals application on the control of sorghum head bugs was tested in Nioro station in the central zone. A synthetic insecticide (Dimethoate) and Neem (*Azadiractha indica*) extract were applied on the variety CE 145-66. Four species of head bugs were observed; (*Creontiades pallidus, Dysdercus völerii, Diploxis floweri*, and *Nezara virudula*). Significant differences were observed between treatments for insect populations, panicle weight and grain per panicle with Neem being effective, but not quite as effective as Dimethoate (Table 9).

Insecticide control of the insect complex at Sinthiou indicated a yield loss of 35% due to insect pests in this eastern station.

Table 9. The effect of head bug control on sorghum performance, Nioro, Senegal, 2002.

Treatment	Number of head bugs/panicle	Panicle weight (g)	Grain weight/panicle (g)
Unsprayed	13.3 a	35.1 a	23.6 a
Neem	5.3 a	41.7 ab	32.7 b
Dimethoate	4.0 b	57.8 b	42.5 c
CV	42.1%	11.6%	8.2

Table 10. Physical-chemical characteristics of grain from lines in the advanced yield trial of medium maturity group (GIII), 2002.

Varieties	Ash %	Flotation %	1000 grains weight g	Tô[1] stability rating	Vitrosity[2] rating	Decortication yield (%)
99-SB-F5DT-49-1	1.19	2.67	18.09	1.50	1.17	75.83
99-SB-F5DT-52	0.96	0.67	19.98	1.00	1.37	76.67
99-SB-F5DT-169	1.14	0.67	17.87	1.00	1.43	79.17
99-SB-F5DT-170-1	1.10	0.80	18.06	1.27	1.47	74.17
99-SB-F5DT-170-2	0.94	0.00	18.89	1.50	1.30	79.17
99-SB-F5DT-189	0.79	1.33	20.72	1.00	1.67	72.50
99-SB-F5DT-190	1.00	0.67	22.71	1.00	1.37	84.17
99-SB-F5DT-196	0.95	5.33	18.34	1.00	2.23	71.67
99-SB-F5DT-198	0.80	0.00	23.63	1.00	1.47	82.50
99-SB-F5DT-206	0.83	2.67	21.51	1.50	1.57	75.00
99-SB-F5DT-209-1	1.03	0.67	20.96	1.00	1.73	74.17
99-SB-F5DT-209-2	0.79	0.67	22.99	1.50	1.70	83.33
99-SB-F5DT-213	0.69	2.67	19.51	1.27	1.43	78.33
99-SB-F5DT-228	0.77	2.00	22.98	1.00	1.60	75.83
99-BE-F5P-53	0.83	3.33	21.45	1.00	1.50	68.33
CSM-388 (check)	1.08	1.33	21.00	1.00	1.63	80.83
97-SB-F5DT-74-2	1.07	0.67	20.63	1.00	1.00	83.33
LOCAL	1.10	5.33	21.55	1.00	1.87	64.17
Mean	0.94	2.15	20.6	1.14	1.53	76.62
Significance	**	**	**	**	**	**
CV%	5.03	80.13	1.29	7.56	6.50	3.43

[1] Rating 1 = very stable to 5 = unstable.
[2] Grain hardness rating: 1 = hardest to 3 = soft.

Food Technology

Characterization of Sorghum Breeding Lines

Improved breeding lines were analyzed for food quality traits. Most of the lines were resistant to grain molds and head bug damage. In the medium maturity grain yield trial (third year evaluation GIII) most showed vitreous grain (range between 1 and 2.23). The variety 99-SB-F5DT-196 and the local check showed the flouriest grain. The decortication yield of lines was good with a minimum of 75% and a maximum of 88 % and an average of 85%. All the lines studied showed a good tô consistency and acceptable tô color. The physical-chemical characteristics of lines in the yield trial of medium maturity group GIII are presented in Table 10.

Diversification of Sorghum End-Use Products

New products:

- Snacks, biscuits and cakes 100% sorghum
- Sorbis fortified with dates
- Sorbis fortified with coco
- Sorbis fortified with peanut
- Sorbis fortified with almonds
- Sorbis with butter
- Cake fortified with dates
- Cake fortified with chocolate
- Cake fortified with banana
- Cake fortified with butter

Non-alcoholic drinks:

Sorghum syrup
Sorghum Malta
In several villages, many women were trained how to make Sorghum Malta

Agronomy

Acid Soil (Sorghum) - Mali

A screening experiment was designed to identify tolerant or susceptible sorghum genotypes to acid soils. Several sorghum exotic genotypes, emerging or promising breeding lines, local cultivars, and improved varieties were tested for tolerance to acid soil condition in Mali at the Cinzana Station in 2002. Each entry was planted in a single row. Planting was performed on the 11th of July, in rows 75 cm apart and within rows, in hills 50 cm apart with three replications planted. The screening was conducted on plot F9 of the toposequence of the Cinzana station with no fertilizer applied. Concentrations of P, Al, and Mn were determined in the shoots of each genotype for the purpose of understanding mechanisms of tolerance. Selected properties of plot F9 are given below:

Selected properties of a Sandy, mixed, hyperthermic Plinthic Paleustalf profile of the Cinzana station (Plot F9).

Parameter	Top-soil	Sub-soil
Depth (cm)	0-20	20-60
Clay (%)	5.0	9.8
Sand (%)	84.9	78.6
pH (H2O)	5.1	4.9
Organic C (%)	0.21	0.16
ECEC [cmol(+) kg-1]	0.91	0.90
Al (%) ‡	37.0	42.0
Bray-1 P (mg kg-1)	4.2	5.0
FCC soil classification	SLdeh	SLdeh

‡ Al saturation in % of ECEC

The results showed local genotypes selected from acid, sandy soils of Niger (El Mota and Bagoba) brought to physiological maturity at least 72% of germinated planting hills (Table 11). Despite variations in their performance from one year to another, these genotypes (including Babadia Fara) have maintained good performance for the last 10 years (Doumbia et al., 1998). Their mechanism of tolerance seems to be related to accumulating acceptable P concentrations (about 2.0 g P/kg) and normal levels of both Al and M (114 to 187 mg/kg).

Improved and exotic genotypes included in this study have different abilities to withstand acid soil conditions through accumulation of low or high concentrations of one or more of the following elements: Mn, P, Si, and Al. These genotypes brought to grain production 39 to 92% of their planting hills (Table 11). The released genotype, N'Tenimissa, performed about 62% better than the susceptible check, Malisor 84-5 (14% survival). N'Tenimissa and similar genotypes accumulate not only low levels of P (just below the deficient level of < 2 g P/Kg), but also low levels of both Al and Mn (200 to 317 mg/kg) under acid soil conditions (low P, but high Al and Mn concentrations).

