PROFIT – Productive Rotations On Farms in Texas
ANNUAL REPORT

1. Project Title and Leaders

Sorghum Utilization and Quality Improvement for Expanded Markets

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This project provides information on grain yields, agronomics and quality of new commercial and experimental food sorghums. It has applied Near Infra Red (NIR) analysis techniques to analyze sorghum quickly for composition and has provided essential end use quality for use in market development activities nationally and internationally.

Information generated from related projects has provided justification for use of sorghum in a wide variety of products including more nutritive baked products and extruded snacks and ready to eat breakfast cereals.

More seed companies are producing food sorghum hybrids using information in part from this project. Based on results generated in this project, producers are selecting and growing food type sorghums. In some cases, premiums for food quality grain have been obtained.

Reliable information on the production and quality of food and feed sorghums grown across Texas is necessary to determine where food sorghums can be competitively grown. Results have indicated that full season food hybrids are comparable to the best full season traditional hybrid but more competitive, early maturity food hybrids are needed. New germplasm and information on tan plant sorghum hybrids provide assistance to commercial seed companies improving commercial hybrids.

Grain molds and weathering continue to be the major problem limiting food sorghum adaptation. Thus work on understanding the role of antifungal proteins in mold tolerance is an important basic part of the project.

This project has found that the antifungal proteins of mold tolerant sorghums do not change significantly from 30 days after anthesis to combine harvesting.

Calibrations for the Near Infrared Perten 7000 DB instrument were obtained for analysis of whole sorghum samples. NIR provides useful information on the composition quickly and efficiently of samples submitted by industry and sorghum researchers.

Data on sorghum composition and processing properties were included in the US Grains Council Value Enhanced Grains reports of 2000-2002. More than 2000 samples were analyzed.

The promotion of sorghum for food and other markets provides an alternative to feed use of sorghum and can diversify sorghum use. The identity preserved production and marketing of sorghum requires quick analysis of inherent quality, which has been addressed by this project.

Results from 1999 – 2003 Tests
New and current tan plant hybrids have been evaluated annually to determine their region of adaptation and grain quality parameters. Poor quality hybrids are eliminated. Seed companies have better information on desirable quality attributes of food sorghums.

Commercial food hybrids are now available in all maturity groups. Good full and medium maturity food hybrids are available but early maturing hybrids are not as competitive. Continued breeding efforts are needed to increase grain yields and stress tolerances in all maturity groups, but especially for early hybrids.

Certain regions of Texas, particularly the Winter Garden area and the High Plains are better suited for production of currently available food hybrids under limited irrigation.

Quality is consistently better in tan plant hybrids than traditional hybrids. Environment significantly affects the quality of all sorghums but the white tans have the best potential for food applications.

Grain molds limit production of white grain types in hot humid areas. It is unlikely that acceptable levels of grain mold resistance will be found to make white sorghums feasible in South Texas production environments. However, red grain, tan plant hybrids have good potential for these regions and they avoid problems of specking in broilers fed sorghum.

The antifungal proteins retained in sorghums subjected to significant mold pressure during maturation are related to mold resistance or tolerance. The relationship was found in 2002 and 2003 grains.

Decortication of sorghum to a constant color is a useful technique to determine the relative abilities of sorghums to produce light colored flour and other milled products. White tan sorghums are superior and sometimes 95% milling yields are acceptable in color.

Extruded white whole and decorticated sorghum produces excellent snack and ready to eat breakfast foods. The use of white food sorghums in Japan is continuing and is based at least in part on our fundamental work of food sorghum processing.

Many publications, presentations and seminars have been made to groups ranging from farmers and elevator operators to potential international and domestic users of sorghum and sorghum milled products.

Several book chapters and presentations at scientific meetings where nutritionists, food scientists and industrial processors obtain information on new grains and grain products were completed.

Poster papers illustrating food sorghums, structure and processing properties of sorghum have been developed and presented at national and international meetings.

Future Work and Activities

Develop improved early and midseason food type hybrids with high yield potential and good stress tolerance. Continue to provide information on agronomics, grain yields and utilization potential of food sorghum hybrids grown in critically important areas of Texas and the sorghum belt. Refine techniques to determine quality of sorghum more efficiently and to understand mold resistance of sorghum. Provide useful information on extrusion and related processing of sorghum into a wide variety of products. Support market development activities internationally and nationally by publication of current information.

Document 2.

1. Project Title and Leaders
Sorghum Utilization and Quality Improvement for Expanded Markets

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2. Project Objectives
Objective 1. Develop early to midseason maturity tan-plant parent lines for high yielding hybrids that have improved end use quality and improved mold and weathering tolerance.

Objective 2. Expand the Tan Plant Hybrid Trial (TPHT) to provide producers, consumers and scientists with data for identifying tan plant (TP) hybrids with acceptable agronomic and quality parameters.

