DEVELOPMENT OF BIOTIC STRESS-RESISTANT SORGHUM CULTIVARS
FOR NIGER AND SENEGAL

Executive Summary:

A multi-disciplinary (entomology, breeding, and agricultural economics) collaborative research program will develop, evaluate, and deploy sorghum genotypes resistant to abiotic and biotic stresses and adapted to indigenous production and storage systems in West Africa. An integrated approach will increase agricultural productivity and economic growth, with attention to human nutrition, environmental conservation, development of host-country capacity, and gender equity.

Production and storage of quality grain in West Africa are constrained by abiotic stresses including drought and biotic stresses including insects (sorghum midge, storage beetles and moths) and diseases (grain mold/weathering). For African small-holder farmers, genetic resistance is the most-feasible option for managing abiotic and biotic constraints. Multiple environments, locations, and years will be used to select sorghum genotypes with resistance to important stress(es) in West Africa and the United States.

The sorghum midge is the most damaging insect pest of sorghum worldwide and can destroy 100% of developing kernels. Inheritance of resistance to sorghum midge is quantitative, recessive, and influenced by spikelet flowering time and morphology. Multiple nurseries will be used to select sorghum genotypes with increased resistance. Segregating breeding populations will be developed to attempt manipulation of diurnal flowering time and thus design resistant sorghums that flower when sorghum midges are not present. Research on sorghum time of flowering in relation to environmental factors will be used to verify the genetic basis of resistance.

Grain mold/weathering and storage beetles and moths are serious problems for grain in most production regions. Beetles and moths destroy as much as 40% of stored grain and often require insecticidal treatment. Germplasm with excellent resistance to grain mold/weathering in a range of environments will be introgressed into sorghums adapted to Niger and Senegal. To protect stored grain, environmentally friendly methods including hermetic storage and plants with natural insecticidal properties will be evaluated. Scanning electron microscopy of the structure of sorghum kernels resistant to storage insects will be used to increase efficiency of evaluating sorghum genotypes for resistance.

Educational materials will be prepared and extension will assist with field demonstrations and workshops to teach farmers how to identify and manage biotic constraints in the field and storage. Human capacity will be improved by educating male and female scientists in conventional and molecular research methodology and in graduate degree programs.

Production profitability and marketing opportunities for sorghum cultivars with increased resistance to abiotic and biotic stresses will be assessed to ensure farmer adoption of the new technologies for West Africa. This project will improve human nutrition, human capacity, and environmental conservation while increasing agricultural productivity and economic growth for sorghum.
**Collaborating Scientists:**

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**Introduction and Objectives:**

Sorghum (*Sorghum bicolor* (L.) Moench) should be the grain of choice for African small-holder farmers and lead the charge for food self-sufficiency and market development of cash-generating, off-farm commercial ventures. This cereal grain native to Africa is endowed with tremendous genetic variability for economically important traits and genetic resiliency in dealing with changing climate. Sorghum is adapted to many cropping systems and a multitude of production environments. Sorghum has many uses: grain can be processed into nutritious food, beverages, and feed, and forage and stalks can be used as animal feed and building materials. Sorghum production in Africa is increasing, with 23.4 million tons produced on approximately 22.7 million ha in 2012. Although production is at an all-time high, productivity per hectare is decreasing, from 1.24 t/ha in 1961 to 0.97 t/ha in 2012. Grain yield in Senegal has increased slowly. In Niger, total production has increased but yield per hectare has decreased. Adverse weather, poor soil fertility, degraded crop genetic material, traditional cultural techniques used in sandy or clay soil, and pests (insects, diseases, weeds, and birds) limit sorghum production in Niger, in Senegal, and in most Sahelian countries of Africa.

Sorghum is a subsistence food staple crop in Sub-Saharan Africa. As a basic staple, sorghum provides food security for small-holder farmers, the majority female. Grain produced above household use can be available for sale in commercial markets. To empower the economic advancement of small-holder farmers, activities need to occur along a sorghum value chain. Advancement begins with research to develop technology packages that will be adopted with components that individually and in harmony increase grain yield and quality while conserving natural resources. Reliable and consistent post-harvest markets are required to provide easy access for farmers to sell grain. As noted in the Feed the Future (FtF) Global Food Security Research Strategy “increased agricultural productivity drives demand for goods and services, especially those produced locally, helping generate employment and further reducing poverty.”

In Niger, sorghum is the second-most important grain crop after pearl millet, with approximately 2,500,000 ha sown in 2012 (FAOSTAT). Large commercial farms grow sorghum hybrids with inputs and mechanization, but most sorghum is grown by small-holder farmers. In Senegal, harvested sorghum acreage (146,557 ha in 2012, FAOSTAT) is third after millet and maize but before rice. However, the Senegal FtF country strategy lists the three important value chains as millet, maize, and rice. Thus, sorghum is probably not receiving necessary emphasis on research and technology transfer to assist Senegal in becoming food sufficient and in developing cash-generating, end-use markets.
Women and their economic empowerment are essential throughout the value chain and critical to the improvement of family food security and on a larger scale, nations and Africa. Estimates are that in sub-Saharan Africa women are involved in more than 50% of the agricultural activity and produce 60-70% of the food (Gawaya, 2008). Women are involved in production, processing, and marketing, are the primary caregivers, and are responsible for meeting the nutritional needs of all family members. The number of female heads of households is increasing; these households tend to be small in size with less income and are less likely to adopt technology. The needs of women producers, processors, and marketers will be considered so the technology developed will be readily adopted. There are few host-country women scientists and few receive graduate degree or short-term training. There is need to identify and collaborate with qualified women scientists.

Production of high-quality grain (and forage) is constrained by abiotic stresses (drought, heat, soil acidity, and salt) and biotic stresses (insects including sorghum midge, *Stenodiplosis sorghicola* (Coquillet); sorghum shoot fly, *Atherigona soccata* (Rondani); sugarcane aphid, *Melanaphis sacchari* (Zehntner); stalk borer, *Sesamia calamista* Hampson; and storage beetles and moths; diseases including anthracnose, *Colletotrichum graminicola* (Ces.) G.W. Wilson; downy mildew, *Peronosclerospora sorghi* (W. Weston & Uppal) C.G. Shaw; and head smut, *Sphacelotheca reiliana* (J.G. Kühn) G.P. Clinton; and witchweed, *Striga hermonthica* (Delile) Benth. Crop production systems continually evolve as crops, pests, and agronomic practices change. The most damaging sorghum insects and diseases in Senegal are sorghum midge, sorghum shoot fly, panicle bugs, storage beetles and moths, and grain mold. In Niger, major biotic stresses include sorghum midge, *Striga*, and various diseases, and drought is the major abiotic stress. Insect pests feeding at different sorghum developmental stages cause low yield and grain quality. Many stresses occur every year and are difficult to manage or alleviate.
An integrated approach including plant resistance is an effective production strategy for small-holder farmers, is environmentally friendly, and compatible with other components for increasing and stabilizing yields, reducing use of pesticides in production and storage, and creating sustainable cropping systems with increased efficiency and profitability while conserving natural resources. Technologies such as sorghum midge-resistant cultivars may not have been widely deployed to alleviate stresses, and introduced technologies may cause additional biotic stresses and production constraints. Low-productivity cultivars are a continual problem, and grain yield can be increased by improving overall productivity and resistance to stress. Susceptibility to grain mold/weathering reduces grain quality, marketability, and utilization and if reduced, would improve marketability and farmer profitability through increasing demand. Economic analysis is needed to assess feasibility and profitability so sorghum and pearl millet farmers are convinced for potential adoption of the technologies.

