

Germplasm Enhancement and Conservation



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

Project ARS 206
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Summary

Pearl millet [*Pennisetum glaucum* (L.) R. Br] provides a staple, primary caloric source to millions of people in semi-arid tropical areas of Africa and Asia, a high quality temporary grazing crop in livestock production in the U.S. and Australia, and a widely grown cover crop in Brazil. The characteristics of the crop have encouraged its development for use as grain crop in certain settings in the U.S.

Despite being a hardy crop for stressful production areas, yield and stability of grain, stover, and forage are vulnerable to a number of biotic and abiotic stresses. Diseases and pests can be significant production constraints and significant effort is directed toward identifying resistance sources. Primary biotic constraints in West Africa include downy mildew (*Sclerospora graminicola* (Sacc.) Schroet.), *Striga* (*Striga hermonthica* Benth.), and head miner (*Heliocheilus albipunctella* (de Joannis)). Constraints in the U.S. include rust (*Puccinia substriata* var. *indica*), pyricularia leaf blight (*Pyricularia grisea* / *Magnaporthe grisea*), root knot nematodes (*Meloidogyne arenaria* and *M. incognita*), and chinch bug (*Blissus leucopterus leucopterus*). Drought is the primary abiotic stress common to all production environments.

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

Objectives, Production and Utilization Constraints

Objectives

- Broaden diversity of pearl millet germplasm available to breeders and researchers.
- Identify sources of disease and pest resistance for pearl millet improvement
- Identify genetic characteristics associated with desirable pearl millet grain quality, and biotic and abiotic influences on grain quality.

- Develop and release pearl millet with resistance to multiple diseases, high yield, and superior quality.

Production and Utilization Constraints

- Developing the commercial potential of pearl millet requires an understanding of the needs of potential markets, identifying specific markets in which pearl millet has a competitive advantage, and providing a consistent product that meets market standards.
- Constraints to producing high-quality grain include both abiotic and biotic constraints. The impact of pearl millet genotype, diseases, and environmental constraints, and grain quality standards for pearl millet are poorly defined. Quality represents the combination of several factors, such as grain shape, color, and size, endosperm hardness, proximate composition, and the presence of grain molds, mycotoxins, and insects.

Research Approach and Project Output

Genotype and Environmental Effects on Pearl Millet Yield

Research Methods

Collaborative, multi-locational trials throughout West Africa are being used for characterizing germplasm with desirable agronomic characteristics and superior resistance to pests and diseases. Multi-location evaluation of genotype x environment interactions affecting grain quality are needed to identify genotypes with inherently superior grain yield and quality, and the relative importance of diseases and other constraints on yield and quality. These studies were designed in part to define more clearly grain characteristics among genotypes, and the stability of expression over a range of production environments. This study will help to identify characteristics that contribute directly or indirectly to stability of grain yield and quality.

Forty pearl millet germplasms selected by colleagues on the basis of their high grain quality, their fertility restoration for specific cytoplasms, resistance to diseases or pests, agronomic traits, or commercial usefulness were distributed to collaborators in Kamboinse, Burkina Faso; Manga, Ghana; Cinzana, Mali; Bengou, Niger; Maiduguri, Nigeria; Bambey, Senegal; and Longe, Zambia for multi-location evaluation of stability of grain yield. Descriptor data recorded included days to flowering, height, panicle dimensions, downy mildew, smut, and head miner incidence, zonate leaf spot severity, striga infestation, and yield. An additional trial was conducted in Kwa Zulu Natal, South Africa to characterize rust resistance to the indigenous rust (*Puccinia substriata* var. *indica*) population.

Research Findings

Data collected represents year two of a two-year study. The germplasm varied for several characteristics (Table 1). ICMV IS 90311 had the lowest incidence of downy mildew and Tifgrain 102 was the most susceptible. Minor variation for zonate leaf spot was observed at Ghana, with early varieties GB 8735, 68A x 086R, and 01MisoNCD2-NE having the greatest severity. Smut incidence was high at Ghana, with incidence up to 65.5% on Tift 99B. Head miner was only found on a few entries, with up to 65.5% incidence on Tift 99B. Grain yield was lowest for the A₄ restorer 99-72, and greatest for Gwagwa.

Grain yield was correlated with days to flowering ($R^2=0.400$, $P=0.01$), plant height ($R^2=0.774$, $P<0.001$), and panicle length ($R^2=0.374$, $P=0.0176$). Grain yield was negatively correlated with downy mildew incidence ($R^2=-0.616$, $P<0.001$), zonate leaf spot severity ($R^2=-0.518$, $P=0.006$), smut incidence ($R^2=-0.575$, $P<0.0001$), and head miner incidence ($R^2=-0.426$, $P=0.0061$)

Twenty pearl millets from West Africa (Zatib, Zongo, HKP-GMS, CIVT, SoSat C-88, Taram, SoSank, ICMV IS 89305, ICMV IS 90311, NKO x TC1, Guefoue, Indiana 05, NKK, Manga Nara, Arrow, PT 732B, P1449-2, Gwagwa, LCIC 9702, GB 8735) and 8 varieties from the Southern Africa region (Bontle, Okashana white, SALR early, SALR photosen, PMV2, P71, 842B, NUP 21 SA gold) were evaluated for rust resistance in a screenhouse trial at Pietermaritzburg, South Africa. All varieties were susceptible to rust. Severities on January 13, 2005 ranged from 35% for the late-maturing varieties NKO x TC1 and Guefoue, to 83% for early maturing GB 8735. Some variation in infection suggests that resistance is heterogeneous within these varieties. Two selections from the U.S. (01-964 and 02-281) were resistant.

Root-Knot Nematode Resistance in Pearl Millets from West and East Africa

Research Methods

Resistance to *Meloidogyne incognita* is important to provide stability to pearl millet production and to reduce nematode populations that can damage crops grown in rotation with pearl millet. *Meloidogyne* spp. are the most economically important plant-parasitic nematodes in the southern United States as well as in West Africa, with *M. incognita* being the dominant species in both regions. The objectives of this study were to determine if resistance to *M. incognita* exists in pearl millets from West and East Africa, and to determine if heterogeneity for resistance exists within selected varieties. Resistance was assessed as nematode egg production/g root in greenhouse trials. Seventeen pearl millets of diverse origin were evaluated as bulk (S_0) populations. Thirty selfed (S_1) progeny selections from SoSat-C88, Gwagwa, Zongo, and

Table 1. Agronomic characteristics and disease and pest resistance of diverse pearl millet varieties grown in Burkina Faso, Ghana, Mali, Niger, Nigeria, Senegal, and Zambia in 2004.

Entry	Flowering (days to 50%)	Height (cm)	Panicle length (cm)	Panicle diameter (cm)	Downy mildew incidence	Zonate Leaf spot (%)	Smut incidence	Head miner incidence
Gwagwa	60.6	213.9	24.1	2.4	4.9	2.0	12.6	0.0
NKK	69.4	263.2	40.2	2.5	11.5	1.8	25.9	0.0
GB 8735	47.2	159.6	20.0	2.5	28.8	4.5	14.2	12.8
SoSat C-88	56.4	200.3	26.9	2.9	6.0	1.5	14.5	0.0
SoSank	58.6	188.6	24.4	3.0	5.7	2.0	19.4	0.0
ICMV IS 89305	59.6	220.9	48.4	2.1	5.4	2.0	21.1	0.0
Taram	58.7	217.5	63.1	2.5	6.3	1.8	22.8	0.0
NKO x TC1	76.5	245.0	34.6	2.2	8.2	1.5	17.6	6.8
Kapielga (Burkina local)	68.1	267.3	26.5	2.2	9.6	1.5	9.4	0.0
Arrow	52.4	217.6	32.9	2.0	15.4	2.0	14.7	0.0
Indiana 05	78.9	257.4	42.6	2.6	9.4	1.3	9.4	0.0
ICMV IS 90311	59.5	204.0	37.1	2.2	3.4	2.8	19.6	0.7
CIVT	55.9	205.7	49.7	2.0	6.1	1.5	16.4	0.0
HKP (GMS)	56.8	210.3	50.5	1.9	9.8	2.0	18.8	1.1
Synthetic 1-2000	73.1	240.5	35.0	2.7	4.0	1.3	16.5	0.0
Toronio (Mali local)	66.7	249.4	34.3	2.3	14.8	1.8	19.3	0.0
P1449-2	59.5	172.5	28.3	2.2	10.8	2.8	35.4	16.7
Manga Nara	49.6	176.3	20.0	2.7	29.4	3.3	23.3	7.4
Zatib	58.7	220.6	48.0	2.5	5.6	3.0	24.8	0.0
Guefoue 16	76.6	261.8	35.3	2.1	7.0	1.3	7.4	1.9
Zongo	62.8	247.0	70.2	2.4	10.7	3.3	32.7	0.0
LCIC 9702	55.4	165.4	25.0	2.7	12.9	2.5	18.8	0.0
IBMV8401Mx68A4R4w	46.7	121.6	30.9	2.3	15.5	3.0	25.1	4.2
Tongo Yellow	51.6	197.7	22.7	2.8	17.2	3.0	29.2	0.0
Sadore (Niger) local	66.2	235.1	54.2	2.3	13.8	2.3	23.6	0.0
PT732B	60.8	130.1	21.8	2.0	43.4	2.5	83.4	0.0
3/4 HK	59.5	134.0	45.1	2.1	15.0	2.5	67.2	0.0
DMR 15	62.6	165.3	23.4	2.5	16.4	2.0	50.2	0.0
DMR 72	62.5	194.0	30.1	2.2	8.1	1.8	36.2	0.0
3/4 Souna	57.6	118.8	38.0	2.1	12.5	3.5	26.4	0.0
3/4 ExBornu	55.6	111.6	38.8	2.1	22.7	2.8	41.0	0.0
Bongo short head	51.1	150.1	13.0	3.2	22.2	3.5	28.0	0.0
68A x 086R	41.8	102.1	21.7	2.0	42.8	4.5	8.4	16.3
DMR 68	58.9	196.0	28.2	2.3	18.4	2.8	58.2	0.0
TG102	42.5	93.0	28.0	2.1	49.3	3.0	30.3	1.9
99M59043Mw x 68A4R4	44.5	90.9	20.9	2.3	30.4	3.8	18.6	1.3
T454	50.3	115.6	27.4	2.0	46.1	2.8	26.8	0.0
01Miso NCD2-NE	49.8	100.1	31.4	1.9	31.8	4.5	30.5	0.0
T99B	51.0	74.2	20.6	2.0	47.8	3.3	65.5	65.5
99-72	56.6	125.8	18.7	3.3	17.9	3.3	57.2	43.8
lsd (P=0.05)	3.4	18.0	4.3	0.1	11.9			
Burkina Faso	.	151.3	31.7	.	2.1	.	.	.
Ghana	.	193.2	33.4	.	32.7	2.5	28.0	4.5
Mali	50.6	194.0	34.0	.	16.5	.	.	.
Niger	67.7	167.2	36.1	2.6	5.8	.	.	.
Nigeria	66.5	154.9	34.0	.	31.8	.	.	.
Senegal	55.7	200.5	37.1	2.3	7.3	.	.	.
Zambia	66.9	217.2	31.0
lsd (P=0.05)	1.3	8.3	1.9	0.1	5.2	1.3	32.7	2.0

P3Kollo were evaluated for heterogeneity of resistance within variety. Reactions were verified in 13 S₂ progeny of each of the four varieties.

Research Findings

All African varieties expressed some level of resistance. P3Kollo was among the least resistant of the African varieties, Zongo and Gwagwa were intermediate, and SoSat-C88 was among the most resistant. In S₁ evaluations, each of these varieties was heterogeneous for resistance. Progeny reac-

tion varied from highly resistant to highly susceptible. Patterns of apparent segregation of resistance varied among the four varieties. Discreet resistant and susceptible phenotypes were identified in Zongo progeny, and it was estimated that two dominant genes for resistance segregated in this variety. Averaged across progenies, egg production on the four varieties was less ($P < 0.001$) than on the susceptible hybrid HGM-100, but was not different from resistant hybrid TifGrain 102. Reproduction of *M. incognita* on the S₂ progeny tended to confirm the results from inoculations of S₁ progeny. Heritability of nematode reproduction (standardized as the ratio of

the value to HGM-100) determined by parent-offspring regression was 0.54. Realized heritability determined by divergent selection was 0.87.

Assessment of Genetic Diversity among Pearl Millet Populations using SSR and EST Markers and Relationship with Resistance to Striga

Research Methods

Wild pearl millets (*P. glaucum* subsp. *monodii*) from sub-Saharan Africa have been identified as potential sources of resistance to the hemi-parasitic weed, *Striga hermonthica*. Eighty wild accessions, nine U.S inbreds and seven African open-pollinated varieties were evaluated with 35 SSR primers and 60 EST primers to identify genetic diversity and identify polymorphic markers that would be useful for facilitating transfer of resistance.

Genomic DNA was extracted from two-three week old seedling leaf tissue. PCR fragments of EST primers were subjected to digestion with *Hinf* I enzyme and fractionated on 12% polyacrylamide on a Hoefer vertical-gel apparatus (SE600). PCR fragments of SSR primers were evaluated for polymorphisms on 3% ultra pure agarose 1000 gels. Gels were stained in ethidium bromide and photographed under the Fluor S multi imager (Bio-Rad). PCR fragments were scored for presence or absence of DNA fragments in each genotype. Dendrograms were constructed with the Numerical Taxonomy Multivariate Analysis System 2.1, which discriminated all pearl millet accessions and grouped them in distinct clusters. Cluster analysis was conducted with the unweighted pair-group method using the arithmetic average. PCR fragments were analyzed using DICE coefficient, with SHAN module for cluster analysis. Level of genetic diversity within and between populations (F-statistics and genetic distance) was calculated with Pop Gene 32 software.

Research Findings

Out of sixty EST primers tested, 30 produced scorable and reproducible fragments. Out of 35 SSR primers, 33 primer pairs gave amplification products in most of the accessions. Twenty-eight marker loci were polymorphic out of 33 amplified primers. In total, 96 putative alleles were observed. A dendrogram constructed using the combined data of SSR and EST data resulted in 23 clusters at 85% similarity coefficient. The seven West African varieties were grouped in one cluster, whereas the U.S. accessions were clustered in two groups. The wild accessions were grouped independently from the U.S. and African cultivated varieties. Resistant accessions PS 202, PS 637, PS 639 and PS 727 showed consistently low *Striga* emergence across multilocation trials and tended to be located in different clusters, suggesting they may possess different resistances to *Striga*.

Statistics of genetic diversity within and between accessions were calculated for the sample of 96 accessions using EST and SSR primer data separately. Maximum genetic diversity values of 0.263 with EST and 0.295 with SSR primer data were found between wild accessions and U.S. varieties. Wild accessions and African landraces were genetically less diverse with minimum genetic diversity value 0.1862 with EST and 0.1882 with SSR data. Comparisons between the three subsets of this population highlighted that African open-pollinated accessions were genetically less divergent from the wild accessions than were the U.S. accessions.

Expression and Segregation of Stay-Green in Pearl Millet

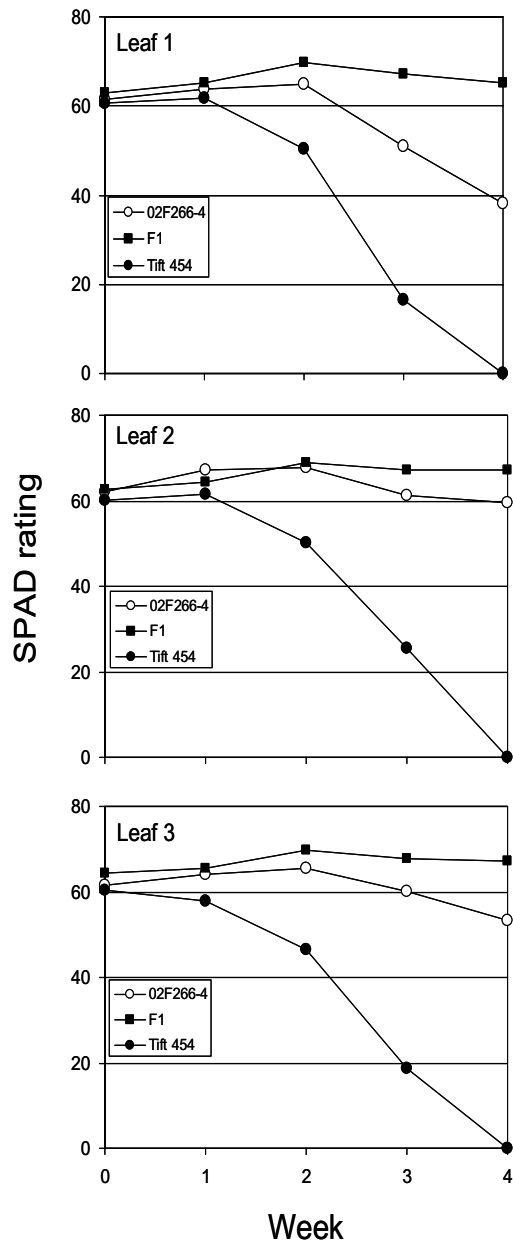
Research Methods

Drought stress occurring from flowering through grain fill results in low and unstable yield of pearl millet. Delayed senescence, or “stay-green” is a mechanism of drought tolerance characterized by the retention of green leaf area at crop maturity under water-stressed environments. Based upon information from the sorghum model, the stay-green trait should have multiple benefits in pearl millet improvement. The objectives of these experiments were to 1) quantitatively compare the chlorophyll content of a putative stay-green and normal senescent pearl millet over time, and 2) obtain preliminary information on the inheritance of the stay-green through segregation in an F_2 population.