Objective 3. Develop information on the role of antifungal proteins (AFP) in mold resistance to determine the feasibility of their use to increase the grain mold resistance of white sorghums.

Objective 4. Develop quick, efficient, inexpensive methods of analysis for major components (moisture, protein, carbohydrates and starch) and physical properties of sorghum using NIR for whole kernels and ground samples.

Objective 5. Provide information on utilization and quality of sorghum for food and industrial markets.

3. Methodology
Objective 1. *Breeding food sorghums:* This project will facilitate the movement of earlier maturity tan plant (TP) germplasm into private breeding programs more quickly. Advanced generation progeny from crosses to produce TP germplasm with increased drought resistance and earlier maturity will be emphasized. Earlier material identified at flowering are evaluated in additional drought environments to confirm early, drought tolerant lines. The testing locations are in Corpus Christi, Beeville, College Station, and Lubbock, Texas. Nurseries will be grown in other sorghum producing states as well as Mexico and Central America.

We have developed numerous populations designed for the selection of improved grain mold resistance in both white and red TP germplasm. In addition to phenotypic screening, molecular markers associated with grain mold resistance may enhance the selection process. The field evaluation will begin in the summer of 2001 and additional selection will be completed in 2002 and evaluation of selection will be finished in 2003.

Objective 2. *Tan plant food hybrid trials*: All sorghum breeding companies have the opportunity to submit their hybrids. The trials are grown in several locations in Texas (Weslaco, Corpus Christi, College Station, Hondo, Lubbock, and Dumas). Most of these locations are dry land or limited irrigation. Agronomic and grain quality data are taken on grain from hand harvested panicles. In addition, two locations in Kansas and one in Nebraska and Oklahoma are grown depending on support from the appropriate Sorghum Producers Boards to cooperators in other states.

Objective 3. *Grain molds and antifungal proteins (AFPs):* Special experiments to evaluate mold tolerant and susceptible lines are planted in College Station. The grain is sampled at physiological maturity and combine-harvest maturity since the change in AFP content during desiccation is related to increased resistance to grain mold deterioration.

Environmental stability of AFP expression requires evaluation over several years. We plan to analyze for several phenolic compounds along with AFP to determine interactions in the biochemical mechanisms to affect increased grain mold resistance.

Objective 4. *Analysis of grain:* Obtain sorghum samples representing the maximum diversity expected in commercial samples across the sorghum belt and obtain analytical data on them for protein, starch and moisture. Calibration equations were developed for whole grain sorghum using the Perten DA 7000 NIR instrument. There have been several upgrades and improvements continue as additional samples are added to the equations.

Apply the NIR method(s) to analyze sorghum samples from agronomic and management trials conducted under the PROFIT package of research and demonstrations.

Density, hardness, single kernel hardness measurements, decortication and other physical properties were determined using standard procedures.

Grains from W.L. Rooney's Tan Plant Hybrid Trials and the International Food Sorghum Adaptation Trials grown in several locations were analyzed.

Objective 5. *Produce proto-type foods and publicize information on utilization:* Sorghum will be dry milled and extruded to produce a wide array of food products including snacks and breakfast foods to demonstrate their functional properties using laboratory extruders and processing equipment.

Interactions
Collaborators for all objectives are crucial to the success of this project. They include Dr. D.T. Rosenow, Dr. Gary Peterson, Dr. G.N. Odvody, Dr. R.R. Klein, Mr. D. Pietsch, Mr. K. Schaefer, Mr. J. Drawe and Mr. S.D. Collins. These individuals are located throughout the state and each contributes to one or more of the objectives. This project collaborates with research objectives in the Grain Marketing Lab in Manhattan, KS to avoid duplication and maximize output.

4. Results and Significant Outputs
This project has been quite productive and has provided useful information of critical importance to emerging markets in Japan, Mexico and the United States. The combination of breeding with grain quality including mold resistance provides for an integrated approach that has been productive from practical to fundamental aspects. The following points illustrate progress and current status in fall of 2003.

Breeding and Evaluation of Food Sorghums
Several lines were released (see citations) that have potential use in the development of tan plant hybrids. Specific lines recently made available to industry include: A/BTx2928 – a white, tan female line with earlier maturity; RTx2917, a red, tan male line for creating red tan hybrids; and Tx2918 and Tx2919 – white, tan male lines for making white tan hybrids. More TP germplasm lines are in various stages of development in the breeding program. Emphasis is on the early and mid maturity hybrids. Several red tan plant lines are included.

White Tan Plant Hybrid Trials
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. The numbers of commercial entries have consistently risen and commercial hybrids are now available in all maturity groups. Current tan plant full season maturity hybrids are high yielding and adapted to limited irrigation environments. Certain regions of Texas especially the Winter Garden area and the High Plains are optimally suited for the production of food hybrids. These hybrids are also adapted in many areas of Kansas and Nebraska, where some small premiums have been received for the improved grain quality. They are also being produced in California for processing.