Insects cause economic damage to sorghum in all production regions. The sorghum midge is the most damaging insect pest of sorghum worldwide (Teetes and Pendleton, 2000). Female sorghum midges oviposit eggs in flowering sorghum spikelets in which the developing larvae feed and abort development of the kernel; 100% of grain can be destroyed. Originating in Africa, sorghum midge is unique among sorghum insect pests by being specific to *Sorghum*, and all members of the genus *Sorghum* are potential hosts. Genetic resistance to the sorghum midge exists within *Sorghum* (Johnson et al., 1972; Jotwan et al., 1971.; Peterson 1993; Peterson et al., 1989; Rossetto and Banzatto, 1967; Rossetto et al., 1975; Wuensche et al., 1981). Because sorghum midges cannot be reared artificially and infest only flowering sorghum, all evaluation must be in large field nurseries dependent on natural infestation. Inheritance of resistance is quantitative and recessive (Boozaya-Angoon et al., 1984, Teetes and Johnson 1978). Resistance mechanisms have been studied and the effect of resistance on sorghum midge larvae determined (Waquil et al., 1986a, b, c). Two theories for resistance to sorghum midge exist. The traditional theory is that resistance is quantitative and recessive, with the number of resistant plants dependent on pest abundance. The newer theory is that spikelet flowering time and morphology influence the level of resistance (Diarisso et al., 1998a,b). Sorghum midge can be controlled by: (1) uniform regional planting such that all sorghum varieties flower within 7-14 days; (2) insecticide at anthesis, but the economically damaging stage is the larva not affected by chemical control inside a spikelet; and (3) genetic resistance that increases non-preference by sorghum midge for resistant florets. For African small-holder farmers, one of the most viable control methods is genetic resistance. Sorghum midge-resistant variety SSD-35 was developed in Niger (Kadi Kadi, 2005). Sorghum midge is most damaging to late-maturing varieties that suffer more than 50% yield loss. Little molecular research for resistance to sorghum midge has been done. Tao, et al. (2003) studied resistance mechanisms and developed molecular markers for the cross ICSV745 x 90652. The resistance sources were DJ6514 in ICSV745 and both TAM2566 and AF28 in 90562. They identified QTLs for two mechanisms, antibiosis and antixenosis, for resistance to sorghum midge.
Beetle and moth pests destroy an average 5-35% of stored grain worldwide, but destroy as much as 40% or more in developing countries of the tropics and subtropics (Schulten, 1975). Post-harvest losses of cereals such as sorghum and pearl millet are a major problem throughout West Africa. In Niger, a survey evaluated sorghum and millet storage facilities, pests, and controls (Kadi Kadi, 2008). Farmers identified the insect pests Angoumois grain moth, *Sitotroga cerealella* (Olivier); lesser grain borer, *Rhyzopertha dominica* (Fabricius); red flour beetle, *Tribolium castaneum* (Herbst), confused flour beetle, *Tribolium confusum* Jacquelin du Val; khapra beetle, *Trogoderma granarium* Everts; and Mediterranean flour moth, *Ephestia kuehniella* (Zeller); and mold, humidity, rats, mice, and birds (INTSORMIL, 2011). During conservation and storage, solutions to eliminate major pests of stored grain and seeds were mostly chemical (with misuse). However, because pesticides can poison non-target organisms, pollute the environment, and result in development and selection of resistant strains of pests, alternatives need to be found. In Niger, farmers use traditional methods including inert substances (ash, sand, and salt) and plant parts alternatively or in combination with pesticides to protect stored sorghum and millet grain. Active substances in the plants need to be isolated to develop botanicals for controlling insect pests of stored sorghum and millet.

The maize weevil, *Sitophilus zeamais* Motschulsky, is one of the most damaging insect pests of stored grain in the U.S. as well as worldwide (Teetes et al., 1981). A female weevil lays 300-400 eggs on kernels in the field or storage, and larvae developing inside destroy the kernels. Fernando Chitio from Mozambique, Madani Telly from Mali, and Suhas Vyavhare from India, former M.S. students funded by the International Sorghum and Millet Collaborative Research Support Program (INTSORMIL CRSP) while at West Texas A&M University, evaluated resistance to maize weevils in sorghum genotypes provided by the Texas A&M AgriLife sorghum breeding program. Chitio (2004) found grain of several genotypes such as Sureño weighed only 2% less, while SC630-11E and CE151 weighed 46% less at 105 days after infestation by five maize weevils per 5 g of grain in a laboratory.

Dr. Michael Pendleton, scanning electron microscopist at Texas A&M University, used scanning electron microscopy (SEM) and energy dispersive spectrometry (EDS) to try to correlate internal morphology of kernels of different sorghum genotypes with resistance to maize weevils. Preliminary results indicated that images and maps of elements obtained by SEM and EDS could be used to predict resistance to maize weevils. As the depth of the concentrated starch layer (with bound iodine as a marker) increased from the seed coat, the grain was more resistant as measured by percentage of weight loss of infested grain. Resistance to storage insect pests might be predicted by SEM and EDS on a single cross-sectioned sorghum kernel instead of spending weeks of time measuring damage and weight loss of grain caused by insect pests. The technique might also be adapted to predict resistance of grain to other storage insects.

**Objectives**

1) Assist national sorghum programs in Niger and Senegal develop biotic stress-resistant cultivars and inbred lines by crossing local or improved cultivars with known resistant sources.

2) Develop and provide to national research programs in Niger and Senegal a diverse array of potentially useful germplasm.

3) Better understand causes of sorghum resistance to sorghum midge, storage insect pests, and other biotic stresses.

4) Develop a stored grain insect program to improve storage capability for high-quality grain.
5) Analyze production profitability of improved sorghum cultivars using on-farm experiments, and analyze potential marketing opportunities for use of sorghum and pearl millet.

6) Provide short-term and graduate degree programs as appropriate.

Testable Hypotheses:

1) Introduction and introgression of sorghum midge-resistant germplasm, and germplasm with known genes for quality grain and resistance to abiotic and other biotic stresses will contribute to development of new sorghum cultivars for Niger and Senegal.

2) Assessment of damage caused by and better understanding of the bioecology of sorghum midge and other sorghum insect pests will aid in developing sustainable resistance.

3) Evaluation of sorghum grain for resistance to biotic stresses in storage will assist in development of superior cultivars that can be stored and provide consistent supplies for home consumption and marketing.

4) Scanning electron microscopy will be used to predict resistance and shorten the time needed for evaluation of damage caused by maize weevil and other storage insects of stored sorghum grain.

5) Human capacity for developing sorghum resistance to abiotic and biotic stresses will be improved through training in conventional and molecular research methodology, and graduate degree programs.

Research Strategy:

This project will primarily involve collaboration between entomology and plant breeding in Niger, Senegal, and the United States. The scientists bring a diverse array of research expertise for increasing understanding of the primary constraints and will collaborate to develop technology to contribute to reducing the grain yield and quality loss by at least some constraints. The primary aim of the research is to provide host-country collaborators with a diverse array of germplasm with resistance to primary constraints (primarily sorghum midge, stored grain pests, selected foliar diseases, grain mold/weathering, and drought) and assist in developing appropriate evaluation methodology and selection tools for environments of Niger and Senegal. Technology developed will be primarily improved cultivars with traits needed for sustainable, increased production of high-quality grain, and better grain storage techniques. As appropriate, collaboration with food scientists at INRAN, CERAAS, and ISRA/CNRA will be established to assess processing traits for female and male users of the advanced experimental germplasm. Economic analysis of the profitability of new cultivars and technology will be assessed to ensure the usefulness of the technologies in the sorghum value chain.

We propose to assist the INRAN, CERAAS, and ISRA/CNRA programs to improve their research capability for developing high grain-yielding cultivars resistant to biotic stress, primarily sorghum midge and maize weevils and other storage insects but also drought and selected disease(s) such as head smut. A primary research objective of the Texas A&M AgriLife Research sorghum program is to develop genotypes resistant to biotic stress and combine resistance to multiple stresses into a single genotype. A number of experimental breeding lines resistant to sorghum midge have been developed by Texas A&M AgriLife Research and are available for evaluation in Niger and Senegal. Most of the lines are tan-plant, white-grain types and will not be used in the United States. Grain of several sorghum lines developed by
Texas A&M AgriLife Research and through the INTSORMIL CRSP in West Africa has moderate resistance to maize weevils in storage. In compliance with the release policy of Texas A&M AgriLife Research, germplasm for the SMIL program and its collaborators is to be used to the benefit of participating nations and sorghum research programs. If the materials are used for the benefit of these programs, they are freely available.

We propose to make the developed germplasm available and to collaborate with entomologists and sorghum breeders in Niger and Senegal to integrate stress-resistant germplasm into their research programs. We will develop research methodology appropriate for their research conditions that will enable selection for genotypes most appropriate for local conditions. In the first year, approximately 60 sorghum midge-resistant genotypes will be provided in addition to lines to provide differentials for adaptation and resistance to drought, selected insects and diseases, and grain mold/weathering. The collaborators will evaluate the germplasm for resistance and other important traits in their local environments. All studies will be replicated to enable data analysis with appropriate statistical comparison to identify superior genotypes. Superior genotypes will be integrated into local breeding programs and evaluated on-farm for performance and farmer acceptability. A duplicate set of lines will be grown in Texas for evaluation. Pending successful completion of initial testing, additional materials will be provided as the individual programs are capable of utilizing. Grain of sorghum genotypes from African countries and Texas A&M AgriLife Research will be evaluated for resistance to maize weevil and other insects in storage. Scanning electron microscopy will be used to correlate morphology of kernels of different sorghum genotypes with resistance without spending months of time measuring feeding rates and damage by maize weevil larvae and other insect pests of stored grain.