Pearl millets developed by the USDA-ARS were evaluated in the field at Tifton, GA in 2004. 02F266-4 is a putative stay-green inbred, resistant or tolerant to prevalent diseases, insect pests and drought in the southeastern U.S. 02F266-4 was crossed with a normal senescent, agronomically elite line Tift 454, which is an A_1 restorer for hybrid production. F_1 and F_2 progenies were produced from crosses between the two parents.

Relative chlorophyll content of 02F266-4, Tift 454 and their F_1 were compared. At stigma emergence, relative chlorophyll content was measured on the top three leaves (with flag leaf taken as leaf 1) of four marked plants per plot from the main tiller with a SPAD 502 Chlorophyll Meter. Data were collected at 7 d intervals for a total of 5 ratings. Segregation of the stay-green trait was assessed in 02F266-4, Tift 454, and their F_1 and F_2 progenies. During early vegetative growth, 236 F_2 s, 19 F_1 s, 29 plants of Tift 454 and 10 plants of 02F266-4 were marked at random and monitored for panicle emergence. Using the SPAD 502 Chlorophyll Meter, relative chlorophyll measurements were taken on the second uppermost leaf of the main tiller. A stay-green value which reflected the magnitude and duration of the relative chlorophyll content was calculated for each plant by the trapezoidal method.

Figure 1. Changes in chlorophyll content, as measured by SPAD ratings, in pearl millet genotypes Tift 454, 02F266-4, and their F₁. First reading was taken at stigma emergence. Leaf 1 = flag leaf, Tift 454 = senescent type, 02F266-4 = stay-green type.



Research Findings

Minor differences in SPAD ratings among genotypes were observed at stigma emergence, but over time, the top three leaves of 02F266-4 and the F₁ maintained greater levels of chlorophyll than Tift 454 (Figure 1). SPAD ratings of 02F266-4 were similar to that of the F₁, but greater (P < 0.05) than that of Tift 454 in weeks one and two. In weeks three and four, SPAD rating of the F₁ was greater (P < 0.05) than that of 02F266-4, and ratings of both genotypes were greater (P <

0.05) than that of Tift 454 (Figure 1). The data indicate a level of dominance or over-dominance in the expression of relative chlorophyll content in the F₁.

Stay-green mean (+ standard error) of Tift 454 (1548 + 237) was less than (P<0.001) the means of 02F266-4 (2001 + 196), the F₁ (2104 + 113), and the F₂ (1917 + 227). Stay-green mean of 02F266-4 did not differ (P>0.05) from that of the F₁ or F₂, but the F₁ and F₂ means differed (P<0.001). Although not statistically different, the numerically greater stay-green value for the F₁ suggested overdominance, with degree of dominance = 1.46. Stay-green in the F₂ population was skewed toward normal senescent types, which may reflect a segregation of homozygous recessive plants with lower stay-green values.

Use of the SPAD meter to measure relative chlorophyll content provided a quantitative assessment of the stay-green trait. The data confirmed previous observations that 02F266-4 expressed stay-green characteristics. Any of the leaves evaluated were suitable for measurements, but expression was greatest in leaf 2. Whereas SPAD ratings indicated the magnitude of the relative chlorophyll content at a point in time, a stay-green value could be calculated as a measure of the magnitude and retention of chlorophyll content over time for assessing the distribution of the trait within populations.

Ethanol Production from Pearl Millet

Research Methods

To expand domestic market outlets for pearl millet grain, four pearl millet genotypes were tested for their potential as feedstocks for ethanol production and coproducts from the fermentation process. Fermentation was performed both in flasks on a rotary shaker and in a 5-L bioreactor by using *Saccharomyces cerevisiae* (ATCC 24860).

Research Findings

For rotary shaker fermentation, the final ethanol yields ranged from 8.7% to 16.8% (v/v) at dry mass concentrations of 20 to 35%, and the ethanol fermentation efficiencies were between 90.0 and 95.6%. The ethanol fermentation efficiency at 30% dry mass on a 5-L bioreactor reached 94.2%, which was greater than that from fermentation in the rotary shaker (92.9%). Results showed that fermentation efficiencies of pearl millets, on a starch basis, were comparable to those of corn and grain sorghum. Because pearl millets have greater protein and lipid contents, distiller's dried grains with solubles (DDGS) from pearl millet also had greater protein content and energy levels than did DDGS from corn and grain sorghum. Pearl millet should be an effective feedstock for ethanol production in the U.S.

Networking Activities

As part of the effort to expand pearl millet production in the U.S. PI presented information on “Grain Pearl Millet for the Southeastern U.S.”, or “Pearl Millet Cooperative Marketing Opportunities” at the following meetings:

Coffee County Grain Pearl Millet Field Day, Douglas GA, September 14, 2004

Workshop for Small, Beginning, and Limited Resource Farmers. Fort Valley State University, Fort Valley, GA. November 4, 2004

Vidalia Onion Growers Committee, Vidalia, GA. November 17, 2004

Sustainable Agriculture and Conservation Tillage Conference, Perry, GA February 16, 2005

Federation of Southern Cooperatives Annual Farmers Conference, Albany, GA February 18, 2005.

Grower training meetings in Sumter, Schley, and Marion Counties (February 22, 2005), Terrell County (March 2, 2005), and Washington County (April 5, 2005), Georgia.

Sunbelt Agricultural Expo, Moultrie, GA, July 12, 2005.
Sumter County “Grain Pearl Millet Field Day”, Plains, GA, July 13, 2005

Georgia Young Farmers Summer Conference, Augusta, GA July 19, 2005

Coordinated with Sorghum and Millet Crop Germplasm Advisory Committee to write “Pearl Millet” section of Sorghum and Millet Vulnerability Statement. Statement outlined status of crop vulnerability, needs, and pests of concern, and was submitted by the committee to USDA-ARS for prioritizing food security issues. August 2004.

Collaborated with George Ewing, Compatible Technology International, Golden Valley, MN, to evaluate small equipment developed by CTI designed to hull and grind pearl millet in a typical Africa village setting.

Research Investigator Exchanges

Traveled to South Africa (March 13-16, 2005), Zambia (March 16-20, 2005), and Namibia (March 21-24, 2005) to review current INTSORMIL research progress and prioritize future collaborative research plans.

Hosted Simon Awala, Ministry of Agriculture, Water and Forestry, Republic of Namibia for scientific research project conducted at Tifton, GA from August 26 to October 25, 2004.

Hosted visits with David Hoisington, ICRISAT Global Theme Leader for Biotechnology. April 26, 2005, and Shankar Poddotturi, Pioneer Hi-Bred International Sorghum and Pearl Millet Project Coordinator and Breeder, July 12-13, 2005.

Publications and Presentations

Journal Articles and other Publications

Wilson, J.P., Hess, D.E., Hanna, W.W., Kumar, K.A., and Gupta, S.C. 2004. *Pennisetum glaucum* subsp. *monodii* accessions with striga resistance in West Africa. *Crop Protection* 23:865-870.

Wilson, J.P. and Devos, K.M. 2004. Linkage groups associated with partial rust resistance in pearl millet. *International Sorghum and Millets Newsletter* 45:51-52.

Jurjevic, Z., Wilson, D.M., Wilson, J.P., Geiser, D.M., Juba, J.H., Mubatanhema, W., Rains, G.C., and Widstrom, N. 2005. *Fusarium* species of the *Gibberella fujikuroi* complex and fumonisin contamination of pearl millet and corn in Georgia, USA. *Mycopathologia* 159:401-406.

Books, Book Chapters, and Proceedings

Dahlberg, J., Wilson, J.P., and Snyder, T. 2004. Sorghum and pearl millet-health foods and industrial products in developed countries. Pgs. 42-59 in: *Alternative Uses of Sorghum and Pearl Millet in Asia*. International Crops Research Institute for the Semi-Arid Tropics. Patancheru 502 324, Andhra Pradesh, India: 364 pp. ISBN 92- 9066-471-1.

Breeding Grain Mold Resistance in High Digestibility Sorghum Varieties

Project TAM 230
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Summary

Combine High Digestibility Sorghum with Grain Mold Resistance

The goal of this proposal is to combine the improved nutritional grain quality sorghum (i.e. high protein digestibility HPD) with high levels of grain mold resistance. Project objectives are to evaluate advanced F₅ recombinant inbred lines (RILs) derived from crosses between HPD parents and male and female lines resistant to grain mold. Lines have been identified from three sets of RILs that carry both the HPD trait and acceptable scores of grain mold resistance. A number of the HPD lines express the floury endosperm phenotype common to the HPD parents. This trait is undesirable for some end-use purposes. However, several lines from two sets of RILs were identified that express a normal flinty/hard endosperm phenotype.

Identify QTLs regulating grain mold resistance and high grain protein digestibility

The three RIL populations derived from elite Texas male/female parents by HPD parent crosses are of insufficient size for mapping QTLs regulating grain mold resistance. Each set is, however, of sufficient size for mapping the high digestibility trait. Thus, a new Fulbright Fellow graduate student from Honduras will join this project in the fall of 2005 and will focus on mapping the HPD trait and testing if the modified

HPD endosperm matrix improves starch digestibility and ethanol production.

Given these results new crosses between HPD parents and grain mold resistant parents such as 'Sureño' have been made. The F₂ progeny from these crosses have been collected during the current growing season. A graduate student from Mexico has been using an existing set of 150 RILs derived from crosses between 'Sureño' and 'RTx430' to map loci regulating resistance to grain mold. In this effort, our strategy has been to score resistance to single-grain mold agents. As such, individual plants for the entire set of RILs have been inoculated with only *Fusarium thapsinum* or *Curvularia lunata*. The entire RIL population is currently being phenotypically scored for resistance to each pathogen. This data will be used to map loci regulating grain mold resistance. It is our hypothesis that this strategy will reveal that smaller discrete sets of QTLs confer resistance to individual species of grain mold. As such, the pyramiding of resistance loci from unique sources into a single package for improved grain mold resistance will become possible. A time course of tissue collection has been collected for each RIL following infection with *Fusarium thapsinum* and *Curvularia lunata*. This tissue will be used as part of our objective to link the expression of key defense genes with the inheritance of individual QTLs for grain mold resistance.

Test the physical and functional properties of highly digestible sorghums in food and feed products.

Each F₆ RIL scored to possess the HPD trait has been planted in replicated plots at five locations throughout Texas. Grain from each location will be evaluated for grain mold resistance to determine if genotype-by-environment variation exists in the HPD lines. The surplus grain collected from these locations will be supplied to collaborators for chicken feed quality analysis (in collaboration with Dr. J. Hancock INTSORMIL project KSU 220B) and a characterization of the potential gain of function that the HPD trait may provide for food products (in collaborations with Dr. L. Rooney INTSORMIL project TAM 226).

Objectives, Production and Utilization Constraints

Objectives

- Evaluate the combinability of the high protein digestible trait with grain mold resistance.
- Identify QTLs regulating mold resistance and high grain protein digestibility.
- Link QTLs controlling mold resistance to changes in the expression of genes that contribute to mold resistance for future utilization in genetically engineering improved resistance to grain mold.
- Test the physical and functional properties of highly digestible sorghums in food and feed products.

Constraints

The development of new high yielding sorghum varieties with improved nutritional quality is a key attribute needed to increase the commercial utilization of sorghum. The HPD trait that is also associated with high lysine content is one such attribute that may spur increased utilization of sorghum. However, for the HPD trait to be widely adopted lines must be developed with hard endosperms for improved milling capacity and better food application potential; as well, the trait must be incorporated into lines possessing grain mold resistance. The overall goal of this project is to use molecular techniques to facilitate the development of HPD varieties with optimal endosperm characteristics and viable levels of grain mold resistance.

Research Approach and Project Output

Evaluation of High Grain Digestibility trait in advanced RIL populations

Three F₅ RIL populations developed by W. Rooney (INTSORMIL project TAM-220C) were examined for the high protein digestibility trait. Grain mold ratings were also determined for each line. The three populations consisted of 21 F5 RILs derived from a cross between the high digestibility line

P850029 and Tx635; 37 F5 RILs derived from a cross between P850029 and Tx436; and 41 F5 RILs derived from a cross between the HPD line P851171 and GCPO124. All RILs, plus the parents for each population, were evaluated for the high protein digestibility trait using the turbidity assay developed by B. Hamaker (INTSORMIL project PRF-212). Those individuals with protein digestibility scores near that of the HPD parent were evaluated a second time using the same turbidity assay. In the second analysis, 2 to 4 sister lines from each line that appeared to carry the HPD trait were also analyzed. Figures 1 and 2 highlight the lines that were scored to possess the HPD trait (HPD parents and RILs are highlight in black bars, low protein digestibility parents and RILs have white bars). One to two lines from each population were identified as having the HPD trait. After confirming the presence of the HPD trait, each HPD RIL, parents, and low digestibility lines from each cross were planted in replicated plots at five locations throughout Texas in conjunction with W. Rooney (TAM 220C). Grain mold ratings and the HPD turbidity assay will be used to determine the genotype-by-environment stability of the HPD trait as it relates to grain mold resistance. The HPD lines identified are being further analyzed by transmission electron microscopy to verify the presence of the abnormal protein bodies.

Hard Vitreous Endosperm in HPD lines

The endosperm texture and microstructure of each RIL that appeared to possess the HPD trait were analyzed by light and scanning electron microscopy. The HPD parent, P851171, exhibits an opaque floury endosperm throughout (Figure 3b). This phenotype was also found in some of the HPD RILs such as 11278-1 (Figure 3d). The parents such as GCPO124, used to derive the populations, have a hard endosperm composed of a central opaque region surrounded by a large vitreous portion (Figure 3a). This same phenotype was found in RIL 11286-1 (Figure 3c). However, the vitreous portion of the 11286-1 endosperm had a modified structure when compared to either parent. The microstructure in this HPD RIL, with a vitreous/flinty endosperm phenotype, had densely packed polygonal starch granules lacking in the continuous protein matrix normally found (Figure 3c). The polygonal starch granules are common to the vitreous endosperm (Figure 3a), yet the lack of surrounding protein matrix is unique to this HPD RIL. We are currently testing the hypothesis that this lack of protein matrix surrounding the starch granules will provide increased access for amylases in ethanol production. As well, this hard endosperm matrix carrying the HPD trait should provide improved milling properties over the opaque/floury HPD lines.

Antifungal Protein Association with Grain Mold Resistance

Sorghums (93 lines and hybrids) were grown in 2004 in TAES Field Plantation in College Station under ambient con-

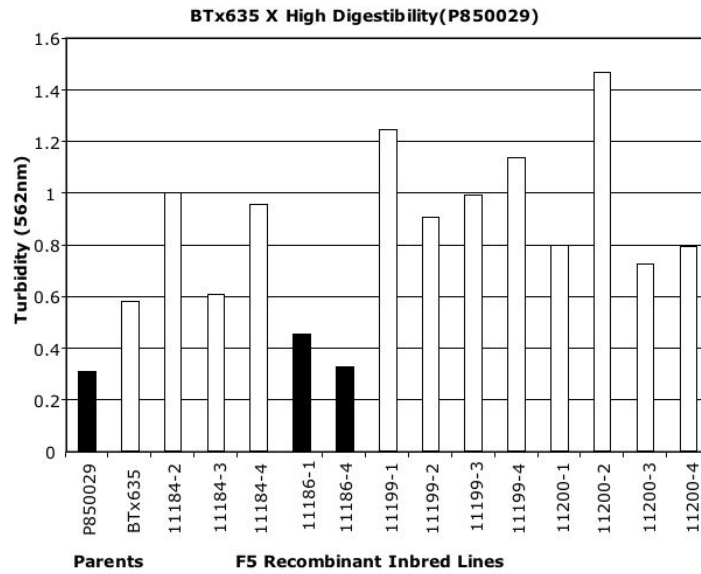


Figure 1. Turbidity assay of RILs and parents of RILs BTx635 and HPD line P850029. A 60 mg flour samples used for each pepsin digestion turbidity assay were incubated at 37°C for 60 min as described by Aboubacar et al., 2003. RILs with the same number are sister lines. The HPD line P85009 and RILs that have been scored as carrying the HPD trait are highlighted in black.