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. Our current efforts are focused on these maturity groups to produce drought tolerant hybrids with food properties.

Results for 2003
Of the forty entries in the test, most were experimental hybrids from both private and public sorghum breeding programs. The majority of these hybrids had white grain on tan plant, but two red grain, tan plant hybrids were included in the test. The test was

grown and harvested in five locations across Texas. Results in College Station, Hondo, Halfway and Perryton were good and informative, but the test in Gregory encountered significant delays in planting due to wet weather and then suffered through significant drought stress after emergence. Producers are referred to results from the test nearest them for specifics, but general trends will be discussed herein.

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 (see table). 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.

Table 1. Mean agronomic data for the tan plant hybrid nurseries grown at five Texas locations in 2003.

Location		Plant Color	Plant Height in.	Panicle Exsertion in.	Days to Anthesis	Desirability Rating	Grain Yield lbs/acre
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

Based on performance in the TPHT in 2002 and 2003, the following commercial hybrids have performed the best across all environments. 902-W and Jowar were the best performing full season hybrids. In the mid-season category, Asgrow Eclipse has produced the best results among tan plant hybrids. In the early season category, only one to two tan-plant hybrids are available on a yearly basis. Performance of these hybrids has been inconsistent, making it difficult to recommend a tan-plant hybrid in this category. These comments are based on combined analysis; therefore, performance in individual environments is subject to variation.

Grain quality in all tan plant hybrids is good; grain is acceptable for dual purpose use. Several of the experimental hybrids had lower grain quality; but, these likely will not be commercially released. In 2003, all trials were harvested before grain weathering was an issue. Continued emphasis on red grain tan plant hybrids should assist in improving grain weathering in tan plant hybrids.

Grain Molds and Weathering Improvement

Antifungal proteins (AFP) in sorghum are effective against grain mold pathogens *in vitro* and *in vivo*. AFP levels vary among sorghum lines, increase during seed development, are highest and most responsive to fungal stress at physiological maturity, bind to pericarp tissues and are mobile within the grain in rainy conditions. We have confirmed that grain mold pressure causes resistant lines to induce and/or retain more AFPs compared to susceptible lines.

Considerable mold infection occurred at College Station in 2002 and 2003. Thus, we had statistically significant negative correlations between the severity of mold infection and the percentage of AFPs retained in the grain at combine maturity (50 Days After Anthesis, DAA) compared to their levels at 30 DAA. The correlation was -0.61. In contrast the same correlations were nonsignificant for AFPs in 2000 and 2001. The AFPs account for only part of the mold resistance and some sorghums, especially those with bright red pericarp color have tolerance to molds and lose most of their AFPs from 30 to 50 DAA.

We know that resistance is complex and affected by numerous factors including kernel structure and hardness, pericarp color and other unknown compounds. Among the mold resistant group, five had white pericarp color and nine had red. However, some of the red sorghums lost high levels of AFPs but still tolerated the molds. Some varieties clearly have additional factors that affect mold resistance, which may be related to phenolic compounds. Recently, in a related project we found that naringinin was present in a bright red sorghum that has tolerance to molds. A8PR1059*BRON139, another bright red cultivar, had good mold tolerance but lost very high levels of AFPs during desiccation, which indicates that different mechanisms are involved.

Results from the 2003

We found negative correlations between grain mold scores and change in AFPs. This means that the ability of sorghums to resist fungal invasion was directly and positively influenced by their retention/production of AFPs. This confirmed conclusions from the 2002 sorghums where generally severe molding occurred (avg. mold rating = 3.0). This year, molding was moderate (avg. mold rating = 2.1). Thus, the correlations between AFP changes and mold scores where higher in 2002 sorghums than in the 2003 crop.

From the evaluation of 2002 sorghums, we have indications that in certain hybrids, mold resistance attributed to changes in AFPs is inherited from the parents. For example, high grain mold ratings in hybrids with as the male parent correlated with high losses in AFPs from 30 to 50 DAA were observed in hybrids with RTx430 as male parent. In 2003, the male and female parents of four elite TAES hybrids were evaluated. BTx399 and BTx378 are moderately mold resistant with good AFP retention. Hybrids of ATx631 and RTx436 appear to retain AFPs and have mold resistance resulting from equal contributions of both parents. However, hybrids with RTx430 as pollinator retained less AFPs and were more susceptible.

So far, we have shown that grain mold resistance of sorghum is related to retention of AFPs during maturation. The AFPs in caryopses limit fungal colonization. Therefore sorghums can be classified as mold resistant or susceptible based on their retention of AFP content. This provides another basis for developing and selecting sorghums with grain mold resistance.