Table 11. Selected properties of the sorghum genotypes tested in acid soil area, Cinzana station, Mali, 2002.

Sorghum variety	Germinated hills (%)	Hills at Maturity (%)	P content in leaves (g/kg)	Al content in leaves (mg/kg)	Mn content in leaves (mg/kg)
El Mota	100	97	2.1	114	124
Bagoba	100	72	2.2	135	187
Gadiaba	100	69	1.7	185	176
Kenike	100	64	1.4	211	231
Malisor 84-5	100	14	0.7	718	746
IS 3553	100	92	2.0	119	91
IS 6902	100	39	1.2	360	518
IS 8577	100	39	0.7	293	494
MN 4508	100	51	1.5	625	118
97-BE-F5P-4	100	69	1.9	311	291
97-SB-F5-DT-63 (Wassa)	100	44	1.0	301	301
97-SB-F5-DT-74-2	100	56	1.5	279	200
98-SB-F2-78	100	54	1.9	198	208
98-SB-F2-82	100	46	1.7	212	221
98-BE-F5P-84	100	61	1.8	219	311
N'Tenimissa	100	76	2.0	192	317

Exotic genotypes such as IS 3553, IS 6902, and IS 8577 confirmed their known properties in acid soils (Gourley et al., 1991). They showed some tolerance (39 to 92% survival) through accumulations of low or igh concentrations of P, Al or Mn.

In conclusion, El Mota, Bagoba, and Gadiaba/CZ have shown, over years, strong abilities to withstand acid soil conditions. At least 72% of the planting hills of these genotypes were harvested this year for grain. They accumulate acceptable concentrations of P (about 2 g P/kg), but low contents of both Al and Mn (>.200 mg/kg).

Sorghum genotypes emerging from the Mali breeding programs have shown some tolerance to acid soil conditions. These genotypes brought to grain production 44 to 76% of their planting hills. These genotypes accumulate not only low levels of P (just below the deficient level of < 2 g P/Kg), but also low levels of both Al and Mn (200 to 317 mg/kg) under acid soil conditions.

Table 12. Influence of Micro-dose fertilizer treatments on millet and sorghum growth and yields on heavy soil at Cinzana in 2002.

Treatments	Population at harvest (ha)	Number of panicle (ha)	Panicle weight (kg/ha⁻¹)	Grain weight (kg/ha⁻¹)	Straw weight (kg/ha⁻¹)
Millet					
Control (No fertilizer)	44167	32361	639	389	1632
Microdose (2 g of DAP/poquet)	49306	26528	729	444	1875
Microdose + 20 kg/ha⁻¹ P	55139	34028	1153	715	2674
Microdose + 40 kg/ha⁻¹ P	45972	25556	660	382	1736
Microdose + 30 kg/ha⁻¹ N	57778	20278	604	368	2153
Microdose + 60 kg/ha⁻¹ N	51528	25694	681	382	1875
Microdose + 20 kg/ha⁻¹ P + 30 kg/ha⁻¹ N	59306	37222	1077	597	2917
Microdose + 40 kg/ha⁻¹ P + 60 kg/ha⁻¹ N	68473	31945	1118	542	3334
P>F	0.29	0.782	0.684	0.852	0.032
sed	9790.2	407.2	407.2	266.1	488.2
CV%	25.7	51.2	69.2	78.8	31.2
Sorghum					
Control (No fertilizer)	38889	26111	647	453	1250
Microdose (2 g of DAP/poquet)	54444	29583	570	344	2014
Microdose + 20 kg/ha⁻¹ P	41806	25139	472	240	1493
Microdose + 40 kg/ha⁻¹ P	50139	53889	1306	796	2465
Microdose + 30 kg/ha⁻¹ N	58195	46111	1118	701	2813
Microdose + 60 kg/ha⁻¹ N	52500	30000	715	563	2361
Microdose + 20 kg/ha⁻¹ P + 30 kg/ha⁻¹ N	73611	60278	1741	1064	2743
Microdose + 40 kg/ha⁻¹ P + 60 kg/ha⁻¹ N	53611	26111	604	347	2570
P>F	0.138	0.014	0.014	0.035	0.032
sed	11147.9	10791.4	341.9	236.2	488.2
CV%	29.8	41.1	53.9	59.3	31.2

Table 13. Grain yield data of millet in the micro dose tests at Kounè, Kamba and Kolodougoukoro.

Village/Collaborators	Soil type	Grain yield (kg ha⁻¹) Micro dose	Control	% yield of control
Kounè				
Abdoulaye Traoré	Sandy	1719	944	182
Balkassoum Diarra	Sandy	1294	925	140
Oumar Diarra	Loamy	1550	1669	93
Moustapha Coulibaly	Sandy	1863	1225	152
Kamba				
Ali Binkè Sacko	Sandy	1250	625	200
Mamoutou Sacko	Sandy	750	375	200
Binkègninè Sacko	Sandy	1875	1625	115
Kobé Kaba	Sandy	2500	1875	133
Moussa Cissé	Sandy	875	625	140
Kolodougoukoro				
Bakaye Coulibaly	Sandy	813	525	155
Ali Coulibaly	Sandy	1225	625	196

Mali - Cinzana

On-Station Trials

Micro-dose fertilizer treatment effects on millet and sorghum growth and yields were investigated at Cinzana research station in 2001 and 2002. The 2001 results indicated that micro dose application may significantly increase crop yield, but soil type and rainfall conditions can severely limit crop response (Table 12). On light soil, micro-dose and recommended fertilizer treatment significantly increased millet plant population and panicle numbers, panicle weight, grain weight and stover weight at harvest. However on heavy soil, no significant differences were observed between treatments for both millet and sorghum. In 2002, millet and sorghum were grown only on the heavier loamy soil at the Cinzana research station. Similar to 2001, rainfall distribution in 2002 at Cinzana research station was erratic.

As in 2001, micro-dose treatment effects on millet growth and yields on heavy soil were not significantly different from the control for all parameters except the total straw weight. Addition of N or P alone did not significantly affect yields. However, combination of N and P fertilizers increased total plant biomass yield.

For sorghum, in contrast to the 2001 results, sorghum growth and yield were significantly affected by fertility treatments. Although differences were not perceptible with panicle and grain yields, total plant biomass was increased by almost 40% with micro dose treatment alone. The results were characterized, however, by large variability with CVs ranging from 30 to 59%.

The present results confirmed those of 2001, where millet responded better to fertility treatments on light soil than on heavy soil. As in 2001, plants on heavy soil suffered from moisture stress, which occurred when millet plants were at flowering stage. This severely affected plants with fertility treatments and decreased their yields compared to those of control plots. Sorghum on heavy soil had better growth compared to millet. Plant height (data not shown) and stover yield tended to increase both with recommended and micro dose fertilizer applications. The results of these experiments indicated that micro dose application may significantly increase crop yield, but soil type and rainfall conditions can severely limit crop response.