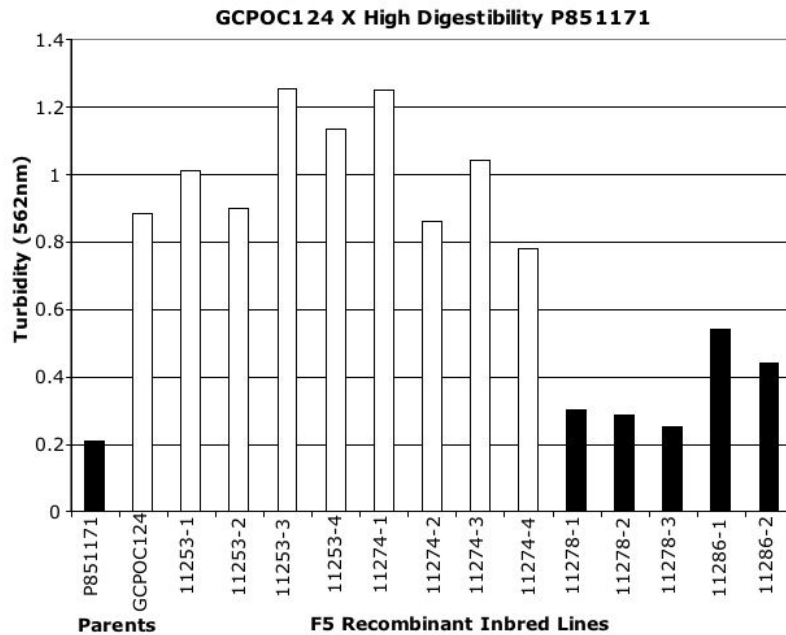


Figure 2. Turbidity assay of RILs, and parents of RILs GCPOC124 and HPD line P851171. A 60 mg flour samples used for each pepsin digestion turbidity assay were incubated a 37°C for 60 min as described by Aboubacar et al, 2003. RILs with the same number are sister lines. The HPD line P851171 and RILs have been scored as carrying the HPD trait are highlighted in black.

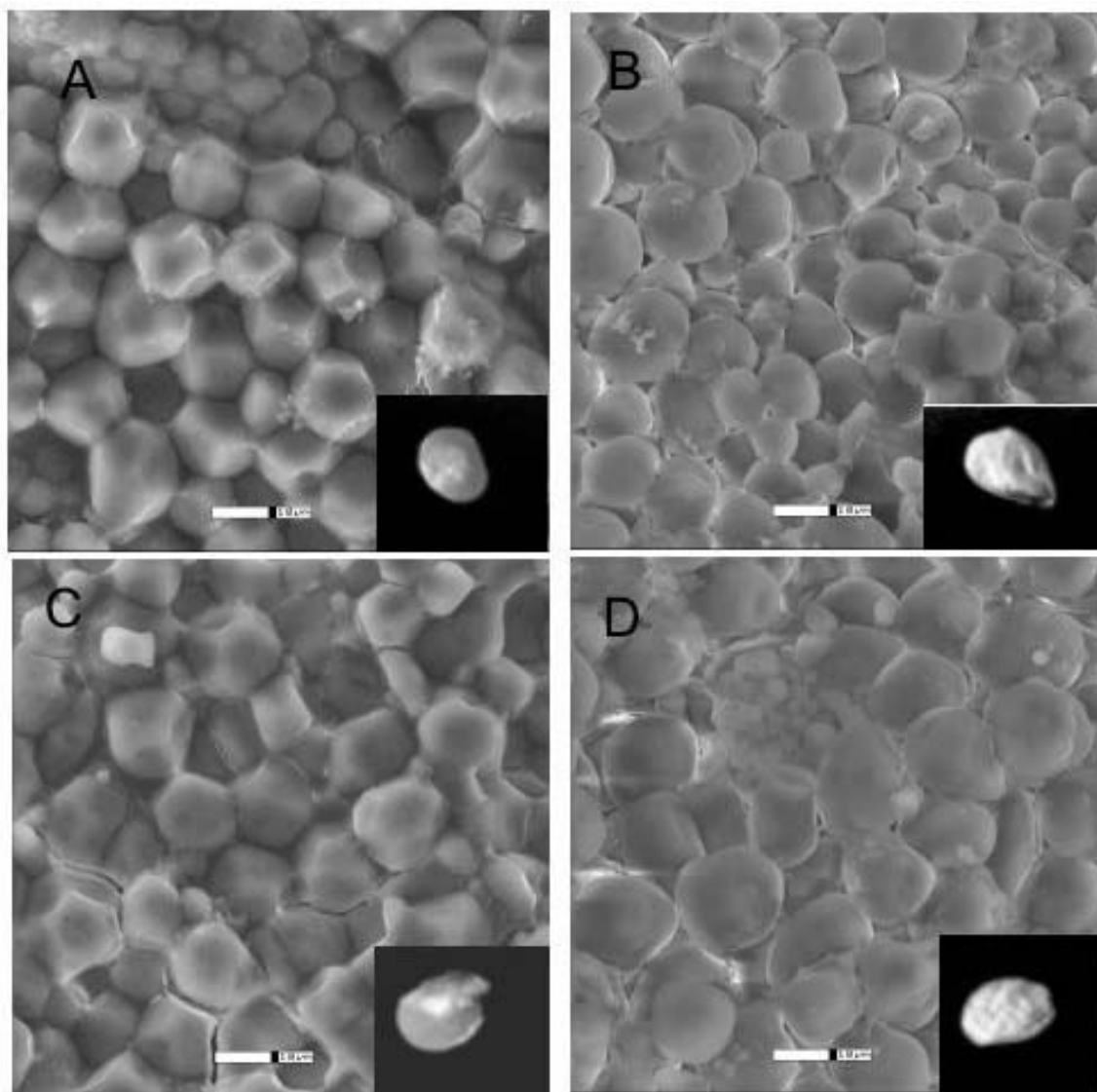


Figure 3. Longitudinal sections (inset) and scanning electron micrographs of (A) hard vitreous endosperm parent GCPOC124, (B) HPD opaque mutant parent P851171 (C) HPD mutant RIL 11278-1 with modified hard vitreous endosperm, (D) HPD mutant RIL 11286-1 with opaque floury endosperm.

ditions (not inoculated, no additional misting). Sorghums (52 red and 41 white) were sampled at physiological (30 DAA) and combined harvest maturity (50 DAA). Chitinase and sormatin in caryopses of sorghum at 30 and 50 DAA were determined. The percentage loss in chitinase and sormatin from 30 to 50 DAA were referred to as the retention rate. Grain mold rating, germination rate, phenol content, seed density, hardness and seed color (L, a and b values) were also measured.

Grain mold rating and germination rate are significantly correlated with both chitinase and sormation retention but not with phenol content and SKHT hardness (Table 1). Seed density is correlated with grain mold rating but not with germination rate. Thus, sorghums that are more resistant to molds re-

tain more chitinase and sormatin from 30 to 50 DAA than those that are susceptible. On the other hand, the study did not show a relationship between mold resistance and phenol content or seed hardness. Clearly, chitinase and sormatin contribute to limit mold damage of sorghum.

Evaluation of 33 hybrids and their respective male and female parents were also conducted in 2004. The hybrids had improved mold resistance, seed germination and seed density and increased retention of chitinase and sormatin when compared to their parents. This indicates a potential additive effect of combining mold resistance loci. More work needs to be conducted to quantify the hybrid vigor component of grain mold resistance.

Table 1. Correlations between grain mold rating score and seed properties (n=93).

Attribute	Mold Rating	Germination Rate (%)	Seed Color (L)	Seed Color (a)	Seed Color (b)	Seed Density	Hardness (SKHT*)	Phenols (mg/g)	Chitinase Retention
Germination Rate	-0.49								
Seed Color (L value)	0.33	-0.20							
Seed Color (a value)	-0.56	0.39	-0.82						
Seed Color (b value)	0.34	-0.24	0.93	-0.73					
Seed Density	-0.21	0.17	0.26	-0.18	0.20				
Hardness (SKHT*)	0.02	0.07	0.09	-0.18	0.08	0.65			
Phenols (mg/g)	-0.16	0.24	-0.57	0.59	-0.52	-0.12	-0.08		
Chitinase Retention	-0.51	0.42	-0.36	0.43	-0.34	0.05	0.05	0.36	
Sormatin Retention	-0.46	0.44	-0.27	-0.24	-0.24	0.07	-0.06	0.31	0.74

Marked correlation in bold type are significant at $p < 0.05$.

*SKHT = Single Kernel Hardness Tester.

Networking Activities

Dr. Hays traveled to Pretoria, South Africa, in October 2004 to present a talk on the use of biotechnology in the development of new high nutritional quality sorghum varieties at the White Food Sorghum Workshop at the University of Pretoria. Collaborations with Medson Chisi, Sorghum Breeding, Golden Valley Research Station, Zambia, and John Taylor, University of Pretoria, were developed at this meeting on priorities for testing potential food products that could be developed from the modified endosperm HPD lines.

We currently have one graduate student from Mexico, one from Honduras, and one domestic student working on and funded by this INTSORMIL project. We have leveraged INTSORMIL research funds to obtain \$125,000 in additional funding for two graduate student fellowships. As well, we re-

cruited a fully funded Fulbright Fellow graduate student from Honduras. Thus, three students are currently being funded by outside sources to work on this INTSORMIL project.

Publications and Presentations

Workshops Meetings

Dirk B. Hays. 2004. Sorghum Biotechnology: Combinability of high grain digestibility with grain mold resistance, USA-AID-INTSORMIL, White Food Sorghum Workshop, University of Pretoria, Pretoria, South Africa.

Dirk B. Hays, 2004. Using biotechnology to develop resistance in cereals to pathogens with extant diversity, Department of Plant Pathology, Texas A&M University.

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

**Project PRF 207
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Summary

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

PRF-207 addresses major biotic and abiotic constraints (drought, cold, grain mold, and other diseases) that limit productivity of sorghum in many areas of the world. We also undertake in this project studies on collection, assessment, and exploitation of sorghum germplasm from around the world. Over the years, significant progress has been made in some of these areas. Superior raw germplasm have been identified, mode of inheritance established, chemical and morphological traits that contribute to productivity as well as to tolerance to these stresses have been identified. Selected gene sources have been placed in improved germplasm background, some of which have already been widely distributed. In this report we document results of a collaborative study on analysis of genetic diversity among sorghums from Sudan.

Objectives, Production and Utilization Constraints

Objectives

Research

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

Germplasm Development, Conservation, and Diversity

- To develop sorghum varieties and hybrids with improved yield potential and broader environmental adaptation.
- To develop and enhance sorghum germplasm with increased levels of resistance to drought, cold, diseases, and improved grain quality characteristics.

- To assemble unique sorghum germplasm, and to encourage and facilitate free exchange of germplasm between U.S. and LDC scientists and institutions.
- To assess applicability of various statistical and DNA fingerprinting technologies for evaluating genomic similarity or for discerning genetic diversity of sorghum and millet germplasm pools.

Training, Networking, and Institutional Development

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

Program Approaches

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

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

vided by industry colleagues particularly at Pioneer HiBred and DeKalb Genetics

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

Project Output

Research Findings

Analysis of Genetic Diversity in Sudanese Sorghums

Sorghum originated in the Northeast quadrant of Africa over 3000 years ago, and slowly dispersed into other parts of Africa eventually spreading its area of cultivation into Asia and the rest of the world. Diversity of sorghum appears to be highly correlated with duration of domestication and the type of farming practiced in an area. High level of diversity was reported in sorghums from Ethiopia, a primary center of origin, from India, a secondary center of domestication, as well as from China, another important center of diversity for sorghum. Phenotypic diversity on 415 sorghum landraces from Ethiopia and Eritrea showed high phenotypic diversity along adaptation zones. Among 2343 Indian landraces from the sorghum ex-situ collection maintained at the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT), higher phenotypic diversity among accessions from different states than those from within a state was reported. Among 10,386 Chinese sorghum landraces kept at the national gene bank in Beijing, high degree of phenotypic diversity was observed in the collection with report of the most diversity in landraces from regions with the longest history of sorghum cultivation.

Sudan is one of the most important centers of sorghum domestication and cultivation. Sorghum is grown in every region of the country where it is possible to raise a crop. Nearly 80% of the total grain production in the country is obtained from sorghum. It is the staff of life for all Sudanese. In many parts of the country the crop is wholly utilized. The grain is used for making kisra (unleavened bread from fermented dough), a local porridge asida, a non-alcoholic beverage abreib, and a local beer marisa. The stalks are used as building material and the straw is utilized as animal feed or as source of fuel. Sorghums from the Sudan have also impacted sorghum improvement efforts globally. They have served as germplasm sources for improvements in yield, drought tolerance, stalk strength, insect and disease resistance, as well as nutritional quality. Early introductions of sorghum into the USA were primarily from Sudan. Sudan was probably the place where mutations for height and maturity took place in nature and where

'U.S. type sorghums' originated providing excellent opportunity for gene transfer between tropical and temperate. Indeed many varieties such as *hegaris*, *feteritas*, *zera zeras* and *kurgis* have contributed much towards breeding of improved sorghum varieties in both USA and India. In spite of their immense global importance, however, no organized diversity analysis has been reported on sorghums of the Sudan except for a few collection reports describing apparent variability among Sudanese sorghum landraces.

We recently completed an extensive evaluation and characterization of Sudanese sorghums kept at gene banks in Sudan, India, and the USA. This was undertaken as a collaborative effort among several institutions, including ICRISAT, the International Sorghum and Millet Collaborative Research Support Program (INTSORMIL), the United States Department of Agriculture (USDA), and the Agricultural Research Corporation (ARC) of the Sudan. As a result of this effort, fresh seeds of approximately 2800 well catalogued Sudanese sorghum landrace accessions are currently kept at gene banks in the USA, India and Sudan. The scientific value of these collections is better appreciated if a comprehensive analysis of the genetic diversity is undertaken. The objective of this study, therefore, is to develop a better understanding of the diversity and distribution of the present collection and to provide a basis for formulating policy for future action.

Univariate analyses were performed on morphological characteristics to describe phenotypic variability and its distribution across regions. Basic descriptive statistics of means, standard error, variance, and coefficient of variation, were performed on 10 quantitative traits. Geographical partitioning of diversity was assessed through variance analysis. Ten qualitative characters were encoded with from two to 13 classes. To reduce the statistical limits due to small group size, we grouped some of these classes. Frequency distributions for the 10 discrete characters were determined by grouping observations according to regional origin. Deviation from the expected frequency, as obtained from the distribution in the total landrace collection, was assessed using a Chi-2 test. Morphological diversity was also estimated by considering multiple characters together. Principal component analysis was performed on the 10 quantitative characters using standardized data.

Racial Classification

Race classification of *Sorghum bicolor* proposed by Harlan and de Wet in 1972 defines five races (Bicolor, Caudatum, Durra, Guinea and Kafir) and their 10 intermediates based on spikelet and panicle shape at maturity. In our landrace collection, all the races except the Guinea-Kafir intermediate, were present (Table 1 & 2). Four landraces belonging to the subspecies *Sorghum drummondii* (an annual weedy species) were also present in the collection. Landraces collected from farmers' fields included all the races except for Kafir, its intermediates, and Guinea-Bicolor. Race distri-

bution in these landraces was heavily skewed toward the Caudatum race (80.5%) and its intermediate forms. Racial distributions were markedly different among regions. Sorghums from El Gezira included 14 races made up mainly of Caudatum and its intermediate races. Among landraces from the Kassala region, six races were present with races Caudatum and Durra equally represented. Race Bicolor represented as high as 16% of the landraces from Kassala. In the Blue Nile region, six races of sorghum were included with race Caudatum as the most dominant (49%) followed by its intermediate Guinea-Caudatum (27%). More races were included in landrace sorghums from Upper Nile where there too, 70% of the landraces were classified as Caudatum. The less diverse region, race-wise, was Equatoria, where only 10 Caudatum, four Guinea, and four Guinea-Caudatum landraces were reported. However, such a bias in the racial distribution may only be a reflection of the reduced number of accessions collected from this region.

