Crop Utilization and Marketing

Chemical and Physical Aspects of Food and Nutritional Quality of Sorghum and Millet

Project PRF 212
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Summary

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

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

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

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

Objectives, Production and Utilization Constraints

Objectives

- Determine the relationships between the physical, structural, and chemical components of grains and food and nutritional aspects to improve quality of sorghum and millet.
- Determine the biochemical basis for the relatively poor protein and starch digestibility of sorghum grain and many cooked sorghum products.
- Develop laboratory screening methods for use in developing country breeding programs to evaluate and improve the food quality characteristics of sorghum and millet grain.
- Optimize processes and improve quality of commercializable sorghum and millet processed foods, and facilitate transfer of technologies.

Constraints

Research on food and nutritional quality of sorghum and millet grains is necessary to improve grain quality characteristics and stimulate commercial processing in developing countries. Factors affecting milling qualities, food quality, and nutritional value critically affect other efforts to improve the crop. If the grain is not acceptable to consumers, then grain yield and other agronomic improvements to the crop are likely to be lost. In addition, breeding grains that have superior quality traits will more probably give rise to processed food products that can be successfully and competitively marketed. This is especially true for sorghum that is perceived by some to have comparably poor quality characteristics to other major cereals. The overall goal of this project is to improve food and nutritional quality of sorghum and millet through a better understanding of the structural and chemical components of the grain that affect quality. This knowledge will be applied to develop useful methodologies for screening germplasm for end-use quality, develop techniques to make the grain more nutritious, and improve grain utilization through processing.

Research Approach and Project Output

Couscous and High Quality Flour Processing

Couscous Processing Unit in Niger

As described in previous annual reports, PRF 212 and INRAN/Niger Food Technology Laboratory set up a cereal processing unit at INRAN to conduct research, demonstration, and testing of sorghum and millet processed products. A central goal of the project has been to optimize the processing system and products, to generate information for entrepreneurial startups, and to work with interested individuals in the private sector. Products produced by the unit include high quality flours and grits, and agglomerated products including fine couscous (or *dambou*), medium couscous, and the coarse particle-size product *degue*. In 1995, the core of the sorghum/millet processing unit was installed at INRAN; consisting of a central mechanized agglomerator designed and fabricated at CIRAD, France by Dr. Jacques Faure, a mixer for flour wetting, a couscousierre (steamer), a small solar drier with through ventilation powered by a solar cell (fabricated in Niamey by ONERSOL), and a sealer for packaging. The initial unit was funded through the then functioning Niger InterCRSP project. Since that time, a much larger passive solar drying unit was built at INRAN to dry approximately 200 kg couscous every 2 days. As high quality flours are essential to make quality couscous, a commercial grain decorticator (dehuller) and hammer mill (Urpata Sahel, Dakar) were procured through PRF 212 to compete the unit. This last addition has also permitting INRAN cereal technologists to begin work on production of high quality sorghum and millet flours and other products made from them. Currently, a regional project funded through IFAD is providing support for a local entrepreneur to start up a similar processing unit with technical support from INRAN.

Market Testing of Packaged Flour and Couscous Products

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

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

Initial Studies on Sorghum Foods Staling Properties

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

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

Sorghum with High Protein Digestibility

Grain Quality

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

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

Swine Digestibility and Feed Value Study

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

Sorghum Starch Digestibility

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

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

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

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

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

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

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

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

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

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

Starch Digestibility in Raw Grain

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

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

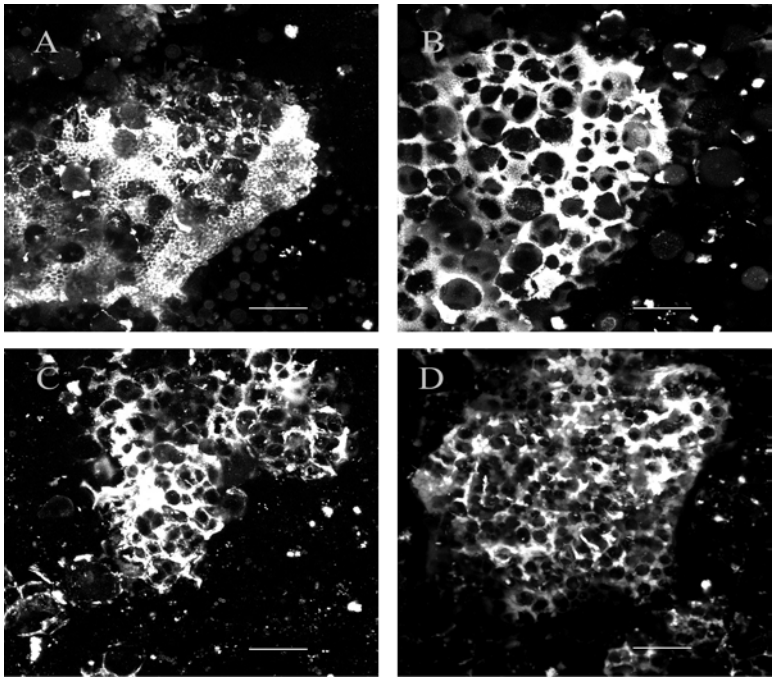
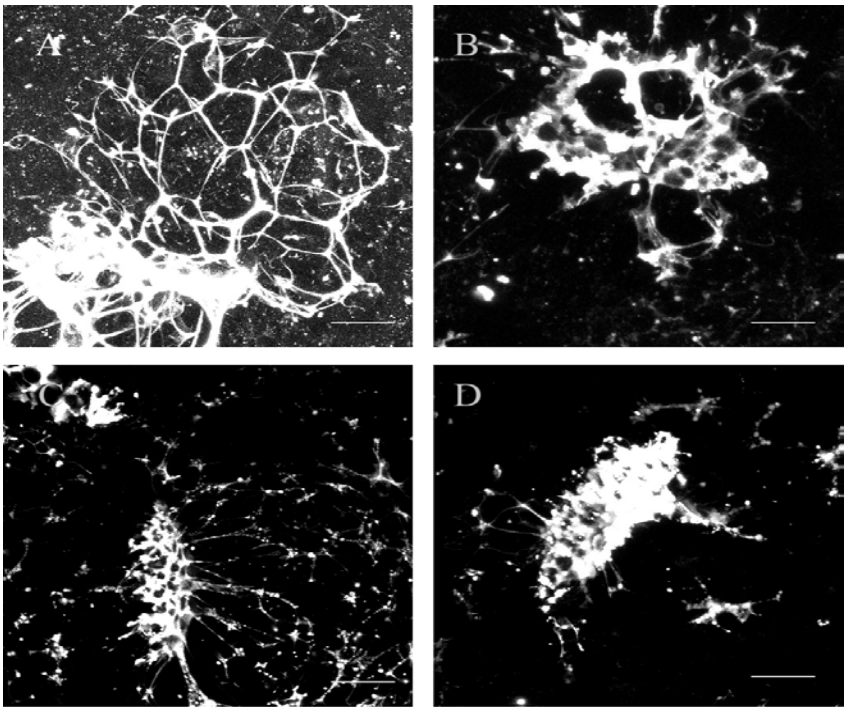