Grain Analysis and Utilization
Quality is consistently better in tan plant hybrids than traditional hybrids. Environment significantly affects the quality of all sorghums especially for food. Mold and weathering discolor the grain which reduces the yield of white meal and flour significantly and gives an off color to processed food products which render the grain unsuitable for applications where light color and bland flavor are desired. We have documented that red grain, tan plant hybrids have very good potential for these regions. In addition they have excellent milling properties compared to red or purple plant color sorghum hybrids.

Near Infra Red (NIR) analysis of whole grain for protein, moisture and starch were developed and applied to numerous samples of grain from commercial breeding and Experiment Station Projects which indicates no difference exists between tan and traditional hybrids for composition. NIR analysis of whole grain was affected by many different factors including cleanliness of the grain, pericarp color and thickness, degree of weathering or mold damage, glumes, pigmented testa and black high anthocyanin kernels. It was unclear if tannin sorghums require separate calibration equations. They caused unacceptable variability in the NIR analysis so we eliminated them since we do not have tannin sorghums for analysis on a routine basis. Clearly the black sorghums require separate calibrations. Efforts to develop calibrations for the black and tannin sorghums would likely be successful. Tannin analysis is possible but we do not see enough of those samples to justify the efforts.

Decortication of sorghum to a constant color is a useful technique to determine the relative abilities of sorghums to produce light colored flour and other milled products. We evaluated 25-30 commercial feed and food sorghums for each of three years for composition and processing properties including yields of decorticated grain adjusted to a common color. The commercial red sorghums had very low yields of decorticated grain and flour while the food types had in some cases more than 90% yield of acceptable color products. This information illustrates the value added potential of the white tan plant sorghums. Hybrids containing ATx 635 as a female had significantly harder, slightly smaller kernels with the highest yield of decorticated grains consistently over several years and environments. These grains with thin pericarp have excellent milling properties.

We conducted extensive extrusion trials using TP white grain. A low cost short barrel friction type extruder was used to extrude white whole, cracked whole and decorticated sorghums into excellent snack and ready-to-eat breakfast foods. The whole grain snack has excellent flavor and texture that is firmer than the usual extruded products. This healthy product has the improved nutrition of whole grain. Extrusion of decorticated white food sorghums produced extrudates with greater expansion similar to corn and rice extrudates. The sorghum has the advantage over corn of a light color and bland flavor comparable to that of rice.

The use of white food sorghums in Japan is continuing and is based at least in part on our earlier sorghum food processing studies. They have successfully produced commercial snacks, cookies, rice like and other products using twin screw extrusion. The high quality sorghum competes with rice for some applications. Cost and availability are important considerations.

In related studies, we have produced breads with natural brown color, high dietary fiber, high levels of antioxidants and omega 3 fatty acids from combinations of tannin sorghum bran, barley flour, ground flax seed, gluten and wheat flour. These and other products demonstrate the utility of sorghum including the tannin types for use in healthy human foods.

The interactions of breeders and food scientists demonstrate the added-value of certain sorghum types for specific food systems. These are relatively small markets but they are growing and interest is increasing. This is a long term effort requiring the ability to deliver cost competitive functional sorghums for use in food and feeds. The health aspects are significant. Improved quality sorghums for food and feed are needed.

5. Technology Transfer and Education Activity

a. Technology Developed and Available for Producers (Ready for Use)

PROFIT funds allowed initiation of the tan plant hybrid test (TPHT) to systematically evaluate the agronomic and grain quality parameters of advanced experimental and commercial tan plant (TP) hybrids. This test has been used to informally certify hybrids as "food-grade" as part of the National Sorghum Producers Association marketing efforts.

Some producers are gaining premiums for value added production of identity preserved food type sorghums. Small companies are exporting and using food sorghums for specialty foods.

Hybrid sorghums exist with good yields, agronomics and food type properties. These were documented and information was presented at field days and seed industry meetings.

Germplasm and parental lines containing TP were released to the commercial seed industry, which eventually will be available to farmers through hybrids that commercial companies will sell.

NIR calibrations for analysis of whole grain sorghum were developed and continue to be refined and improved. This provides more efficient analysis of sorghum.

Quality evaluation techniques for milling and food processing were refined and used to demonstrate value added potential of sorghum.

Extrusion of sorghums into acceptable proto-type food products was demonstrated. Whole sorghum extrudates have excellent potential for healthy snacks and related products.

Information on quality and utilization was transferred to domestic and international clients through seminars, special workshops, briefings and hosting international visitors in our laboratory and field plots.

Information and samples were sent to industrial companies in the United States. This is necessary to create markets for the value added sorghums.

b. Publications
Several presentations were made at field days (Winter Garden, Coastal Bend, High Plains) and special meetings to discuss the potential of white food sorghum production including limited irrigation.

