

Sustainable Plant Protection Systems



Grain Molds, Mycotoxins and Stalk Rots of Sorghum and Millet

Project KSU 101
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Introduction and Justification

Sorghum and millet are plagued by numerous diseases, most of which have a fungal etiological agent. Stalk rot and grain mold, the most important diseases on a worldwide basis for which there is no effective management regime can be caused by several species of *Fusarium*, although at least 25 additional fungal genera may be present as secondary invaders or members of a disease complex. Separating and identifying the roles and risks associated with the various members of this complex fungal community is necessary to estimate the risks posed by different members of the community and to provide breeders with the correct targets for resistance breeding. Fungi that cause grain mold also are linked with stand establishment problems as the seeds that are produced may germinate poorly or the germinated seedlings may be killed by fungi that accompanied the seed.

Fusarium spp. and the secondarily invading *Aspergillus* spp. may produce mycotoxins such as aflatoxins, fumonisins, ochratoxin, deoxynivalenol and zearalenone. These toxins may reduce the quality of the grain as a food/feed source as well as the value of the grain in a cash market scenario. These toxins are associated with a variety of human and animal health problems including acute toxicity and death, increased incidence of cancer, inhibition of normal growth and development, immune suppression and increased disease susceptibility, increased risks of birth defects, and reduced nutritional and economic value of the resulting grain. In most host-country settings these risks are inadequately quantified due to limited medical data reporting systems.

Fusarium and related species and the diseases they cause offer the most attractive targets for improved management that could be of importance in a global context. Isolates of *Fusarium* re-covered

from sorghum and millet have long been a taxonomist's nightmare. Many species lack morphological characters that can be used to clearly and cleanly differentiate them from other related species, and many cultures have been misidentified. Many of these cultures also have been identified as *Fusarium moniliforme*, a name that has now been abandoned due to the numerous species that it has been associated with. As all strains with the *F. moniliforme* name often were assumed (incorrectly) to be equivalent, breeding materials often were challenged with an improper strain with correspondingly inconsistent results. For example, *F. verticillioides* is a common pathogen of maize that once was termed *F. moniliforme*, as was *F. thapsinum*, a major cause of sorghum stalk rot. Challenging sorghum plants with *F. verticillioides* when screening for stalk rot resistance results in unpredictable results, as the only plants that become diseased are those infected by *F. thapsinum* due to natural causes. A similar challenge with *F. thapsinum*, however, can effectively flatten an experiment planted with a sensitive variety. Results from previous studies sponsored by INTSORMIL have indicated that the dominant *Fusarium* species varies by location, e.g., *Fusarium andyazi*, in southern Africa, *F. thapsinum* in West Africa, *F. proliferatum* in Egypt, and an as yet unnamed new species that is common from West Africa through Egypt and east Africa (Kenya and Uganda). Within region variation suggests that as many as 20 additional species remain to be described. Until they have been effectively separated it is difficult to determine which species are common in one area and less common in others. Such studies also are needed to enable breeders to effectively challenge the materials in their programs. The *Fusarium* species associated with pearl millet and finger millet also have been examined in a somewhat cursory manner. *Fusarium pseudonygamai* is the dominant species on pearl millet, while finger millet is host to an amazingly diverse group of *Fusarium* spp. (between 40 and 60 from samples taken in Uganda in 2000). The *Fusarium* species on these

crops are not known to be associated with production problems, but many can produce mycotoxins that could contaminate grain. Such contamination is particularly important for finger millet as this grain often is used to produce a weaning food for children. These children would be particularly susceptible to the reductions in mental and physical development that can result from sub-lethal exposure to these toxins.

Objectives and Implementation Sites

- Identification of *Fusarium* species associated with pearl and finger millet and with grain mold and stalk rot of sorghum. Kansas, South Africa, Mali and Uganda.
- Fungal localization and caryopsis health. Kansas and South Africa.
- Mycotoxins in sorghum and millets. Kansas, South Africa and Nigeria.
- Strengthen host-country research capacity. Kansas, South Africa (Malaysia & South Korea)

Contribution to INTSORMIL Objectives

Collectively, the planned work impacts INTSORMIL objectives 2, 4, 5 and 7. Fewer mycotoxins in the grain improve food and nutritional quality of sorghum and pearl millet. Reduced disease pressure increases the yield and yield stability. Information on biotic stresses is being disseminated through the existing workshops and co-authored scientific publications and the training of graduate students and visiting scientists. Assisting INTSORMIL breeders with the development of germplasm resistant to various pathogens increases yield and yield stability.

Research Methodology and Strategy

Species Identification

After field collection, strains are subcultured to a selective medium to purify cultures from bacterial and most other fungal contaminants. These cleaned cultures are then purified further by sub-culturing individual microconidia that have been separated from the remainder of the colony by micromanipulation. Three different species concepts are used in *Fusarium*-morphological, biological and phylogenetic. Most species from sorghum and millet are very similar to one another morphologically, which means that the morphological characters are insufficient to differentiate the species, thus either biological or phylogenetic concepts and strategies are usually employed after an initial morphological observation confirms that the strains have the morphological characters common to most sorghum *Fusarium* species. At this point cultures are grown for three days and DNA is isolated from all strains. DNA from strains is run through an Amplified Fragment Length Polymorphism (AFLP) protocol. At the end of the first run, strains with visibly similar patterns are grouped together and rerun to confirm their similarity. Genes with species specific sequences, usually one encoding β -tubulin (*tub-2*) and/or another encoding translocation elongation factor 1- α (*tef-1*) are amplified by PCR and sequenced. If there is less than 1% difference between the sequences obtained and those available for standard strains, then the group is considered to have been successfully identified.

If there are tester strains available for sexual crosses for a known species, then the identity of the remaining strains in the group are confirmed by crosses.

In many cases for strains from sorghum and millets in Africa, the species is one that has not been described. In such cases, additional strains are sequenced to confirm that the first set of sequence data typifies the group. At this time, a search for the sexual stage begins. Crosses are made in all possible pairwise combinations of all strains, with each strain serving as both the male and as a female parent in a cross (this results in the number of crosses made being the square of the number of strains in the group, e.g., 50 strains = 2500 crosses that must all be re-peated at least twice = 5000 crosses total), with the goal of finding strains that are fertile as the female parent. The number of crosses can be reduced by up to $\frac{1}{2}$ if the mating type of the strains can be determined molecularly before the crossing process begins. Once fertile strains are identified, female fertility usually must be improved through crosses with other female fertile strains, which may be a very time-consuming process. Once the sexual stage has been successfully identified then photographs of critical morphological features are made, strains are deposited in appropriate international culture collections and herbaria and the new species can be written up for publication. No more than 2-3 new species can be processed at any single time.