Plant Morphology and Phenology

Among sorghums originating from Kassala and Blue Nile regions, number of basal tillers (BT) always exceeded the unit. Sorghums from El Gezira had the highest number of basal tillers, with up to six basal tillers per plants, and consequently showed the largest coefficient of variation (CV=0.52). The shortest and earliest sorghums recorded during the post-rainy season (PHTR=85 cm and FLR=41 days) were also found in El Gezira. Accessions from the Blue Nile region were the tallest (PHTR=350 cm) and among the latest (FLR=103 days) sorghums. Sorghums from the Upper Nile region were among the smallest and earliest sorghums with the smallest upper limit of range values for both height (PHTR_{max}=260 cm) and days to flowering (FLR_{max}=82 days). The lowest limits in range of both PHTR and FLR values were the highest for sorghums from Equatoria (PHTR_{min}=170 cm and FLR_{min}=84 days). In addition, sorghum from Equatoria had very small coefficient of variation for flowering (CV=0.07) and for height (CV=0.12). Furthermore, the earliest sorghum accessions from Equatoria flowered later than the latest flowering sorghum from Upper Nile.

Panicle Characteristics

The range of values for peduncle exertion (PEDEX) showed that no sorghum from Equatoria had poor exertion as the minimal exertion recorded was nine centimeters. There was reduced variability for exertion among Equatoria sorghums as reflected by the small coefficient of variation (CV=0.31). Variances among regions were homogeneous and mean comparison indicated that landraces from Equatoria were significantly more exerted than accessions from all other regions. The highest values for ear head length (EHLG) and ear head width (EHWD) were found among sorghums from Kassala region (EHLG=44 cm and EHWD=25 cm). Sorghum from Blue Nile tended to include mostly accessions with long and large panicles. Based on mean comparison for these two

panicle characteristics, sorghums from Kassala and Blue Nile regions appear to possess larger panicles than those from Gezira, Upper Nile and Equatoria.

Kernel Characteristics

In comparison with other regions, sorghum originating from Kassala had both the smallest and the largest kernel size (GRS), 1.8 mm and 5 mm, respectively, as well as the highest 100-seed weight (SWT=7.3 g). Consequently landraces from Kassala exhibited the largest coefficient of variation for GRS (CV=0.17) and for SWT (CV=0.34). El Gezira appeared as the region for sorghums with the smallest seed weight (SWT=1.32 g). Sorghums originating from Equatoria showed both the highest value for the lower boundary and the lowest value for the upper boundary of GRS ($GRS_{min}=2.5$ mm, $GRS_{max}=3$ mm) and the lowest upper boundary for SWT ($SWT_{max}=3.4$ g). This reduced variability was also expressed by the smallest coefficient of variation for GRS and SWT (CV=0.05 and CV=0.15, respectively).

Nodal Tillers

Agronomic evaluation for presence or absence of nodal tillers (NT) showed that Sudanese landraces have a great tendency to produce nodal tillers. Though classified as a qualitative trait, nodal tiller production is highly affected by the environment. Despite a predominance of sorghums with presence of nodal tillers in the collection (92%), significant differences were found among regions. Landraces from Upper Nile and Equatoria were characterized with higher frequency of absence of nodal tillers. In Equatoria, the proportion of accessions without tillers to those with nodal tillers was reverse of what was found in the total collection. At the other extreme were accessions from El Gezira and Blue Nile region where almost all landraces produced nodal tillers and all landraces from Kassala were uniquely characterized with presence of nodal tillers.

Table 1. Geographical distribution and local source of the landraces from Sudan.

Province	Locality	Landraces from Institute	Landraces from Farmer's	Total
El Gezira	Gezira	749	0	749
	Wad Medani 124 E	0	1	1
	El Rafda	0	1	1
	El Nagi (Rufa)	0	2	2
	Rufa	0	1	1
	Missing	58	0	58
	<u>Total</u>	<u>747</u>	<u>5</u>	<u>752</u>
Kassala	Alareida	0	1	1
	Doka	0	4	4
	Doka 10 N	0	1	1
	El Azaza	0	2	2
	El Rwashida	0	1	1
	Gedaref 82 W	0	9	9
	Huri	1	0	1
	Kafai	0	3	3
	Kassab	0	3	3
	Komshetta	0	3	3
	Kumur	0	2	2
	Omshidara	1	0	1
	Sabarna	0	2	2
	Samsun 16 SE	0	2	2
	Samsun 20 SW	0	1	1
Samsun 37 N	0	1	1	
Umsinebra	0	5	5	
Umgargura	0	3	3	
<u>Total</u>	<u>2</u>	<u>43</u>	<u>45</u>	
Blue Nile	Abugarin (41 SW Damazin)	0	2	2
	Abu-ramad	0	4	4
	Amarasazili (61 NW Damazin)	0	1	1
	Bau	0	8	8
	Bel-ar	0	1	1

Table 1. cont'd - Geographical distribution and local source of the landraces from Sudan.

Province	Locality	Landraces from Institute	Landraces from Farmer's	Total
	Buck	0	2	2
	Damazin	0	7	7
	Dindro (144 SW Damazin)	0	3	3
	Duel (93 NW Assossa)	0	1	1
	Galgani (158 NW Damazin)	0	1	1
	Geneisa	0	1	1
	Kurmuk	0	8	8
	Lawni (Abu Hugar)	0	1	1
	Onsa (13 N Kurmuk)	0	2	2
	Radeef	0	2	2
	Singa	0	19	19
	Sennar	0	3	3
	Ulu (177 SW Damazin)	0	1	1
	Ulu (219 SW Damazin)	0	2	2
	Wad el Nile	0	4	4
	<u>Total</u>	<u>0</u>	<u>73</u>	<u>73</u>
Upper Nile	Tozi	144	0	144
	<u>Total</u>	<u>144</u>	<u>0</u>	<u>144</u>
Equatoria	Imeila	0	1	1
	Labalwa	0	2	2
	Lowudo	0	1	1
	Loronyo	0	3	3
	Lafon	0	4	4
	Mura-Ikotos	0	6	6
	Magwe	0	1	1
	<u>Total</u>	<u>0</u>	<u>18</u>	<u>18</u>
<i>Missing</i>		972	13	985
Total landraces		1865	152	2017

Table 2. Race distribution in different regions and in the total collection of sorghum landraces from Sudan.

Race	El Gezira	Kassala	Blue Nile	Upper Nile	Equatoria	Total
Bicolor	8	7	1	1	0	79
Caudatum	292	12	36	101	10	889
Durra	90	13	8	10	0	209
Guinea	14	0	0	2	4	35
Kafir	2	0	0	0	0	2
CB: Caudatum-Bicolor	55	0	1	3	0	110
DB: Durra-Bicolor	16	2	0	0	0	42
GB: Guinea-Bicolor	3	0	0	0	0	7
KB: Kafir-Bicolor	3	0	0	1	0	7
DC: Durra-Caudatum	104	7	7	12	0	231
GC: Guinea-Caudatum	129	4	20	13	4	342
KC: Kafir-Caudatum	15	0	0	1	0	34
GD: Guinea-Durra	19	0	0	0	0	24
KD: Kafir-Durra	2	0	0	0	0	2
Drummondii	0	0	0	0	0	4
Total	752	45	73	144	18	2017

Plant, Glume and Midrib Color

Most entries in the Sudan collection (93%) had plants with pigmentation (PIG) with no significant differences among regions for pigmentation. Approximately one-half of the collection contained dark (black/purple) glumes (53%) and again evenly distributed among regions. Approximately, 11% of the landraces from El Gezira had red glume (GLC) which was significantly different from frequency of red glumes in the total collection (16%). The proportion of accessions with sienna glume color was the smallest in accessions from the Upper Nile (6%) in contrast to a higher proportion in collections from Blue Nile (37%), Kassala (33%) and El Gezira (24%) regions as well as in the entire collection (19%). Mahogany glume color represented 12% of the collection and this trait was the lowest (3%) among sorghums originating from Blue Nile and the highest (20%) in accessions from the Upper region. Midrib color (MRC) for the entire Sudan collection was mainly distributed between two classes, white and dull midrib colors represented 62% and 36% of the collection, respectively. Yellow midribs were rare in the Sudan collection. Only a small portion of the landraces in the total collection had yellow midrib (2%), but sorghums from Kassala had an unusually high (29%) frequency of yellow midrib types.

Panicle Characteristics

For panicle compactness and shape (EHCS), a higher proportion of accessions of the entire collection were characterized with compact panicles (56%). Frequency of compact panicles was significantly higher in sorghums from El Gezira and from Upper Nile (69% for each). In the total collection, sorghums with loose panicles included 40% with loose and stiff branches and 3% for panicles with loose drooping branches. El Gezira sorghums were less commonly characterized with loose panicles. Sorghums from Upper Nile had a significantly smaller (17%) frequency of landraces with loose stiff branches, and a relatively higher frequency of landraces with loose drooping branches (14%). In major contrast to sorghums from all the other regions as well as the entire collection, landraces from Ekuatoria were more uniquely characterized with loose panicles. Most of the Sudan collection (68%) was classified as containing easily threshable (THR) panicles, except for sorghums from Kassala where 20% were recorded as difficult to thresh in contrast to a 6% average for the entire collection. Partly threshable sorghums were significantly higher in collections from El Gezira and Upper Nile, and significantly reduced for accessions from Kassala, Blue Nile, and Ekuatoria. Only sorghums originating from Blue Nile contained a very high frequency, 97%, of freely threshable panicles.

Kernel Color

This trait (GRC) was characterized as physical appearance of the kernels, notwithstanding the genetic basis for the expression of this trait. Approximately 55% of the collection

was evenly distributed between sorghums with brown seeds and those with grey seeds. Straw, red, white, and yellow kernels were found in 15%, 13%, 11% and 5% of the collection, respectively.

Glume Coverage

Assessment of glume coverage of kernels (COV) in the Sudan collection resulted in 48% of the collection to be uncovered with only up to 1/4 of the seed covered by the glume, 40% of the collection with 1/2 of kernel covered by glume, and 12% of the collection with kernels 3/4 to fully covered by glume.

Endosperm Characteristics

Endosperm texture (TEX) was significantly different among sorghums from different regions. Fewer landraces in the Sudan collection possessed corneous endosperm (6%). A higher proportion of landraces had kernels with either partly corneous or partly to completely starchy endosperm 40% and 54%, respectively.

Estimates of Diversity

Diversity was estimated using the Shannon-Weaver diversity index calculated from frequency distribution of multiple morphological traits. Estimates were based on phenotypic variability of the landraces, only considering the qualitative characters. Great global index of diversity was found in the total collection ($H' = 0.80$). Within region, however, the range of index of diversity varied from $H' = 0.60$ for accessions from Ekuatoria, to $H' = 0.79$ for sorghums from El Gezira. Pair-wise comparison of the indices using *t*-test revealed significant differences (at $p < 0.05$ probability-level) between the diversity indices obtained from Blue Nile ($H' = 0.67$) and the total collection ($H' = 0.80$) as well as between Blue Nile and El Gezira ($H' = 0.79$).

Germplasm Exchange

We continue to provide an array of sorghum germplasm from our breeding program to national research programs in developing countries. Our germplasm is provided in either a formally organized nursery that is uniformly distributed to all collaborators that show interest or upon request by a national program of specific germplasm entries or groups from or germplasm pool. Germplasm was distributed to cooperators in 10 countries in 2004.

Publications

Refereed Papers

Grenier, C., P.J. Bramel, J.A. Dahlberg, A. El-Ahmadi, M. Mohammed, G.C. Peterson, D.T. Rosenow and G. Ejeta.

2004. Sorghums of the Sudan: Analysis of regional diversity and distribution. *Genet. Res. and Crop Evol.* 51: 489-500.

Ejeta, G. and C. Grenier. 2005. Sorghum and its weedy hybrids. pp123-135, In: J. Gressel (ed.) *Crop Fertility and Volunteerism: A Threat to Food Security in the Transgenic Era*, CRC Press.

Kapran, I. and G. Ejeta. 2005. Increased yield and adaptation of sorghum hybrids in Niger. *African Crop Sci. Journal* (In Press).

Conference Proceedings

Grenier, C., LA. Deressa, Z. Gutema, G. Gebeyehu, H. Shewayrga, M. Mekuria, A. Belay, T. Tadess, N. Mengistu,

O. Oumer, A. Adugna, B. Tsegaw, and G. Ejeta. 2004. *Integrated Striga Management (ISM) in East Africa*. McKnight Foundation

Invited Presentations

Ejeta, G. 2004. African Green Revolution: A Mirage? Presented as a Public Talk at University of Chicago, May 20, 2004

Ejeta, G. 2004. The Promise of a Green Revolution in Africa. Presented to a Forum on World Hunger, University of Chicago, and May 21, 2004.

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

Project KSU 220

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Summary

The marketing and utilization of sorghum grain often has been limited by lower grain quality and feed value compared to other cereals. This research project attempts to address this weakness through plant breeding to develop elite varieties and hybrids with improved nutritional and grain quality traits including mold resistance and through development and transfer of animal feed and production technologies to developing countries. Breeding efforts continue with the exchange and testing of new germplasm and improved varieties through collaboration of scientists around the world. Animal feed workshops and seminars as well as poultry feeding demonstrations are being conducted with collaborators in countries in Africa and Central America.

Improve Nutrition and Yield

The major emphasis of this project is to develop sorghum varieties and hybrids with enhanced nutritional and grain quality characteristics. Large-seeded sorghum genotypes with enhanced feed-value and grain-quality characteristics have been identified and these genes are being incorporated into improved genetic backgrounds for deployment in regions of Africa, Central America, and the United States. Efforts are also being made to determine if high protein digestibility and grain

mold resistance can be combined. Currently, small populations have been developed to test this relationship. Genes that contribute to grain mold and disease resistance are being tagged to simplify future incorporation into useful cultivars.

Past breeding efforts have significantly enhanced yield potential in semi-arid regions of the world, but little attention has been focused on feed value and grain quality in these production environments. Tan-plant sorghum hybrids with improved drought tolerance are being developed to address this problem. In the United States, food-grade hybrids are now commercially available in all maturity groups. These hybrids are high-yielding and well-adapted to dryland and limited-irrigation environments.

Improve Institutional Capacity

Our training program focuses on the transfer of technology and knowledge to allow development and utilization of improved sorghum and pearl millet cultivars for animal feeding and human food. A key component of technical assistance and technology transfer in Central America is the RAPCO Short Course for animal nutrition. This week-long short courses in animal feeding and nutrition is held each year and

includes participants from Mexico, Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica, Panama, the Dominican Republic, Columbia, Venezuela, Peru, and Ecuador. These short courses were designed specifically to address issues (real and perceived) that limit the expanded use of sorghum as a feedstuff for poultry farming in Nicaragua and El Salvador. Technology transfer efforts in West Africa also were initiated in 2003 through interaction with Dr. Salissou Issa, Head of the Animal Husbandry Unit at the INRAN Rainfed Crops Program in Niger. These efforts include farm visits, feeding trials, and poultry field days to demonstrate the relative feed value of local and improved sorghum varieties in comparison to traditional corn-based feed rations.

In addition to providing new cultivars and the technology to utilize them effectively, graduate students and visiting scientists with interest in crop improvement, crop utilization, animal nutrition and molecular biology are being hosted for short-term and graduate training at Kansas State University and Texas A&M University. Student projects are strongly multidisciplinary and provide opportunities for collaboration with investigators from different departments and universities. The focus of this training is to enhance the human and institutional capacity of research institutions in developing countries.

Promote Economic Growth

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

Objectives, Production and Utilization Constraints.