The Texas Seed Trade conference in Dallas included presentations on white food sorghums and related matters by W. L. Rooney.

Presentations at the Kansas-Nebraska sorghum meetings were made regarding food sorghums and food utilization.

Progress reports summarizing annual TPHT results were presented with Kansas sorghum scientists.

c. Funds Leveraged
Private Industry, analysis, $20,000
Private industry, travel, $3,000
US Grains Council, travel, $15,000 (travel and per diem, etc. for market development)

Tom Slick Fellowship, student support, $19,000 (support for last year of PhD candidate)
Grains Council, value enhanced grains, $18,000 over 3 years
TAES, salaries of budgeted personnel assigned to the three PI's projects
Texas Grain Sorghum Producers Board, $50,000, over 2 years

Student Education
Dr. Joseph Awika, completed his PhD this summer (2003), and is currently a research associate working on this project with salary from TAES and partial funds from other grants. A PhD student in grain quality is currently supported and two MS students were partially supported. Three PhD students in sorghum breeding graduated.

Publications
On-line
Rooney, Lloyd W. and C. McDonough. 2001. Profit Annual Report: Near Infrared Analysis for Marketing of Sorghum. http://sorghum.tamu.edu/report _database/ files/rep21/ProfitfinalversionLWR.html.

Rooney, W.L., Dennis Pietsch and Lloyd W. Rooney. 2001. Profit Annual Report: The evaluation of high yielding, weathering resistant, tan-plant sorghum hybrids under Texas production environments.
http://sorghum.tamu.edu/report_database/files/rep42/2001TPHTReportText.html.

Waniska, Ralph D., William L. Rooney, Robert R. Klein, Lloyd W. Rooney, and Feliciano P. Bejosano. 2001. Profit Annual Report: Mold and Toxin-free Grain Through Host Plant Resistance,
http://sorghum.tamu.edu/report_database/files/rep18/WaniskaProfit01Report.html

Books
Lusas, Ed and Rooney, Lloyd W. (eds.) 2001. Snack Foods Processing. Technomic Publishing Company, Lancaster, PA. 639 pp.

Book Chapters
Rooney, L.W. and Serna-Saldivar, S.O. 2003. Sorghum. In: Encyclopedia of Food Sciences and Nutrition, 2^{ND} ed. (B. Caballero, LC Trugo, PM Finglas, eds.) Volume 8, pp 5370-5375. London: Academic Press.

Bandyopadhyay, Ranajit, Little, Christopher R., Waniska, Ralph D., and Butler, David R. 2002. Sorghum grain mold: through the 1990s into the new millennium, chapter in Sorghum and Millet Diseases, Leslie, J.F. (ed.), Iowa State Press, pp. 173-183.

Rodriguez-Ballesteros, Oscar R., Mansuetus, Anaclet S.B., Frederiksen, Richard A., Odvody, Gary N., Waniska, Ralph D. and Rosenow, Darrell T. 2002. Free and bound phenolic acids in mature sorghum caryopses as affected by inoculation with *Fusarium thapsinum*, chapter in Sorghum and Millet Diseases, Leslie, J.F. (ed.)., Iowa State Press, pp. 269-272.

Waniska, R.D. and Rooney, Lloyd W. 2002. Sorghum grain quality for increased utilization. Sorghum and Millet Diseases. Leslie, J.F. (ed.). Iowa State Press 327-335.

Waniska, Ralph D., Venkatesha, R.T., Chandrashekar, A., Krishnaveni, S., Bejosano, F.P., Jeoung-Mee Jeoung, Jayaraman, Jayaraj, Muthukrishnan, Subbaratnam, and Liang, George H. 2002. Antifungal proteins and other mechanisms in the control of sorghum stalk rot and grain mold. Sorghum and Millet Diseases, Leslie, J.F. (ed.), Iowa State Press, pp. 287-297.

Rooney, Lloyd W. and Serna-Saldivar, Sergio. 2000. Sorghum, chapter in: Handbook of Cereal Science and Technology: Second Edition, Marcel Dekker, Inc., Kulp, Karel and Joseph Ponte (eds.) 149-175.

Waniska, R.D. and Rooney, L.W. 2000. Structure and chemistry of the sorghum caryopsis, in Sorghum: Origin, History, Technology, and Production. C.W. Smith and R.A. Frederiksen (eds.), Wiley, 649-688.

Rooney, L.W. and R.D. Waniska. 2000. Sorghum food and industrial utilization, in Sorghum: Origin, History, Technology, and Production. C.W. Smith and R.A. Frederiksen (eds.), Wiley, 689-729.