Most of this work is done at KSU with samples collected from numerous African countries including Egypt, Ethiopia, Mali, Nigeria and South Africa with the help of colleagues based there.

Fungal Localization and Caryopsis Health

Disease severity parameters such as caryopsis formation, germination, emergence, vigor, seed weight, and peduncle colonization are being measured. Tissues within the caryopsis, including germ, endosperm, pericarp, and black layer, are dissected for isolation of fungi after natural and artificial inoculations. *Fusarium* spp. are then isolated from caryopsis tissues and identified with morphological characters and DNA sequences. Control and inoculated caryopses are evaluated for viability by staining of the scutellum, radicle, coleoptile, plumule, and embryo axis tissues with tetrazolium violet. Kernels from artificial inoculations are measured for grain hardness, diameter, and crush strength via the single kernel classification system. In vitro competition assays are being used to determine the interactions between grain molding species, grain weathering species and storage fungi.

To assess caryopsis quality, sorghum flours (from white-tan genotypes) are being screened for grain mold, grain weathering and storage fungi. Caryopses are decorticated to remove pericarp and black layer prior to flour preparation by using a tangential abrasive dehulling device. Samples also are decorticated by drilling to remove only the pericarp and the black layer tissues. α -, β -, and γ -kafirin proteins and protein complexes in caryopsis endosperm are being measured in sorghum endosperm from seed derived following fungal inoculation at anthesis.

Most of this work has been done at KSU in Dr. Little's laboratory and at the University of the Free State in Dr. McLaren's laboratory.

Mycotoxin Contamination

The primary work reported this year is of a joint experiment conducted with IITA and MRC and evaluated for aflatoxin contamination. Similar work also has been conducted on fumonisin contamination but the necessary analyses for publication are not yet finished.

IITA routinely runs multi-location “on-farm” trials of traditional and improved maize, sorghum and pearl millet lines to determine yields and the effects of agronomic and other parameters not always observable in fields at research stations. The cooperating farmers are provided with seed and other inputs, e.g., fertilizers and pesticides, and allow the collection of data on yield, maturity and pest and disease incidence. For this study we used samples grown by farmers at 14 locations in the Northern Guinea savanna and the Southern Guinea savanna of Nigeria. Maize, sorghum and pearl millet are the primary cereal components in this cropping system. All three crops were grown at two locations, maize and sorghum only at 11 locations and maize and pearl millet only at one location. Crops were planted and tilled according to standard practices that varied somewhat by region.

Grain was harvested at plant maturity and stored in paper bags at 4°C until analyzed. One hundred kernels of each sample were placed on moist filter paper in a petri dish and incubated for 6 days on a laboratory bench at 25-28°C. The proportion of kernels infested with one or more *Aspergillus* spp., one or more *Fusarium* spp., and free of any fungal contamination was determined. This method underestimates the frequency of *Fusarium* in millet and sorghum as it often is outcompeted by other faster growing fungi that are already present.

Five hundred grams of grain from each sample was ground to a fine powder and passed through a 20-mesh sieve. One g of the powder was suspended in sterile H₂O to make 10 ml total volume. Ten µl of the suspension was spread on plates of a medium selective for *Aspergillus*. The number of colony forming units (cfu) of *A. flavus* “S” (more toxigenic) and “L” (less toxigenic) types, *A. parasiticus* and *A. tamarii* determined based on their morphology and toxin production potential. Twenty g of powdered grain was extracted by blending at high speed with 100 ml of 70% methanol for 3 min. The slurry was allowed to settle, the supernatant was filtered through filter paper, and 15 ml of the filtrate used for further evaluation. Aflatoxin was measured by using a commercial ELISA kit and following the manufacturer’s instructions. Results are based on a standard curve with OD₄₅₀ as the measure of aflatoxin present. Samples with more aflatoxin than that in the most concentrated standard were diluted and reassayed. The minimum detection limit was 1 ng/g. The amount of variation between subsamples was < 15%. Based on spiked recovery controls, ≥ 80% of the aflatoxin present was recovered by this method.

The field work was done in Nigeria and organized by IITA. Toxin analyses were conducted at IITA (for aflatoxin) and at MRC in South Africa (fumonisins). Book editing has been done primarily at KSU with assistance from colleagues at IITA in Nigeria and at ISPA in Italy. Authors were from 23 countries in North America, Europe and Asia, and included economists, plant pathologists, plant breeders, chemists, policy makers and politicians.

Strengthening Research Capacity

Present workshops on Scientific Writing and Scientific Research Ethics as requested. Organize annual *Fusarium* Laboratory workshop.

Research results

Species Identification

A large pre-existing fungal population isolated from sorghum stored on farm in rural Mali is being analyzed for DNA polymorphisms and species identification. All cultures have been cleaned and purified by the micromanipulation of single spores to yield pure cultures. DNA has been extracted from most of the nearly 1200 strains, some AFLP comparisons have been run, enabling preliminary working groups of strains to be identified. These AFLP comparisons are being rerun with different primer pairs to confirm the preliminary results. Most of the observed patterns are significantly different from those of known species. A group of 400 strains from finger millet collected in Uganda are at a similar state of evaluation. We have done enough molecular work to have identified two putative new species, one from each set of strains. The finger millet strain appears to be limited to Uganda, but the sorghum strain has a broader distribution and includes isolates from Egypt and East Africa in addition to those from West Africa. Mating type tester isolates are being developed for both species. Both species are a part of the *Liseola* section of the genus, i.e., the section to which most of the other *Fusarium* strains isolated from sorghum belong.

Fungal Localization and Caryopsis Health

This work has just begun this year at KSU. Work at the University of the Free State has been planned and will parallel the work to be done in Kansas, but is waiting for a student to do the work to be identified. To date, data from caryopsis tissue studies at KSU, indicates that most of fungi derived from undamaged sorghum seeds are found in black layer tissues.

Mycotoxin Contamination

Edited book on mycotoxins is complete and will be published by CABI in 2008.

Sorghum, maize and pearl millet grain all could be contaminated with *Aspergillus*, *Fusarium* and other species of filamentous fungi, but these species were not equally present on all of the grains. Kernels of maize were four- and nine-fold more likely to be contaminated with *Aspergillus* than were comparable samples of sorghum and pearl millet, respectively, and 1.8-fold more likely to be contaminated with *Fusarium* than sorghum and pearl millet. Sorghum, however, was more likely to be contaminated with other filamentous fungi than were either maize or millet. Within the *Aspergillus* species recovered, the *A. flavus* “L” type was always dominant (> 80%) with one or two of the other types occasionally isolated, but never at a frequency > 17% of the total.