The overall goal of this project is to use our expertise and germplasm to improve the capability of collaborating national programs to develop technology beneficial to increase production for on-farm use and for potential cash-generating enterprises. We will use the environments at the project sites (Niger, Senegal, and Texas) to evaluate germplasm and to generate and evaluate additional populations each year based upon research data.

Breeding activity in Texas will backstop many activities in Niger and Senegal. A diverse germplasm array exists in the Texas A&M AgriLife breeding program and is available for transfer to national programs, provided the germplasm is used for the benefit of the national program. The national programs will use procedures developed for the INTSORMIL CRSP to acknowledge receipt of the germplasm. Included in our germplasm base are exotic lines collected during previous international research along with breeding lines. Additional exotic lines will be obtained as needed from the USDA Germplasm Bank or introduced directly from the collaborating programs. Exotic introductions will be grown in USDA quarantine but will be available for use without undue delay.

Sorghum nurseries in Texas will be used to provide preliminary evaluation and data on the most appropriate genotypes for transfer to Niger and Senegal and to develop new breeding populations for selection. The nursery locations capitalize on the geographical diversity of Texas and contribute to development and selection of segregating populations for either a single trait or multiple traits. The nursery locations and most appropriate traits to be selected include: Weslaco (Rio Grande Valley) – tropical adaptation and resistance to grain mold/weathering; Corpus Christi (Coastal Bend) – tropical adaptation and resistance to sorghum midge, diseases (head smut, downy mildew, various foliar), and grain mold/weathering; College Station (Central Texas) – resistance to sorghum midge, grain
mold/weathering, and anthracnose; Lubbock/Halfway (Southern High Plains) – temperate adaptation, drought tolerance (both pre- and post-flowering), seed increase, and nursery preparation; Puerto Rico – off season generation advancement and seed increase.

The same sorghum populations evaluated at several locations enable selection for wide adaptation and resistance to multiple biotic and abiotic stresses. Germplasm developed by Texas A&M AgriLife Research frequently is adapted to numerous environments throughout the world. For sorghum midge, prior research found resistance might be density dependent – as sorghum midge population density increased the number of resistant genotypes decreased. Two environments will be used for selection of resistance – College Station for moderate population density (usually six to 10 female midges per panicle at anthesis) and excellent pressure for resistance to grain mold/weathering, and Corpus Christi for generally high population density. Prior research indicated sorghum genotypes resistant to sorghum midge at Corpus Christi should be resistant anywhere in the world. Resistance to grain mold or weathering is an environmentally dependent variable. Conditions that promote susceptibility to mold or weathering might not be present every year. Thus multiple environments, locations, and years are required to select genotypes with increased resistance. These locations provide excellent consistent environments in which to develop and evaluate source germplasm potentially useful in Niger and Senegal. With adequate knowledge, the correct crosses and selection criteria will eliminate lower priority germplasm and enable transfer of elite, readily useful germplasm.

An off-season nursery in Puerto Rico is available to advance selected populations a generation, grow F1 seed from crosses to provide F2 seed for the year, produce additional hybrids, and advance potential new seed parents an extra generation. Ergot (Claviceps africana) is often present in the nursery in Puerto Rico and will eliminate some genotypes.

Primary Niger nursery locations are Konni, Madaoua, and Tillabery. Konni is at 13°47' N and 5°14’ E and 417 km from Niamey. Annual rainfall is 350-450 mm, and limited irrigation is available. The Konni INRAN agricultural research station has 36 ha of which 25 ha are sandy and 11 ha have heavy clay soils. The main sorghum production constraint at Konni is sorghum midge. Research can be done for yield potential, resistance to sorghum midge, Striga, and diseases, and drought tolerance. Konni is an off-season nursery for making crosses, advancing generations, advancing hybrids, and increasing seed. Madaoua is at 14°04' N and 5°57’ E, 504 km from Niamey and 87 km east of Konni. Soils at Madaoua are clay-loam, and irrigation is available and used off-season to produce horticultural crops. At Madaoua, breeding nurseries for resistance to sorghum midge and drought tolerance will be grown in farmers’ fields. Tillabery is in western Niger at 14°13’ N and 1°27’ E about 150 km from Niamey. Annual rainfall is 250-300 mm, and irrigation is available. The soil is sandy clay. The main constraints are drought, Striga, and diseases, in addition to selecting for grain yield and superior agronomic traits. Tillabery can also be used as on off-season nursery. On-farm testing of new inbreds/lines will be done for: 1) sorghum midge in fields of 10 farmers in each of four villages in Konni and Madaoua; and 2) drought-tolerant lines in fields of 10 farmers each in four villages in Konni, Madaoua, and Tillabery.

Four locations in Senegal are available for this research. The main research station at Bambey has irrigation available and 500-600 mm of rainfall annually. Bambey will serve as the primary location for research on grain mold and stored grain pests. Mbour and Nioro are in a region with 600-800 mm of rainfall and clay soils. Irrigation is available to assure plant establishment and moisture. Sorghum midge pressure is generally high at Mbour and moderate to low at Nioro. These are additional environments to
evaluate resistance to grain mold/weathering. Sinthiou Maleme research station is in the most important sorghum-growing zone, with 800-900 mm of rainfall annually. The site has moderate disease pressure.

In Texas, replicated plots will be scored at maturity for damage on a scale of 1 = 0-10% aborted florets, 2 = 11-20% aborted florets, to 9 = 81-100% aborted florets. The data will be analyzed as a randomized complete block and statistical separation calculated. The primary resistance source in the Texas program is TAM2566, a selection from SC175-9. Other sources, primarily AF28 through Tx2782, are used to a lesser extent. AF28 is a line of unknown African origin identified in Brazil in the mid-1970s.

The INRAN program in Niger has done some breeding for resistance to sorghum midge, and as a result of INTSORMIL collaboration released sorghum midge-resistant variety SSD-35 with good yield potential. The variety will provide an excellent baseline to evaluate against Texas germplasm. The diversity in background between SSD-35 and Texas germplasm will provide an excellent platform to introgress germplasm.

Grain mold and weathering is a common problem in sorghum, especially with photoperiod-insensitive, white-seeded cultivars or hybrids. Improvements have been made in source germplasm but have not translated into widely adapted cultivars or hybrids with excellent grain yield potential. Previous research by the Senegal program identified three lines potentially useful for growing conditions in Senegal. Sureño was a joint Texas A&M/INTSORMIL/ICRISAT release in the mid-1980s. The tan-plant, white-grain line has excellent resistance to grain weathering in a range of environments, and the grain has excellent processing characteristics. Macia is a tan-plant, white-grain cultivar from southern Africa. Selection 90EON343, released as Tx3405 by Texas A&M AgriLife in 2013, is a tan-plant, red-grain line with good resistance in a range of environments. These lines will form the basis for introgression of grain mold/weathering resistance into the Senegal and Niger breeding programs. Additionally, a Grain Weathering Test from Texas A&M AgriLife will be available. The 20 entries (including checks) represent diverse parentage and excellent resistance to weathering. Data collected in Niger, Senegal, and Texas will be used to select parents for introgression of other weathering-resistant lines to generate new segregating
populations. Selection for resistance must be done at multiple locations over years. Populations will be evaluated in Texas, Niger, and Senegal, and genotypes with good resistance selected. Selections from Texas will be provided to Niger and Senegal, and if possible, selections from Niger and Senegal exchanged, to provide populations selected in a range of environments. Bambey, Mbour, and Nioro are suitable locations in Senegal in which to select for resistance to grain mold. Grain mold is not a major problem because of the dry climate in Niger, and experimental lines might not have sufficient disease pressure to accurately phenotype the response.

Although sorghum is a naturally drought-tolerant crop, many sorghum genotypes express less than desired tolerance to drought. Two distinct drought responses exist, pre-flowering (from planting to anthesis) and post-flowering (from anthesis to maturity). Unique symptoms are diagnostic for each response. Texas A&M AgriLife has a 70-entry drought line test. The entries include standard checks for susceptibility, pre-flowering response, and post-flowering response. Based on data collected, determination will be made on the appropriate breeding response for each country. Irrigation capability at Bambey, Mbour, and Nioro (Senegal) and at Madaoua and Tillabery (Niger) will provide opportunity to select for specific drought response. Selection protocol for pre-flowering drought response calls for restricted moisture availability from emergence to flowering and then sufficient moisture from flowering to maturity. Selection protocol for post-flowering drought response calls for excellent moisture available pre-flowering and then no moisture from flowering to maturity. Rainfall at inopportune times highlights the need to plant nurseries in multiple environments to increase the probability of receiving the correct moisture regime.