Objectives

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

Constraints

New entrepreneurial opportunities for production of animal feeds and products in developing countries including meat and eggs are needed to move sorghum and millet from subsistence crops to value-added commodities. However, the marketing and utilization of sorghum grain often has been limited by lower grain quality and feed value than other cereals. Sorghum kernels are exposed to the environment as they mature and grain mold problems are common. Grain mold involves a complex of potential pathogens and as for other diseases, selection for resistance leads to changes in the pathogen populations. Thus breeding efforts must be continuous just to maintain high production and quality standards. However, even in the absence of contaminating fungi, sorghum grain typically has lower digestibility and metabolizable energy values as compared to other cereals, providing another target for improvement through application of technology-assisted plant breeding.

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

Research Approach and Project Output

Research Methods

Collaborative research efforts in Africa and Central America are supported through short and long-term training programs, germplasm exchange and evaluation, and complementary basic research support activities. These research efforts are conducted in three regional programs including West Africa, Southern Africa, and Central America.

Crop improvement efforts to develop cultivars adapted to environments in West Africa, Southern Africa and Central America utilize elite varieties and cultivars that are adapted to each of the regions. The lines used to create these populations are selected through evaluations of elite U.S. and host country germplasm in the target region. This material is evaluated in the target region in conference with collaborating plant breeders. Improvement efforts in Western and Southern Africa focus on the development of early-maturing, drought-tol-

erant cultivars and hybrids that incorporate *Striga* resistance while efforts in Central America are on improved food-type and Macio Criollos cultivars. These efforts are focused on the development of photoperiod sensitive hybrids using maturity genes *Ma5* and *Ma6*.

The underlying objective for research to identify and map genes related to grain quality is to develop a better understanding of the genetic control of important quality traits and generate genetic markers that can be used by sorghum improvement programs in the near future. Combining these traits into one genotype is a significant challenge that could be facilitated by the use of molecular technology. The development of these technologies should enhance the efficiency of combining grain quality factors including feed quality characteristics and grain mold resistance into varieties with high yield potential. Mapping populations are being developed and characterized in cooperation with collaborators at domestic and international sites. These populations are being genotyped in laboratories in the U.S. using various types of genetic markers. In general, PCR based methods are being used. These include AFLP and SSR protocols that permit rapid identification of DNA polymorphisms linked to key characters in segregating populations. In addition, prospective disease resistance genes have been identified based on DNA sequence homology to conserved regions found in cloned genes from other species. These resistance gene analogs are being mapped on the standard sorghum mapping population (BTx623 X IS3620C). Students from Africa, Honduras and the U.S. are being trained who will be able to take advantage of marker technology, either directly in their respective national programs or through continued collaboration following return to their home countries.

Technical assistance and technology transfer efforts in poultry production and nutrition are focused on workshop and short course activities as well as feeding trials and demonstrations. In 2004-2005, feeding trials were conducted to demonstrate and compare feed value of corn- and sorghum-based poultry rations in West Africa. Replicated trials to evaluate performance of broiler chickens in Niger were completed in 2004. At the conclusion of the study, poultry producers from the region were invited to participate in a review of the research project. The producers were very interested in the results and suggested that the researchers at INRAN conduct a similar study to evaluate the efficacy of sorghum-based feed rations for layer production. The dialogue that developed around this project ultimately led to the formation of the Nigerian Poultry Producers Cooperative in 2004.

Research Findings

Analysis of Sorghum and Maize for Differences in Poultry Feed Quality

Poultry and egg production is increasing in countries throughout the developing world. Maize-based feed rations

are common in many areas of Africa and Central America because grain is cheap and readily available. In most of these areas, sorghum is valued for human consumption and sells for a higher price than maize. However, in certain areas such as Niger, locally produced sorghum is generally less expensive than imported maize. In these areas, sorghum could play an important role in formulating feed rations for animals such as poultry; however, animal producers generally will not feed sorghum-based rations because of misconceptions about tannins in sorghum and the relative feed value of the grain. These concerns generally are unfounded because improved sorghum cultivars are low in tannin and have feed-value nearly equivalent to maize given the appropriate processing to maximize the feed value.

A technical assistance and technology transfer program was developed in Niger through interactions with Dr. Salissou Issa, Head of Animal Husbandry, INRAN. A research exhibition area was developed to highlight best management and production practices for sorghum cultivars as well as demonstrate applied poultry production procedures using sorghum-based feed rations.

The objective of this study was to evaluate the feed quality of traditional coarse-ground (> 1,200 microns) and finely-ground (< 700 micron particle size) maize-based rations using maize imported from Nigeria in comparison with finely-ground (< 700 micron particle size) sorghum-based rations using a locally produced landrace variety called Mota Galmi and an improved tan-plant variety called IRAT204. Rations formulated using 60% milled corn or sorghum were fed to broiler chicks in government production facilities near Niamey, Niger. The experiment was conducted with five replications for each treatment and 25 chickens per pen with pens arranged in a randomized complete block design. Feed intake was determined daily and the bird weights were determined at day 7, 21, 35, 49, and 60.

No significant differences in poultry performance were detected in comparisons between the fine- or coarse-grind maize at any point in the experiment (Table 1). Poultry performance was significantly better with the maize-based diets as compared to the sorghum-based diets at 21, 35, 49, and 60 days for bird weight and feed intake. Comparisons among the sorghum-based diets indicated that broiler chickens produced using the sorghum landrace Mota Galmi were significantly heavier than the chickens produced using IRAT204 at 21, 35, 49, and 60 days. Feed intake was highest for the maize-based diets followed by the Mota Galmi- and IRAT 204-based diets. Differences in bird weight were strongly correlated with differences in feed intake and no differences in the gain to feed ratio were detected at day 60. Yet even with the slight nutritional advantages for the maize-based diets, the results of this study were consistent with previous reports indicating that chickens fed locally produced sorghum varieties perform quite well given the price advantage for sorghum compared to maize.

Table 1. Average broiler chicken performance using feed rations based on fine- and coarse-ground maize samples in comparison with feed rations based on fine-ground improved and local sorghum varieties.

Treatment	Bird weight					Feed Intake g bird ⁻¹	Gain to Feed Ratio
	7d	21d	35d	49d	60d		
Maize – Coarse grind	90.4	307	868	1601	2355	4553	0.52
Maize	91.4	310	884	1603	2341	4690	0.50
IRAT204	83.6	233	638	1193	1896	3733	0.51
Mota Galmi	90.8	281	773	1435	2188	4230	0.52
LSD [†] (p<0.05)	6.5	25.3	46.4	68.5	83.1	302	0.03
	NS	***	***	***	***	***	NS

[†] LSD = least significant difference; NS=nonsignificant differences among rations; *** indicates significance at $\alpha=0.001$

Table 2. Effects of imazapyr and metsulfuron herbicide seed dressings on emergence, height, and plant injury of tolerant and susceptible sorghum genotypes at 21 days after planting.

Herbicide	Seed Dressing	Emergence [†]		Height		Plant Injury	
		Tol.	Susc.	Tol.	Susc.	Tol.	Susc.
		---- % ----		---- mm ----		---- % ----	
Control	0 g seed ⁻¹	80	90	236	204	0	0
Imazapyr	0.01875 g seed ⁻¹	83	46	183	19	16	91
	0.0375 g seed ⁻¹	83	33	160	10	28	99
	0.075 g seed ⁻¹	83	28	151	5	33	100
	0.15 g seed ⁻¹	78	28	132	9	47	100
	0.3 g seed ⁻¹	76	28	145	6	53	100
Metsulfuron	0.00625 g seed ⁻¹	78	37	154	14	24	96
	0.0125 g seed ⁻¹	82	28	118	13	37	97
	0.025 g seed ⁻¹	76	24	107	8	50	99
	0.05 g seed ⁻¹	73	23	86	5	61	100
	0.1 g seed ⁻¹	72	30	76	5	68	100

[†] Tol=Herbicide tolerant; Susc=Herbicide susceptible
*** indicates difference is significant at $\alpha=0.001$ level

Striga Resistance

Several researchers attending the 2004 West Africa Regional Workshop in Ouagadougou, Burkina Faso indicated an interest in developing a regional research effort focusing on control of *Striga*. The use of crop cultivars with resistance to *Striga* has been widely acknowledged as the most practical and economically feasible control measure for subsistence farmers in Africa. Sources of genes conditioning host-plant resistance to *Striga* have been identified in sorghum. These resistance genes disrupt the intricate relationship between the parasite and its host. The mechanisms of resistance that have been identified to date include: 1) low production of germination stimulant, 2) low production of haustorial factor, 3) hypersensitive response, and 4) incompatible response. Vari-

eties that incorporate *Striga* resistance in high yielding genetic backgrounds are being developed through the efforts of researchers in national programs in West Africa and abroad. Continued effort is needed in identifying and cataloging genes that can be used to control *Striga* and in technology transfer to incorporate these traits into adapted varieties.

Although genetic resistance has been shown to provide good control of *Striga*, varying degrees of infestation generally are observed even in resistant varieties. Although this level of control improves plant health and yield potential, the seed bank for *Striga* continues to be regenerated each year since each of the surviving *Striga* plants can produce thousands of seeds. Furthermore, given the virulence and extent of genetic variability in *Striga*, it is likely that recurring use

of resistant varieties may result in weed populations that are capable of overcoming host-plant resistance.

This project focuses on the development of a new technology to control *Striga* that complements research efforts in host-plant resistance. The technology is based on the use of low-dose herbicide seed treatments and has been shown to be effective in controlling *Striga* in imidazolinone (IMI)-herbicide tolerant maize. A similar technology for controlling *Striga* should be effective in sorghum and should contribute both to control of *Striga* as well as improved management of the seed bank. Experiments were conducted to evaluate the tolerance of sorghum to seed treatments with imazapyr and metsulfuron herbicides. The results of these experiments are shown in Table 2. In the control treatment with no herbicide application, emergence values for a tolerant and susceptible genotype were similar and no plant injury effects were noted. The resistant genotype was somewhat taller than the susceptible genotype. In contrast, very large and significant differences in emergence, height, and plant injury were noted between the tolerant and susceptible genotypes for each of the imazapyr and metsulfuron seed treatments. In each case, the tolerant genotype expressed better emergence, greater height, and lower plant injury. Based on the results of this study, three rates of each herbicide were selected and are being evaluated to determine the efficacy of these treatments in controlling *Striga* under field and greenhouse conditions.

Host Pathogen Interactions

Molecular tags suitable for use in marker-assisted selection were identified for the anthracnose resistance gene in SC748. Map data for sorghum disease resistance gene analogs, though limited, suggests that the genes are distributed to chromosome segments in clusters matching those of rice. Messenger RNA extracts were prepared from florets of two mold resistant and two susceptible cultivars 48h after inoculation at anthesis with spores of *F. thapsinum* and/or *C. lunata*. The most notable observation to date is increased expression of a chitinase gene in resistant vs. susceptible cultivars. In a related project, AFLP DNA fingerprinting has shown considerable differences in pathotypes 1 and 3 of *P. sorghi* (the downy mildew pathogen), and that a new metalaxyl resistant pathotype most likely arose as a mutant of pathotype 3. Many of the accessions in the sorghum germplasm collection are already being screened to identify potential sources of resistance to the new pathotype..

Breeding Activities

Efforts to incorporate the large seeded trait with grain mold resistance are being continued. Several F₄ generation lines have been identified that possess large seed with mold resistance improved from that of KS115. Because mold resistance is not yet suitable for use in production systems, it is likely that additional backcrossing of these F₄ lines will be necessary to continue the improvement of grain mold resis-

tance. We also are cooperating with TAM 224 to determine whether high protein digestibility and grain mold resistance can be combined. Currently, small populations have been developed to test this relationship and we have begun to create larger populations in order to completely characterize this relationship.

In cooperation with Drs. Medson Chisi and Neal McClaren, a set of Southern African cultivars and breeding lines were used as pollinators to create a set of hybrids to determine the level of heterosis present in this germplasm. The field evaluation has been completed and preliminary analysis of the data indicates that several lines show superior levels of heterosis with A-lines from the TAES program (Table 3). Quality analysis is currently being completed at this time.

Efforts in the development of tan plant hybrids are continuing. New and current tan plant hybrids have been evaluated in Texas, Kansas and Nebraska annually to determine their region of adaptation and grain quality parameters. Current tan plant full season maturity hybrids are high yielding and adapted to limited irrigation environments. While early and mid-season tan plant hybrids are now available, additional breeding efforts are needed to increase grain yields and adaptability of these maturity groups. Currently, early maturity tan plant hybrids are not as competitive in yield potential as traditional feed type hybrids, with emphasis on the development of disease resistant, drought tolerant types.

When comparing traditional hybrids with tan hybrids, trends observed in past years are similar to those observed this year. Across all hybrids, tan hybrids tend to be later but they are similar in yield and plant height (Table 3). This is reflected in maturity classes and the availability of hybrids. For example, there are several full season tan-plant hybrids on the market that have high yield potential, and good quality. There are only a few tan-plant hybrids in the early and mid-season, and in general, their performance relative to the traditional hybrids needs to be improved.

Grain Molds and Weathering Improvement

In collaboration with TAM 224, several progeny with high digestibility have been derived from crosses of TAES germplasm with P850029 and P851171. These lines have been grown in multi-location trials to determine if highly digestible lines with grain mold resistance can be developed. These trials were established and are currently ongoing. In addition, several populations segregating for multiple grain quality traits are being grown to determine the mode of inheritance for each trait.

Related Studies- Characterization and inheritance of anthracnose resistance - Anthracnose is a major disease of sorghum [*Sorghum bicolor* (L.) Moench]. Breeding for stable host plant resistance to this disease has been difficult due to the variable nature of the pathogen and an incomplete under-

Table 3. Comparison of the productivity of tan plant and pigmented plant hybrids in the 2003 Tan Plant Hybrid Test. Data included in this table is combined from five locations in Texas.

Location		Plant Color	Plant	Panicle	Days to Anthesis	Desirability Rating	Grain Yield lbs/acre
			Height in.	Exsertion in.			
College Station	Purple (Traditional)	P	52	3	74	5.1	5,036
	Tan (Food Type)	T	52	2	77	4.7	4,622
	L.S.D. (P<.05)		ns	ns	***	ns	ns
Gregory	Purple (Traditional)	P	48	5	69	4.5	3,279
	Tan (Food Type)	T	45	4	73	4.8	2,303
	L.S.D. (P<.05)		ns	ns	***	ns	*
Hondo	Purple (Traditional)	P	55	4	67	4.3	5,868
	Tan (Food Type)	T	52	4	70	3.9	5,275
	L.S.D. (P<.05)		ns	ns	***	*	ns
Halfway	Purple (Traditional)	P	46	3	73	4.3	7,024
	Tan (Food Type)	T	47	4	74	3.6	6,643
	L.S.D. (P<.05)		*	ns	*	**	ns
Perryton	Purple (Traditional)	P	53	4	78	4.5	7,123
	Tan (Food Type)	T	53	5	79	3.9	7,073
	L.S.D. (P<.05)		ns	*	**	**	ns
Combined	Purple (Traditional)	P	51	4	72	4.5	5,666
	Tan (Food Type)	T	50	4	75	4.2	5,183
	L.S.D. (P<.05)		*	ns	***	**	ns

standing of the host/pathogen interaction. To develop new lines with possibly more durable forms of resistance, different sources of genetic resistance must be identified and characterized. The objectives of this study were (1) to determine if different sources with anthracnose resistance possess different genes for resistance, (2) to determine the inheritance of anthracnose resistance in the groups identified in objective 1, and (3) to identify which sources provide resistance across environments. Populations created from hybridizing resistant by resistant lines were evaluated to determine if segregation for resistance occurred within a family. The presence of segregation (susceptible plants) within a population indicated that the parents have different resistance genes. In the eleven germplasms evaluated, six different sources of resistance were identified. Segregation ratios in resistant × susceptible F₂ populations were consistent with the expectations of simply inherited traits and resistance was dominant in some lines and recessive in others. Evaluation of the sources of resistance across environment indicated that one source (SC748-5) provided resistance in all evaluation environments. We are collaborating with Clint Magill in an effort to map the resistance in SC748-5.

Networking Activities

Workshops and Meetings

Great Plains Sorghum Conference – September 14-15, 2004, Manhattan, Kansas, USA.

Sorghum Genomics Planning Session – September 26-27, 2004, Ithaca, New York, USA.

NSF Sorghum Genomics Workshop – November 9, 2004, St. Louis, Missouri, USA.

Sorghum Improvement Conference of North America (all 4 PIs)– February, 2005, Reno, Nevada, USA.

Sorghum Germplasm Committee Meeting – February, 2005, Reno, Nevada, USA.