Average aflatoxin contamination was much higher in maize (36 ng/g) than in either sorghum (8.8 ng/g) or pearl millet (4.6 ng/g). The median amount of aflatoxin in a sample was similar for all three grains (4.2 ng/g, 5.0 ng/g and 4.4 ng/g, respectively), suggesting that the major problem was with samples that were heavily contaminated. Of the 23 maize samples, four (17%) exceeded the 20 ng/g FAO guideline as did two (5%) of the 40 sorghum samples and none of the pearl millet samples. In addition to having a higher proportion of samples that did not meet the guidelines, maize samples also contained higher levels of aflatoxin than did non-conforming sorghum samples. Maize samples could have up to 24-fold the recommended maximum aflatoxin level, while those for sorghum (4.5-fold) were considerably less heavily contaminated with aflatoxin even at their worst. The likelihood of aflatoxin exposure to humans from maize is particularly high in zones where the frequency of maize consumption, the presence of aflatoxin in maize or the presence of *A. flavus* on maize is relatively high. The levels of aflatoxin we measured would be the lowest possible, as toxin levels may increase, but may not decrease, during storage. The toxin levels we measured will be higher than those observed in most commercial markets because the grain will be sorted at the farm level before being sold, with the better quality grain being sold for commercial purposes and the poorer quality grain being retained for on-farm consumption.

Strengthening Research Capacity

Workshops held and number of attendees included in non-degree training report.

Networking Activities

Editorial and Committee Service (2007)

- Editor, Food Additives and Contaminants (2006-2009)
- International Society for Plant Pathology, Fusarium Committee (2000-2007)
- MycoGlobe Steering Committee (2003-2007)
- MycoRed Steering Committee (2007-2013)

Research Investigator Exchanges (2007)

- Australia – August 25 - September 6
- Italy – September 30 - October 6
- Malaysia – September 6-13
- Netherlands – September 26-30
- Norway – March 10-18
- People's Republic of China – April 22-30
- South Africa – November 2-19
- South Korea – April 30 - May 5

Other Collaborating Scientists (Host Country)

- Dr. Sofia Chulze, Department of Microbiology, National University of Rio Cuarto, Rio Cuarto, Argentina.
- Dr. Sandra Lamprecht, Plant Protection Institute, Agricultural Research Council, Stellenbosch, South Africa.
- Drs. Yin-Won Lee & Jungkwan Lee, Dept. of Plant Pathology, Seoul National University, Seoul, South Korea.

- Drs. Antonio Logrieco, Antonio Moretti & Giuseppe Mulé, Inst. Sci. of Food Production, CNR, Bari, Italy.
- Dr. Maya Piñeiro, FAO, Rome, Italy.
- Dr. Baharuddin Salleh, School of Biological Sciences, Universiti Sains Malaysia, Penang, Malaysia.
- Dr. Brett Summerell, Royal Botanic Gardens, Sydney, Australia.

Other Collaborating Scientists (U.S.)

- Drs. Charles W. Bacon and Tony Glenn, USDA Russell Research Center, Athens, Georgia
- Dr. Gary N. Odvody, Texas Agricultural Experiment Station, Corpus Christi, Texas

Recipients of Fusarium Cultures in 2007 (Other than Collaborators)

- Ridao Azucena, University of Buenos Aires, Buenos Aires, Argentina.
- Alison Bentley, Faculty of Agriculture, University of Sydney, Sydney, Australia.
- David Geiser, Pennsylvania State University, University Park, Pennsylvania.
- Fungal Genetics Stock Center, University of Missouri-Kansas City, Kansas City, Missouri.
- Bian Jiang, Chinese Academy of Sciences, Beijing, People's Republic of China.
- Ralf Kristensen, Institute of Veterinary Medicine, Oslo, Norway.
- Randy C. Ploetz, Tropical Research & Education Center, Univ. of Florida, Homestead, FL.
- David Schmale, Dept. Plant Pathol. & Weed Science, Virginia Tech. Univ., Blacksburg, VA.
- Keith Seifert, Agriculture and Agri-Foods Canada, Ottawa, Ontario, Canada.
- Amir Sharon, Department of Plant Sciences, University of Tel Aviv, Tel Aviv, Israel.
- Frances Trail, Department of Plant Pathology, Michigan State University, East Lansing, MI.
- Bettina Tudzynski, Westfaelische Wilhelms University, Muenster, Germany.
- Cees Waalwijk, DLO Institute for Plant Protection, Wageningen, The Netherlands.

Publications and Presentations (2007)

Seminar, Workshop & Invited Meeting Presentations (International Locations Only)

- Bioforsk, Ås, Norway – 03/07
- College of Life Sciences, Dalian Nationalities University, Dalian, China – 04/07
- Shenyang Agricultural University, Shenyang, China – 04/07.
- Faculty of Agricultural & Life Sciences, Seoul National University, Seoul, Korea – 05/07
- FABI, University of Pretoria, Pretoria, South Africa – 11/07.

Journal Articles (2007)

- Bandyopadhyay, R., M. Kumar & J. F. Leslie. 2007. Relative severity of aflatoxin contamination of cereal crops in West Africa. *Food Additives and Contaminants* 24: 1109-1114.
- Hornok, L., C. Waalwijk & J. F. Leslie. 2007. Genetic factors affecting sexual reproduction in toxigenic *Fusarium* species. *International Journal of Food Microbiology* 119: 54-58.
- Jeney, A., E. Béki, A. Keszthelyi, J. F. Leslie & L. Hornok. 2007. Inactivation of *Fpmtr*, an amino acid transporter gene causes communication disturbances in *Fusarium proliferatum*. *Journal of Basic Microbiology* 47: 16-24.
- Leslie, J. F., L. L. Anderson, R. L. Bowden & Y.-W. Lee. 2007. Inter- and intra-specific genetic variation in *Fusarium*. *International Journal of Food Microbiology* 119: 25-32.
- Ramirez, M. L., M. M. Reynoso, M. C. Farnochi, J. F. Leslie & S. N. Chulze. 2007. Population genetic structure of *Gibberella zeae* from wheat in Argentina. *Food Additives and Contaminants* 24: 1115-1120.
- Lee, J., R. L. Bowden & J. F. Leslie. 2007. Pheromone functions in *Gibberella zeae*. *Fungal Genetics Newsletter* 54(Suppl.): 67.
- Lee, J., J. F. Leslie & R. L. Bowden. 2007. Functions of the sex pheromones of *Gibberella zeae*. *Proceedings of the 2007 National Fusarium Head Blight Forum* (Kansas City, Missouri): 134.
- Reynoso, M. M., M. L. Ramirez, J. F. Leslie & S. N. Chulze. 2007. Trichothecene chemo-types of isolates of *Gibberella zeae* recovered from wheat in Argentina. *Proceedings of the 2007 National Fusarium Head Blight Forum* (Kansas City, Missouri): 30.
- Swett, C., L. L. Anderson, J. F. Leslie & J. Y. Uchida. 2007. Evaluating genetic diversity of *Fusarium proliferatum* from orchids in Hawaii. *Fungal Genetics Newsletter* 54(Suppl.): 69.