Figure 2. Confocal micrographs of reconstructed three dimensional images of cooked porridges showing protein (bright areas). A, B, C, and D represent wild-type sorghum, high protein digestibility sorghum mutant, maize, and rice, respectively. Bar size 25μm.



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

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

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

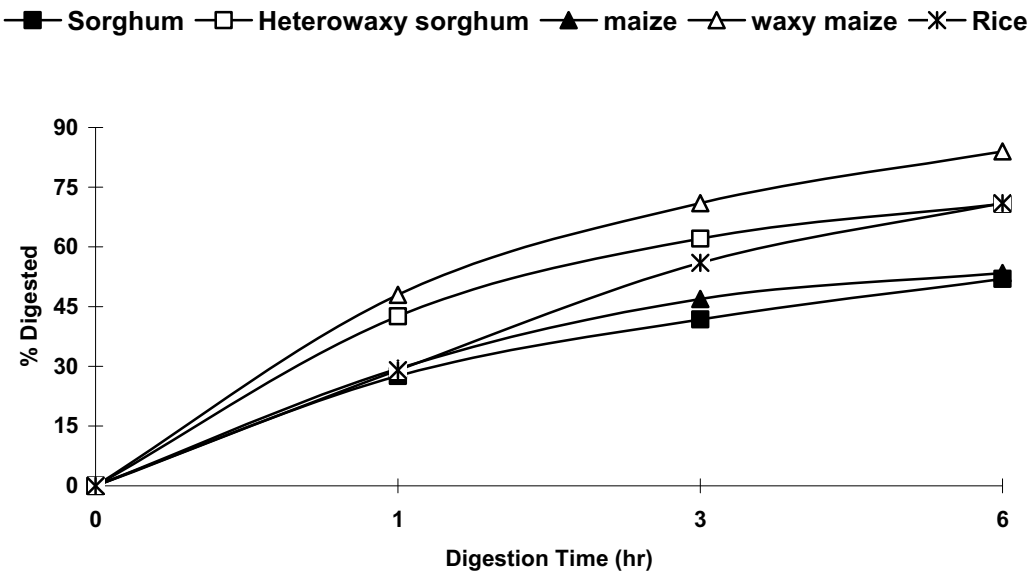
Our working hypothesis as to the structural basis of these digestibility differences is that the length of the shorter chains of amylopectin determines degree of crystallinity of starch granules that in turn impacts digestion rate. Therefore, longer degree of polymerization of the short chains that is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

Networking Activities

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

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

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



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

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

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

Publications and Presentations

Abstracts

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

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

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

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

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

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

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

Journal Articles

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

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

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

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

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

Dissertations and Theses

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

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

Food and Nutritional Quality of Sorghum and Millet

Project TAM 226

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Summary

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

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

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

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

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

Special sorghums with high levels of phenols and antioxidants produce excellent chips and baked products. The antioxidant level in brown sorghum bran is higher than that of blueberries. Special sorghum brans and their extracts have excellent antioxidant properties in various food systems.

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

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

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

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

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

Objectives, Production, and Utilization Constraints

Objectives

- Develop new food products from sorghum and millet using technology appropriate for use in less developed areas.
- Determine physical, chemical and structural factors that affect the food and nutritional quality of sorghum; seek ways of modifying its properties or improving methods of processing.
- Develop simple, practical laboratory methods for use in breeding programs to assess important grain quality characteristics.
- Determine the factors that affect resistance to grain molds and field deterioration in sorghum and devise laboratory procedures to detect genotypes with resistance.

Constraints

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

This project relates quality to measurable characteristics that can be used to select sorghum and millets with acceptable traditional and industrial utilization attributes. It defines quality attributes and collaborates with breeders to incorporate desirable properties into new cultivars at early stages in the breeding and improvement programs. The project also seeks to find more efficient ways of processing sorghums and millets into new foods with better acceptability that can generate income for farmers and entrepreneurs.

Grain molds significantly reduce the quality of sorghum for food and feeds. Information on the factors that affect mold damage of sorghum and methods to develop mold resistant sorghums is needed. This project addresses those critical issues.

Research Approach and Project Output

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

Significant Accomplishment

Applications of Technology in Mali

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

Another positive development is that farmers growing the white tan sorghums prefer the porridge made from these grains. This is similar to farmers in Honduras and El Salvador who prefer tortillas made from white tan plant sorghum varieties instead of the native Criollos, which have purple glumes. This project has interacted with the Malian program for more than 20 years. We hope that significantly faster progress will continue now that Malian business people are involved.