To provide a diverse array of germplasm for characterization in a range of environments, Texas A&M AgriLife distributes a 30-entry International Disease and Insect Nursery (IDIN). The IDIN contains standard checks for yield, diversity, and resistance to disease or insect pests. The IDIN will be provided to collaborators for use and will enable characterization of lines with known responses for the conditions at nursery locations in Niger and Senegal. This will allow the breeding objectives to be refined and to develop appropriate sorghum populations.

Texas A&M AgriLife nurseries are available to all SMIL collaborators regardless of location. The IDIN and IDLT are freely available without restriction or Material Transfer Agreement (MTA). The Midge Line Test and Grain Weathering Test are available with an MTA. Recipients will be asked to provide data collected at their respective locations to create a database of genotypic response over several environments.

Sorghum genotypes identified as flowering at night and resistant to sorghum midge (Diarisso et al., 1998 a) will be crossed in various combinations to determine if flowering time and thus resistance can be manipulated to create genotypes with increased resistance. Yaro Diarisso and Pendleton found that resistant TAM2566 sorghum began flowering at 0100 hours (Diarisso et al., 1998 a), about the time when the temperature cooled to 26°C during the night. They also found most spikelets of susceptible RTx430 flowered at 0800 hours, the daily time when sorghum midge abundance began to increase. When resistant Tx2755 was crossed with RTx430, the daily time when most spikelets of the hybrid flowered coincided with that of resistant Tx2755 and not RTx430. It may be possible to design sorghums that flower when sorghum midges are not in the field and thus are resistant as well as exhibit increased grain yield potential. To better understand causes and mechanisms of sorghum resistance to sorghum midge,
Entomologists in Niger and Senegal will assess spikelets of resistant sorghum genotypes in relation to time of day that flowering occurs, temperature, relative humidity, and other factors.

Eggs and adults of lesser grain borer, flour moth, and rice moth (Corcyra cephalonica (Stainton)) will be collected from fields and warehouses in Senegal to establish colonies and infest sorghum cultivars or lines including F2-20 and 151-262 (resistant and susceptible) checks or other potential sources of resistance. A cage technique will be used and bioassays will be done in laboratories, at research stations, and on farms in Bambey, Point Sarenne (Malicounda), and Sinthiou Maleme. The parameters monitored will include numbers of insects per panicle and deadhearts, 1-9 score of damage to panicles (Sharma, 1992), grain yield, hardness, protein, and weight. The Dobie (1974) index of susceptibility will be used to separate cultivars into different groups of resistance based on the number of emerged insects able to survive.

Genotypes, including local African landraces, of sorghum resistant to moth and beetle pests in stored grain will be obtained from Texas A&M AgriLife Research and breeding programs in the African countries. Kernels of the sorghum genotypes will be evaluated for resistance to maize weevil and other insect pests of stored grain. Damage scores and weight loss of 5 grams of grain of a sorghum genotype in a vial infested with three female and two male maize weevils or other storage beetles will be determined every 3 weeks for 105 days to assess resistance. A representative sample of kernels of each sorghum genotype also will be measured for grain hardness, moisture content, and size. The experiment will be done in laboratories at West Texas A&M University and in Niger and Senegal.

Scanning electron microscopy (SEM) will be used to correlate morphology of kernels of different sorghum genotypes with resistance without spending months of time measuring damage by maize weevil larvae. The depth from the seed coat to the starch layer in the kernel will be related to resistance defined by weight loss of infested grain. Dry samples of grain of sorghum genotypes will be cut with a razor blade (1 mm depth), fixed in 2.5% glutaraldehyde - 1% acrolein in HEPES buffer (pH 7.3), followed by 1% osmium in HEPES buffer (pH 7.3). Methanol dehydration will be in 5% steps, followed by three changes of hexamethyldisilazane. The dry kernels will be embedded in an ultra-low-viscosity epoxy resin and sectioned with an ultra-microtome. Thin sections will be mounted on carbon stubs and coated with iodine vapor using the method of Ellis and Pendleton (2007) to bind to starch. An evaporative coater will be used to apply an additional coating of 50 nm of carbon to the thin sections to reduce charging effects during the production of secondary and backscatter SEM images and SEM energy dispersive spectroscopy (EDS) plots. An SEM (15 KeV, 15 mm working distance) will be used to produce secondary and backscatter images of the sectioned sorghum kernels. EDS plots will be produced using a PGT detector and PGT Spirit software interface to show the areas of starch bound to iodine in the sectioned kernels. Preliminary results indicated that as the depth of concentrated starch areas (with bound iodine as a marker) from the seed coat increased, the percentage of weight loss of grain infested with maize weevils decreased. Using EDS with SEM, the morphological position of the aleurone cell layer within a sorghum kernel will be measured and correlated to resistance traditionally determined during several months of evaluating feeding and damage by maize weevil larvae. Resistance of other genotypes of sorghum that have not been evaluated for several months in the traditional way might be predicted with SEM images and EDS maps of elements of a single cross-sectioned kernel per sorghum genotype. The technique also will be used to assess whether it can predict resistance to other storage insects.

Botanicals from Acacia, Asclepius, and other plants used in different geographical regions of Niger and Senegal to manage insect pests of stored grain will be determined by surveying farmers. The plants with
insecticidal properties will be analyzed to try to determine alkaloids and other chemicals they contain that naturally repel insect pests.

Collaboration among different partners (Extension, non-governmental organizations, and development projects) and farming communities will be used to evaluate practical and sustainable methods of hermetic storage of sorghum and pearl millet grain and seeds. This would enable longer storage of quality grain for healthier food without contamination by pests. The Purdue Improved Cowpea Storage project evaluated and demonstrated the effectiveness of hermetic storage only on cowpeas in West Africa. Our goal is to test variations (storing in a double bag or recycled oil or fuel barrel) of hermetic storage to assess the impact on grain and seed quality. Hermetic storage can be done inexpensively by adapting the IRRI double-bagging system using a SuperBag. Inexpensive or recycled 6-mil or thicker polyethylene or similar polymer might be used to line a thatched vessel, free-standing vessel, or underground pit for hermetic storage of as much as 50 kg of grain. A free-standing plastic hermetic storage vessel might be a recycled 55-gallon oil or fuel barrel available in most villages and reusable for many cropping seasons. Storage structures used for this project will be “rodent-proof” according to common practices of storing grain off the ground or in other ways to ensure rats and mice do not chew through the thatch or dig into a sealed container, thus destroying the hermetic seal and the grain. For the polyethylene liner to be sustainable long term, it should be manufactured in Niger or a neighboring trading-partner country and be cost-effective for the owner(s) of the stored seed. Initial assessment of plastic bags and hermetic storage containers will be done in villages. Different kinds of storage containers will be tested and compared: a low-upkeep structure with locally derived cement as a sealant, hermetic structure using low-cost synthetic polymer, and traditional non-hermetic structure. Hermetic storage of grain and seeds of sorghum and pearl millet has potential for success and subsequent adoption to store grain of other cereals such as maize, rice, and wheat. Hermetic storage requires no insecticide or other inputs that must be purchased outside the farming communities. We anticipate that collaboration with local businesses will result in hermetic storage systems using existing raw materials or, at most, low-cost materials readily available locally.

Educational materials such as posters and/or brochures written in French and the common language of the region will be prepared to identify major storage pests of sorghum and millet. Additional posters and/or brochures on procedures to best manage major storage insect and disease pests will be prepared. The posters and/or brochures will be distributed to farmer organizations, storage facilities, and sorghum marketing associations in towns and villages in the host countries. The posters can be hung on walls at storage facilities to assist farmers and marketers with identifying and managing pests of stored grain.

Field demonstrations will be planned for three locations in Niger and Senegal. Extension workers will be asked to assist with workshops to teach farmers in three regions of each country how to identify and manage insect and disease pests. Separate workshops might be needed for male and female farmers if the farmers are more comfortable and better able to learn in workshops segregated by gender.