Abstracts (2007)

- Anderson, L. L., Y.-W. Lee, R. L. Bowden & J. F. Leslie. 2007. Relationships between *al*-leles at lineage diagnostic loci in

Ecologically-Based Management of Sorghum and Pearl Millet Insect Pests in Africa and the United States

Project WTAMU 101
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Dr. Gary C. Peterson – Sorghum Breeder, Texas AgriLife Research, Lubbock, TX 79401

Dr. Gerald J. Michels, Jr. – Entomologist, Texas AgriLife Research, Amarillo, TX 79106

Dr. Roxanne A. Bowling – Extension-Agent Pest Management/Entomologist, Texas AgriLife Extension, 310 E. 1st Street, Room 100, Dumas, TX 79029

Dr. Michael W. Pendleton – Electron Microscopist, Microscopy and Imaging Center, Texas A&M University, College Station, TX 77843-2257

Introduction and Justification

Entomologists, breeders, pathologists, economists, and extension agents in Mali, Niger, Mozambique, Botswana, and the U.S. are educating students and farmers in IPM and developing, evaluating, and transferring pest management technologies for insects of sorghum and millet. Development and adoption of ecologically-based technologies will decrease loss by insects in the field and storage, reduce pesticide use, conserve soil and water without contamination by pesticides, and increase yield of food and feed for domestic use and income from marketing. Sorghum and millet are damaged by such biotic stresses as larvae of shoot fly, *Atherigona soccata*, that kill the growing point of seedlings. Greenbug, *Schizaphis graminum*, in the U.S. and sugarcane aphid, *Melanaphis sacchari*, in Africa suck juice from leaves and vector viruses. Banks grass mite, *Oligonychus pratensis*, kills leaves and causes lodging. Bollworms such as *Heliothis armigera* eat leaves and kernels. Larvae of sorghum midge, *Stenodiplosis sorghicola*, feed on the ovary and can cause 100% loss of grain. Armoured bush cricket, *Acanthoplus discoidalis*, eats developing kernels. Larvae of millet head miner, *Heliocheilus albipunctella*, tunnel in spikes. Southwestern corn borer, *Diatraea grandiosella*, in the U.S. and maize stalk borer, *Busseola fusca*; and spotted stem borer, *Chilo partellus* in Africa tunnel in stalks, causing susceptibility to disease and lodging. Grain storage can take advantage of greater market price but result in more damage by insects that annually destroy 35% of grain worldwide. Pests of stored grain include the maize weevil, *Sitophilus zeamais*.

Objectives and Implementation Sites

This project is contributing to INTSORMIL objectives to fa-

cilitate markets by managing insects that damage yield and quality of sorghum and millet; improve food and nutritional quality to enhance marketability and consumer health by grain not contaminated by pests or pesticides; increase stability and yield through crop and natural resources management by IPM strategies not dependent on pesticides; develop and disseminate information on biotic stresses to increase yield and quality by integrated management strategies against insects; enhance stability and yield through genetic technologies by determining differences among strains of insects and speeding development of resistant cultivars with yield and quality; and develop partnerships with agencies improving sorghum and millet and betterment of people through collaboration among scientists at West Texas A&M University, Texas AgriLife Research and Extension, and Texas A&M University in the US and Institut D'Economie Rurale in Mali, Institut National de la Recherche Agronomique du Niger, Instituto de Investigacao Agraria de Mocambique, Botswana College of Agriculture, private industries, volunteer organizations, and other agencies.

Specific objectives of this project were to: 1) support entomology and IPM research and education of scientists in African countries; 2) collaborate with scientists in Africa and the U.S. to develop and deliver IPM strategies against insects that damage sorghum and millet in the field and storage by improved understanding of biology, ecology, and population dynamics of insect pests and damage they cause; evaluation of potential arthropod pests; agronomic practices to prevent damage by insects and reduce pesticides; cultivars with greater yield and resistance to biotic and abiotic stresses; 3) provide education for students; and 4) develop partnerships with ICRISAT and PVOs engaged in improvement of sorghum and millet production and betterment of people. By presentations and publications, extension and other agencies

will be assisted with transferring pest management information to farmers, scientists, and others in Africa and the U.S.

Research Methodology and Strategy

Evaluating Potential Pests and Understanding the Life Histories of Insect Pests and Natural Enemies

Populations of Banks grass mites were monitored for resistance to miticides on the Texas High Plains. Natural enemies of sorghum aphids were assessed by Dr. Munthali in Botswana. Using agronomic practices to manage pests. Intercropping grasses to draw stalk borers from sorghum or millet was evaluated by Dr. Yaro Diarisso in Mali and planned with Mr. Chitio in Mozambique. Developing germplasm resistant to biotic constraints. The PI and African entomologists collaborated with breeding projects in Mali, Mozambique, Niger, and Texas, and Milo Genetics for evaluating sorghum and millet for resistance to millet head miner, sorghum midge, greenbug, sugarcane aphid, shoot fly, stalk borers, and storage beetles. Studying pests of stored grain. Effectiveness of facilities against insect damage to stored sorghum and millet grain were evaluated in Africa. M.S. student Madani Telly studied when storage insects infest sorghum in the field and evaluated resistance to maize weevils. Microscopy was used by Dr. Michael Pendleton to relate starch and seed morphology to resistance to maize weevil.

Identifying and Evaluating Current and Novel Pest Management Tactics

Ph.D. student Tebkew Damte Belete assessed whether spectrophotometry of phytochrome could be used to predict daily flowering times of sorghum and resistance to sorghum midge. M.S. student Camilo Garzon used pheromones to monitor seasonal abundance of southwestern corn borer moths in Texas. Pheromones were evaluated by Dr. Munthali to monitor lepidopteran pests of sorghum in Botswana.

Transferring Insect Pest Management Technologies

Field demonstrations, workshops, and training manuals were used or being prepared to teach farmers to recognize and analyze pest problems and evaluate, adapt, and implement IPM options. Undergraduate and graduate university students in the U.S., Botswana, and Niger assisted with the research and were educated in entomology and IPM.