Research Investigator Exchanges

Dr. Hancock lectured about feedstuffs and feed manufacturing to nutritionists, veterinarians, and feed manufacturers (30 to 35 people representing 12 to 14 Central/South American and Caribbean countries) at the week-long RAPCO (Cursos Regionales en Produccion Animal) Short Course in Atenas, Costa Rica, August, 2004.

The External Evaluation Panel was hosted at Kansas State and Texas A&M Universities as part of the INTSORMIL review process in September 2004.

Dr. Tuinstra visited the INRAN and IER research programs in Niger and Mali in October of 2004 to review collaborative research activities and coordinate research activities for 2005.

Dr. David Jordan, Sorghum Breeder from Hermitage Research Station in Queensland, Australia, was hosted in visits to Kansas State and Texas A&M Universities during November of 2004.

Mr. Souley Soumana, a M.S. student at KSU, was sponsored in a trip to Niger and Mali to conduct his thesis research project.

Dr. Hancock participated in the INTSORMIL Crop Utilization Meeting held in Ouagadougou, Burkina Faso, December 2004.

Dr. Tuinstra visited collaborators at Wageningen University in the Netherlands on sabbatical leave to conduct greenhouse trials to test efficacy of herbicide seed dressings in controlling *Striga*

Dr. Hancock collaborated with Dr. John Sanders on a visit to Senegal for a review of the potential for expanding poultry markets to increase demand for sorghum as a feed grain, January 2005.

Dr. W.L. Rooney, accompanied by Dr. Gary Peterson, traveled to Central America in January 2005. In Nicaragua the pair met with René Clara and Rafael Obando to plan activities and evaluate germplasm. In Guatemala, Mr. Clara, Dr. Peterson and Dr. Rooney visited with seed companies Cristiani Burkhard and ProSemillas regarding the potential use of germplasm from INTSORMIL breeding programs.

Dr. Hancock lectured about feedstuffs and feed manufacturing to nutritionists, veterinarians, and feed manufacturers (30 to 35 people representing 12 to 14 Central/South American and Caribbean countries) at the week-long RAPCO (Cursos Regionales en Produccion Animal) Short Course in Atenas, Costa Rica, February 2005.

A collaborative IPM-CRSP proposal was prepared, involving Dr. Magill, TAMU, Adama Neya, Burkina Faso, Mamourou Diourté, A.M. Maliu, and S.K. Nutsugah, Ghana but was not funded. Other potential sources of funding are being queried.

Dr. Magill and Seriba Katilé, Mali met with Dr. Norman Borlaug to seek his advice on potential donors for improving technology capacity useful for breeders in Africa.

Dr. Hancock collaborated with Drs. Lloyd Rooney and John Sanders to present a seminar on "Myths About Sorghum as a Feedstuff" during the Sorghum Utilization Conference in Managua, Nicaragua, May 2005.

Germplasm and Research Information Exchange

Coordinated the tan plant hybrid trial that is designed to evaluate commercially available tan plant (improved grain quality) sorghum hybrids for agronomic adaptation and grain qual-

ity parameters. The test was grown at nine locations in Kansas and Texas.

Distributed 12 elite parent lines, 20 elite hybrids, 90 large-seeded breeding lines, and 12 large-seeded hybrids from KSU 220A to national program scientists for evaluation in Niger, Mali, Ghana, and Senegal.

Distributed a replicated experiment to evaluate efficacy of herbicide seed treatments in controlling *Striga* to collaborators in Niger and Mali.

Distributed a replicated experiment to evaluate new sources of *Striga* resistance from West African with the appropriate checks, and corresponding hybrids to collaborators in Niger and Mali.

Distributed three new KSU parent lines to seven commercial seed companies.

Publications and Presentations

Journal Articles

- Hodnett, G.L., B.L. Burson, **W.L. Rooney**, S.L. Dillon, and H.J. Price. 2005. Pollen/pistil interactions result in reproductive isolation between *Sorghum bicolor* and divergent Sorghum species. *Crop Science* (in press)
- Klein, R.R., P.E. Klein, J.E. Mullet, P. Minx, **W.L. Rooney**, and K.F. Schertz. 2005. Fertility restorer locus *Rf1* of sorghum (*Sorghum bicolor* L.) encodes a pentatricopeptide repeat protein not present in the colinear region of rice chromosome 12. *Theoretical and Applied Genetics* (in press).
- Little, C. R. and **Magill**, C. W. (2004) Elicitation of defense response genes in *Sorghum bicolor* (L.) Moench in response to infection by *Fusarium thapsinum* and *Curvularia lunata* at anthesis. *Mol. & Physiol. Plant Pathology* 63:271-279.
- Menz, M.A., R.R. Klein, N.C. Unruh, **W.L. Rooney**, P.E. Klein and J.E. Mullet. 2004. Genetic diversity of public inbreds of sorghum using mapped AFLP and SSR markers. *Crop Sci.* 44:1236-1244.
- Mehta, P.J., C.C. Wiltse, **W.L. Rooney**, S.D. Collins, R.A. Frederiksen, D.E. Hess, M. Chisi, and D.O. TeBeest. 2005. Classification and Inheritance of Genetic Resistance to Anthracnose in Sorghum. *Field Crops Research* 93:1-9.
- Nagaraj N, Reese JC, **Tuinstra MR**, Smith CM, St Amand P, Kirkham MB, Kofoid KD, Campbell LR, Wilde GE. 2005. Molecular Mapping of Sorghum Genes Expressing Tolerance to Damage by the Greenbug (Homoptera: Aphididae). *Journal of Economic Entomology* 98:595-602.
- Price HJ, Dillon SL, Hodnett G, **Rooney WL**, Ross L, Johnston JS. 2005. Genome evolution in the genus *Sorghum* (Poaceae). *Annals of Botany* 95: 219-227.
- Price HJ, Hodnett GL, Burson BL, Dillon SL, **Rooney WL**.

2005. Hybridization of *Sorghum bicolor* (L.) Moench and *S. macrospermum* E. D. Garber. *Australian Journal of Botany* (in press).
- Prom, L.K., R.D. Waniska, A.I. Kollo, **W.L. Rooney**, and F.P. Bejosano. 2005. Role of chitinase and sormatin accumulation in the resistance of sorghum cultivars to grain mold. *Journal of Ag and Food Chemistry*. (in press).
- Rooney, W.L.**, S. Aydin* and L.C. Kuhlman*. 2005. Assessing the Relationship between Endosperm Type and Grain Yield Potential in Sorghum (*Sorghum bicolor* L. Moench). *Field Crops Research* 91: 199-205.
- Tesso T.T., **Tuinstra MR**, Claflin LE. 2005. Analysis of stalk rot resistance and genetic diversity among drought tolerant sorghum genotypes. *Crop Science* 45:645-652.
- Tesso T.T., **Tuinstra MR**, Claflin LE. 2004. Estimation of combining ability for resistance to Fusarium stalk rot in grain sorghum. *Crop Science* 44: 1195-1199.
- Yu J., **Tuinstra MR**, Claassen MM, Gordon WB, Witt MD. 2004. Analysis of cold tolerance in sorghum under controlled environment conditions. *Field Crops Research* 85:21-30.
- Ridder, D. 2005. Early-season cold tolerance in grain sorghum: the relationship with seed characteristics and evaluation of molecular tools for breeding. M.S. Thesis. Kansas State University, Manhattan, KS.

Miscellaneous Publications

- Little, C. R. and **Magill, C. W.** (2004) Colonization of Sorghum peduncles by *Fusarium thapsinum* and *Curvularia lunata*: Subsequent pigment accumulation. *International Sorghum and Millets Newsletter* 45: 28-30.

Abstracts

- Nagaraj N., Reese J, **Tuinstra MR**, Smith MC, St. Amand PC, Kirkham MB, Kofoid KD, Campbell LR, Wilde GE. 2004. Molecular mapping of sorghum genes expressing tolerance to damage by the greenbug (Homoptera: Aphididae). 2004 ESA Annual Meeting and Exhibition. Salt Lake City, Utah, USA. 14-17 November 2004
- Ridder D.D., Pandravada S, **Tuinstra MR**. 2004. Conversion of sorghum AFLPs to sequence tagged site (STS) markers for use in marker assisted selection. 2004 ASA-CSSA-SSSA International Annual Meetings with the Canadian Society of Soil Science, Seattle, Washington - Oct 31 - Nov 4, 2004
- Ridder D.D., Pandravada S, Kaufman RC, Bean SR, **Tuinstra MR**. 2004. Genetic and phenotypic associations between sorghum seed quality and seedling performance under cold temperature stress. 2004 ASA-CSSA-SSSA International Annual Meetings with the Canadian Society of Soil Science, Seattle, Washington - Oct 31 - Nov 4, 2004

Books, Book Chapters, and Proceedings

- Muthukrishnan S., Weeks T, **Tuinstra MR**, Jeoung JM, Jayaraj R, Liang GH. 2004. Sorghum transformation for resistance to fungal pathogens and drought. p. 203-223. *In* D Skinner and GH Liang (eds.) *Genetically Modified Crops: Their Development, Uses, and Risks*. Haworth Press, Inc..
- Thakur, R.P., S. Sivaramakrishnan, S. Kannan, V.P. Rao, D.E. Hess and **C.W. Magill**.- (2004) Genetic and pathogenic variability among isolates of *Sclerospora graminicola*, the downy mildew pathogen of pearl millet. in "Advances in Downy Mildew Research, Volume 2" ed. Peter Spencer-Phillips Kluwer Pres
- Kresovich S, Barbazuk B, Bedell JA., Borrell A, Buell CR, Burke J, Clifton S, Cordonnier-Pratt MM, Cox S, Dahlberg J, Erpelding J, Fulton TM., Fulton B, Fulton L, Gingle AR, Hash CT, Huang Y, Jordan D, Klein PE, Klein RR, Magalhaes J, McCombie R, Moore P, Mullet JE, Ozias-Akins P, Paterson AH, Porter K, Pratt L, Roe B, **Rooney W**, Schnable PS. Stelly DM, **Tuinstra MR**, Ware D, Warek U. [PLANTPHYSIOL/2005/065136 - Accepted]. Toward sequencing the sorghum genome: a US National Science Foundation-sponsored workshop report. *Plant Physiology*.
- Hancock, J.D.** 2005. Myths about sorghum grain as a feedstuff. Proc. of the NGSPA/SICNA Sorghum Conference, Reno, NV.

Dissertations and Theses

- Cho, Jae-Min, (2005) "Isolation and Characterization of Resistance Gene Analogs in Sorghum. Ph.D. Dissertation, TAMU
- Pandravada, S. 2004. Genetic analysis of cold tolerance in sorghum. Ph.D. Thesis. Kansas State University, Manhattan, KS.

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

**Project TAM 223
Gary C. Peterson
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Summary

Increase Yield and Promote Economic Growth

Research activity emphasizes developing sorghum germplasm, parental lines, or varieties with resistance to selected insects as well as resistance to other selected biotic or abiotic stresses. Primary objectives are to identify, characterize and utilize the genetic diversity of grain sorghum to develop improved cultivars, germplasm, or parental lines resistant to biotic and abiotic stresses. Primary insect pests are the greenbug (*Schizaphis graminum*), sorghum midge (*Stenodiplosis sorghicola*), and sugarcane aphid (*Melanaphis sacchari*). Segregating populations are concurrently selected for resistance to economically important diseases including but not limited to: sorghum downy mildew (caused by *Peronosclerospora sorghi* (Westan and Uppal) Shaw), head smut (caused by (*Sphacelotheca reiliana* (Kuhn) Clinton), and anthracnose (caused by *Colletotrichum graminicola* (Cesati) Wilson). Selections are also made for resistance to zonate leaf spot (caused by (*Gloeocercospora sorghi* Bain and Edgerton), bacterial leaf streak (caused by *Xanthomonas holcicola* (Elliot) Star and Burkholder), bacterial leaf stripe

(caused by *Pseudomonas andropogoni* (E.F. Smith) Stapp), rust (caused by caused by *Puccinia purpurea* Cooke) and charcoal rot (caused by *Macrophomina phaseolina* (Tassi) Goid). Project emphasis has evolved with increased emphasis on drought resistance and food type sorghums and a smaller resistance to insects component. Research activities use primarily conventional methodology. Populations with diverse parents are evaluated to identify superior lines with wide adaptation, and resistance to specific diseases and/or insects. Relevant populations are also evaluated for drought resistance, primarily stay-green (post-flowering drought tolerance).

Increase Yield, Promote Economic Growth, Improve Nutrition

Sorghum varieties or hybrids with resistance to multiple stresses provide farmers with the potential to produce a consistent supply of high quality grain for household or off-farm

use by end-use industry. The also will be used by private industry in hybrid development programs and by public scientists as a source of novel genetic combinations. Seventeen biotype E greenbug/disease resistant lines and 17 biotype E/I greenbug resistant have been proposed for release. The biotype E resistant lines also express wide adaptation and resistance to several diseases. The lines are tan plant, white grain or tan plant, red grain. Tan plant red or white grain sorghum hybrids with multiple stress resistance and high yield potential may help increase utilization of sorghum in new or non-traditional uses.

Improve Institutional Capacity

The principal investigator serves on the graduate committee of one Ph.D. student (from Mali) at Texas Tech University and two M.S. students (from Zimbabwe and Mozambique respectively) at Texas A&M University. Mr. Leo Mpofo (Zimbabwe) and Mr. Joaquim Mutiliano (Mozambique) will complete their M.S. degrees at Texas A&M University in mid- to late-2005. Mr. Mpofo is a non-INTSORMIL supported student. Mr. Niaba Teme (Mali) will complete requirements for the Ph.D. degree at Texas Tech University in late 2006.

Objectives, Production and Utilization Constraints

Objectives

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

Sorghum Production Constraints

Grain sorghum yield stability and production is constrained by biotic (insects and diseases) and abiotic (drought) stresses. Insects pose a risk in all sorghum production areas with damage depending on the insect and locale. Sorghums with enhanced environmental fitness will reduce the impact of abiotic and biotic stress. In a cropping system, stress occurs concurrently. Genetic resistance to multiple stresses will reduce environmental risk and enhance productivity. This becomes especially important as production ecosystems change the natural balance between the crop and the ambient environment.

Farmers use hybrids or cultivars with improved genetics for adaptation, stress resistance, and quality to meet the demands of increased food production in economically profitable, environmentally sustainable integrated production sys-

tems. In an integrated production system plant stress does not occur as single event sequentially but as concurrent multiple events. Thus while research can be conducted on individual stress (abiotic or biotic) factors, resistance to multiple stress must be present in a hybrid or variety to promote sustainable, environmentally friendly, and economically profitable production systems. Incorporation of improved genetics (new hybrids or varieties) into an integrated crop production system requires a multi-disciplinary research program. Varieties or hybrids genetically resistant to stress will readily integrate with other inputs into an integrated, ecologically sound production and stress control strategy with large potential benefits in subsistence and mechanized agriculture. Development of multiple stress resistant sorghum is a continual effort in response to a dynamic evolving production agroecosystem.

Research Approach and Project Output

Research Methods

Collaborative host country research is supported through short-term training, graduate education, germplasm exchange and evaluation, site visits, and research at nursery locations in Texas and in two regional programs - Southern Africa and Central America. Southern Africa research is primarily focused on incorporating resistance to sugarcane aphid, disease resistance, adaptation, and improved end-use traits into potential new cultivars. Activity in Nicaragua and El Salvador involves research on sorghum midge, drought resistance, disease resistance, adaptation, and end-use traits. In the United States, sorghum midge and greenbug-resistant sources have been identified and used to develop elite resistant sorghums. Through collaborative ties with other projects genetic inheritance, resistance mechanisms, molecular mapping, and marker-assisted selection research has been conducted. Appropriate selection methodology is used to develop germplasm with multiple stress resistance, wide adaptation, and improved end-use traits.

Germplasm is evaluated for resistance to economically important insects in field nurseries and/or greenhouse facilities. Sources of germplasm for evaluation are introductions from other sorghum research programs, exotic lines, and fully converted exotic lines from the sorghum conversion program. Introduced germplasm is crossed to elite resistant germplasm and to germplasm with superior trait(s). A primary selection criteria is insect resistance in addition to wide adaptation, resistance to diseases, drought resistance, weathering resistance and improved end-use traits. Based on phenotypic evaluation and data analysis crosses are made among elite lines to produce germplasm for subsequent evaluation. The goal is to combine resistance genes for several stresses into a single high grain yield genotype with improved end-use traits. For insects important in host countries but not in the U.S., germplasm is selected for adaptation, grain yield potential, and disease resistance in nurseries in the Texas Coastal Bend (Corpus Christi and/or Beeville). The germplasm is provided

to the host country cooperator in replicated trials for evaluation for resistance to the specific insect under the local pro-

duction system (fertilizer, tillage, plant population, etc.). Disease readings, agronomic and yield data are collected if possible.