Sorghum genotypes developed for resistance to stress should be evaluated for food qualities to ensure the food-processing characteristics are at least equivalent to traditional cultivars. INRAN has a food technology laboratory directed by Moustapha Moussa and Kaka Saley. Evaluation of varieties with white grain and tan color can be done simultaneously in the field and for food quality in the food-technology laboratory. Research on sorghum will focus on dual-purpose sorghum for animal feed. Research in other Texas A&M AgriLife cereal quality and breeding programs could complement this activity.
Yield and input data from the different experiments will be collected and used to estimate a yield response function. For extended analysis of yield response to water application (if any), irrigation methods, soil types, and fertilizer application, data will be collected from the experiments as well as commercial farmers in different production regions of Niger and Senegal. The estimated response function will be transformed into a value function measuring the value of resistant sorghum produced corresponding to different amounts of inputs. The cost function will be estimated in terms of seed, fertilizer, and other inputs as well as other production practices in West Africa. These value and cost functions will be used to determine the profit-maximizing amount of input for various prices of sorghum for best management practices.

Alignment:
This research is focused on Research Theme 1 – Advancing the Productivity Frontier. The strategy will focus on constraints including biotic (insect pests and diseases) and abiotic (drought, heat, and environmental) stresses known to severely impact availability of staple crops. Emphasis will be on developing a multi-disciplinary collaborative research program with three U.S. scientists (entomology, breeding, and agricultural economics) at two universities and research personnel from three institutions in two countries [INRAN (Niger) and CERAAS and ISRA/CNRA (Senegal)]. The research strategy will provide opportunity for short- and longer-term results and begin with technology currently in the pipeline. It will integrate tested methodology with new technology to advance the productivity frontier. Research will focus on host countries, with U.S. programs supplying technical backstopping and additional sorghum population development as needed. Genotypes developed for resistance to sorghum midge will be evaluated in Niger and Senegal for resistance to the insect, diseases, and adaptation to the indigenous cropping systems. Methodologies and activities will contribute to enabling INRAN, CERAAS, and ISRA/CNRA researchers to use experimental germplasm in crossing programs to develop germplasm with better adaptation and resistance to local biotic and abiotic stress(es) for both cultivar and inbred hybrid parents. This project will strive to increase agricultural productivity and economic growth, with attention to human nutrition, environmental conservation, development of host-country capacity, and gender.

Theory of Change Statement:
The goal of this research is to provide source germplasm, technical knowledge, and resources to empower collaborating host-country scientists to: 1) increase research capability and output, 2) develop technology to increase sorghum production and utilization, 3) deploy the technology in production systems economically profitable to participants including men and women farmers and marketers in the sorghum value chain. This goal will be accomplished through different pathways including germplasm exchange to broaden the genetic base of the host-country breeding programs, increase the educational and technical training level of collaborators through a mixture of short-term technical training programs and longer-term graduate degree programs, provide access to state-of-the-art research methodology in plant breeding, entomology, and economics. We will encourage collaboration across disciplines to develop a complete technical package that includes improved seeds, grain utilization, and end-use markets where possible. We believe that successful completion of this activity will enable host-country scientists to create and sustain productive programs to continually generate new technology for their countries.
Cultivars or parental lines/hybrids with increased yield of quality grain and resistance to selected biotic and abiotic stresses suitable for on-farm use and off-farm sale

Increased technical knowledge and capacity of scientific staff and technicians

Introduced germplasm with traits to improve the national program sorghum genetic base

Technology packages from on-farm to post-harvest processing increase utilization

Increased genetic diversity, stress resistance, heterosis, and grain quality provide cultivars to improve the production system

Methodology for field and laboratory research in entomology, breeding, and grain quality

Research on plant resistance and grain quality eliminate undesirable cultivars

Field, on-farm, and end-user experiments to evaluate potential new cultivars and eliminate those deficient in one or more traits

Economic analysis to validate the new technology for profitability throughout the value chain

Workshops and meetings to inform and educate clientele in the new technology and its applicability to their respective places in the value chain

Cultivars or parental lines/hybrids with increased yield of quality grain and resistance to selected biotic and abiotic stresses suitable for on-farm use and off-farm sale
We hypothesize that the lack of cultivars, and possibly hybrids, either resistant to sorghum midge or susceptible to other biotic (diseases or insects) or abiotic stresses results from lack of: adequate expertise by staff of national programs to address the problem, access to germplasm with traits of interest, operational funds to do research, and ability to deliver the technology to appropriate clientele. We believe development of an appropriate technology or technology package and delivery to appropriate clientele will result in increased and sustainable production of higher quality grain that will improve the food security of small-holder farmers (most probably female) and potentially provide grain for off-farm sale in cash-generating markets.

The project will work primarily with host-country collaborating research scientists. We will encourage each scientist and provide assistance needed to be successful in each individual component of the research program. Each scientist successfully fulfilling his/her role will create a synergistic effect for increased scientific productivity. This will provide the impetus to successfully transfer the technology package to appropriate clientele. We will encourage the scientists to engage appropriate farmer, extension, and NGO representatives whenever possible to ensure the technology will be used by male and female farmers or end-users and thus is economically profitable. We will not create linkages ourselves but encourage collaborators to do so.

We have a diverse array of germplasm and research methodology to initiate this project. The technology will be transferred to collaborators at appropriate times throughout the duration of this project. Based upon lessons learned, additional new technology will be developed for transfer to collaborators. We will also equip and encourage collaborators to develop their own technologies. The project principal investigators are long-time collaborators and experienced in cooperative interdisciplinary research. They provide an excellent model for others to observe how to cooperate across disciplines. The principal investigators have extensive experience over many years in international research including in West Africa. Input will be sought from host-country clientele including men and women farmers and end-users to ensure that technology developed and disseminated is responding to actual needs and will be adopted. This is particularly relevant in development of cultivars and in selecting grain that meets needs for on-farm or end-use markets.

National programs are frequently hindered by lack of access to technology, technical backstopping, and operational funds to accomplish their research missions. This project will provide needed inputs in a timely process consistent with efficient utilization and understanding of the problems and possible solutions. Funds will be provided to primary collaborators to manage, provided progress toward objectives is made each year.

Success will be measured in several ways: release to farmers or end-users of cultivars capable of producing in harsh environments a more consistent supply of high-quality grain with traits needed for adoption and use, improved capability of scientific staff to address problems important to their clientele, and dissemination of information through appropriate media. Possible parameters for measuring success include: number of cultivars released, number of farmers (female and male) who adopt the cultivars or hybrids, increased grain yield of the cultivars or hybrids, amount utilized on-farm, amount available for off-farm markets, and technology disseminated (farmer field days and demonstrations, workshops for farmers, scientific publications, popular press articles, interviews with media).
Gender Issue Planning:

Women and their advancement are vitally important throughout the value chain and are key figures to improve the food security of families and on a larger scale, nations and Africa. It has been estimated that in sub-Saharan Africa women are involved in more than 50% of the agricultural activity and produce 60-70% of the food (Gawaya, 2008). Women are involved in production, processing, and marketing. They are the primary caregivers and responsible for meeting the nutritional needs of all family members. The number of female heads of households is increasing, and these households tend to be smaller in size, lower income, and less likely to adopt new technology. The needs of women producers, processors, and marketers will be considered in this project, so technology developed will be readily adopted. There are few host-country women scientists and few receive advanced degree or short-term training. There is need to identify and collaborate with qualified women scientists.

The three U.S. principal investigators have many years of international experience and recognize differences among cultures including gender issues and the roles of women and men. Dr. Bonnie Pendleton has a Master’s degree in Anthropology including education in women’s issues and taught several university courses in cultural anthropology. She has been involved with international sorghum and millet collaborative research and education for 30 years, first as a Ph.D. entomology/integrated pest management student and for 11 years as principal investigator of entomology for the INTSORMIL CRSP. She has advised more than 50 graduate students, both male and female. Many have been international students through the INTSORMIL program, including many students from African countries. During the past 13 years while at West Texas A&M University, Dr. Pendleton advised 28 M.S. and Ph.D. students of which 33% were female, 50% international students, and 18% from Africa. Through her INTSORMIL entomology project, she worked closely on research with African scientists and former students, including Hamé Abdou Kadi Kadi, cereal entomologist for INRAN in Niger, and Dr. Niamoye Yaro/Madame Diarisso, currently the Entomologist and the Coordinatrice Scientifique des Cultures Irriguées (Scientific Coordinator of Irrigated Crops) for the Institut d’Economie Rurale in Mali. Dr. Pendleton assisted Niamoye with her all-night Ph.D. research determining that the cause of resistance to sorghum midge was related to the time spikelets of resistant sorghums flowered during the night. As Co-coordinator of the INTSORMIL West Africa regional program, Dr. Pendleton collaborated with Dr. Yaro Diarisso and Mr. Abdou Kadi Kadi on entomology, as well as with women and men scientists involved with sorghum and millet food production and marketing in West Africa. Dr. Peterson served as a long-time coordinator of the INTSORMIL Southern Africa regional program. Partial or full graduate stipend and research support was given to several female students at the University of Pretoria and the University of the Free State. The most qualified students were selected, and they were female. Support was also given to two Zambia agronomists to the University to Nebraska -- one to complete her M.S. degree and one to participate in a short-term training program for agronomy research and computer statistical packages. Dr. Almas has advised graduate students at West Texas A&M University since 2003. He was Chair of M.S. committees of 16 students in agricultural business and economics. Six (38%) of the students were females from China, India, and the U.S. He currently supervises two female and one male M.S. students.