Research Results

In Botswana, Dr. Munthali found shoot fly and stalk borers attacked sorghum 26-38 days after planting, while sugarcane aphid attacked at the milk stage. Blue panicle bug, armoured bush cricket, and birds attacked during grain filling to harvest. Panicle pests caused total loss. (Table 1)

Dr. Yaro assisted farmers with using *Andropogon gayanus* in 3 border rows 50 cm apart with 30 cm between plants planted on 7 and 8 July at Finkolo and Zanradougou in the Sikasso region of Mali, to attract stalk borers away from millet. *Andropogon* was attractive to stalk borers and/or parasitoids and selected by farmers for use and economic return. A randomized complete block with 5 farms was used. Millet was planted on 17 and 18 July in 15 x 10-m plots 2 m apart at Zanradougou and Finkolo. Millet was surrounded by *Andropogon* or millet (check). Pests and natural enemies were sampled on 10 plants 30, 70-80, and 100-110 days after emergence. Percentage of deadhearts and numbers of larvae and pupae were determined on 6 and 7 September, 30 days after emergence at Zanradougou and Finkolo. Damage was greater at Finkolo. Millet was less damaged surrounded by *Andropogon* (1.7%) than millet (5.3%). Damage scores were 5.8, 4.4, and 1.7 for millet surrounded by millet, *Andropogon*, and millet surrounded by *Andropogon* at Finkolo. Damage at Zanradougou was 4.7, 2.2, and 1.7 for millet surrounded by millet, *Andropogon*, and millet surrounded by *Andropogon*. (Table 2)

Rows of *Desmodium* grass as a border to trap stalk borers were planted before sorghum by Mr. Chitio in Mozambique. Rains stopped and sorghum died; the experiment will be repeated.

Serere and Tswana millets were planted in 3, 10 x 10-m plots by Dr. Munthali in Botswana. Seeds were sown 50 cm between plants in rows 80 cm apart. Pests were counted on 10 plants per plot. Ranges of 0-5 and means of 1.1 ± 0.4 and 1.0 ± 0.56 armoured bush crickets were found per plant of Tswana and Serere, respectively, that were equally susceptible.

Mr. Abdou Kadi Kadi, with Dr. Kadri Aboubacar and an intern from the University Abdou Moumouni at Niamey, evaluated at INRAN Kollo resistance to millet head miner of millet developed with Issaka Ahmadou, millet breeder. Millets evaluated were HKB, H80-10GR, TARAM, SOSAT-C, MANGARANA, HKP-GMS, ICMV IS89305, ZATIB, MANGARANA x ICMV IS89305, SOSAT-C x HKB, SOSAT-C x ZATB, and TCHOUMO. A completely randomized block with 3 replications was used.

Table 1.

Pest species	Period of attack		Stage of growth of sorghum attacked	Plant part damaged
	First day on sorghum	Damaging time (day after planting)		
Shoot fly	5 February	26	Seedling to vegetative	Shoot
Sorghum stalk borer	5 February	26	Seedling to vegetative	Leaf, stem
Sugarcane aphid	29 February	50-69	Milk (panicle formation)	Leaf
Blue bug, <i>Calidea</i> sp.	4 April	85-120	Milk-dough (grain fill)	Kernels
Armoured bush cricket	4 April	85-120	Milk-dough (grain fill)	Kernels
<i>Quelea quelea</i> birds	4 April	85-120	Milk-dough (grain fill)	Kernels

Table 2.

Village	Farmer	% vegetative plants with deadhearts by stalk borers		
		Millet surrounded by Andropogon gayanus	Millet surrounded by millet	Andropogon gayanus
Finkolo	Diakalia Ballo	1.5	10.3	2.0
	Issouf Ballo	1.5	4.3	3.0
	Abdoulaye Kone	2.8	5.2	5.5
	Seybou Kone	2.3	6.6	7.1
	Oumar Traore	0.5	2.5	4.6
Zanradougou	Nouhoum Djourthe	3.7	0.0	1.2
	Siaka Djourthe	0.0	12.5	3.0
	Tidiani Sanogo	1.5	1.5	2.4
Mean damage		1.7	5.3	3.6

Each sub-plot 12 m² had 4 rows 3 m long, with 1 m between rows and 1 m between hills. Yield will be recorded when the millet is harvested.

The PI evaluated 402 sorghum lines developed by Milo Genetics for resistance to greenbug biotype I and found 52.5% as, or more, resistant than the resistant check. Results were reported to Milo Genetics for release of sorghums produced from the lines to farmers in the U.S.

Mr. Abdou Kadi Kadi involved 4 extension agents, 12 men and 4 women farmers from 4 villages, and TAYMAKO farmer's association of 74 men and 6 women to introduce sorghum midge-resistant 99-SSD35 and its early parent Mota Maradi at farms in 5 villages in 2 regions of Niger. The group did 4 tests with 2 planting dates at a site. Farmers at one site are producing SSD35 in many fields. The farmer's association and FAO grew 60 and 30

hectares of 99-SSD35 to provide seed for farmers. The sorghum is not mature and yield data not available yet.

Sorghum genotypes in the Midge Line Test differed in resistance to sorghum midge ($F = 2.1$, $P = 0.0048$) and stalk borers ($F = 5.57$, $P = 0.0001$) in Mozambique. Four resistant sorghums scored 1.0/5 for damage by sorghum midge and one scored 1.0 for stalk borers. Lines 03LI6220.21 (1.0 score) and 03LI6206.07, 03LI6201, and 03LI6150.51 (1.5 score) were least damaged by stalk borers ($F = 1.64$, $P = 0.21$) in the All Disease and Insect Nursery.

Twenty-five ICRISAT Kenya sorghum varieties differed in damage by shoot flies ($F = 2.3$, $P = 0.007$) and stalk borers ($F = 1.78$, $P = 0.045$) at Namialo, Mozambique. ICSV700, ICSB654, ICSB324, and SPV1411 were resistant to shoot flies. S35,

Table 3.

Sorghum	Damage (1-5) by shoot fly	Damage (1-5) by stalk borers
ICSV700	1.0 e	
S35		1.0 d
ICSB654	1.3 de	1.0 d
IESB92008DL	2.7 bcd	1.3 cd
SPV1411	1.7 cde	3.0 a
IESB91104DL	4.3 a	2.7 a
Local check		2.7 a
CV%	38.6	37.2

Table 4.

Sorghum	Sugarcane aphid damage (1-5)	Sorghum midge damage	Stalk borer damage
03CS487	1.0 c	1.0 d	1.0 c
03BRON245	1.0 bc	1.0 cd	
02CS30736	1.0 bc		
02CS5247	1.0 bc		
01CS22295			1.0 bc
98LB1886-B			1.0 bc
03CS174	1.25 abc	1.0 cd	
00CS21492	1.25 abc	1.0 cd	2.5 ab
BOTT75-B		2.5 a	
02CS4495-1	2.0 a		3.0 a
98LB2838B	2.0 a		3.0 a
CV%	39.4	32.5	48.4

ICSB654, and ICSB324 were resistant to stalk borers. ICSB654 and ICSB324 were resistant to both pests. (Table 3)

Varieties 03CS487, 02CS30736, 03BRON245, 02CS5247, and 00CS21492 were resistant to sugarcane aphid; 03CS487, 00CS21492, 03BRON245, and 03CS174 to sorghum midge; and 03CS487, 01CS22295, 98LB1886-B, and 01CS20804 to stalk borers in the Drought Line Test in Mozambique. Variety 03CS487 was resistant to the three pests. (Table 4)