New Markets for Food Sorghums

Several extruded salty snacks and milled products based on IP U.S. white food sorghums continue to be sold by Japa-

nese food companies. South Korea and other countries are interested in using white food sorghums. Utilization of sorghum in these highly developed countries will help our efforts to convince food companies in other countries that sorghum is a good food ingredient. Similar findings in Mali, Central America, Mexico and other countries of West Africa demonstrate that sorghum of good quality is necessary for value-added products. The products are acceptable and purchased by consumers provided convenience, good taste, appearance and consistent quality is available at competitive prices. In South Africa, significant quantities of Mabella meal are consumed even though the price is significantly higher than mealy meal (maize) because a 14% value-added tax is assessed to sorghum processed products. Botswana is an example where maize consumption is decreasing while sorghum consumption is increasing even though red or brown sorghum must be imported from South Africa.

Applications in Honduras and El Salvador

Our research on sorghum has been applied in Honduras and El Salvador. The variety Sureno, and others with white tan plant color are used in Central America for tortillas, rosquillos, and rosquetes. In El Salvador, sorghum flours from white tan plant varieties are used in small bakeries to produce pan dulce, muffins, bread, rosquetes, rosquillos and other variations of these products. There is significant interest in use of sorghum flour in blends and alone for baked products. There is a lack of milling equipment to secure flour although there appears to be sufficient production of food-type sorghums. The ability to IP food sorghums for processing must be developed for consistent success. The opportunities exist to stimulate use of white food sorghums in Central America since a source of grain is available, but technologies that can be used to decorticate sorghum and mill it into flour or meal are required along with production of a consistent supply of IP grain.

Sorghum Phenols and Catechins as Antioxidants

Specialty sorghums and their products were analyzed for antioxidant potential using three methods; oxygen radical absorbance capacity (ORAC), 2,2-azinobis (3-ethylbenzothiaziline-6-sulfonic acid) (ABTS), and 2,2-diphenyl-1-picrylhydrazyl (DPPH). The sorghums were also analyzed for total phenol contents (Table 1, Figure 1, 2). The brown and black sorghum brans had the highest levels of antioxidant activity along with the most total phenols. The catechin levels were highest for the brown sorghums. Since the phenols are concentrated in the outer layers of the sorghum kernel, the bran obtained by abrasive decortication or roller milling has 3-4 times the antioxidant activity of the whole grains.

The three methods for measuring antioxidants were compared to determine if a less expensive and more convenient method could be used for analysis of antioxidant activity. The ABTS and DPPH methods correlated highly with ORAC (R2 = 0.98). The ABTS method was the most suitable for sorghums; it had a cost advantage over ORAC and was more consistent

Table 1. Phenol contents and antioxidant properties of sorghum and sorghum products measured by three methods.

Sample	ORAC[a]	ABTS[a]	DPPH[a]	Phenol[b]
White grain	22	6	6	3
White grain extrudate	26	7	6	3
White bran	64	28	21	6
Red grain	140	53	28	7
Red bran	710	230	71	20
Black 2001 grain	219	57	41	6
Black 2001 extrudate	94	37	32	5
Black 2001 bran	1,008	250	184	26
Bread (30% Black 1999 bran)	92	45	28	5
Cookie (50% Black 1999 bran)	170	90	51	9
Hi Tannin (brown) grain	453	108	118	13
Hi Tannin grain extrudate	286	90	74	6
Hi Tannin bran	2,400	512	495	55
Sumac (brown) grain	868	226	202	23
Sumac bran	3,124	768	716	66
Bread (30% Sumac bran)	254	108	78	8
Cookie (50% Sumac bran)	324	130	106	14
CV	6.8	3.5	5.3	6.0

*a*mmol TE/g DM basis
*b*mg GAE/g DM basis (Folin-Ciocalteu method)
*Based on highest value reported by Moyer et al (2003)[a] from among 29 varieties.
[a]Moyer, RA; Hummer, KE; Finn, CE; Frei, B; Wrolstad, RE. 2002. Anthocyanins, phenolics, and antioxidant capacity in diverse small fruits: *Vaccinium, Rubus,* and *Ribes*. J Agric Food Chem. 50:519-525.

Fig. 1. Antioxidant (ORAC) levels in different sorghum brans compared to wheat bran and fruits (dry basis)

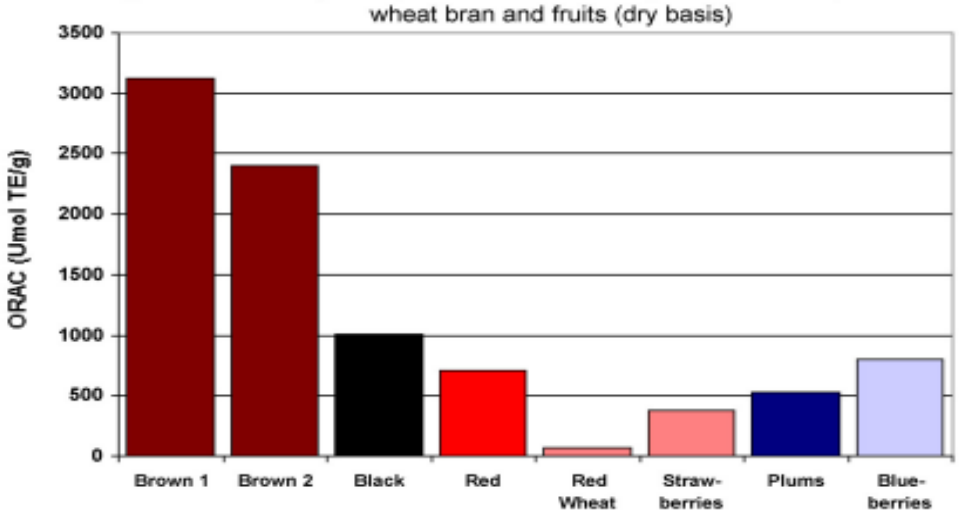
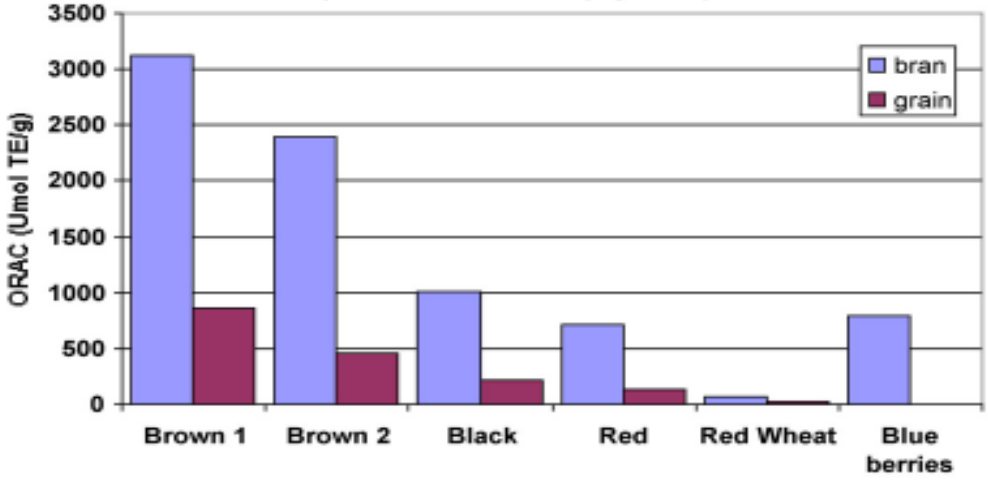