On-Farm Trials

On-farm experiments with millet were conducted in three villages around Ségou. The objective was to determine the performance of micro dose fertilizer treatment compared to farmer's practice. Two treatments were studied: T1 = farmer's practice; T2 = 4 T ha^{-1} manure + micro dose (2g per seeding hole).

The experiment sites were characterized by low organic matter content, low pH and low nutrient status. At the planting time, some difficulties related to plant germination were observed. For both grain yield and straw yield, crop response to micro dose treatments also depended on soil type. On heavy soil, no response was observed while on sandy soil, the percent yield increase due to micro dose varied from 40% to 82% a

KounP, from 15% to 100% at Kamba and from 55 to 96% at Kolodougoukoro (Table 13).

Mali - Sorghum

To study the effect of planting date, plant population, and the interactions on two tan-plant sorghum varieties (97-SB-DT-154 and Malisor 92-1), three planting dates, seven plant populations with varying row width and hill sparings, and three fertilizer levels (Kebila only) were evaluated at Sotuba and Kebila. At Sotuba, for both grain and biomass yield, the earliest planting date (June 20) was the best, while at Kebila, the middle planting date (July 5) was superior for both grain yield and biomass. There was no significant interactions of planting date x population or with cultivar. However, significant differences due to plant population were observed at both Sotuba and Kebila with the highest plant populatio (0.75 m x 0.25 m, with 53,000 hills/ha, and 2 plants per hill) giving the highest yield. At Kebila, the highest fertilizer rate (92-92-0) gave higher yields than (41-46-0) or (0-0-0), but there was no interaction with planting date or plant population. The conclusion from the 2002 results indicated a need to increase plant population up to 100,000 plants per ha to realize the yield potential of these two cultivars.

Ghana - Sorghum

The major objective of this long-term experiment at the Wa Station was to determine if fertilizer Phosphorus (P) rates (0, 30, 60 and 90 kg P/ha) applied to one crop (direct for current crop and residual for succeeding crop) or to both crops (cumulative) would enhance soil P availability enough to maintain both sorghum and cowpea yields when grown in rotation.

Sorghum yield response to frequency of P application was not significant in 2000, but in 2001 and 2002, fresh (direct and cumulative) application of P to sorghum produced significantly greater kernel number and grain yields than its application to previous cowpea crop. Grain yields with fresh P applications were significantly increased by an average of 23% (508 kg ha^{-1}) in 2002 (Table 14). Over the years, added fertilizer P consistently increased kernel numbers and grain production in a linear manner. Additionally, grain yield was often more correlated with seed number than seed weight. Grain yield was linearly related to P rates ($Y = 1908.44 + 13.97P$, $R^2 = 0.38$) when averaged across frequency of P application in 2002. Sorghum yields were not increased significantly beyond the 30 kg P/ha level in 2001 and 2002. Frequency of P application did not influence cowpea yield and yield components in 2000 through 2002.

Table 14. Sorghum grain yield and yield components as affected by added fertilizer P, Wa, Ghana, 2002.

Frequency of P application	Days to 50% flowering	100-seed weight g	Kernels m^{-2} no	Grain yield kg ha^{-1}
Cumulative	68	2.35	9681	2692
Direct	68	2.32	9938	2721
Residual	68	2.27	8467	2199
LSD (0.05)	NS	NS	962	406
P rate kg/ha^{-1})				
0	69	2.15	7048	1760
30	68	2.26	9666	2543
60	68	2.40	9856	2763
90	67	2.45	10878	3084
P linear	**	NS	**	**
P quadratic	NS	NS	*	NS
CV %	2.2	14.7	12.0	18.6

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

In another agronomy trial at the Wa Station the effect of previous-crop (sorghum, groundnut, cowpea, and soybean) on grain sorghum growth and response to four N fertilizer rates (0, 40, 80 and 120 kg ha^{-1}) was studied. The experiment was initiated in 2000 and rotation effects were determined in 2001 and 2002. During both years, the effects of previous crops and the rates of nitrogen applied to the sorghum did not interact significantly. In 2002, apart from stover production, agronomic and physiological traits of sorghum measured or calculated in this experiment were not influenced by the previous crops. However, on average, sorghum following groundnut tended to have the greatest grain yields (2151 kg ha^{-1}) and numerically the most kernels, followed by sorghum following cowpea (1954 kg/ha) or soybean (1721 kg ha^{-1}), while the least grain yield and fewest kernels were recorded after a previous crop of sorghum (1627 kg ha^{-1}). Similar results were obtained in 2001. The results support the need for enhancing biological nitrogen fixation of grain legumes to furnish some of the N requirements of non-legumes in rotation cropping systems.

In a third agronomy trial at Wa, the effects of fertilizer use and crop residue management on soil organic matter content, extractable nutrient concentration and production of maize and sorghum in the savanna zone were studied.

Results indicate that crop residue return rate did not influence parameters measured or calculated for sorghum in 2001 and 2002. When averaged across residue return rates, fertilized sorghum flowered 4 days earlier than did unfertilized sorghum. However, added fertilizer increased plant height, seed number, stover and ultimate grain yields. A yield advantage of 113% (732 kg ha^{-1}) was obtained from fertilized sorghum when compared with unfertilized plants averaged over crop residue rates. The results obtained for the two seasons reveal that fertilizer application regardless of crop residue can increase sorghum grain yields on a savanna soil low in plant available nutrients.

Economic Analysis/ Ghana Agronomy

Economic analyses suggest that when cowpea is grown in rotation with sorghum, P fertilizer should be applied directly to sorghum at the rate of 90 kg P/ha (the maximum net benefit is obtained with the rate and frequency of application). For four cropping seasons the results indicate that when cowpea is grown in rotation with sorghum, it is better to apply P fertilizer to the sorghum crop and allow cowpea to benefit from the residual P effect.

Partial budget analysis indicates that when no nitrogen fertilizer is applied cowpea is the best preceding crop to sorghum. Sorghum as a preceding crop exhibited consistent increases in net return with increase in nitrogen fertilizer application. In all uses sorghum benefits from legumes as preceding crops in the rotation. The highest net return was obtained using groundnut as a preceding crop with 80 kg ha^{-1}.

When the effect of residue return and fertilizer use were considered, results showed that a 100% residue return rate combined with 2.5 bags each of 15-15-15 and sulphate of ammonia was the best option. When no fertilizer was used the highest net return came from a 50% crop residue return rate.