Varieties 03CS-GWT115, 03CS-GWT102, 02CS-30455, and 01CS-20528 were resistant to sugarcane aphid ($F = 6.36$, $P = 0.0024$); 02CS-30455, 01CS-20528, 02CS20550, and 03CS3 to sorghum midge ($F = 7.13$, $P = 0.0015$); and 03CS234, 03CS-GWT115, and 02CS20550 to stalk borers ($F = 11.02$, $P = 0.0002$) in the Grain Weathering Test in Mozambique. Variety 02CS20550 was resistant to sorghum midge and stalk borers. (Table 5)

Seventy sorghum genotypes from the U.S. breeding program differed in damage by stalk borers in Mozambique ($F = 4.24$, $P = 0.0001$). Genotypes 04CS826-1-1, 04CS58-6-1, 04CS608-7-1, and 04CS804-2-1 were scarcely damaged (1-1.5 scores), while 04CS452-4-1 scored 3.75.

Three SADC varieties and 50 Texas-bred sorghum lines were evaluated by Dr. Munthali for resistance to aphids, shoot fly, and stalk borers in Botswana. Each genotype was planted in 3, 7-m rows in a completely randomized block. Damage was assessed on 5 plants per plot. Texas 06L12661, 07CA20174-BK, 07CA20053-BK, and 07CA20187-BK were most infested with sugarcane aphids (72.1, 61.1, 57.2, and 55.5% of plants) and most damaged (2.5, 2.2, 1.9, and 1.8 scores). *Coccinellids Chilopomenes lunata*, *Dysis quadrilineata*, *Exochomus flavipes*, and *Exochomus nigromaculatus* were abundant. Most predators were on 07CA20021-BK (58.3% of plants). Predators were on >30% of plants of 06PR420, 07CA20019-BK, 07CA20053-BK, 07CA20114-BK, 07CA20126-BK, 07CA20168BK, 07CA20175-BK, and 07L13471-BK. Damage by sugarcane aphids was not severe enough (1.2 score) to cause significant yield loss. (Table 6)

M.S. student Madani Telly from Mali found fewest live (1.6 and 2.0) or total maize weevils (1.9 and 2.0) in grain of Tx7078 and BTx2959. Most dead weevils (1.9) were in PM12713* Tx2882. BTx2959 and Tx7078 were least damaged (1.2 and 1.3 scores) and

lost least weight (0.8-1.6%). Dr. Michael Pendleton is relating starch in the sorghums to resistance to weevils. (Table 7)

A survey of 290 men and 30 women farmers from 16 villages in 2 regions by Mr. Abdou Kadi Kadi, 14 extension agents, and 4 interns from University Abdou Moumouni, Niamey identified storage insects, evaluated facilities, and assessed botanicals and cultural methods to prevent damage to sorghum and millet. Andropogon and stalks were used for cylindrical granaries at Maradi and bricks with a grass cover were used at Tahoua. Dry spikes and/or panicles were stored. Grain was stored in barrels, burlap bags, plastic bags, and storage houses. (Table 8)

Dr. Munthali used pheromones to trap lepidopteran pests in sorghum in Botswana. Moths were first trapped 50 days after planting. Spotted stem borer, *C. partellus* was most abundant, especially in mid-May and increased 10-fold between February and June. Early detection will enable timing of management for eggs and early instars. Bollworm, *H. armigera* was minor. (Table 9)

A M.S. student from Colombia monitored southwestern corn borer moths in pheromone traps from June to September in Texas. Numbers of moths varied among locations and differed with weather. Moths of the 1st generation were trapped from late-June until mid-July. Second-generation moths were trapped from the 1st week of August through 1st week of September, with most in mid-August. Plants were checked for eggs and larvae. The 1st larva was found 28 July.

Ph.D. student Tebkew Damte Belete from Ethiopia found that at 0600, 0900, 1200, 1800, and 2400 hours, phytochrome of susceptible RTx430 that flowers at daylight when sorghum midges are ovipositing was 1.7 times more than resistant TAM2566 that flowers at night. Resistant A8PR1013 x Tx2882 had 2.3 times more phytochrome than susceptible ATx399 x RTx430. All spikelets of TAM2566 and RTx430 closed before 0600 and 1000 hours, respectively.

Tebkew Belete surveyed sorghum farmers in Texas and found 54.1, 2.8, and 29.2% believed sorghum midge was a pest of dry-land sorghum, irrigated, and both. Estimates of yield loss ranged from 0-40%. Most farmers (97%) scouted their sorghum. Two-thirds applied insecticide 1-3 times. Dr. Lal Almas, Agricultural Economist at West Texas A&M University, assisted with compar-

Table 5.

Sorghum	Sugarcane aphid damage (1-5)	Sorghum midge damage	Stalk borer damage
02CS-30455	1.0 b	1.0 c	1.25 de
03CS234	1.25 b	1.25 bc	1.0 e
02CS20550	1.25 b	1.0 c	1.25 de
01CS-20528	1.0 b	1.0 c	1.5 cde
03CS-GWT115	1.0 b	1.75 b	1.0 e
02CS30425	1.25 b	1.25 bc	1.25 de
02CS-30445	1.5 b	1.25 bc	1.5 cde
03CS-GWT102	1.0 b	1.75 b	1.75 bcd
01CS20529	1.25 b	1.25 bc	2.25 b
03CS3	1.75 b	1.25 bc	3.25 a
03CS6	3.5 a	3.0 a	2.0 bc
CV%	29.7	20.8	16.8

Table 6.