Fig. 2. Antioxidant (ORAC) values of sorghum grain and bran compared to blueberries (dry basis)



across samples than DPPH. Actually the total phenol contents of the sorghums were correlated highly with their antioxidant activity (R2 = 0.96 to 0.98). Thus, it is possible to predict antioxidant levels in sorghum by using total phenol analysis with confirmative tests using ABTS or the ORAC methods when more nutritionally relevant data is required. Trials with animals and humans are needed.

The bran is high in dietary fiber, phytates and natural brown or black pigments that impart attractive colors to baked products such as cookies and multigrain breads. A healthy bread that contains modest levels of high tannin sorghums as a source of antioxidants is currently being sold by a commercial bakery.

Ms. Crystal Rudiger completed her M.S thesis and developed a bread mix containing brown or black. sorghum bran with flax seed, gluten, barley and wheat flour. The bread made there from has excellent flavor, texture and outstanding levels of dietary fiber, antioxidants, ligans and omega 3 fatty acids with a natural brown color. Black sorghum bran in breads resulted in appearance, texture, color and specific volume (cm3/g) similar to commercial specialty or dark rye breads.

The HPLC analysis of procyanidins (condensed tannins) indicated that tannin or brown sorghums had a large number of oligomers that comprised the condensed tannins. The processing of tannin sorghums using extrusion significantly reduced the polymer size of the procyanidins. The increased percentages of oligomers with less than 10 units may positively affect the biological significance of the antioxidants. The type of processing is important since similar changes did not occur when the brans were mixed into cookie and breads. The potential to produce healthy foods from sorghum is quite high.

Ms. Linda Dykes, Ph.D. student, continues to characterize sorghum phenols and tannins using HPLC and other techniques. Dr. J. Awika, Kenya, completed his Ph.D. degree on antioxidants in sorghum and is currently a research associate continuing research on sorghum and wheat quality here in our laboratory. Our laboratory is collaborating with Dr. Prior's group at

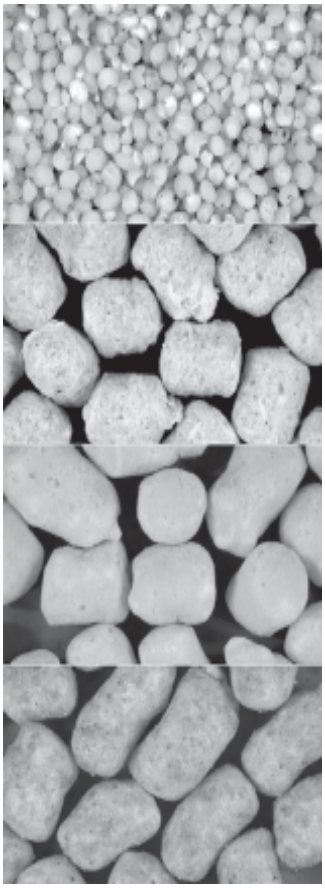


Figure 3. Bongos sorghum snack, in order from top, decorticated grain, extrudates without seasoning, and extrudates with cheese and nacho seasoning.

the USDA Nutrition Lab in Little Rock, Arkansas to explore the relationship of processing of sorghum brans and its affect on health.

Extrusion

It is possible to produce expanded sorghums directly from whole ground undecorticated white or brown sorghum grains using low-cost friction extruders. More research will be done to demonstrate the utility of sorghums of various kinds in low-cost extrusion of snacks. These smaller extruders are used in areas where infrastructure does not permit use of more costly sophisticated extruders and processes. Low-cost friction extruders can be used to produce an array of products. Thus, the ability to produce snacks directly from whole clean grain is a distinct advantage for sorghum. Extrudates of 100% whole brown or tannin sorghums would have excellent nutritional properties. More work is needed to document their properties.

The evaluation of sorghum as an ingredient in extrusion of snacks and breakfast foods was initiated to compare their properties with corn and rice. This information is of interest to potential users of sorghum around the world. Rice produces extrudates with white, bland flavor and excellent crispness. The goal of these experiments is to test the extrudate properties of sorghum directly against corn and rice ingredients. The white food sorghums have a bland flavor, light color and produce acceptable food products of various kinds.