Refereed Journal Articles

Earp, C.F., McDonough, C.M., Awika, Joseph M. and Rooney, L.W. 2004. Microscopic changes during development of sorghums with and without pigmented testa. J. Cereal Sci. (in press)

Awika, J.M., Dykes, L., Gu, L., Rooney, L.W., and Prior, R.L. 2003. Processing of sorghum (*Sorghum bicolor*) and sorghum products alters procyanidin oligomer and polymer distribution and content. J. Agric. Food Chem. 51:5516-5521.

Awika, J.M., Rooney, L.W., Wu, X., Prior, R.L., Cisneros-Zevallos, L. 2003. Screening methods to measure antioxidant activity of sorghum and sorghum products. J. Agric. Food Chem. 51: online DOI 10.1021/jf034790i.

Bejosano, F.P., Rooney, W.L., Klein, R.R., Rooney, L.W. and Waniska, R.D. 2003. Antifungal proteins in commercial hybrids and elite sorghums. J. Ag. and Food Chem. 51(20); 5911-5915.

Hugo, Leda F., Lloyd W. Rooney, and John R. N. Taylor. 2003. Fermented sorghum as a functional ingredient in composite breads. Cereal Chem. 80(5):495-499.

McDonough, C.M., Floyd, C.D., Waniska, R.D., and Rooney, L.W. 2003. Effect of accelerated aging on corn, sorghum, and sorghum meal. J. Cereal Sci. (in press)

-Villanueva, M. and Serna Saldivar, S.O. 2003. Effect of a protease on starch recovery and steeping requirements of sorghum and maize. Cereal Chem. (submitted)

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

Prom, L.K., Waniska, R.D., Kollo, Abdourhamane I., Rooney, William L. 2003. Response of eight sorghum cultivars inoculated with *Fusarium thapsinum*, *Curvularia lunata*, and a mixture of the two fungi. Crop Protection 22:623-628.

Rooney, W.L. 2003. Registration of Tx2912 to Tx2920 Sorghum Germplasm. Crop Sci. 43:442-3.

Rooney, W.L. 2003. Registration of Tx2921 to Tx2928 Sorghum Germplasm. Crop Sci. 43:443-4.

Rooney, W.L., Miller, F.R., Rooney, L.W. 2003. Registration of RTx437 Sorghum Parental Line. Crop Science 43:445-446.

Awika, Joseph M, Suhendro, Elly L. and Rooney, Lloyd W. 2002. Milling value of sorghums compared by adjusting yields to a constant product color. Cereal Chem. 79:(2):249-251.

Beta, Trust, Corke, Harold, Rooney, Lloyd W. and Taylor, John RN. 2001. Effect of steeping treatment on pasting and thermal properties of sorghum starches. Cereal Chem. 78(3):303-306.

Beta, Trust, Corke, Harold, Rooney, Lloyd W. and Taylor, John RN. 2001. Starch properties as affected by sorghum grain chemistry. J. Science Food and Agriculture 81(2):245-251.

Waniska, Ralph D., Venkatesha, R.T., Chandrashekar, A., Krishnaveni, S., Bejosano, F.P., Jeoung, J., Jayaraj, J., Muthukrishnan, S. and Liang, G.H. 2001. Antifungal proteins and other mechanisms in the control of sorghum stalk rot and grain mold. J. Agric. Food Chem. 49:4732-4742.

Experiment Station Progress Reports

Rooney, W.L., Collins, S.D., Prihoda, K.L., Rooney, L.W., Pietsch, D., Schaefer, K. and Suhendro, E. 2001. Results of the 2000 Tan Plant Hybrid Sorghum Trials.

Rooney, W.L., Pietsch, Dennis, Rooney, Lloyd W. 2001. Profit Annual Report: The evaluation of high yielding, weathering resistant, tan-plant sorghum hybrids under Texas production environments. http://sorghum.tamu.edu/report_database/files/rep42/2001TPHTReportText.html.

Dissertation and Thesis
Acosta, David. December 2003. White food-type sorghum in direct-expansion extrusion applications. MS Thesis. Texas A&M University, College Station, Texas. 120 pp.

Awika, Joseph. May 2003. Antioxidant properties of sorghum. PhD Dissertation. Texas A&M University, College Station, Texas. 118 pp.

Aydin, S. 2004. The relationship between grain yield and waxy endosperm in *Sorghum bicolor* (Linn) Moench. PhD Dissertation. Texas A&M University. College Station, Texas.

Franks, C.D. 2003. The efficacy of marker-assisted selection for grain mold resistance in sorghum. PhD Dissertation. Texas A&M University. College Station, Texas.

Maranphal, Nitit. May 2003. Direct expanded snacks from sorghum. MS Thesis. Texas A&M University, College Station, Texas. 65 pp.

Moran, J.L. 2003. Quantitative trait loci affect in the agronomic performance of a Sorghum bicolor L. Moench recombinant inbred restorer line population. PhD Dissertation. Texas A&M University, College Station, Texas.