Both Dr. Pendleton and Dr. Peterson have a long history of involvement with sorghum and pearl millet improvement in western, eastern, and southern African countries and have always included both genders in research and teaching activities. The Texas A&M University System by which the three U.S. principal
investigators are employed has a long and successful history of working collaboratively worldwide with countless public and private institutions, including international and local organizations that consider gender differences in international development projects. INTSORMIL scientists, especially former students who now are scientific leaders of government agricultural agencies in their countries, have been well educated and ideal collaborators who provide valuable input on planning, conducting, and reporting results of research. We have always collaborated fairly and valued the input and needs of the host-country scientists who understand their countries’ needs better than we do. From the viewpoint of a cultural anthropologist who emphasizes the systems approach, one realizes that the opinions of host-country scientists should take precedence over gender-based programs not desired or suitable in the culture of a particular country, or that country’s systems might be disrupted to the detriment and failure of an international development project. All proposed activities will be done with national program staff or their representative(s). The intent will be to promote development of the best possible collaboration and national programs.

For our technical approach, both men and women scientists, farmers, and marketers will participate in activities proposed through this project, and funding will be allocated equitably without discrimination between men or women. In West Africa, both men and women participate in agriculture. Often men do the more labor-intensive work such as clearing land, while women grow and process cereals such as sorghum and pearl millet and vegetables near their homes. In some areas and countries of West Africa, women participate together in agricultural production on communal land, as well as individually on land owned by their families. The ‘Taymako’ farmer organization with 74 men and six women farmers at Dogueraoua, Niger, has for several years assisted INRAN with multiplying seed of sorghum midge-resistant sorghums; this and other organizations of men and women farmers will assist with evaluating and disseminating the technologies developed by this project. The input of in-country programs as well as extension, farmers, food processors, and marketers with whom they work will be used to provide valuable input for participation in planned activities.

Input will be sought from all relevant participants, both men and women, for farmer field days, grain-quality evaluation, and discussions on the type of plant or grain needed. It is anticipated that in many cases females will provide the most relevant information, and their participation and input will be actively sought. Women-only groups have been effective in transferring technology to poor, female farmers, who usually are illiterate. In consideration of potential cultural and religious differences in women’s and men’s participation, for example, training workshops could be segregated by gender. Gender impacts will be monitored including such indicators as the numbers of women and men who participate in project activities such as training workshops and who adopt the new technologies. In collaboration with the host-country programs, students will be selected to participate in educational opportunities, either long-term degree or short-term professional. The most qualified individual, whether female or male, will be selected based on the objective of the specific activity.

Successful development and deployment of technology resulting from this research should impact each of the five domains of the Women’s Empowerment in Agriculture Index (WEAI, IFPRI, 2012): 1) **Production** because on most small-holder farms women are responsible for food production and preparation. If a new cultivar sustainably produces more grain with better quality and processing characteristics the family has greater probability of access to consistent, quality nutrition. 2) **Resources** because women will have major input into resource allocation for production. 3) **Income** because more
grain may allow off-farm sale to generate a previously non-existent income stream that will enable purchases not previously made. Consistent purchases would contribute to stimulation of a local economy.  

4) **Leadership** because women are members of farmers’ organizations such as the ‘Taymako’ group in Niger.  

5) **Time** because a sorghum cultivar with better yield and resistance to stress when cultivated correctly should reduce time required in the field. Input into the type of grain-processing characteristics needed would come primarily from women. Women grow and process the grain. Who better than women to know what makes ‘good-quality’ grain? We will work through our collaborators so activities are compatible with the different cultural norms that need to be considered.

**Human and Institutional Capacity Development Strategy:**

Research and training of scientists from Niger and Senegal will increase capacity of INRAN, CERAAS, and ISRA/CNRA in developing stress-resistant germplasm for use by local farmers. On-going learning of host-country scientists will include planning and conducting collaborative research and reporting results through publications and field days and workshops for male and female farmers and others. University education of male and female graduate students will better prepare scientists for work in Niger and Senegal. Graduate-degree education will be with coursework in the U.S., with research in the home country of the students.

Educational opportunities will be identified at the graduate level and training for existing national program scientists. Specific opportunities will depend on the personnel and the research. Each year at least one collaborator (or two depending on cost) will have the opportunity to participate in a short-term training program. The opportunities will range from meetings/conferences to several weeks at a U.S. institution, working directly with scientists and students in the discipline (entomology, breeding, economics, food science, etc.). This kind of program provides national scientists the opportunity to learn new technology, broaden collaboration, and remain up-to-date in the state of the art.

West Texas A&M University has sorghum entomology/integrated pest management and agricultural economics programs. The entomologist has educated more than 50 students, foreign and domestic. The entomologist has done sorghum entomology research on sorghum midge, aphids, stalk borers, and stored grain pests. Texas A&M AgriLife Research scientists have for many years researched sorghum resistance to insects including sorghum midge and aphids, disease, grain mold/weathering, drought tolerance, adaptation, grain yield, and novel grain traits for health foods. Collaboration is on-going between sorghum research at West Texas A&M University and Texas A&M AgriLife Research and will be used during educational activities.

**Graduate student education** – an M.S. requires approximately two years and a Ph.D. degree three years at West Texas A&M University. After collaborators help identify host-country scientists for advanced degrees, one host-country scientist will begin an entomology degree the first year and one agricultural business and economics student will earn a M.S. degree starting in the third year of the project.

**Short-term training** – variable based on objectives. Most programs will involve working for 4-8 weeks in a program based in the U.S. Time during a year will be based on objectives and commitment of the scientist to activities in his or her own program.
Citations and Curriculum Vitae:

LITERATURE CITED


Peterson, G.C. 1993. Sources of midge resistance of selected converted exotic sorghum cultivars. p. 37. 18th Biennial Grain Sorghum Research and Utilization Conference. Lubbock, TX.


**Curriculum Vitae:**

**BONNIE B. PENDLETON, Ph.D.**

Department of Agricultural Sciences, West Texas A&M University, Canyon, TX 79016-0001

E-mail: bpendleton@wtamu.edu; Telephone: (806) 651-2554; FAX: (806) 651-2938

**RECENT EMPLOYMENT:** Professor (2011-), Associate Professor (2006), and Assistant Professor (2000), Integrated Pest Management-Entomology, West Texas A&M University, 75% research on management of insect pests and 25% teaching of Economic Entomology and Field Crop Entomology. Major advisor since 2002 for 28 graduate students at West Texas A&M University.

**EDUCATION:** Ph.D. – Entomology, Texas A&M University, Dissertation - “Predicting sorghum midge (Diptera: Cecidomyiidae) population dynamics and dispersal”. M.A. – Anthropology, B.A. – Biological Sciences (Invertebrate Zoology), Minor Chemistry, California State University, Chico.

**LANGUAGES:** English and French written and oral

**PROFESSIONAL ACTIVITIES:** Include International Sorghum and Millet CRSP (West Africa regional program Co-coordinator - 2007-13 and Advisory Committee - 2003-7, 2009-12); Sorghum Improvement Conference of North America (Entomology Chair - 2001-3, 2005-13), Association for International Agriculture and Rural Development - 2005-13; Entomological Society of America (Plant-Insect Ecosystems - 2011-12, National Program Chair - 2010-11, Judge for Starks Plant Resistance to Insects Graduate Student Award - 2004-12; Southwestern Branch President - 2008-9, Executive Committee - 2005-11, Graduate Student Paper and Poster Awards Chair - 2003-13); Society of Southwestern Entomologists (Executive Committee - 2005-13, President - 2006-7, Editor of Southwestern Entomologist - 2008-13); West Texas A&M University Faculty Senate Executive Committee - 2011-13; West Texas A&M University Ag Development Association. Manuscript reviewer for 19 international journals.