Economics/Marketing

The IER developed and released white-seeded, tan-plant Guinea type cultivar, N'Tenimissa, was use in identity preserved (IP) marketing and in value-added products and commercial utilization. In building upon the initial success in 2001 of a local entrepreneur in grain trading from the Bamako area of Mali, Mr. Diawara, he arranged in 2002 with assistance of Dr. Jupiter Ndjeunga (ICRISAT) and Mr. A. Diallo (IER) for a much larger increase of N'Tenimissa grain. In 2001, 11 tons of grain were available for the entrepreneur to sell and/or process. The goal in 2002 was 200 tons of grain. Four villages were involved, 2 in the Bamako area and 2 in the Sikasso area in Southern Mali, Kafara, Safebougoula, Garalo, and Yanfoliye. It involved 110 farmers and about 200 ha. Farmers in these villages contracted with the grain trader. More than 220 tons were harvested with an average grain yield of 2,000 kg ha^{-1}. Unfortunately, because of financial and other problems involving the grain trader and his company, the contracts were not fulfilled. Understandably, the farmers were "very unhappy" over this situation. However, part of this production was sold to the grain trader and in local markets for an increased priceof 10-20 FCFA per kg compared to the local market price. The short and long term impact of this unfortunate situation is unkown at this time, and its effect on 2003 plans is unclear.

In 2001, Mr. Diawara was successful thru contracting with farmers in receiving 11 tons of N'Tenimissa grain. When the demand for the flour from GAM declined due to the removal on tariffs on wheat, causing wheat prices to fall, the entrepreneur was successful in utilizing alternate markets. He sold about one ton as 1 kg bags of sorghum flour called Sorgho Phar for 500 CFA in local markets and the demand was excellent. He sold 7 tons as whole grain in markets around Bamako, and the grain sold for a good price premium. The demand for this good quality N'Tenimissa whole grain was excellent according to the grain trader, even maybe better than for the 1 kg bags of flour. This illustrates the important point that enhanced quality grain is recognized and can be used to develop new IP marketing of sorghum grain and stimulate the involvement of local entrepreneurs in developing and marketing new urban food products in addition to being a marketable product itself in Mali. Also, most farmers have a preference for the grain for their own use due to its white color and clean grain.

Institution Building

The sorghum and millet programs received, through INTSORMIL collaboration, a computer, 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 Traoré (Nebraska) - Currently Agronomist and Mali National Coordinator for Millet.

Dr. Niamoye Yaro Diarisso (Texas A&M) - Currently sorghum entomologist, and head of the 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. Sidi Bekaye Coulibaly (Nebraska and Texas Tech/Texas A&M) - Previously sorghum physiology/agronomy and sorghum breeding and INTSORMIL Coordinator. Currently sorghum/millet breeder, Cinzana.

Students currently in training include Niaba Témé who successfully completed his B.S. and M.S. at Texas Tech University and is currently a Ph.D. student at Texas Tech University. Karim Troaré, former IER millet and sorghum breeder is now a Ph.D. student at Texas A&M University. Mr. Tiecoura Traore has initiated a M.S. program in sorghum entomology at West Texas A&M University.

Bocar Sidibé, Abocar Toure, Kissima Traore, SibPne Déna, and Moussa Sanogo received short term training in the USA provided by INTSORMIL in breeding and plant pathology.

Dr. Aboubacar Touré, Malian sorghum breeder, is a member of the streering committee of the West and Central Africa Sorghum Research Network, WCASRN (ROCARS).

U.S. scientists traveling to the region included: Dr. Bonnie Pendleton (Mali - October, 2002), Dr. Jeffrey Wilson (Mali-October, 2002), Dr. John Sanders (Mali and Senegal - October, 2002), Dr. Darrell Rosenow (Mali - November, 2002), Dr. Lloyd Rooney and Bruce Hamaker (Senegal - January, 2003).

Several host country scientists traveled to Ethiopia in November, 2002, and participated in the INTSORMIL P.I. Conference where they interacted extensively with U.S. and other host country scientists and planned future collaborative activities. Scientists traveling to the P.I. Conference in Addis Ababa, Ethiopia included Aboubacar Touré, Niamoye Diarisso, Mamadou Doumbia, Mamourou Dioute, Mamadou N'Diaye, Abdoul Demba M'Baye, Mamdou Balde, and Ababacar N'Doye (ITA), from Senegal; and Sakka Buah, Ibrahim Atokple; Steve Nutsugah, and Paul Tanzubil from Ghana.

Dr. Aboubacar Touré also attended a R.F. sponsored Conference on Biotechnology, Breeding, and Seed Systems for African Crops, November 2002, Entebbe, Uganda. IER scientists also attended a workshop on Alternative and protein-enriched sorghum and millet food products, Pretoria, South Africa.

Mr. Steven Nutsugah, Pathologist, Ghana participated in the Fusarium Workshop, Kansas State University, Manhattan, Kansas, June 2003.

Networking

An efficient sorghum and millet research and technology transfer network has existed though the West African regional sorghum and millet networks, WCASRN (ROCARS) 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 particularly in the areas where head bugs, drought, and grain mold which are common. 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 was initiated in Ghana and Senegal in the 2001 season, and 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. and grown out under quarantine. The seed increase and characterization were completed in 2001 and the complete set of data on the over 40 grain, glume, and plant characters was compiled and sent to the USDA/ARS for entry in the GRIN system. 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

Plans to initiate INTSORMIL collaborative research in Ghana and Senegal began in November 2000, with arrangements to bring two scientists each from Ghana (Drs. S. Buah, agronomist and I. Atokple, sorghum breeder) and Senegal (Ndiaga Cissé, sorghum breeder and Demba M'Baye, pathologist) to Bamako to meet with Darrell Rosenow, Aboubacar Touré, and other key Malian IER scientists. Dr. Buah already had previously initiated a collaborative program in agronomy with Dr. Maranville. The discussions were all 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. Touré 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 Dr. Gebisa Ejeta evaluated at several sites. The lines will be assembled in Mali and distributed by Acar Troare. Also Dr. Ejeta will look at some of the sources for types of resistance involved. In addition, INTSORMIL scientists 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 has continued his collaborative activities in Ghana based on previously developed work plans with Maranville.

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 the INTSORMIL, and is functioning well in Mali.

Breeding

From on-farm trials, the Guinea-type cultivar 97-SB-F5-DT-63 (N'Tenimissa*Tiemarfing) has been selected, seed saved, and grown by local farmers and has been released and named "Wassa" which mean 'satisfaction' in Bambara. Farmers like it over N'Tenimissa because of its whiter, higher quality grain.

Two other new breeding lines, true Guinea cultivars (N'Tenimissa*Tiemarfing) were widely tested and given the names Zarra and Keninkedie, and will be increased for use in value-added products. All three of these new cultivars have superior grain quality and less stem breakage then N'Tenimissa.