White sorghum samples prepared by combining 4 decortication levels (0, 10, 20 and 30%) and three particle sizes were extruded in a Maddox single screw friction-type extruder. A commercial yellow cornmeal and polished rice were extruded as controls. The extrusion conditions were held constant for all samples. The expansion ratio, bulk density, color and texture of the extrudates were significantly affected by both particle size and decortication level. As the decortication level increased, the extrudates were whiter, more expanded, less dense, more crisp and more thoroughly cooked. The extrudates made from coarse particle size materials had the most desirable characteristics compared to the other particle sizes used. Some sorghum products had a higher expansion ratio than both rice and corn, and had similar bulk density and texture characteristics. With increasing decortication level, whiter, more expanded, stronger and crispier, bland flavored extrudates were produced. The decortication level and particle size can be used to vary expansion ratio, crispiness and bulk density.

Three graduate students in our laboratory produced "BONGOS", a whole grain sorghum extruded snack, which won first place in the National American Association of Cereal Chemists Product Development Competition (Figure 3). The product was made from whole grain white food sorghum via a short barrel friction type extruder followed by baking the extrudates and seasoning with different flavors. The whole grain products are healthy with a very acceptable texture that is firmer than the usual extrudates made from milled rice, maize and sorghum. Moreover, the shelf life is excellent and the product looks and tastes great. This illustrates the functionality of sorghum for use in extrusion and as a food ingredient.

The Japanese are interested in sorghum because it has a bland flavor, light color, can carry mild flavors and seasonings similar to rice, has good extrusion properties similar to rice, and is potentially less expensive. Participants in our Snack Foods short course from Central America are interested in using sorghum but finding a consistent supply of good quality grain is a significant problem.

Sorghum Flour in Specialty Products

Sorghum flour (SF) can be substituted for 100% of the wheat flour in a variety of products that are used in gluten free diets for Celiac-Sprue patients who are intolerant of wheat and other cool weather cereals. Sorghum flour produces acceptable baked products with additives to substitute for its lack of gluten. Various prepared mixes, flours and other products containing sorghum have been introduced into specialty markets recently. The National Sorghum Producers Association is promoting sorghum as a healthy food ingredient and it has ethnic appeal to many immigrants.

Sorghum Starch, Malting and Brewing Studies

Dr. Serna-Saldivar, ITESM, Monterrey, Mexico, is continuing to collaborate on sorghum research, especially with stu-

dents working on sorghum for brewing, industrial films and as a source of antioxidants. His group has conducted significant research on wet milling of sorghum and evaluated its use as brewing adjuncts. Dr. Serna has provided assistance to our project in El Salvador and Nicaragua by presenting a summary of his research activities on sorghum to Central American scientists at a planning workshop in Nicaragua.

Central American Use of Sorghum

Ms. Herrera working with CENTA in El Salvador has conducted many trials in local bakeries showing that sorghum can be used effectively in baking of rosquetes, sweet breads and many other products as well. We have a program to work with her to assist in sorghum flour production from the improved white, tan plant food sorghums that are available in Salvador. This work along with the breeding program in El Salvador and Nicaragua will continue to improve sorghum quality for use in foods.

The lack of commercial production of sorghum flour by small operators is a major constraint to more widespread use of sorghum by small holders in the region. The need for IP food sorghum production and processing is critical. Bland flavor sorghum flour has an advantage over corn flour as a substitute for wheat flour. This affords an opportunity to utilize sorghum in popular food items. As we work to enhance utilization at the entrepreneur level, the combination of cereals and legumes to produce value-added foods is critically important.

The price of rice is such that locally grown sorghums could compete for markets in certain snacks, ready-to-eat breakfast cereals and composite flours for baking. In rural non-rice producing areas, a decorticated sorghum could serve as a cost effective substitute or diluent for rice in many households. Success could lead to significant economic activity.

Tan Plant Food-type Hybrid Performance and Quality Trials

Attributes of sorghums that produce light colored meals, flour and grits with bland flavors were evaluated under different environments in uniform yield trials with 40 entries. This work was in collaboration with Dr. Tuinstra and W. Rooney, who conducted the evaluation trials. Red and white sorghum varieties grown at locations in Texas, Kansas and Nebraska from 1999-2002 were evaluated for hardness using a SKHT (single kernel hardness tester), decortication properties using TADD (tangential abrasive dehulling device), TKW (thousand kernel weight), color (L, a, b), test weight, density, proximate composition and relative mold damage. Mean quality data for some of the most relevant hybrids are presented in Table 2.

Environment and hybrids significantly affected composition, physical and processing properties. White tan sorghum (WT) hybrids were harder, more dense and lighter in color than white purple (WP) hybrids or red hybrids (Figure 4). WP hybrids were more adversely affected by weathering and molds than WT hybrids. All of the ATx635 hybrids had significantly improved physical properties and higher milling yields than the other white hybrids. This grain also has a thin pericarp that is particularly suited to whole grain extrusion.

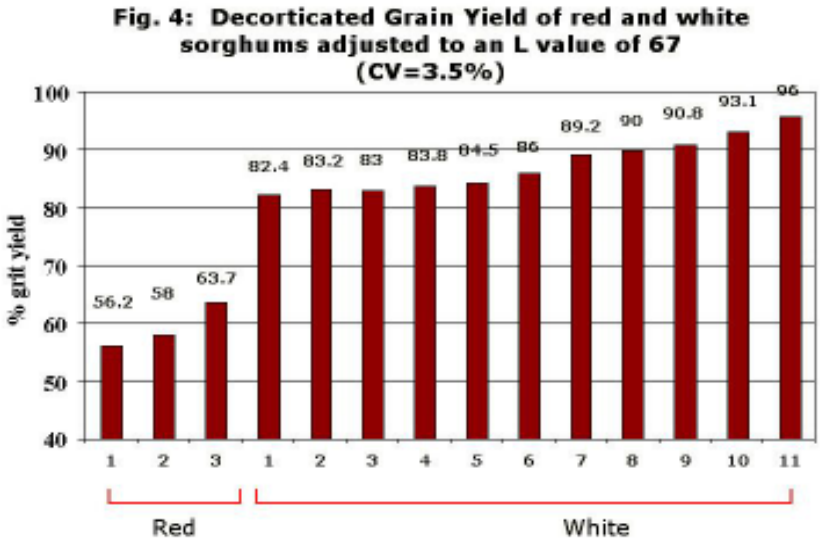
White sorghums had better milling performance than red hybrids. A significant correlation (r=0.69, n=105) was found between SKHT and TADD hardness values, suggesting SKHT could be used to predict decortication properties. Efforts by breeders, agronomists and food technologists have produced tan white food-type sorghums with significantly improved food quality attributes.