**HONORS AND AWARDS:** 75 including West Texas A&M University Agriculture, Science and Engineering Intellectual Contributions Award, 2011-12; West Texas A&M University Research and Creative Excellence Award - 2006-7; WTAMU Farm and Ranch Club Awards - 2002, 2003; Rotary District Rotaract Awards - 2009, 2010, 2012; Rotary District Service Above Self Award - 2008

**SELECTED GRANTS:** $1,761,096.68, and $18.173 million for continuing sorghum programs


**PRESENTATIONS:** 324 at sorghum, entomology, and pest management meetings
SELECTED PUBLICATIONS: 216 including refereed journal articles, feature articles, books/book chapters, proceedings, and Internet sites


CURRICULUM VITAE

Gary C. Peterson

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E-Mail: g-peterson1@tamu.edu or gpeterso@ag.tamu.edu


Professional Experience:  Sorghum breeding and genetics, Texas A&M AgriLife Research; Assistant Professor (1982-1989), Associate Professor (1989-1996), Professor (1996-present)

Research Interests:
Develop sorghum germplasm resistant to selected biotic and abiotic stresses with improved yield and adaptation.  Develop germplasm resistant to multiple stresses and with improved end-use qualities.  Acquire and evaluate exotic germplasm for resistance to economically important stresses.  International (INTSORMIL) research including evaluation visits, graduate education and short-term training to improve host country research and technology transfer capability.

Society and Committee Membership:
American Society of Agronomy/Crop Science Society of America, Sigma Xi, Gamma Sigma Delta, Phi Beta Delta
Graduate Faculty - Texas A&M University and Texas Tech University (Adjunct Professor)


Sorghum Advisory Committee (USDA), Member, 1995-present, Vice-chair, 1997-present

International Experience:
Principal Investigator, International Sorghum and Millet (INTSORMIL) collaborative research support program, 1982-2007; Sorghum, Millet and Other Grains (INTSORMIL) collaborative research support program, 2007 – 2013.

Travel to Central America (Honduras, Nicaragua, Guatemala and El Salvador), West Africa (Mali), and Southern Africa (Botswana, Mozambique, South Africa, Zambia) to advise national program scientists on sorghum research and research methodology. Consultant to Sorghum Research Institute, Liaoning Academy of Agricultural Sciences, Shenyang, China (1993) on breeding sorghum for resistance to insects and utilization of germplasm in a breeding program. Evaluate and characterize sorghum collections in Sudan (1991) and Mali (1997).

Sorghum releases:
Germplasm lines resistant to: greenbug biotype C – 12, biotype E – 27, biotype I – 17, sorghum midge – 37; Inbred A-/B-lines resistant to sorghum midge – 3; Inbred A-/B-lines with high grain yield potential or resistance to post-flowering drought stress— 4; Germplasm lines resistant to downy mildew – 60. Germplasm lines resistant to grain weathering – 44. Converted exotic lines (cooperator) – 519.

Awards:
2009 Texas A&M University Vice Chancellors Award in Excellence for International Involvement

Publications:
Refereed journal articles – 35; Book chapters - 5; Conference or symposium proceedings – 17; Newsletter articles – 43; Abstracts – 58; TAES Publications – 19.


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Academic Background
Ph.D. (Agricultural and Applied Economics) Texas Tech University, Lubbock, Texas
M.S. (Statistics) Texas Tech University Lubbock, Texas
M.S. (Agricultural Business and Economics) West Texas A&M University Canyon, Texas
DAIBP-I Institute of Bankers in Pakistan (IBP), Pakistan
D.V.M. University of Agriculture Faisalabad, Pakistan

Professional Training Received

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<td>Advanced GAMS: Improved Use Model</td>
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<td>Debugging and New Features, Advance</td>
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<td>FAO sponsored Project Management Training</td>
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Professional Experience

8/12-Present Professor of Agricultural Business and Economics
Department of Agricultural Sciences, West Texas A&M University, Canyon,

2/12-7/12 Fulbright Scholar Visiting Professor of Agricultural Business and Economics
Azerbaijan State Economics University, Baku, Azerbaijan

9/07-2/12 Associate Professor of Agricultural Business and Economics
Department of Agricultural Sciences, West Texas A&M University, Canyon, TX

5/01-8/06 Assistant Professor of Agricultural Business and Economics
Department of Agricultural Sciences, West Texas A&M University, Canyon, TX

1988-98 Deputy Director, Appraisal and MIS Wing, Project Analysis, Monitoring and Evaluation Department, Agricultural Development Bank of Pakistan (ADBP) Head Office, Islamabad, Pakistan.

1983-87 Assistant Director (Project Appraisal Officer), Project Loans Department, Agricultural Development Bank of Pakistan, Head Office Islamabad, Pakistan.

Honors and Awards
Fulbright Scholar Award for Teaching at Azerbaijan State Economic University, 2011-12
Texas A&M University System Chancellor’s Teaching Excellence Award, Fall 2009.
Inducted into Phi Beta Delta (Honor Society of International Scholars), 2004.
Graduate Scholarship, Department of Agricultural and Applied Economics, 1995-1999.
Division of Agriculture, Competitive Academic Graduate Scholarship, 1993-1994.
Gold Medal in Doctor of Veterinary Medicine, 1982.

Relevant Courses Taught
Research and Scholarly Achievement

**Summary of Grant**

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<td>$12,000</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>$1,901,685</strong></td>
<td><strong>$1,106,942</strong></td>
<td><strong>$400,000</strong></td>
<td><strong>$394,743</strong></td>
</tr>
</tbody>
</table>

External grants include funding from USDA, US Department of State, Texas Water Development Board

**Graduate Students Trained:**

Doctoral Dissertations Advised/Directed as Chair or Member (11) and served on 12 advisory committees from 2006-13, Master’s Committees (Chair 20, Member 10 students from 2003-13), Master’s Theses Directed as Chair or Member (16). Trained 2 MS students from Mali under INTSORMIL Program

**Published Work:**

Peer Reviewed/Refereed Publications - Refereed Journal Articles Published/In press/Accepted 13, Refereed Journal Articles Under Review 4, Abstracts in Journals (Full Paper at Agecon Search Website) 30; Professional Conference Proceedings 57; Research Papers/Grant Reports 24; Selected Research Poster Presentations 18; Outreach and Extension Publications 26; Scholarly Paper Presentations 91

**Selected Recent Publications:**


Hamé Abdou Kadi Kadi
Scientist/Entomologist
INRAN BP 429 Niamey Niger
Mobile: +227 90 36 08 97
Email: <hkadikadi@yahoo.com>

Training

1999 **Master of Science** in Entomology. Department of Entomology, Texas A&M University, College Station, Texas, U.S.A.
1989 **Bachelor of Science** in Entomology. Department of Entomology, Texas A&M University, College Station, Texas, U.S.A.

Professional Expertise

**Mai 1991-present.** Scientist/Entomologist at INRAN (Institut National de la Recherche Agronomique du Niger) to conduct entomological research.

**September 2011-March 2013.** Consultant at ICRISAT-Niger to conduct entomological research on managing the major insect pests of pearl millet and sorghum under the BMGF/HOPE Project.

**August 2003-October 2004.** Senior Scientific Officer at the Entomology Unit (ICRISAT-Niger) headed by Dr. Ousmane Youm, Principal Scientist/Entomologist.

**Avril 2002-Novembre 2004.** National Coordonnateur of the West and Centre Africa Sorghum Research Network (WCASRN) or (Réseau Ouest et Centrafricain de Recherche sur le Sorgho-ROCARS) funded by USAID.

**Juillet 2002-July 2003.** Interim Director of CERRA (Centre Régional de Recherches Agronomiques) /INRAN of Maradi.

**Octobre 2000-July 2003.** Associate Director of CERRA/INRAN of Maradi.

**1996-1999.** Research Assistant to Dr. Frank E. Gilstrap, Professor. Department of Entomology, Texas A&M University, College Station, Texas, U.S.A. 1996 & 1997 cropping seasons. Laboratory life-fertility tables and field biology of millet head miner (Lepidoptera: Noctuidae) in Niger (*Research for Master of Science thesis*). Research works conducted at ICRISAT-Niger (International Crops Research Institute for the Semi-Arid Tropics) under the supervision of Dr. Ousmane Youm, Principal Scientist/Entomologist.

**Short term training and/or courses**

2011 **February 1st-April 30.** Research Fellowship in the Entomology Laboratory at ICRISAT India—(Certificate awarded). Fellowship sponsored by C V Raman International Fellowship for African Researchers.

2010 **Octobre 18-19.** Comment valoriser vos travaux de recherche par la publication ? – (Attestation de stage). Marseille, France.

2009 **Mars 16-26.** Formation en Analyse de Données Environnementales (ADE4) par Mr Patrice Cadet–(Certificate awarded). IRD-Niger, Niamey, Niger (*in French*).