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 DeliKen by the private company, GAM, in Bamako.

A local entrepreneur in Mali successfully produced , in 2001, over 11 tons of grain of the white, tan plant guinea cultivar, N'Tenimissa, under identity preserved (IP marketing procedures. This grain trader also developed a new market by packaging and selling one kilo bags of flour (Sorgho Phar) in Bamako markets, with a demand so strong he was having trouble keeping the product on the shelf. In 2002, his contracted production for 200 tons was derailed due t financial and other problems in his company unrelated to the N'Tenimissa effort.

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 the 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, 2000-01, 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*) in a non-Guinea type sorghum, 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.

Sorghum selfing bags work equally well with cages in head bug evaluations and are much more cost and labor efficient.

Natural infestation appears superior to infested cages for head bug screening.

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

Micro-dose fertilizer application increases the grain and stover yield of millet on sandy soils. Its effect on sorghum and on heavier soils is highly variable.

INTSORMIL/IER research has demonstrated that millet or sorghum planted after peanut or cowpea results in 36-63% yield increases.

INTSORMIL collaborative research has shown an increase in pearl millet grain yield and biomass production due to previous cowpea crops and equivalent to the application of 30 to 40 kg ha^{-1} N.

The joint INTSORMIL/Soil Management CRSP 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.

New IER developed sorghum cultivars show moderate levels of acid soil tolerance.

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 US 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.

Several new Guinea breeding line/cultivars such as Wassa show good *Striga* tolerance.

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 yieds, especially for soft grains. The cooked milled products can be eaten like rice.

The combination of cowpea and millet flour (1:3) significantly improved the nutritional status of young children. This technology has been transferred to many villages especially in the Cinzana area.

Mileg, a weaning food using primarily millet flour has been developed by private entrerprise and marketed in stores in the Bamako area. The product was developed using technology developed in the IER Cereal Technology laboratory.

New white-seeded, tan-plant, tan-glume guinea-type breeding cultivars, have good potential for use in developing new high quality, value added food products. They posses excellent guinea traits and yield potential.

Deli-ken, a cookie using 20% N'Ténimissa flour and 80% wheat flour has been developed by private entrerprise GAM and marketed in stores in Mali.

A new market for N'Tenimissa flour has been developed with the successful marketing of 1 kg bags of N'Tenimissa flour in Bamako by a local entrepreneur.

Economics/Marketing

In Mali, a local entrepreneur successfully produced grain from the white-seeded, tan-plant Guinea cultivar, N'Tenimissa, under identity preserved (IP) marketing procedures, involving 38 ha and 50 farms in 4 villages. From 38 tons harvested, over ll tons were sold to the grain trader. When the demand for sorghum flour by GAM for cookies dropped due to reduced tariff on wheat imports, a new market for the N'Tenimissa flour was developed with the marketing of one kilo bags of N'Tenimissa flour (Sorgho Phar) in markets in Bamako. Demand was so strong, there were problems keeping the product on the shelf. A portion of the grain was also sold directly in local Bamako markets, and sold well at a premium price.

An economics study on the benefits of new technology in Mali suggests that new technology in the traditional cereals of sorghum and pearl millet would provide a greater increase in benefits compared to new technology introduction in the new cereals, maize and rice.

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

Year 24 Educational Activities

INTSORMIL gives high priority to training host country scientists who will have major responsibilities for sorghum and millet research in their home countries. Training is also provided for young U.S. scientists who plan for careers in international development work.

The most frequently used mode of training is graduate study for advanced degrees, with the students' research forming an integral part of an INTSORMIL project. During the year covered by this report, 58 students from 21 different countries were enrolled in an INTSORMIL advanced degree program. Approximately 72% of these students come from countries other than the U.S. which shows the emphasis placed on host country institutional development (Figure 1).

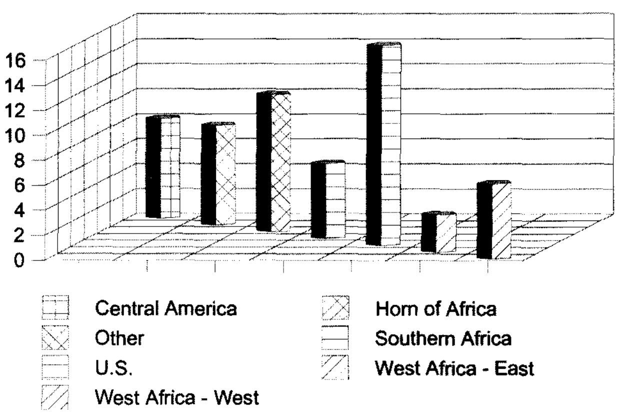

Figure 1. Degree Participants by Region.

INTSORMIL also places a high priority on training women which is reflected in Figure 2. In 2002-2003, 24% of all INTSORMIL graduate participants were female. Twelve of the total 58 students received full INTSORMIL scholarships. An additional 43 students received partial INTSORMIL funding and the remaining four students were funded from other sources as shown in Figure 3.

All 58 students worked directly with INTSORMIL principal investigators on INTSORMIL projects. These students are enrolled in graduate programs in eight disciplinary areas, agronomy, animal nutrition, breeding, pathology, entomology, food quality, economics, and molecular biology.

The number of INTSORMIL funded students has decreased gradually over the years. This is related to decreases in program budget and lower numbers of U.S. principal investigators. In 1993-94 there were 25 U.S. PIs with the program and in 2002-2003 there were 18.

Graduate degree programs and short-term training programs have been designed and implemented on a case by case basis to suit the needs of host country scientists. Five post doctoral scientists and 12 visiting host country scientists were provided the opportunity to upgrade their skills in this fashion during 2002-2003.

Figure 4 is a compilation of all INTSORMIL training activities by discipline for the period July 1, 2002 through June 30, 2003.

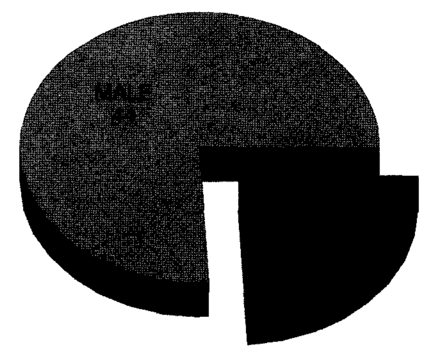

Figure 2. Degree Participants by Gender.