Table 1. Grain yield, midge damage rating, and days to 50% anthesis, for selected entries in the 2004 Midge Line Test at Santa Rosa, Nicaragua, and Corpus Christi and Lubbock, TX.

Designation	Yield Santa Rosa kg ha ⁻¹	Midge Damage Rating Corpus Christi†	Days to 50% Anthesis		Plant Height		
			Santa Rosa	Lubbock	Santa Rosa	Corpus Christi	Lubbock
(Tx2883*(Tx2864*(Tx436*(Tx2864*PI550607))))-PC1-SM1-CM2-SM2-CM2-CABK-CMBK	6002	2.5	65	69	142	130	86
(Tx2883*(Tx2737*(Tx436*(Tx2783*PI550607))))-PC4-SM1-CM2-SM2-CG2-CABK-CMBK-CGBK	5194	5.0	60	68	151	140	112
(Tx2880*(86EO361*(Tx2880*PI550607)))-PC2-PR6-LG7-CG3-CM2-CM2-CGBK-CMBK-CG2	5144	4.5	62	69	152	128	122
(Tx2880*(86EO361*(Tx2880*PI550607)))-PC1-PR10-LG34-CG2-CM3-CG1-BGBK-CABK-CG2	5066	7.5	69	68	154	118	110
(Tx2880*(86EO361*(Tx2880*PR550607)))-PC1-PR10-LG34-CG1-CG1-CG2-CMBK-BGBK-CG1	4784	8.5	58	71	147	110	117
(Tx2883*(Tx2737*(Tx2783*PI550607)))-PC2-SM3-CM1-SM1-LGBK-CABK-CABK	4609	2.0	59	70	148	118	100
(Tx2783*(Tx2737*(Tx436*(Tx2783*PI550607))))-PC1-SM2-CM1-SM1-CMBK-CABK-BGBK-CGBK	4223	5.5	66	70	139	122	122
(91CC515*MR114-90M11)-SM4-LMBK-CM1-SM2-SM1-HM1-CMBK-CMBK	3943	2.0	62	69	121	105	105
(7ML54/7BRON132/((IS2549C*Tx2767)*Tx2876)*MB108B)-SM3-SM1-CM1-CM1-CMBK	3852	2.5	64	70	148	135	130
00MLT165/01MLT156/(PM12713*Tx2880)-CM5-CM3-	3709	3.5	58	72	136	115	107
(Tx2883*(Tx2737*(Tx436*(Tx2783*PI550607))))-PC1-SM2-CM1-SM2-SM2-CABK-BGBK-CMBK	3626	4.0	64	70	122	120	99
(Tx2880*(Tx2880*(GR108-90M24*(Tx2862*(Tx430*(Tx2862*PI550607)))))-PR1-SM1-CM1-CM2-LGBK-BGBK-BGBK	3556	4.0	59	72	157	120	105
(Tx2880*(Tx2880*(Tx2864*(Tx436*(Tx2864*PI550607))))-PR3-SM6-CM3-CM1-CM2-CABK	3430	3.5	60	69	131	108	107
Tx2880	3392	2.9	67	69	141	100	94
(Tx2880*(Tx2880*(Tx2864*(Tx436*PI550607))))-PR2-LG24-CG2-CG1-CG1-CA1-CMBK	3333	2.0	67	70	118	115	115
(Tx2880*(GR127-90M39*(Tx2862*(Tx2864*PI550607))))-PC1-SM1-SM1-CM2-CG2-BGBK-CABK	3303	7.0	67	69	125	118	105
(Tx2883*(Tx2864*(Tx436*(Tx2864*PI550607))))-PC1-LG4-CG2-CM1-CM2-CABK-BGBK	3263	3.0	65	69	118	115	86
(Tx2880*(Tx2880*(Tx2864*(Tx436*(Tx2864*PI550607))))-PR3-SM6-CM3-CM3-CG3-BGBK-CABK	3130	5.0	58	68	148	113	105
MEAN	2249	4.3					
LSD.05	550	1.8					

†Rated on a scale of 1 = 0-10% damaged kernels, 2 = 11-21%, up to 9 = 80-100% damaged kernels.

Research Findings

Sorghum Midge Resistance

Sorghum midge is the most ubiquitous insect of sorghum. It poses a production risk in many areas where sorghum is grown. Four primary means exist to control sorghum midge - cultural, biological, chemical, and genetic. Within many production systems, cultural and biological methods provide some measure of control. Genetic resistance can provide a low cost, stable, and durable measure of control. However, there is concern that it will not be possible to develop sorghum midge resistant hybrids for use in the United States. The primary constraint to wide-spread use of currently potentially available resistant hybrids is the lower grain yield potential (averaging 10-15%) of resistant than susceptible hybrids in a normal planting. However, for production delayed at planting two weeks or more resistant hybrids will generally out-yield susceptible hybrids without insecticide application. With increas-

ing environmental concern regarding pesticide application and fewer insecticides available to control sorghum midge interest in the development and use of midge-resistant hybrids could increase. The grain yield discrepancy for sorghum midge resistant hybrids in the United States results primarily from the research methodology required to screen for sorghum midge. A small portion of the research program is still directed at the development of superior A- or R-lines suitable for use in hybrid production systems.

Primary emphasis in the sorghum midge resistance program has shifted to developing varieties suitable for use in host country production systems. The varieties should be tan plant, white grain, possess disease resistance, drought tolerance, about 1.5 meters in height, and express a moderate level of resistance to sorghum midge. The 2004 Midge Line Test (63 entries x 2 replications) was grown at Corpus Christi and Lubbock, Texas and Santa Rosa, Nicaragua. Partial results are shown in Table 1. The midge damage rating of 4.3 indicated a

Table 2. Greenbug damage rating and selected disease and agronomic characteristics of Tx2945 through Tx2961 and selected checks.

Line	Plant color	Grain color	Greenbug damage rating ¹	Head smut ²	Rust ³	Grain mold - CC ⁴	Grain mold - CS ⁴	Insecticide phytotoxicity ⁵	Days to 50% anthesis ^{6,7}	Plant height
				%						cm
Tx2945	Tan	Red	3.5	0	1.2	2	2	1.1	75	112
Tx2946	Tan	Red	3	1	1	1.5	1.8	1.1	73	117
Tx2947	Tan	White	1.5	0	1	2.2	2.5	1.2	76	109
Tx2948	Tan	Red	2	0	1	1.5	1.8	2	74	109
Tx2949	Tan	Red	2.5	0	1	1.5	1.8	1.6	76	109
Tx2950	Tan	Red	4	0	1	2	1.5	1.5	76	107
Tx2951	Tan	White	2	0	1	2.2	2.2	1.2	76	89
Tx2952	Tan	Red	3.5	0	1	1.8	2.2	1.2	73	79
Tx2953	Tan	Lemon Yellow	3	0	1	2	2.5	1.1	78	101
Tx2954	Tan	Red	4	0	1	2.2	2.5	1.2	78	86
Tx2955	Tan	Red	2	0	1	2	2	1.1	73	102
Tx2956	Tan	Red	3	0	1	1.6	2.2	1.6	74	91
Tx2957	Tan	White	4	0	1	2.2	2.5	1.2	72	107
Tx2958	Tan	White	2	0	1	2.5	2.8	2	74	112
Tx2959	Tan	White	1	0	1.1	2.2	1.8	1.5	74	91
Tx2960	Tan	White	2	0	1	2.8	2.2	1.8	74	112
Tx2961	Tan	Red	3	0	1.4	2.8	2.2	1	74	99
Tx2783 (check)	Purple	Red	3	0	1.2	2	2	1.8	74	119
RTx430 (check)	Purple	White	8	3.3	1.1	3	3.2	2.2	78	102
RTx436 (check)	Tan	White		0	1	2.5	2.2	1.8	80	117

¹Rated on a scale of 1 = 10% leaf tissue death, 2 = 20% leaf tissue death, etc., 9 = 100% leaf tissue death.

²Average over two years at Corpus Christi, TX.

³Average over two years at Isabela, PR. Rated on a scale of 1 = disease inconspicuous or present on an occasional plant, 2 = disease over 50% prevalence with low severity causing little damage, 3 = disease 100% prevalent, up to 25% of leaf area destroyed, 4 = disease 100% prevalent, over to 25% of leaf area destroyed, 5 = leaf death.

⁴CC = Corpus Christi, TX. CS = College Station, TX. Average over two years on a scale of 1 = no mold damage, 2 = moderately resistant to mold with seed slightly discolored, 3 = moderately susceptible with significant discoloration, 4 = extensive discoloration and deterioration of seed, 5 = seed destroyed.

⁵Rated on a scale of 1 = no leaf discoloration to 5 = 100% leaf discoloration.

^{6,7}Average over two years at Lubbock, TX.

Table 3. Greenbug damage rating and selected disease and agronomic characteristics of Tx2962 through Tx2978 and selected checks.

Line	Plant color	Grain color	Greenbug damage rating [†]		Head smut [‡]	Rust [§]	Grain mold -	Grain mold -	Insecticide phytotoxicity [#]	Days to 50% anthesis ^{††}	Height
			Biotype E	Biotype I							
Tx2962	Purple	Red	3	6	0	1	2	2	2	76	102
Tx2963	Tan	Red	2.7	7	0	1	1.5	2.2	1.6	72	102
Tx2964	Tan	Red	2	4.5	0	1	1.4	2	1.5	73	102
Tx2965	Purple	Red	2.4	5	0	1	2	1.8	3	70	107
Tx2966	Purple	White	2.8	2	0	1.5	3.2	2.5	2.8	74	91
Tx2967	Purple	White	3	3	9	1.5	3.2	2.8	2.8	68	91
Tx2968	Purple	White	2.7	2.5	4.5	2	3.5	3.2	2.4	71	81
Tx2969	Purple	White	2.7	3	15.6	1.5	3.5	3.5	2.1	71	102
Tx2970	Purple	Red	2	6	0	1.2	1.8	1.5	1.5	74	91
Tx2971	Purple	Red	2.3	6	5.4	1	1.8	1.8	2	75	97
Tx2972	Purple	Red	2.8	4	3.8	1	2.2	4.2	2.8	77	102
Tx2973	Purple	Red	2.4	4	3.8	1	2.2	2.2	2	71	102
Tx2974	Purple	Red	2.8	5	2.5	1	3	1.8	1.6	76	97
Tx2975	Purple	White	5.2	5	20.6	1.7	2.8	2.5	2.2	72	102
Tx2976	Tan	White	5.8	6.5	1.5	1.8	3	3	1.7	74	102
Tx2977	Purple	White	2.2	3.5	0	1.8	2.8	2.7	2.8	71	102
Tx2978	Purple	White	6	4.7	2.9	1.2	2.8	2.5	2.2	71	97
Tx2783	Purple	Red	3	8	0	1.2	2	2	1.7	74	119
(check)											
Tx430	Purple	White	8	8	1.7	1.2	3	3.2	2.2	78	102
(check)											
Tx436	Purple	White			0	1.2	2.5	2.2	1.7	79	117
(check)											

[†]Rated on a scale of 1 = 10% leaf tissue death, 2 = 20% leaf tissue death, etc., 9 = 100% leaf tissue death.

[‡]Average over two years at Corpus Christi, TX.

[§]Average over two years at Isabela, PR. Rated on a scale of 1 = disease inconspicuous or present on an occasional plant, 2 = disease over 50% prevalence with low severity causing little damage, 3 = disease 100% prevalent, up to 25% of leaf area destroyed, 4 = disease 100% prevalent, over to 25% of leaf area destroyed, 5 = leaf death.

[¶]CC = Corpus Christi, TX. CS = College Station, TX. Average over two years on a scale of 1 = no mold damage, 2 = moderately resistant to mold with seed slightly discolored, 3 = moderately susceptible with significant discoloration, 4 = extensive discoloration and deterioration of seed, 5 = seed destroyed.

[#]Rated on a scale of 1 = no leaf discoloration to 5 = 100% leaf discoloration.

^{††}Average over two years at Lubbock, TX.

moderate population density of sorghum midge at anthesis. Several entries sustained less than 30% yield loss. Sufficient midge were not present during anthesis at Santa Rosa, Nicaragua to evaluate the trial for midge damage. Thus the yield (kg ha⁻¹) should be a good indication of the lines performance as varieties in a tropical environment. Despite a low test mean (2249 kg ha⁻¹) many entries produced significantly (LSD.05 = 550 kg ha⁻¹) more grain than the test mean. Analysis of the data led to the conclusion that it is possible to select varieties for a moderate level of resistance to sorghum midge with moderate to high grain yield potential. Several of the lines were selected for continued evaluation.

Greenbug Resistance and Germplasm Release

Selections to develop germplasm resistant to biotype I were made. Resistance to greenbug biotypes is conditioned by several genes and a moderate level of resistance is desired. Crosses to introgress resistance gene(s) into other germplasm were made. Progress is apparent in selecting for biotype I greenbug resistance and resistance to other biotic or abiotic stresses. A number of advanced progeny of diverse background were selected for additional evaluation as lines (for agronomic traits, adaptation, disease resistance, and grain weathering re-

sistance) or a hybrid parents (for grain yield potential, adaptation, disease resistance, and grain weathering resistance.

Thirty-four germplasm lines have been proposed for release. The lines are in two sets based upon resistance to greenbug. Seventeen lines designated as Tx2945 through Tx2961 are resistant to biotype E greenbug (Table 2). All of the lines are tan plant and possess either red, white, or lemon yellow pericarp. The lines possess excellent resistance to several diseases including head smut and rust. Maturity varies from 73 to 78 days after planting and is in the range of Tx2783 (74 days after planting) and RTx430 (78 days after planting). All of the lines are earlier than RTx436 (80 days after planting). The lines will provide breeders with a source of multiple biotic stress resistance in a tan plant background and be useful as a source of novel gene combinations or directly as hybrid parents. The seventeen lines designated as Tx2962 through Tx2978 are resistant to both biotype E and biotype I greenbug (Table 3). Fourteen of the lines are purple plant color and three are tan plant color. The level of disease resistance will vary with the line and disease. All of the lines reach 50% between 68 and 76 days after planting and reach anthesis earlier than Tx2783 (74 days after planting), RTx430 (78 days after planting), and RTx436 (79 days after planting). In 2003,

the lines were evaluated as hybrid parents in a replicated yield trial (94 entries x 3 replications) grown at Lubbock, TX under moderate drought stress. Fourteen of the top 15 hybrids with the highest grain yield were resistant to biotype I greenbug.

Sugarcane Aphid Resistance

The sugarcane aphid (*Melanaphis sacchari*) is an insect pest of sorghum throughout Southern Africa. Collaborative research between TAM-223, the South African Agricultural Research Corporation - Grain Crops Research Institute, the University of the Free State, the Botswana College of Agriculture (BCA), and WTU-200 is directed at developing improved varieties with aphid resistance and other acceptable

characteristics (maturity, height, grain yield, grain quality, disease resistance) for use in low input, small farmer areas of South Africa and the region. Resistance sources including TAM428, CE151, WM#177, Sima (IS23250), SDSL89426, FGYYQ336 have been crossed to locally adapted cultivars (include Segeolane, Marupantse, Macia, Town, SV1, and A964) and to elite lines from the Texas program to develop a range of populations. The segregating populations are planted at Corpus Christi, Texas for evaluation and selection in semi-tropical south Texas. Selection criteria include plant height, foliar disease resistance, head smut resistance, grain yield potential, and lodging resistance. Evaluation for sugarcane aphid resistance and adaptation to local environments is done at the mid-altitude ARC-GCI in Potchefstroom and the low-altitude,

Table 4. Sugarcane aphid damage rating, grain yield, and grain mold rating of selected entries in the 2004 Sugarcane Aphid Test at Potchefstroom and Burgershall, South Africa.