Sorghum genotype	% plants with shoot fly 50 DAP	% plants with stalk borer 50 DAP	% plants with sugarcane aphid 50 DAP	Overall damage score by aphids	Overall % plants with coccinellids
05L1384	8.3	9.3	13.1	1.1	6.6
06PR397	13.9	13.3	8.3	1.0	12.2
06PR399	12.3	18.9	40.3	1.2	29.6
06PR405	0.0	23.4	18.6	1.1	27.3
06PR398	4.9	0.0	6.7	1.0	7.9
06PR414	3.7	17.8	20.0	1.0	14.0
06PR404	0.0	59.2	13.1	1.0	16.7
06PR415	0.0	0.0	0.0	1.0	7.8
06PR419	8.3	17.9	22.2	1.0	8.3
06PR420	4.8	25.0	14.3	1.0	32.7
05L1390	12.2	16.7	50.0	1.0	27.8
06L12661	25.0	12.4	78.0	2.5	12.5
07CA20013-BK	0.0	0.0	33.3	1.0	25.0
07CA20016-BK	33.3	13.3	13.3	1.0	6.7
07CA20019-BK	0.0	0.0	33.3	1.0	33.3
07CA20021-BK	0.0	25.0	8.3	1.0	58.3
07CA20042	5.5	12.2	16.7	1.0	22.9
07CA20043	0.0	16.7	16.7	1.0	16.7
07CA20053-BK	16.7	4.8	42.9	1.9	30.5
07CA20057-BK	6.7	12.0	28.9	1.1	29.7
07CA20061-BK	0.0	0.0	11.1	1.0	13.9
07CA20062-BK	22.2	16.7	16.7	1.0	29.4
07CA20065-BK	8.3	6.7	15.0	1.0	3.3
07CA20067-BK	0.0	11.1	0.0	0.0	17.0
07CA20072- BK	21.4	4.8	4.8	1.0	2.4
07CA20088-BK	21.4	4.8	0.0	1.1	22.2
07CA20089-BK	0.0	20.0	17.8	1.0	15.6
07CA20096-BK	0.0	44.4	6.1	1.0	4.6
07CA20099-BK	0.0	11.1	0.0	1.0	16.7
07CA20101-BK	11.1	11.1	5.6	1.2	16.7
07CA20114-BK	11.1	11.1	0.0	1.3	33.3
07CA20122- BK	13.3	0.0	20.0	1.3	10.0
07CA20123-BK	0.0	0.0	16.7	1.0	8.3
07CA20126-BK	15.0	0.0	35.0	1.3	32.5
07CA20153-BK	0.0	0.0	22.2	1.0	11.1
07CA20161-BK	0.0	22.2	33.3	1.0	16.7
07CA20165-BK	33.3	0.0	0.0	0.0	0.0
07CA20168-BK	11.1	22.2	33.3	2.2	39.3
07CA20174-BK	22.2	0.0	16.7	1.1	25.6
07CA20175-BK	8.3	26.8	5.6	1.0	32.9
07CA20177-BK	0.0	21.7	23.3	1.0	12.5
07CA20181-BK	0.0	0.0	33.3	1.0	0.0
07CA20187-BK	15.9	11.4	54.0	1.8	15.9
07CA20223- BK	0.0	0.0	0.0	1.0	0.0
07L13467-BK	11.1	9.7	21.4	1.0	19.6
07L13468-BK	3.3	8.3	12.4	1.0	18.6
07L13469-BK	6.2	8.3	4.2	1.5	15.0
07L13470-BK	0.0	32.2	18.9	1.1	29.4
07L13471-BK	5.6	44.4	5.6	1.0	52.8
07L13472-BK	0.0	15.1	13.9	1.0	12.5
BSH1	22.5	29.2	39.1	2.0	20.9
Mmabaitse	57.1	0.0	42.9	1.4	23.8
Macia	16.7	26.8	31.7	1.8	29.0
Overall mean	9.3 ± 1.55	13.6 ± 1.77	19.6 ± 2.22	1.2 ± 0.05	19.4 ± 1.59

Table 7.

Sorghum genotype	Maize weevils per gram	Damage score (1-5)	Weight loss (g)/5 g
Tx7078	1.9 ± 0.65 f	1.3±0.20 ef	0.04 ± 0.07 c
BTx2959	2.0 ± 0.76 ef	1.2±0.19 f	0.08 ± 0.09 c
BTx645	6.3 ± 1.50 d-f	1.7±0.27 d	0.6 ± 0.16 b
SDSL89426 * 60B124	7.3 ± 1.73 d-f	1.8±0.45 cd	0.7 ± 0.17 b
SV1 * Sima	8.5 ± 2.47 de	1.5±0.28 de	0.7 ± 0.21 b
Sureno	8.3 ± 1.44 d-f	1.5±0.22 de	0.8 ± 0.12 b
CE151 * TAM428 (06PR410)	10.0 ± 1.57 cd	1.7±0.26 cd	0.9 ± 0.16 b
Segaolane * WM#322	8.3 ± 1.52 d-f	1.8±0.27 cd	0.9 ± 0.15 b
Macia * TAM428	9.1 ± 2.54 d	1.9±0.39 b-d	0.9 ± 0.24 b
ICSR-939	16.4 ± 2.32 bc	2.1±0.21 bc	1.4 ± 0.15 a
CE151 * TAM428 (06PR407)	16.7 ± 2.22 b	2.2±0.30 ab	1.4 ± 0.19 a
PM12713 * Tx2882	23.7 ± 5.08 a	2.5±0.36 a	1.7 ± 0.33 a
87EON366 * 90EON328	24.9 ± 3.19 a	2.4±0.23 a	1.9 ± 0.16 a

Table 8.

Pests	Botanical plants/methods of use	Inert
Grain moth, <i>Sitotroga cerealella</i> ;	Cowpea, <i>Vigna inguiculata</i> , leaves repulse storage pests;	Ash,
Confused flour beetle, <i>Tribolium confusum</i> ;	Zouray, <i>Boscia Salicifolia</i> , leaves under spikes or panicles during drying, leaves superposed between tied spikes or panicles within granary;	Salt,
Red flour beetle, <i>Tribolium castaneum</i> ;	Yakuwa, <i>Hibiscus sabdariffa</i> , leaves and branches pounded and put on granary poles;	Ash and salt mix to control termites and ants,
Lesser grain borer, <i>Rhyzopertha dominica</i> ;	Karanguia, <i>Cenchrus biflorus</i> , spiny fruit used on path of mice and rats;	
Grain trogoderma, <i>Trogoderma granarium</i> ;	Komeya, <i>Eragrostis tremula</i> , threading of the superior part of <i>Eragrostis</i> and superposed between tied spikes or panicles in granary;	
Flour pyralid, <i>Ephestia kuehniella</i> ;	Dorowa, <i>Parkia biglobos</i> , fruit pounded and powder used around granary poles;	
Birds;	Rumfu, <i>Cassia singueana</i> , and neem, <i>Azadirachta indica</i> , flowers of <i>Cassia</i> and leaves of neem mixed with seeds of cereals;	
Mice;	Houda Sartche, <i>Caralluma dalzielii</i> , leaves and branches pounded and put in granary poles;	Fine sand,
Rats;	Onion, <i>Allium cepa</i> , and garlic, <i>Allium sativum</i> , powder to prevent damage	Sun drying
Mold;		
Humidity		

Table 9.