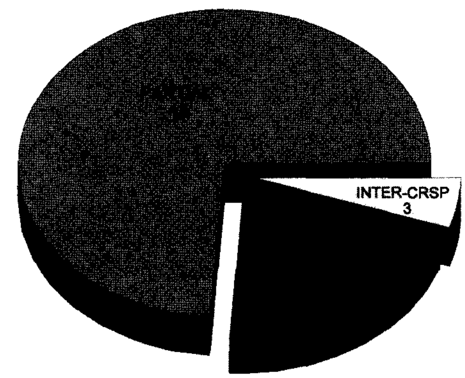

Figure 3. Degree Participants Funding

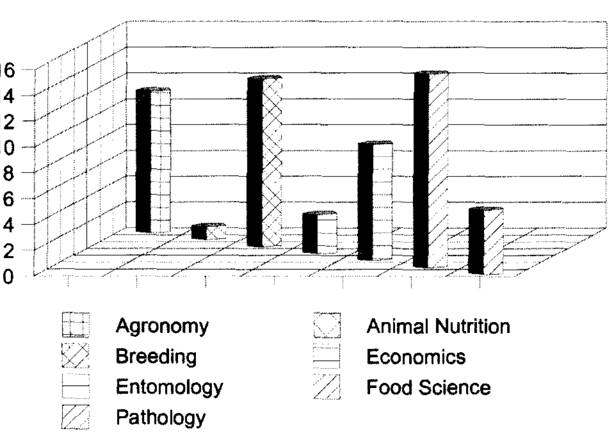

Figure 4. Degree Participants by Discipline

Year 24 INTSORMIL Degree Training Participants July 1, 2002 - June 30, 2003

Name	Country	Univ.	Discipline	Advisor	Degree	Gender	Funding
Kathol, Delon	U.S.	UNL	Agronomy	Mason	MSC	M	P
Kaye Mady, Nanga	Chad	UNL	Agronomy	Mason	MSC	M	P
Mesfin, Tewodros	Ethiopia	UNL	Agronomy	Wortmann/Mamo	MSC	M	P
Miller, Greg	U.S.	UNL	Agronomy	Wortmann/Mamo	MSC	M	P
Ngulube-Msikita, R.	Zambia	UNL	Agronomy	Eastin	MSC	F	I
Tesfahungen, G.B.	Ethiopia	UNL	Agronomy	Wortmann/Mamo	MSC	M	P
Xerinda, Soares	Mozambique	UNL	Agronomy	Wortmann/Mamo	MSC	M	IC
Daniel, Christian	St Lucia	UNL	Agronomy	Wortmann/Mamo	PHD	M	P
Maman, Nouri	Niger	UNL	Agronomy	Mason	PHD	M	P
Quincke, Andreas	Uruguay	UNL	Agronomy	Wortmann/Mamo	PHD	M	P
Regassa, Teshome	Ethiopia	UNL	Agronomy	Maranville	PHD	M	I
Baudon, Edouard	France	KSU	Animal Nutrition	Hancock	MSC	M	P
Kriegshauser, Travis	U.S.	KSU	Breeding	Tuinstra	MSC	M	P
McCartor, Kayla	U.S.	TTU	Breeding	Rosenow	MSC	F	P
Mutaliano, Joaquim	Mozambique	TAM	Breeding	W. Rooney	MSC	M	IC
Stamm, Michael	U.S.	KSU	Breeding	Tuinstra	MSC	M	P
Teme, Niaba	Mali	TTU	Breeding	Rosenow	MSC	M	P
Coulibaly, Sidi B.	Mali	TTU	Breeding	Rosenow/Peterson	PHD	M	P
Ellicott, Alexis	U.S.	PRF	Breeding	Ejeta	PHD	F	P
Franks, Cleve	U.S.	TAM	Breeding	W. Rooney/Rosenow	PHD	M	P
Knoll, Joseph	U.S.	PRF	Breeding	Ejeta	PHD	M	I
Krishnamorthy, G.	India	TAM	Breeding	W. Rooney/Rosenow	PHD	M	P
Mateo, Rafael	Honduras	TAM	Breeding	W. Rooney	PHD	M	I
Teme, Niaba	Mali	TTU	Breeding	Rosenow	PHD	M	I
Traore, Karim	Mali	TAM	Breeding	Rosenow/Peterson	PHD	M	P
Uaiene, Rafael	Mozambique	PRF	Economics	Sanders	MSC	M	IC
Wubeneh, Nega	Ethiopia	PRF	Economics	Sanders	MSC	M	I
Tahirou, Abdoulaye	Niger	PRF	Economics	Sanders	PHD	M	I
Ayyanath, M.	India	WTU	Entomology	Pendleton	MSC	M	P
Chitio, Fernando	Mozambique	WTU	Entomology	Pendleton	MSC	M	P
Palousek, Anastasia	U.S.	WTU	Entomology	Pendleton	MSC	F	P
Sambaraju, Kishan	India	WTU	Entomology	Pendleton	MSC	M	P
Traore, Tiecoura	Mali	WTU	Entomology	Pendleton	MSC	M	I
Veerabomma, Suresh	India	WTU	Entomology	Pendleton	MSC	M	P
Gorena, Roberto	U.S.	TAM	Entomology	Peterson	PHD	M	P
Johnson, Zeledon	Nicaragua	MSU	Entomology	Pitre	PHD	M	I
Pichard, Sergio	Nicaragua	MSU	Entomology	Pitre/Claflin	PHD	M	P
Acosta, David	Mexico	TAM	Food Science	L. Rooney	MSC	M	P
Barron, Marc	U.S.	TAM	Food Science	L. Rooney/M. Riaz	MSC	M	P
Barth, Alison	U.S.	PRF	Food Science	Hamaker	MSC	F	P
Cedillo, Guisselle	Mexico	TAM	Food Science	L. Rooney	MSC	F	P
Garza, Jessica	Mexico	TAM	Food Science	L. Rooney/R. Waniska	MSC	F	P
Maladen, Michelle	India	PRF	Food Science	Hamaker	MSC	F	P
Maranphal, Nitit	Thailand	TAM	Food Science	L. Rooney	MSC	M	P
Suhendra, Budhi	Indonesia	PRF	Food Science	Hamaker	MSC	M	P
Rudiger, Crystal	U.S.	TAM	Food Science	L. Rooney	MSC	F	P
Turner, Duane	U.S.	TAM	Food Science	L. Rooney	MSC	M	P
Wortham, Lindsay	U.S.	TAM	Food Science	L. Rooney	MSC	F	P
Awika, Joseph	Kenya	TAM	Food Science	L. Rooney/R. Waniska	PHD	M	P
Bueso, Francisco	Honduras	TAM	Food Science	L. Rooney/R. Waniska	PHD	M	P
Bugusu, Betty	Kenya	PRF	Food Science	Hamaker	PHD	F	I
Dykes, Linda	U.S.	TAM	Food Science	L. Rooney/R. Waniska	PHD	F	P
Viswanathan, A.	India	TAM	Molecular Biology	Magill	MSC	F	P
Cho, Jae-Min	Korea	TAM	Molecular Biology	Magill	PHD	M	P
Katile, Seibe	Mali	TAM	Molecular Biology	Magill	PHD	M	I
Sabry, Ahmed	Egypt	TAM	Molecular Biology	Magill	PHD	M	P
Ditshipi, Phoebe	Botswana	UFS	Pathology	McLaren/Swart	PHD	F	I
Salah, Amgad	Egypt	KSU	Pathology	Leslie	PHD	M	P