Pedigree	Potchefstroom ¹	Burgershall ¹	Greenhouse ²	Grain Yield		Grain Mold ³
				Potchefstroom -kg ha ⁻¹ --	Mt. Makulu -kg ha ⁻¹ --	
(CE151*TAM428)-LG8-B G1-LG1	2.3	1.7	1.0	5390	4008	3.8
(Macia*TAM428)-LL9	1.3	1.7	1.0	4430	6401	3.5
(SV1*Sima/IS23250)-LG1 5-CG1-BG2-BGBK-LBK	2.0	2.3	1.0	4290	3090	4.0
(Segaolane*WM#322)-CG 1-BGBK-CCBK-LBK	3.0	2.3	1.0	4260	5503	3.2
((6BRON126/87BH8606-6 *GR107-90M46)*CE151)- LG2-CG1-BG2-BG1-CG1- CABK	3.7	2.7	1.7	4030	4977	4.0
(Town*EPSON2-40/E#15/ SADC)-LG1-BGBK-CCBK -LBK	3.3	2.3	1.3	4020	1936	4.5
(SDSL89426*6OB124/GR 134B-)-LG5-CCBK-CCBK -LBK	2.7	2.3	1.7	4000	4651	3.8
(EPSON2-40/E#15/SADC* A964)-CG3-BGBK-CCBK- LBK	3.7	2.7	5.0	3870	2747	3.3
(CE151*TAM428)-LG15-L G1-BG1-BGBK-LBK	2.3	2.3	1.3	3760	4644	3.8
(EPSON2-40/E#15/SADC* A964)-LG2-CG1-BG1-BG 2-CGBK	3.3	2.7	3.0	3550	3336	3.3
(6OB128/(Tx2862*6EO36 1)*CE151)-LG16-CG1-LG BK-LG2-LBK	2.3	1.7	1.3	3440	2079	4.0
Kuyuma	4.3	3.3	3.0	3410	5943	4.2
(Macia*TAM428)-LL2	1.0	1.3	1.0	3320	3302	3.7
WM#177	1.0	1.0	1.7	3270	4268	3.5
(6BRON161/((7EO366*Tx 2783)-HG54)*CE151)-LG1 -BGBK-CCBK-LBK	1.3	1.0	1.0	3250	5435	3.8
(Marupantse*TAM428)-H M7*CA1-CG1-CA3	3.3	3.3	1.7	3230	1262	3.7
(Macia*GR128-92M12)-H M20-CA2-CG1-CGBK	1.7	2.0	1.0	3220	3968	3.8
(6OB128/(Tx2862*6EO36 1)*CE151)-LG27-LG1-BG 1-LG1-CGBK	3.0	2.3	1.3	3200	1117	3.3
PRGC/E#69414	1.7	2.0	1.0	3180	4815	4.2

Table 4. cont'd - Sugarcane aphid damage rating, grain yield, and grain mold rating of selected entries in the 2004 Sugarcane Aphid Test at Potchefstroom and Burgershall, South Africa.

Pedigree	Potchefstroom ¹	Burgershall ¹	Greenhouse ²	Grain Yield		Grain Mold ³
				Potchefstroom -kg ha ⁻¹ --	Mt. Makulu -kg ha ⁻¹ --	
(96AD34/6BRON116/5BR ON131/(80C2241*GR108- 90M30)-HG46-*WM#177) -CG2-BG1-LG1-CGBK	3.3	2.0	1.0	3180	4086	3.3
CE151	2.0	3.3	2.0	3110	2921	4.5
TAM428	1.7	2.0	1.3	3090	4586	3.8
Sima (IS23250)	1.7	1.3	1.0	2970	7082	3.8
WM#322	1.7	1.3	1.3	2650	3186	4.0
FGYQ353	2.7	2.0	1.0	2590	2687	3.3
Ent.62/SADC	1.3	1.3	2.0	2480	3988	4.2
SDSL89426	2.7	1.7	1.7	2310	3571	4.0
Segaolane	5.0	5.0	4.3	670	5040	3.3
Macia	5.0	5.0	3.3	620	2866	3.7
Mean	3.2	2.9	2.4	2350	3689	3.6

¹Rated on a scale of 1 = 0-10% plant necrosis or plant tissue covered by aphids, 2 = 11-25%, 3 = 26-50%, 4 = 51-70%, 5 = 71-90%, up to 6 = 91-100% plant necrosis or plant tissue covered by aphids.

²Rated on a scale of 1 = no aphids present, 2 = light infestation and no dead leaves, 3 = moderated infestation and no dead leaves, 4 = high infestation and many dead leaves, up to 5 = majority of plants dying.

³Rated on a scale of 0 = no grain mold present to 5 = grain mold on all kernels with significant grain deterioration.

sub-tropical Burgershall Research Station near Hazyview, South Africa or Gaborone, Botswana.

A 100-entry test, three replication test was evaluated for resistance to sugarcane aphid and adaptation to local production systems. Spreader row of susceptible sorghum were planted two weeks prior to the test to insure presence of aphids. Aphid damage is evaluated when the majority of entries are in the milk stage. Severity of infestation is evaluated using a 1 to 5 scale, where 1 = no aphids present on plants, 2 = light infestation with aphids present on a few leaves (no dead leaves), 3 = moderate infestation with many aphids present of two to three leaves (one or two dead leaves may be present), 4 = high infestation with many aphids on nearly all leaves (many dead leaves) and 5 = majority of plants in plot dying. Plants with a rating of 1 or 2 were considered to be resistant, while a rating of 3 indicated an intermediate level of resistance. Plants with a rating of 4 or 5 were considered susceptible. Partial results of the trial are presented in Table 4.

The local check cultivar Segaolane (from Botswana) was rated at 4.3 and the resistant check TAM428 was rated at 1.3. Forty-seven entries and 36 entries respectively at Potchefstroom and Burgershall were rated as highly resistant (one or two). Many entries (43 at Potchefstroom and 35 at Burgershall) were rated as susceptible. A greenhouse seedling stage trial was also conducted. Partial results are shown in Table 4. Seedlings were inoculated 10-days after emergence and plants were rated for damage 21 days after infestation. Plants were rated using a 1 to 6 scale, where 1 = 0-10% plant necrosis or plant tissue covered by aphids and plants highly resistant, 2 = 11-25% plant necrosis or plant tissue covered by aphids and plants highly resistant, 3 = 26-50% plant

necrosis or plant tissue covered by aphids and plants resistant, 4 = 51-70% plant necrosis or plant tissue covered by aphids and plants slightly susceptible, 5 = 71-90% plant necrosis or plant tissue covered by aphids and plants susceptible, and 6 = 91-100% plant necrosis or plant tissue covered by aphids and plants highly susceptible. Partial results of the trial are presented in Table 4. Sixty-seven entries were rated as highly resistant (50 entries rated at one and 17 entries rated at two). Only 21 entries were rated as susceptible to highly susceptible. Results of the field and greenhouse trials led to the conclusion that a number of entries express resistance in the seedling stage and consistent resistance over locations. The objective of this research is to develop an improved cultivar with resistance to sugarcane aphid. Insect screening data identified a number of entries with excellent resistance. To be useful to the small farmer, grain yield and processing characteristics must be at least equal to local standard checks. The Potchefstroom trial was harvested to collect data on grain yield. The average grain for the test was 2300 kg ha⁻¹. Sixty entries produced more grain than the mean. The eleven entries with this highest grain yield was all experimental entries that produced more grain than the highest yielding local check (Kuyuma). Of the 60 entries that produced more grain than the mean, 26 are highly resistant to sugarcane aphid in field at two locations (rating 2.3 or less) and the greenhouse trial (rating 1.7 or less). The three entries with the highest grain yield also possess excellent resistance to sugarcane aphid. For the Mt. Makulu location forty-three entries produced more grain yield than the test mean (3689 kg ha⁻¹). Differences in grain yield between the two locations were apparent with only a few entries ranking high for grain yield at both locations. The entry with the highest yield at Mt. Makulu ranked 97th in the Potchefstroom test. Two entries produced excellent grain

yield at both locations. Entries with high grain yield and excellent resistance to sugarcane aphid were also identified at Mt. Makulu.

Based on the data obtained a replicated yield test will be developed for evaluation at three locations in South Africa. The objective of the test will be to identify potential varieties use to the small hectareage South Africa farmer. The experimental entries will be compared to standard check varieties for adaptation, grain yield, and end-use process traits. Additionally, 39-entries from the sugarcane aphid test were selected for subsequent evaluation and use in the new ARC-GCI sorghum breeding program.

The sugarcane test is provided to collaborators under a Memorandum of Agreement (MOA) between the Texas Agricultural Experiment Station (TAES) and the collaborating institution. The MOA restricts use to other than the stated evaluations, and prohibits secondary distribution or seed increase. To enable subsequent evaluations of selected experimental entries TAES has sent a new MOA to the ARC-GCI permitting seed increase and testing of the selected entries. Those that will be identified as suitable for use as open pollinated varieties will be jointly released by the TAES and ARC-GCI, and ARC-GCI will control seed stocks and distribution to small farmers.

West Africa (Mali) Graduate Education

Research was on-going in the Ph.D. research of Mr. Niaba Teme. The title of the dissertation is "Molecular marker analysis of quantitative trait locs (QTL) in BC₂ derived lines influencing grain yield and yield components in sorghum (*Sorghum bicolor* (L.) Moench)". The research hypothesis is that progeny derived from the backcrossing of SC170-14E (a fully converted zera zera sorghum from Ethiopia) will produce more grain yield as lines and hybrid parents, and that QTLs influencing grain yield can be identified. All field research and data have been collected. Activity is now directed at molecular analysis of the progeny. Screening of 197 BC₂ derived SC170-14E population progeny to detect simple sequence repeat (SSR) loci in the progeny is on-going. At the present time 144 primer pairs have been screened of which 32 were informative. Screening for informative loci will continue in the next year. It is anticipated that the research will be completed in the fall of 2006.

Networking Activities

Workshops and Meetings

Participated in the White Sorghum Workshop at the University of Pretoria co-sponsored by the South Africa Sorghum Forum and INTSORMIL, 21-22 October 2004, Pretoria, South Africa.

Participated in INTSORMIL Technical Committee meeting 19-20 February 2005, Reno, NV.

Participated in INTSORMIL Technical Committee meeting 5-6 May 2004, Kansas City, MO.

Participated in ad-hoc committee meeting to draft a long-term Strategic Technical Plan, 13-15 June 2005, Lincoln, NE.

Research Investigator Exchanges

Zambia and South Africa - 10-23 October 2004. In Zambia met with Ministry of Agriculture, Department of Agricultural Research scientists to discuss national and regional sorghum and millet research. Met with representatives of South African Breweries (SAB) to discuss use of sorghum in "Eagle" beer. Met with the Executive Director of the Golden Valley Agricultural Research Trust to discuss future collaboration between Golden Valley and INTSORMIL, and to deliver a copy of the Memorandum of Understanding (MOU) to formally establish collaboration. In South Africa, met with representatives of the University of Free State to discuss the status of the Ph.D. program of an INTSORMIL sponsored student. Discussed options for expanding graduate education at the University of the Free State. In Potchefstroom, met with ARC-GCI collaborators to discuss on-going research for sugarcane aphid resistance. In Pretoria, participated in the White Sorghum Workshop at the University of Pretoria co-sponsored by the South Africa Sorghum Forum and INTSORMIL

Nicaragua and Guatemala - 3-8 January 2005. In Nicaragua, evaluated cooperative trials provided to INIA by the INTSORMIL/Texas A&M University sorghum breeding programs. Trials provided to INIA include the ADIN (All Disease and Insect Nursery), Midge Line Test (MLT) and hybrid observations. Discussed and evaluated on-farm trials of improved and indigenous varieties in the Estelí region. In Guatemala, evaluated sorghum trials provided to Cristiani Burkard through a Texas Agricultural Experiment Station Materials Transfer Agreement. Viewed hybrid production fields at the Cristiani Burkard research facility. Discussed opportunities for future collaboration. Discussed sorghum research with Prosemillas representatives and viewed hybrid production fields. Discussed possible future collaboration in testing and developing hybrids for Central America.

South Africa, Botswana, and Zambia - 17 April - 1 May 2005. During a visit to the University of the Free State at Bloemfontain reviewed the progress and status of an INTSORMIL supported graduate student (Ms. Phoebe Ditshipi). Ms. Ditshipi is conducting research on stalk rots of sorghum. Reviewed research progress of Mr. Michael Tesfaendrias (Eriteria). Mr. Tesfaendrias (a non-INTSORMIL supported graduate student) is conducting Ph.D. research on "Grain Mold of Sorghum with Specific Reference to Grain Quality in South Africa" under the supervision of Dr. Neal McLaren. Met with Drs. Charl van Deventer and McLaren to

discuss development of an INTSORMIL sponsored Ph.D. research program on grain mold resistance in white grain sorghum. The program will involve plant pathology and plant breeding. At Cedara, viewed several sorghum research trials provided to collaborators by the Texas A&M University sorghum breeding program. Cedara is an excellent location to screen for foliar diseases. At Potchefstroom, evaluated the sugarcane aphid test and planned future activity. Discussed the possibility of testing selected entries in on-farm trials for potential use as varieties. In Botswana, traveled to Maun to meet with Dr. Stephen Chite (DAR sorghum breeder). Evaluated replicated trials provided by Texas A&M University. Discussed the status of the DAR sorghum breeding program. In Gaborone, met with Dr. G.S. Maphanyee (DAR Director) and Dr. Pharoah Mosupi (Chief Arable Research Officer) to discuss INTSORMIL collaboration and the future of DAR sorghum and pearl millet research. Met with DAR crops researchers to discuss INTSORMIL regional activities. Met with Dr. David Munthali (Botswana College of Agriculture entomologist) to discuss on-going research and plan future activity. In Zambia, discussed the status of collaborative activity in the country and region. Met with an USAID team that was evaluating training in Southern Africa. The team was composed of John Thomas (interim head of USAID/Washington Office of Agriculture), Cristin Springet (USAID/Washington), Dr. Irv Witter (Bean/Cowpea CRSP Director) and Dr. Mywish Maredia (Bean/Cowpea CRSP Associate Director). Traveled to Ndola to visit the Northern Breweries (South African Breweries subsidiary) plant. Met with Mr. Orwell Monga, Plant Manager to discuss the use of sorghum to brew a new mid-level lager beer for Zambia named Eagle.

Germplasm and research information exchange

- Germplasm was distributed to private companies as requested and to the following countries, including but not limited to: Nicaragua, El Salvador, Guatemala, South Africa, Botswana, Zambia and Mozambique. Entries in the All Disease and Insect Nursery (ADIN) were evaluated at many locations domestically and internationally.
- Germplasm previously developed and released by this project is used by commercial seed companies in hybrid production.
- Serve on Ph.D. committee of N. Teme (Mali) at Texas Tech University. Serve on the M.S. committee of L. Mpofu (Zimbabwe) and J. Mutiliano (Mozambique) at Texas A&M University.

Other Cooperators

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

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

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

Dr. Roy Parker, Extension Plant Pathologist, Texas Cooperative Extension, Texas A&M University Agricultural Research and Extension Center, Route 2 Box 589, Corpus Christi, TX 78406-9704

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

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

Dr. D.T. Rosenow (retired), Sorghum Breeding, Texas Agricultural Experiment Station, Texas A&M University Agricultural Research and Extension Center, Rt. 3 Box 219, Lubbock, TX 79403-9803 (TAM-222)

Publications and Presentations

Abstracts

Peterson, G.C. 2004. Cultivation of white sorghum - a U.S. perspective. White Sorghum Workshop, October 21-22, 2004, University of Pretoria.

Presentations

Peterson, G.C. 2004. Cultivation of white sorghum - a U.S. perspective. White Sorghum Workshop, October 21-22, 2004, University of Pretoria.

Teme, N., D.T. Rosenow, G.C. Peterson, W. Xu, M.S. Pathan, H.T. Nguyen, C.A. Woodfin, A. Herring, and R.J. Wright. 2004. Identification of QTLs influencing heterosis in grain sorghum (*Sorghum bicolor* (L.) Moench). North American Grain Congress Conference and 24th Biennial Grain Sorghum Research and Utilization Conference, February 21-22, 2005, Reno, NV.

Miscellaneous Publications

Rosenow, D.T., J.A. Dahlberg, G.C. Peterson, J.E. Erpelding, J.W. Sij, L.E. Clark, A.J. Hamburger, P. Madera-Torres and C.A. Woodfin. 2003. Release of 49 converted sorghum germplasm lines from the sorghum conversion program. International Sorghum and Millets Newsletter 44:57-59.

Teme, N., D.T. Rosenow, G.C. Peterson, and R.J. Wright. 2004. Improvement of harvest index in sorghum through use of exotic germplasm. International Sorghum and Millets Newsletter 45:20-23.