2008 **Novembre 26-30.** Atelier 2.1 : Création et gestion d’un site web dynamique (PHP/MySQL) – (Attestation de stage). Campus Numérique francophone (CNF) de Niamey, Niger (*in French*).

2007 **Décembre 26-30.** Atelier 3.2 : Conception, développement et utilisation d’un cours en ligne–(Certificat de stage). Campus Numérique francophone (CNF) de Niamey, Niger (*in French*).

**Décembre 03-07.** Atelier 3.4 : Tutorat dans une formation ouverte et à distance– (Attestation de stage). Campus Numérique francophone (CNF) de Niamey, Niger (*in French*).

**Novembre 26-30.** Atelier 2.0 : Accès et recherche documentaire en ligne– (Attestation de stage). Campus Numérique francophone (CNF) de Niamey, Niger (*in French*).

**Communication (C), studies (S), publications (P) and reports (R)**


**Languages spoken and written:** French (Very good)     English (Very good)     Hausa (Very good).
Surname: SOUMANA  
First name: Souley  
Address: INRAN, BP: 429 Niamey-Niger  
Mobile: 00227 + 96 38 47 58  
E-mail: nsoumana@yahoo.com

TRAINING

2004-2007: Kansas State University – M.Sc in Genetic and Plant breeding

1990-1995: Faculty of Agronomy, University of Niamey – Engineer of Agricultural Techniques (Grade A)

1982-1984: IPDR (Practical Institute of Rural Development) of Kollo – Niger – Rural Development Technician, Agriculture specialty (Grade B)

1975-1977: Agricultural Technical Agent (Grade B)

PROFESSIONAL REFERENCES

2013: Sorghum breeder, at INRAN

2010-2012: Principal Sorghum breeder, AGRA/Breeding Coordinator.  
Supervising and training private Seed companies on Hybrids Seed production  
Supervising University of Ouagadougou students in Hybrids seed production

2007-2010: Principal Sorghum breeder ,INTSORMIL National coordinator, MCKNIGHT/Breeding Coordinator, AGRA/Breeding Coordinator

1999-2003: Sorghum breeder, in charge of an experimental station in Tillabéri:  
⇒ Seed production (sorghum hybrid) in Tillabéri’ station;  
⇒ Conducting breeding and trials at the support site of Lossa;  
⇒ Supervising IPDR of Kollo’ students in seed production;  
⇒ Supervising and training private producers in seed production (Say-manoma);  
⇒ Supervising and training farmers’ associations and NGO’S interested in seed production (Office National Office of Irrigated Plots development (ONAHA) of Konni and PSN II IFAD Tillabéri;

1995-1998: Researcher at CERRA (Regional Center for Agronomic Research) of Kollo; Breeder in the framework of rainfed crops program and as such I Conducted sorghum’s breeding and trials. I supervised 3 Technicians of whom 2 are contract based technicians. I was also Sorghum Project manager of Tillabéri and Dosso districts.

1984-1990: Research technician at CERRA of Kollo: in charge of sorghum’ breeding and trials; team member in charge of developing promising line and hybrid such as: 90SN-2, 90SN-3, 90SN-4, 90SN-5, 90SN-6, 90SN-7, NAD-1, F1 223A, and the identification of Sepon 82. I participated actively in the department research activities of rural (DECOR) in sites like Liboré, Sona and Konni.  
In charge of conducting the exhibition of sorghum’s varieties at the first national agro forest and pastoral trade fair held in 1986 in Niamey. I also conducted the exhibition of sorghum’s varieties at the scientific research forum held in Niamey in 1989.  
Teacher at IPDR of Kollo (Plant improvement) for 4th year students in agriculture specialty.  
I supervised one student of 4th year at IPDR of Kollo for his dissertation entitled “Behavior study of some sorghum crops”
1980-1982: Agricultural technical agent at Kollo’s experimental station; under the supervision of the station manager I conducted sorghum breeding and trials. I developed a good skill of hybridization at sorghum.

1978: I conducted trials of millet, cowpea and sorghum. Facilitator of a team of laborers and 3 observers.
1977: Agricultural technical agent at Kollo’s experimental station. I conducted trials on sorghum and wheat.

SUPPLEMENTARY TRAINING

2010: Training on Monotoring and Evaluation
2009: Training on Genestat
2001: Training on phylogenetic resources in Kollo.
1999: Training on agronomic experiment and biometrics in Togo, training on phylogenetic resources in Benin.
  ➔ Training on phylogenetic resource preservation organized by IPGRI in Abidjan (RCI) 1996.
    The major addressed topics are:
    o Characterization and evaluation of collections;
    o Use of phylogenetic resources in plants’ improvement;
  ➔ Training on agronomic experiment organized by ROCARS Ouagadougou (Burkina Faso) in 1996;
    ➔ The examined points are:
    o Experimental mechanisms;
    o Initiation to GenSatat software;
    o Statistic processing of data (Certificate);
  ➔ Training on phylogenetic resources organized by IBPGR – ICRISAT Sadoré in 1989.
    The training mainly focused on conservation techniques of germplasm (Certificate);
  ➔ Training in seed technology organized by the cereal project in Lossa in Niger in 1981;
    The major points are:
    o Production techniques of improved seeds;
    o Seeds packaging (Certificate);
  ➔ Training on millet - sorghum plants improvement organized by Icrisat Hyderabad in India in 1979;
    o Course on millet-sorghum genetics and breeding;
    o Theoretical and practical course on agronomic experiment (Certificate)
    o English classes at the American Cultural Center from 1990 to 1992 (Certificate).

PUBLICATIONS COMMUNICATION STUDY

 ➔ Collaborative drafting of the annual report activities on Sorghum 56 pages in 1996;
 ➔ Dissertation “Varietal resistance of cowpea to Striga gesnerides” 78 pages in 1995;
 ➔ Team work on editing an experiment manual in full farm in 1988;
 ➔ “Critical observations on major crops” 9 pages;
 ➔ Genetics and herbicide control to fight against Striga hermonthica in West Africa;

COMPUTER KNOWLEDGE

KNOWLEDGE IN LANGUAGES
 ➔ French
 ➔ English
 ➔ Djerma
 ➔ Hausa
NDIAGA CISSE  
Director ISRA/CNRA Bambey  
Senegalese Institute of Agricultural Research (ISRA)  
ISRA/CERAAS BP 3320 Thiès-SENEGAL  
Office: +221 33 951 49 93/94  
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Email: ncisse@refer.sn

EDUCATION  
Purdue University, Indiana, USA; Genetics and Plant Breeding, PhD 1991-1995  
University of California Davis; Plant Breeding, Master of Science (MS) 1981-1983  
Nicolae Balcescu Institute, Bucharest, Romania, Engineer in Agronomy 1975-1979  
University of Dakar: History and Geography, DUEL 1 1973-1974

EXPERIENCE  
February 2011-Present: Director: of the Regional Center for the improvement of plant Adaptation to Drought (CERAAS) and Coordinator of the National Center of Specialization (NCoS) of dry cereals and associated crops for the West African Agricultural Productivity Program (WAAPP). Manage a team of scientists (8), technicians, administrative officer, chief accountant and support personnel in the design and implementation of research and training activities. Liaise with funding agencies (World Bank, German development agency, DAAD etc). Supervise infrastructure construction and rehabilitation and equipment acquisition.  
July 2009 –February 2011: Director of Bambey Agronomic Research center (CNRA). Head a team of researchers (10), technicians, administrative officer, chief accountant and support staff in the formulation and execution of activities in various fields of agricultural research. Develop effective partnerships with national and international agencies engaged in the improvement of crop production and the betterment of people in Senegal dependent on agriculture for their livelihoods. Develop strategies for fund raising and reporting. Supervise various CNRA rehabilitation projects (GCP, COM-arachide, PSAOP2).  
2001- 2012: Coordinator of ISRA-INTSORMIL CRSP (International Sorghum Millet Collaborative Research Support Program) an USAID funded project. Coordinate the development and dissemination of technologies and information for the management of an integrated system to increase millet and sorghum grain yield and quality in the field and in storage.  
2001 – Present; Sorghum Breeder. ISRA/CNRA Bambey: Improve the food and nutritional quality of sorghum to enhance marketability and consumer health. Increase the stability and yield of sorghum and pearl millet through genetic improvement. Released in 201, four sorghum varieties
1983 – Present: Cowpea breeding. Focus on breeding early maturing lines with high yield potential, desired seed quality traits, and resistances to drought, *Striga* and economically important diseases and insects in Africa. Provided leadership for the development and release of Mouride, Melakh and Yacine cowpea varieties in Senegal with USAID support. Received President of Senegal Award for Science and Technology in 1999 for these innovations.