I = Completely funded by INTSORMIL P = Partially funded by INTSORMIL IC = InterCRSP funding

KSU = Kansas State Univ. TAM = Texas A&M Univ. USDA = Tifton, Georgia
MSU = Mississippi State Univ. TTU = Texas Tech Univ. WTU = W. Texas A&M Univ.
PRF = Purdue Univ. UNL = Univ. of Nebraska, Lincoln

Year 24 INTSORMIL Non-Degree Training Participants July 1, 2002 - June 30, 2003

Name	Country	Univ.	Discipline	Advisor	Activity	Gender	Funding
Hess, Dale	U.S.	PRF	Breeding	Ejeta	PD	M	I
Tesso, Tesfaye	Ethiopia	PRF	Breeding	Ejeta	PD	M	P
Ditshipi, Phoebe	Botswana	TAM	Breeding	Peterson	VS	F	I
Kapran, Issoufou	Niger	PRF	Breeding	Ejeta	VS	M	I
Kaula, Godwin	Zambia	TAM	Breeding	Peterson	VS	M	I
McLaren, Neal	South Africa	TAM	Breeding	Peterson	VS	M	I
Mpofu, Leo	Zimbabwe	TAM	Breeding	W. Rooney	VS	M	P
Belay, Amare	Ethiopia	PRF	Economics	Sanders	VS	M	I
Georgis, Kidane	Ethiopia	PRF	Economics	Sanders	VS	M	I
Benmoussa, Mustapha	Indonesia	PRF	Food Science	Hamaker	PD	M	P
N'Doye, Ababacar	Senegal	PRF	Food Science	Hamaker	VS	M	P
Zeller, Kurt	U.S.	KSU	Pathology	Leslie	PD	M	P
Gutierrez, Yanet	Nicaragua	KSU	Pathology	Claflin	VS	F	I
Jurgenson, Jim	U.S.	KSU	Pathology	Leslie	VS	M	P
Mule, Giuseppe	Italy	KSU	Pathology	Leslie	VS	M	P
Narro, Jesus	Mexico	KSU	Pathology	Claflin	VS	M	I
Traore, Hamidou	Burkina Faso	PRF	*Striga* Research	Ejeta	PD	M	P

VS = Visiting Scientist PD = Post Doctoral

Year 24 INTSORMIL Conference/Workshop Activities July 1, 2002 - June 30, 2003

			Participants		
Name	Location	Date	Male	Female	Total
Casteñeda, José W.	El Salvador	April, 2003	1	0	1
Grenier, Cecile	Uganda	Nov. 1 - Nov. 27, 2002	0	1	1
Pichardo, Sergio T.	Nicaragua	June 22 - 27, 2003	1	0	1
Sirifi, Seyni	Niger	October, 2003	1	0	1
Ethiopia First National Workshop	Nazret, Ethiopia	Nov. 12 - 14, 2002	4	2	6
Green Revolution/Gene Revolution	Bologna, Italy	May 28 - 31, 2003	5	0	5
INTSORMIL PI Conference	Addis Ababa, Ethiopia	Nov. 18 - 20, 2002	130	17	147
Fusarium Workshop	Manhattan, Kansas	June 23 - 28, 2003	20	22	42
Scientific Workshop	Penang, Malaysia	February 4, 2003	30	20	50
Scientific Workshop	Seoul, South Korea	February 6, 2003	30	40	70
Scientific Workshop	Ibadan, Nigeria	April 30, 2003	40	34	74
TOTAL			262	136	398

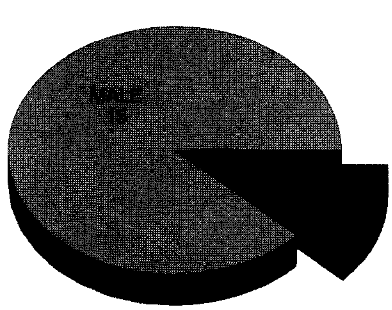

Figure 5. Total Non-Degree Participants by Gender

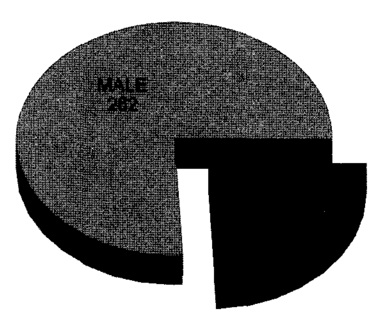

Figure 6. Total Conference/Workshop Participants by Gender

Appendices

INTSORMIL Sponsored and Co-Sponsored Workshops 1979 - 2003

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. Agrimetorology 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 80's	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	2/84
22. Evaluation 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. INTSORMIL PI Conference	Kansas City, Missouri	1/87
31. Maicillos Criollos and Other Sorghum in Middle America Workshop	Tegucigalpa, Honduras	12/87
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. ARC/INTSORMIL Sorghum/Millet Workshop	Wad Medani, Sudan	11/89
36. Workshop on Sorghum Nutritional Grain Quality	West Lafayette, Indiana	2/90
37. Sorghum for the Future Workshop	Cali, Colombia	1/91
38. INTSORMIL PI Conference	Corpus Christi, Texas	7/91
39. Workshop on Social Science Research and the CRSPs	Lexington, Kentucky	2/92
40. Workshop on Adaptation of Plants to Soil Stresses	Lincoln, Nebraska	8/93
41. International Conference on Genetic Improvement of Sorghum and Millet	Lubbock, Texas	9/96
42. Conference on Ergot of Sorghum in the Americas	Sete Lagos, Brazil	6/97
43. Ethiopia Sorghum and Millet Traveling Workshop	Ethiopia	9/97
44. Mali Sorghum Characterization Workshop	Cinzana, Mali	11/97
45. INTSORMIL PI Conference	Corpus Christi, Texas	6/98
46. Impact Assessment Workshop	Corpus Christi, Texas	6/98
47. Conference on the Status of Sorghum Ergot in North America	Corpus Christi, Texas	6/98
48. Regional Hybrid Sorghum and Pearl Millet Seed Workshop	Niamey, Niger	9/98
49. CRSP Symposium/Annual Meeting of the American Society of Agronomy	Baltimore, Maryland	10/98
50. Global 2000 Sorghum and Pearl Millet Diseases III	Guanajuato, Mexico	9/00
51. INTSORMIL PI Conference	Addis Ababa, Ethiopia	11/02