The red tan hybrid sorghums could be grown in areas where molds and weathering are serious problems, such as in the coastal bend of Texas, in areas where the Kharif sorghums are grown in India and in many African countries where the sorghums mature during moist conditions. The problem of molding and staining is decreased with tan plant sorghums that have straw colored glumes. For example, the Kharif sorghums of India become black with mold damage and sell for 50-60% discount. This is rapidly reducing the sorghum production in India. The red tans might be useful for decortication and pro-

Table 2. Physical and composition attributes of selected sorghum hybrids grown over four years at four locations in Texas, Kansas, and Nebraska.

Pedigree	Type	Hardness Index	Decortication Yield (%)	Grain L Value	Grit L Value	TK W (g)	Diameter (mm)	Density (g/cc)	Protein (%)	Fat (%)
ATx635*RTx436	WT	94.9 a	85.8 a	63.1 a	68.2 a	23.2	1.97	1.396 a	11.0	3.8
ATxArg-1*RTx436	WT	91.5 a	82.7 ab	62.6 ab	69.6 a	22.6	1.83	1.389 ab	10.8	3.6
888Y	WT	90.3 ab	86.4 a	59.5 c	67.8 ab	25.8	1.92	1.396 a	11.2	3.9
ATx378*RTx430	RP	83.4 bc	75.9 cd	47.7 d	65.3 b	30.0	2.22	1.376 cd	11.5	3.8
ATx623*RTx430	WP	83.0 c	74.9 cd	59.5 c	68.2 a	29.0	2.17	1.373 cd	10.0	3.5
ATx631*RTx436	WT	79.9 cd	79.1 bc	63.8 a	69.6 a	25.6	2.07	1.381 bc	11.1	3.9
ATx631*RTx2903	RT	74.1 de	72.3 d	46.8 d	69.9 a	24.3	2.03	1.369 d	12.5	4.0
AOK11*RTx2741	WP	70.6 e	70.7 d	60.4 bc	68.2 a	25.9	1.97	1.368 d	9.5	3.5
LSD (a=0.05)		7.2	5.9	2.3	2.4	4.0	0.22	0.011	1.3	0.3

Means with same letters not significantly different



duce better food and poultry feed than the white sorghums currently being grown. The Kharif hybrids sell for significantly less money than the rabbi or dry, post rainy season sorghum called maldandi. Similar problems occur in much of Africa except the Sudan, Ethiopia and others where sorghum matures in the very dry season.

Yield, Agronomics and Quality Attributes of Commercial White Tan Food Sorghum Hybrids

Samples of commercial sorghums exported from the Gulf Coast (11) and value-enhanced white food sorghums grown on farmers' fields (21) were analyzed for composition, physical and milling properties for each of three crop years. The white food grains had higher test weight, increased true density, reduced floaters and significantly higher yields of decorticated grain than the commercial export sorghum samples for each of the three years. The protein content of the food sorghums was significantly higher than that of the commercial sorghum samples. These data were used by the United States Grains Council to provide information on the new food sorghums available. Partial support for the analysis was provided.

Improved Methods of Analysis

NIR equipment to analyze for protein, moisture and starch in whole grains was calibrated. The use of NIR to analyze for starch, protein and moisture is successful but continuous improvements in the calibrations are needed. A large number of samples were analyzed with good repeatability. Numerous factors like color, cracked and broken kernels, glume content and degree of molding appear to affect the analytical values obtained.

A single kernel characterization system used for wheat kernel hardness was modified slightly for sorghum hardness, diameter and moisture measurements. This must be confirmed with a larger set of samples. At this time the abrasive milling procedure appears to be necessary to assess hardness, especially if one wants to compare yields vs. color of the decorticated grain.

Role of Antifungal Proteins (AFP) in Minimizing Grain Molding of Sorghum

Drs. Waniska and Bejosano have evaluated the role of AFP for several years. The results of the 3-year study (2000-2002) were analyzed and summarized in a manuscript submitted for publication entitled "Antifungal proteins in commercial hybrids and elite sorghums" by F.P. Bejosano, R.D. Waniska, and W.L. Rooney. The report consolidates the findings on the commercial hybrids and public parental lines grown in College Station in 2000, 2001 and 2002 that were selected for the study. Previous studies evaluated small numbers of sorghum genotypes. In this study a larger (98 lines in 2000 and 2001; 42 in 2002) and more diverse collection was evaluated to determine if previous findings apply when sorghums are grown in normal agronomic practices and typical environments.

The sorghum growing environments in 2000 and 2001 did not result in sufficient mold damage to correlate AFP content with grain mold resistance. However, the sorghum growing environments in 2002 resulted in significant mold damage. The environment in 2002 caused significant fungal deterioration of grain. The variation in mold infection among the genotypes increased as the grains reached combine harvest maturity. Consequently, significant changes in AFP content from physiological to combine harvest maturity were observed. Genotypes, which lost more AFP at combine harvest maturity, had significantly greater mold damage. Thus, we were able to demonstrate that sorghums with higher levels and increased retention of AFP had significantly reduced grain molding.