Rudiger, Crystal. May 2003. The formulation of a nutraceutical bread mix using sorghum, barley, and flaxseed. MS Thesis. Texas A&M University, College Station, Texas. 97 pp.

Gordon, Leigh Ann. December 2001. Utilization of sorghum brans and barley flour in bread. MS Thesis. Texas A&M University, College Station, Texas. 118 pp.

Zelaya, Nolvia. May 2001. Characterization of tortillas and tortilla chips from sorghum varieties high in phenolic compounds. MS Thesis. Texas A&M University, College Station, Texas. 129 pp.

Other Published Articles
US Grains Council. 2002. 2001-2002 Value-Enhanced Grains Quality Report, US Grains Council, 1400K St., NW, Suite 1200, Washington, DC 20005. http://www. vegrains.org/documents/2002veg_report/veg_report.htm, 142 pp.

US Grains Council. 2001. 2000-2001 Value-Enhanced Grains Quality Report, US Grains Council, 1400K St., NW, Suite 1200, Washington, DC 20005. http:// www.vegrains.org/documents/2001veg_report/ intro_page.htm, 135 pp.

Reports
Rooney, L.W. 2002. Food and nutritional quality of sorghum and millet, Project TAM-226. INTSORMIL Annual Report 2002, University of Nebraska, 54 Nebraska Center, Lincoln, NE 68583, pp 88-95.

Rooney, L.W. 2001. Food and nutritional quality of sorghum and millet, Project TAM-226. INTSORMIL Annual Report 2001, University of Nebraska, 54 Nebraska Center, Lincoln, NE 68583, pp 105-114.

Abstracts

Acosta, David, M. Barron, M. Riaz, R.D. Waniska and L.W. Rooney. 2003. Factors affecting extrusion of white sorghum to produce whole grain snacks. AACC 88th Annual Meeting, September 28 - October 2, Portland, OR, p. 132-133.

McDonough, C.M. and L.W. Rooney. 2003. Factors affecting near infrared reflectance (NIR) analysis of whole kernel sorghum. AACC 88th Annual Meeting, September 28 - October 2, Portland, OR, p. 122.

Turner, D.L., J. Awika , M. Riaz, and L.W. Rooney. 2003. Effects of extrusion on antioxidant and phenols levels among sorghum grains . AACC 88th Annual Meeting, September 28 - October 2, Portland, OR, p. 138.

Acosta, David. 2003. Extrudates made from a food-type white sorghum. In J. A. Dahlberg, R. Kochenower, R. Klein, B. Rooney, S. Bean, B. Pendleton, J. Stack, and B. Maunder (eds.) Proc. 23rd Biennial Grain Sorghum Res. and Util. Conf., Feb. 16-18, 2003, Albuquerque, New Mexico. pp. 119-127.

Acosta, D., Riaz, M., Waniska, R.D. and Rooney, L.W. 2003. Decortication level and particle size effects on extrudates made from a food-type white sorghum. In J. A. Dahlberg, R. Kochenower, R. Klein, B. Rooney, S. Bean, B. Pendleton, J. Stack, and B. Maunder (eds.) Proc. 23rd Biennial Grain Sorghum Res. and Util. Conf., Feb. 16-18, 2003, Albuquerque, New Mexico. pp. 119-127.

Leal-Diaz, A., N. Maranphal, and L. Silva. 2003. Bongos the cool snack. In J. A. Dahlberg, R. Kochenower, R. Klein, B. Rooney, S. Bean, B. Pendleton, J. Stack, and B. Maunder (eds.) Proc. 23rd Biennial Grain Sorghum Res. and Util. Conf., Feb. 16-18, 2003, Albuquerque, New Mexico. p. 39.

Maranphal, N., M. Barron, L. Rooney, R. D. Waniska, and M. N. Riaz. 2003. Extrusion properties of sorghum for direct expanded snacks. In J. A. Dahlberg, R. Kochenower, R. Klein, B. Rooney, S. Bean, B. Pendleton, J. Stack, and B. Maunder (eds.) Proc. 23rd Biennial Grain Sorghum Res. and Util. Conf., Feb. 16-18, 2003, Albuquerque, New Mexico. p. 37.

McDonough, C.M., L. Dykes, J. Awika, L. W. Rooney, and R. D. Waniska. 2003. False positives for tannin sorghum in non-tannin sorghum using the bleach test. In J. A. Dahlberg, R. Kochenower, R. Klein, B. Rooney, S. Bean, B. Pendleton, J. Stack, and B. Maunder (eds.) Proc. 23rd Biennial Grain Sorghum Res. and Util. Conf., Feb. 16-18, 2003, Albuquerque, New Mexico. p. 35.