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
AFLP	Amplified Fragment Length Polymorphisms
AID	Agency for International Development
AID/H	Agency for International Development in Honduras
ALDEP	Arable Lands Development Program
AMEDD	Association Malienne d'Eveil Au Dévelopement
ANOVA	Analysis of Variance
ANPROSOR	Nicaraguan Grain Sorghum Producers Association
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
AVES	Associación de Avicultores de El Salvador
BAMB	Botswana Agricultural Marketing Board
BIFAD	Board for International Food and Agricultural Development
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 EnseZanza, Costa Rica
CEDA	Centro de EnseZanza y Adiestramiento, SRN, Honduras
CEDIA	Agricultural Document and Information Center, Honduras
CENTA	Centro Nacional de Technologia Agropecuaria y Forestal, 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 Développement
CITESGRAN	Centro Internacional de Tecnologia de Semilla y Granos, EAP in Honduras
CLAIS	Comisión Latinoamericana de Investigadores en Sorgho
CMS	Cytoplasmic Male-Sterility System
CNIA	Centro Nacional de Investigaciones Agricoles, 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	Dirección 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
EAGA	Extended Agar Gel Assay
EAP	Escuela Agricola Panamericana, Honduras
EARO	Ethiopian Agricultural Research Organization
EARSAM	East Africa Regional Sorghum and Millets
EAVN	Extended Anthracnose Virulence Nursery
EWA	Austrian NGO
ECARSAM	East Central Africa Regional Sorghum and Millet
ECHO	Educational Concerns for Hunger Organization
EEC	Euorpean 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
ESBESA	Escobar Betancourt S.A.
EZC	Ecogeographic Zone Council
FAO	Food and Agriculture Organization of the United States
FDS	Fonds de Développement pour la Solidarité
FEDEARROZ	Federación HondureZa de Investigación Agricola, Honduras
FENALCE	Federación Nacional de Cultivadores de Cereales
FHIA	Fundación HondurenZa de Investigación Agricola, Honduras
FPX	Federation of Agricultural and Agro-Industrial Producers and Exporters
FSR	Farming Systems Research
FSR/E	Farming Systems Research/Extension
FUNDESYRAM	Fundación Para E Desarrollo Socio-Económico y Restauración Ambiental

FUNPROCOOP	Fundación Promotora de Coopertivas
GASGA	Group for Assistance on Systems Relating to Grain after Harvest
GMB	Grain Marketing Board
GOB	Government of Botswana
GOH	Government of Honduras
GRADECOM	Groupe de Recherche et d'Action pour le Développement Communautaires
GTZ	German Agency for Technical Cooperation
GWT	Uniform Nursery for Grain Mold
HIAH	Honduran Institute of Anthropology and History
HOA	Horn of Africa
HPLC	High Pressur Liquid Chromatography
HR	Hypersensitive Response
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 HondureZo de Antropologia e Historia
IICA	Instituto Interamericano de Cooperación para la Agricultura
IIMYT	International Improved Maicillo Yield Trial
IITA	International Institute of Tropical Agricultura
ILRA	International Livestock Research Institute, Niger
INCAP	Instituo de Nutrición de Centro America y Panama
INERA	Institut d'Environnement et de Recherche Agricoles
INFOP	National Institute for Professional Development
INIA	Instituto Nacional de Investigaciónes Agricoles, 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	Instito Nicaragüense de Tecnologia Agropecuaria, Nicaragua
INTSORMIL	International Sorghum/Millet, Collaborative Research Support Program (CRSP)
IPA	Instituto de Pesquisas Agronómicas, Brazil
IPIA	International Programs in Agriculture, Purdue University
IPM	Integrated Pest Management
IPR	Intellectual Property Rights
IRAT	Institute of Tropical Agriculture and Food Crop Research
IRRI	International Rice Rsearch Institute, Philippines
ISAVN	International Sorghum Anthracnose Virulence Nursery
ISC	ICRISAT Sahelian Center
ISM	Integrated *Striga* Management
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
LC/MS	Liquid Chromatography/Mass Spectrometry
LCRI	Lake Chad Research Institute
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
MAVS	Ministerio de Agrcultura y Ganadería
MC	Maicillo Criollo
ME	Management Entity
MFC	Mechanized Farming Corporation, Sudan
MHM	Millet Head Miner
MIAC	Mid-America 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 Agricultural 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
OFDA	Office of Foreign Disaster
OICD	Office of International Cooperation and Development
ORSTOM	L'Institut Français de Recherche Scientifique pour le Développement en Coopération, France
PCCMCA	Programa Cooperative 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
PRODAP	Proyecto de Desarrollo Rural en la Región Paracentral
PROMEC	Program for Research on Mycotoxicology and Experimental Carcinogensis, South African Medical Research Council
PROFIT	Productive Rotations on Farms in Texas
PROMESA	Pryecto de Mejoramiento de Semilla - Nicaragua
PSTC	Program in Science and Technology Cooperation

PVO	Provate Volunteer Organization
QTL	Quantitative Trait Loci
QUEFTS	Quantitative Evaluation of the Fertility of Tropical Soils
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
RI	Recombinant Inbred
RIIC	Rural Industry Innovation Centre, Botswana
ROCAFREMI	Réseau Ouest et Centre Africain de Recherche sur le Sorgho, Mali
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
SRVCO	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
TPHT	Tan Plant Hybrid Trial
TropSoils	Tropical Soils Collaborative Research Program, CRSP
UANL	Universidad Autonóma de Nuevo Leon, Mexico
UHSN	Uniform Head Smut Nursery
UNA	Universidad Nacional Agraria, Nicaragua
UNAN	Universidad Nacional Autónoma de Nicaragua, Leon, Nicaragua
UNILLANOS	Universidad Technológica de los Llanos
UNL	University of Nebraska, Lincoln
UPANIC	Union of Agricultural Producers of Nicaragua
USA	United States of America
USAID	United States Agency for International Development
USAID-RAPID	Regional Activity to Promote Integration through Dialogue and Policy Implementation
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
WASDON	West Africa Sorghum Disease Observation Nursery
WASIP	West Africa Sorghum Improvement Program
WCAMRN	West and Central African Millet Research Network (ROCAFREMI), Mali
WCASRN	West and Central African Sorghum Research Network (ROCARS), Mali
WVI	World Vision International

Dr. Sylvie Pazoutova (left) of the Institute of Microbiology, Czech Republic and Dr. Neal McLaren (right) from ARC-Grain Crops Institute, Republic of South Africa participate in the 2002 INTSORMIL PI Conference three day post-conference tour to the Amhara Region, Lalibela, Woldiya, Kobo, Sirinka and Dessie Research Stations.