Assessment date	Day after planting	Sorghum growth stage	Number of moths of each species		
			<i>C. partellus</i>	<i>B. fusca</i>	<i>H. armigera</i>
10 January	Planting date	Seed	0	0	0
5 February	26	Seedling	0	0	0
17 February	38	Vegetative	0	0	0
29 February	50	Panicle forming	2	1	2
19 March	69	Milk stage	2	1	0
4 April	85	All plants with panicles	3	2	0
9 May	120	Kernel maturation	19	2	3
3 June	145	Harvest	20	1	3

ing cost of development to benefit of a resistant hybrid. Estimated yield losses ranged from 94.2 to 890.8 and 12.9 to 188.8 kg/ha for susceptible and resistant hybrids, respectively. Estimated farm-level benefits would be \$93.3, -371.2 and -153.6 per hectare, if a susceptible hybrid was grown in the absence, presence, and protected by insecticide from sorghum midge, respectively. Benefits for a resistant hybrid would be \$47.5, 1.0, and 26.7. Total state-level benefits from a susceptible hybrid were \$-5.1, -39.4, and -25.2 million in the absence, presence, and protected by insecticide from sorghum midge. For a resistant hybrid, the values were \$-8.6, -12.0, and -12.1 million.

The IIAM sorghum and millet program in Mozambique produced 2.8 and 3 tons of Sima and Macia seed to distribute to farmer associations or sell to NGOs to give to farmers. Seeds of 5 new varieties from pure lines are being multiplied for on-farm testing in January 2009.

Networking Activities

Workshops and Meetings

The PI and collaborators presented research at the INTSORMIL West Africa regional meeting, Bamako, Mali, 14-16 April 2008; INTSORMIL PI meeting, Lincoln, NE, 18-19 September 2007; 56th Meeting of Southwestern Branch of Entomological Society of America, Fort Worth, TX, 23-26 February 2008; Microscopy and Microanalysis, Albuquerque, NM, 3-8 August 2008 and Texas Society for Microscopy, Austin, TX, 17-19 April 2008; and attended the 55th Meeting of Entomological Society of America, San Diego, CA, 9-12 December 2007. Mr. Abdou Kadi Kadi taught farmers in the field in Niger identification, biology, and ecology of millet head miner and sorghum midge. He provided information on sorghum among researchers, extension, NGOs and development project personnel, private sector, and farmers at an ICRISAT/ INRAN open house. Dr. Munthali on 14-16 March 2008 visited Kasane, Botswana by invitation of the Chairmen of the "Pandamatenga Farms Association" to assess feasibility of a collaborative project on "Environmentally friendly methods of controlling major pests of sorghum and sunflower in commercial farms" and submitted a preliminary assessment report.

Research Investigator Exchanges

From 25 October–9 November 2007, the PI discussed and reviewed research with scientists from INRAN in Niger and IER in Mali. The PI and collaborators met for a INTSORMIL West Africa regional meeting in Bamako, Mali, 14-16 April.

Research Information Exchange

The PI advised extension, National Sorghum Producers, and seed companies on management of sorghum insects. Four hundred two sorghums developed for resistance to biotype I greenbug were evaluated for Milo Genetics. Supplies and funding were provided to Mr. Chitio in Mozambique, Dr. Yaro Diarisso in Mali, Mr. Abdou Kadi Kadi in Niger, and Dr. Munthali in Botswana. At Botswana College of Agriculture, insect pins, pinning boards, vials, boxes, rearing cages, and traps from INTSORMIL funds were used to teach insect pest management to 76 B.S. and 5

M.S. students in 7 Economic Entomology, Insect Taxonomy and Systematics, Introduction to Crop Pests, Pests of Field Crops, and Student Research courses. INTSORMIL experimental plots were used for teaching identification and monitoring pests and natural enemies, using scouting and pheromone traps for monitoring and identification of pests, and a student project "Evaluation of pest status of sorghum aphids and abundance of their natural enemies on five sorghum varieties." Published journal articles, research project reports, and other literature are being reviewed for use in solving pest management problems in Botswana. The PI, Dr. Yaro Diarisso in Mali, Mr. Abdou Kadi Kadi in Niger, and Dr. Alain Ratnadass, Entomologist, CIRAD/ICRISAT Niger, planned collaborative entomology research for the "Cereals for the Drylands" proposal to the Bill and Melinda Gates Foundation.

Publications and Presentations

Journal Articles

- Ayyanath, M.M., B.B. Pendleton, G.J. Michels, Jr., and R.A. Bowling. 2008. Effect of greenbug (Hemiptera: Aphididae) from resistant sorghum on developmental rates of convergent lady beetle (Coleoptera: Coccinellidae). *Southwestern Entomologist* 33: 191-197.
- Pendleton, B.B., M.W. Pendleton, and E.A. Ellis. 2008. Using energy dispersive spectrometry to compare the efficiency of metal coating techniques for scanning electron microscopy of insects. *Texas Journal of Microscopy* 39: 14.

Proceedings

- Pendleton, B.B., M.W. Pendleton, and E.A. Ellis. 2008. Using energy dispersive spectrometry to compare the efficiency of metal coating techniques for scanning electron microscopy of insects. In *Proceedings of 56th Annual Meeting of Southwestern Branch of Entomological Society of America, 23-26 February 2008, Fort Worth, TX*. Pp. 33-34.

Dissertations and Theses

- Damte Belete, Tebkew. 2007. Phytochrome content and economic assessment of sorghum resistant to sorghum midge (Diptera: Cecidomyiidae). Ph.D. dissertation. West Texas A&M University, Canyon, TX.
- Telly, Madani. 2008. Resistance of stored sorghum to maize weevil (Coleoptera: Curculionidae). M.S. thesis. West Texas A&M University, Canyon, TX.

Presentations

- M. W. Pendleton, E. A. Ellis, B. B. Pendleton, and A. Holzenberg. Two methods of conductive coating for scanning electron microscopy of maize weevils (*Sitophilus zeamais*) compared by energy dispersive spectroscopy. *Microscopy and Microanalysis*, 3-8 August 2008, Albuquerque, NM. B. B. Pendleton, M. W. Pendleton, and E. A. Ellis. Using energy dispersive spectrometry to compare the efficiency of metal coating techniques for scanning electron microscopy of insects. *Texas Society for Microscopy*, 17-19 April 2008, Austin, TX. B. Pendleton.

Ecologically-based management of sorghum and millet insect pests in Africa and the U.S. INTSORMIL West Africa regional meeting, 14-16 April 2008, Bamako, Mali. R. Bowling, B. B. Pendleton, G. Michels, Jr., and R. Bowling. Spider mite management since resistance to Capture – effective alternatives. 56th Annual Meeting of Southwestern Branch of Entomological Society of America, 23-26 February 2008, Fort Worth, TX. B. B. Pendleton, M. W. Pendleton, and E. A. Ellis. Using energy dispersive spectrometry to compare the efficiency of metal coating techniques for scanning electron microscopy of insects. 56th Annual Meeting of Southwestern Branch of Entomological Society of America, 23-26 February 2008, Fort Worth, TX. B. Pendleton. Ecologically-based management of sorghum and millet insect pests in Africa and the U.S. SMOG CRSP PI meeting, 18-19 September 2007, Lincoln, NE.