Rooney, L.W. 2003. Market development for white food sorghums. In J. A. Dahlberg, R. Kochenower, R. Klein, B. Rooney, S. Bean, B. Pendleton, J. Stack, and B. Maunder (eds.) Proc. 23rd Biennial Grain Sorghum Res. and Util. Conf., Feb. 16-18, 2003, Albuquerque, New Mexico. p. 32.

Rooney, L.W. 2003. Sorghum composition, structure, and quality. In J. A. Dahlberg, R. Kochenower, R. Klein, B. Rooney, S. Bean, B. Pendleton, J. Stack, and B. Maunder (eds.) Proc. 23rd Biennial Grain Sorghum Res. and Util. Conf., Feb. 16-18, 2003, Albuquerque, New Mexico. pp. 33.

Acosta, D., M. Barron, M. Riaz, L. Rooney and R. Waniska. 2002. Comparative analysis of rice and sorghum extrusion properties. 87th Annual Meeting, October 13-17, Montreal, Quebec. http://www.aaccnet.org/meetings/2002/abstracts/a02ma340.asp

Awika, J.M., D. Gualberto, L.W. Rooney and W.L. Rooney. 2002. Properties of white food sorghums grown in different environments. AACC 87th Annual Meeting, October 13-17, Montreal, Quebec. http://www.aaccnet.org/meetings/2002/abstracts/a02ma378.asp

McDonough, C.M., Dykes, L., J. Awika, L.W. Rooney and R.D. Waniska. False positives for tannin sorghum in non-tannin sorghum using the bleach test. AACC 87th Annual Meeting, October 13-17, Montreal, Quebec.http://www.aaccnet.org/meetings/2002/abstracts/a02ma286.asp

Maranphal, N., Barron, M., Rooney, L., Waniska, R.D., Riaz, M.N. 2002. Extrusion properties of sorghum for third generation snacks. AACC 87th Annual Meeting, October 13-17, Montreal, Quebec.http://www.aaccnet.org/meetings/2002/abstracts/a02ma347.asp

Zelaya, Nolvia, Yeggy, H., Suhendro, E.L. and Rooney, L.W. 2001. Characterization of table tortillas from sorghum high in phenolic compounds. Proceedings of the Tortilla Industry Association Seminar, May 20-23, City of Industry, CA. 22:1-4

Rooney, W.L., Rooney, L.W., Pietsch, D., Collins, S.D. 2001. The tan plant hybrid sorghum test - purpose, use and function. 2001 Sorghum Industry Conference & 22nd Biennial Grain Sorghum Research and Utilization Conference, February 18-20, Nashville, TN., p. 35-36.

Zelaya, N., Yeggy, H., Suhendro, E.L. and Rooney, L.W. 2001. Characterization of table tortillas from sorghum high in phenolic compounds. 2001 Sorghum Industry Conference & 22nd Biennial Grain Sorghum Research and Utilization Conference, February 18-20, Nashville, TN, p. 55.

January 2002 – Presentation on the potential of Tan Plant Sorghum Hybrids in the Coastal Bend at the San Patricio County Crop Production and Research Update in Portland, Texas.

June 2002 – Field tour stop at the Tan Plant Hybrid Test in Hondo, Texas. It was held during the Medina-Uvalde County Summer Field Crop Tour.

June 2003 - Field tour stop at the Tan Plant Hybrid Test in Gregory, Texas. It was held during the San Patricio County Summer Field Crop Tour.

September 2003 – Field tour stop at the Sorghum Performance Test and Tan Plant Test in conjunction with a TCE sorghum field day in Ochiltree County, Texas in Perryton, Texas.

Rooney, L.W. 2003. Utilization of sorghum and millet in food products - successes, failures and progress. Papers Presented at the CFC Expert Meeting on Alternative Uses of Sorghum and Pearl Millet in Asia, ICRISAT, July 1-4, 2003, Patancheru, India.

Rooney, L.W. 2002. White food sorghum utilization properties and advantages for extrusion. US Grain Council Japanese Trade Team, one-day special seminar, September 19-21, College Station, TX.

Awika, J. M., Rooney, L.W., and Waniska, R.D. 2001. Exploring the potential of sorghum phenols as antioxidants. 2001 Sorghum Industry Conference & 22nd Biennial Grain Sorghum Research and Utilization Conference, February 18-20, Nashville, TN, p. 103-107.

Rooney, Lloyd W. 2001. Food sorghums-perspectives and marketing. 2001 Sorghum Industry Conference & 22nd Biennial Grain Sorghum Research and Utilization Conference, February 18-20, Nashville, TN, p. 40-44.

Rooney, Lloyd W. 2001. Future sorghum food and industrial utilization markets. 4th Australian Sorghum Conference. February 5-8, 2001.

Rooney, Lloyd W. 2001. White food sorghum technology. US Grains Council, Food Products Development Project and Sorghum Food Products, June 19-21, Tokyo, Japan.