Grain mold is considered a complex disease, which is influenced by interaction of qualitatively and quantitatively inherited traits. Although other caryopsis traits are known to con-

tribute to grain mold resistance specifically tannins, harder endosperm, and red pericarp color, these studies have shown that presence of AFP is a major factor. Hence, sorghums can be classified as mold resistant or susceptible based on their AFP content and retention when they are exposed to environmental conditions that promote mold infection.

The AFP content is reduced by increased mold pressure during maturation. Mold resistant sorghums retain more AFPs than susceptible ones when grown under conditions causing mold damage. Both white and red sorghums had the same response. Thus, it is possible to analyze for AFP content to determine resistance only under conditions where high levels of molding occurs. Under this situation, the sorghum breeders can make selections subjectively as to relative mold resistance among the lines. AFP cannot be used on mature, dry grain to predict mold resistance.

Work to complete the studies continues but additional studies are required, especially those that follow AFP levels in mold resistant lines from one generation to the next. Once this is wrapped up the work will be complete. New efforts to understand the role of certain phenols in the bright red cultivars with resistance will be initiated applying recent new analytical techniques for their separation.

Networking Activities

Southern Africa

The PI, Dr. Lloyd Rooney, made 3 trips to Africa and one trip to ICRISAT India to present information on management of the grain supply chain to improve sorghum and millet food products. Graduate students in the Food Science Department at University of Pretoria are from many African countries. Many participate in the Regional Master of Science program, which consists of joint programs between CSIR and University of Pretoria. Thus, INTSORMIL's interaction with the University of Pretoria informs many future African food industry leaders of the potential role of sorghum and millets as food and industrial ingredients. INTSORMIL is providing significant assistance to the region by involvement in these key programs.

Dr. Leda Hugo, Mozambique, completed her Ph.D. with Dr. Taylor at the University of Pretoria on the use of malted and fermented sorghum in composite breads. She is currently a professor at University of Eduardo Mondlane University teaching in the food science program and conducting research on post harvest grain processing. Her process to ferment sorghum flour prior to baking has significant potential for commercialization.

Ms. S. Yetneberk from Ethiopia has continued her Ph.D. program at University of Pretoria under Dr. John Taylor. She has made excellent progress to determine major factors affecting the quality of injera from sorghum cultivars grown in Ethiopia. She found significant differences among sorghum cultivars in injera quality. Also the addition of emulsifying agents appears to improve quality and prolong shelf life of injera from sorghum. Some hard white cultivars have acceptable injera quality. She is nearly through with her dissertation and works as part of the Ethiopian National Sorghum Improvement Program.

Mr. Steve Barrion, M.S. candidate, University of Pretoria, is working on milling of pearl millet from Namibia. Commercial milled products from a major millet variety were produced and analyzed for components and physical properties. He made plans to obtain several commercial varieties of pearl millets from Namibia for analysis, especially of the phenols. This project should provide useful information relative to commercial milling of pearl millet compared to traditional milling.

Ms. Nomsua, Bulawayo, Zimbabwe, is working on a Ph.D. in food science at the University of Pretoria, involving antioxidants from sorghum. She teaches food science courses at the National University of Zimbabwe in Bulawayo. She is just starting her program with Dr. Taylor's group. She will probably come to our laboratory to work with phenol and antioxidant analyses in 2004.

Dr. Lloyd Rooney participated in the AFRIPRO conference that was held in April 2003 in Pretoria to assess the current status of research in Africa on sorghum proteins and related subjects. The European Economic Community has sponsored work in several African and European Universities and Research Centers. The conference brought together a critical mass of African and European scientists. INTSORMIL must maintain and develop a continuing dialog with these scientists since our interests are complementary. Many of the African scientists participating were trained as part of our INTSORMIL program. They have been exercising leadership in some of these projects. Dr. Rooney presented information on the importance of supply chain management for securing a consistent supply of grain for processing into value-added products for urban consumers. Professor Taylor, University of Pretoria, is funded by both groups and facilitates interactions quite well. These projects are synergistic and complementary.

Honduras, Salvador, Mexico and South America

René Clará, Sorghum Breeder, El Salvador and sorghum breeders from Nicaragua spent time in the Cereal Quality Lab, TAMU. Dr. Rooney traveled to Managua, Nicaragua to develop collaborative research plans. The information obtained in Japan applies quite well to the situation in Salvador and elsewhere in Central America. A small Central American food company has initiated use of modest amounts of sorghum in their extruded snacks as the result of participation in our snack foods short course.

Dr. Rooney has long term cooperative projects with Dr. S. Serna-Saldivar, Professor and Head, Food Science, Instituto Tecnologico y de Estudios Superiores de Monterrey (ITESM),

Monterrey, Mexico, to evaluate the usefulness of new improved food sorghum hybrids in wet and dry milling and as adjuncts in brewing. His PhD and subsequent post doctorate experience in our laboratory was partially funded from INTSORMIL.

We currently have three graduate students from Mexico partially funded on TAM 226. We are able to leverage our INTSORMIL funds by using additional research funds from private industry and other agencies to conduct joint research activities. The practical short course on snack foods provides opportunities to conduct proprietary research projects for participants. These short courses generate funds that are used to partially support graduate students.

Dr. Javier Bueso, Honduras, completed his Ph.D. He was partially supported by INTSORMIL and worked on sorghum but his dissertation was on staling of tortillas since his last year was funded by a Tom Slick Graduate Fellowship from Texas A&M University. Our current level of funding did not permit him to work only on sorghum.

We are actively recruiting a graduate student from El Salvador and Nicaragua to develop skilled personnel for those programs in Central America where food science related to crop improvement programs are unavailable or scarce. Travel to El Salvador and Nicaragua is scheduled for late July 2003.

Mali and West Africa

Dr. A. Touré, IER, Mali, and his associates have made progress in utilization and breeding research to develop IP production and use of the new white tan plant photosensitive sorghum varieties for value-added production. It is clear that many scientists and others understand that acquisition of good quality sorghum and millet grains for processing is necessary to produce profitable, competitive food products for urban markets. This is a continuous painstakingly slow process but progress is occurring. This same concept has been demonstrated in Niger and other places where poor quality grain produced unacceptable products that consumers will not buy.

Dr. Rooney participated in an intensive short-term mission to Dakar, Senegal in January 2003 to evaluate utilization of millet as processed foods. The progress in Dakar is spectacular and gives a positive indication of what can be done. The long term efforts of Institute of Technology Alimentaire (ITA) in Dakar has led to a large number of small businesses that process millet couscous of various kinds, flour, meal and more sophisticated products like yogurt containing 30% millet and a snack made by extrusion puffing using locally produced materials. The products were of excellent quality overall; processors realize they need improved quality and consistency of grain and are willing to pay more for it. The organization of farmers to produce higher quality grain and supply chain management and sharing in profits by all parties are the next steps toward more efficiency. These developments are the results of long-term efforts on the part of numerous international agencies that assisted ITA and other organizations to lay the groundwork for these entrepreneurs. The time is ripe to develop a supply chain to provide value-enhanced grain for increased profits for all participants from seed producers through to the consumer. A supply chain for improved quality grain will make delivery and adoption of new cultivars much easier and will permit processors to expand production to meet market demands that appear to exist.

North America

Several papers were presented at the annual American Association of Cereal Chemists Conference, Montreal, Canada. Dr. Rooney presented sorghum quality/ utilization discussions to Texas Sorghum Producers Board Members and panels and U.S. Grains Council sponsored trade teams. A special seminar at TAMU was developed for a Japanese trade delegation interested in white sorghum for food processing. Mr. David Acosta, one of our graduate students, won first prize for the best paper at the National Sorghum Producers Association Conference. He presented his research on extrusion of sorghum to produce snacks.

Three of our graduate students won first place for Bongo's at the National AACC Conference Product Development Competition.

Visitors and collaborators from Southern Africa, Australia, Mali, Niger, Botswana, Honduras, Guatemala, El Salvador, Korea, Japan, Venezuela, Colombia, and China were presented information.

Practical Snack Foods Short Course

Our laboratory conducts an annual short course on practical snack foods production for private industry in which sorghum utilization is part of the program. A book on Snack Food Processing co-edited by Dr. Rooney contains information on food sorghum. Participants from all over the world enrolled in the short course, including several from Central America and Mexico. This short course produces a profit, which is used to partially support our research activities, another example of leveraging of resources.

Sorghum Market Development Activities

The U.S. Grains Council has market development activities to capitalize on value-enhanced sorghums for use in value-added products in Japan, Taiwan, Mexico, Central and South America. Our research activities on development of food-type sorghums, milling properties, composite flours, tortillas, snacks and other prototype food products were presented at U.S. Grain Council sponsored value-enhanced market development work shops in the United States and Japan. At the request of the U.S. Grains Council, we presented a one day workshop on white food sorghum quality and processing properties to several Japa-

nese food processors in our laboratory where we discussed value-enhanced sorghums for food processing.

Training, Education and Human Resource Development

Monterrey Institute of Technology: our collaboration with Dr. Serna-Saldivar, Head, Food Science Dept., ITESM, Monterey, Mexico has led to completion of six M.S. degrees. These young scientists have positions in the Mexican food industry, which transfers the technology directly to industry.

Drs. J. Awika from Kenya and J. Bueso from Honduras completed Ph.D. degrees. Two M.S. thesis were completed. Two graduate students from Mexico and two from the U.S. currently work on INTSORMIL related research in our laboratory, with partial financial support while several others are supported from non INTSORMIL funds. Inflation has significantly reduced the number of graduate students that can be supported.

Publications and Presentations

Journal Articles

Awika, J.M., L. Dykes, G. Liwei, L.W. Rooney, and R.L. Prior. 2003. Processing of sorghum (Sorghum bicolor) and sorghum products alters procyanidin oligomers and polymer distribution and content. J. Ag and Food Chem. (In Press)

Bejosano, F.P., W.L. Rooney, R.R. Klein, L.W. Rooney, and R.D. Waniska. 2003. Antifungal proteins in commercial hybrids and elite sorghums. Journal of Agricultural and Food Chemistry. (In Press)

Earp, C.F., C.M. McDonough, and L.W. Rooney. 2003. Microscopy of pericarp development in the caryopsis of *Sorghum bicolor* (L.) Moench. J. Cereal Sci. (In Press).

Earp, C.F., C.M. McDonough, J.M. Awika, and L.W. Rooney. 2003. Testa development in the caryopsis of *Sorghum bicolor* (L.) Moench. J. Cereal Sci.. (In Press)

Hugo, Leda F., Lloyd W. Rooney, and John R. N. Taylor. 2003. Fermented sorghum as a functional ingredient in composite breads. Cereal Chemistry. (In Press)

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

Serna Saldivar, S.O. and M. Mezo-Villanueva. 2003. Effect of cell wall degrading enzymes on starch recovery and steeping requirements of sorghum and maize. Cereal Chem. 80(2):148-153.

Books, Book Chapters and Proceedings

Rooney, L.W. and S.O. Serna-Saldivar. 2003. Sorghum. In B. Caballero, LC Trugo, and PM Finglas (Eds.). Encyclopedia of Food Sciences and Nutrition, 2nd ed., Volume 8, Academic Press, London. Pp 5370-5375.

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

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

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

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

Acosta, David. 2003. Extrudates made from a food-type white sorghum. Pp. 119-127.. 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 Research and Utilization Conference, Feb. 16-18, 2003, Albuquerque, New Mexico, U.S.

Rooney, L.W. 2003. Overview: sorghum and millet food research failures and successes. 9 Pp. In P.S. Belton and J.R.N. Taylor (Eds.). Proceedings of the AFRIPRO Workshop on the Proteins of Sorghum and Millets: Enhancing Nutritional and Functional Properties for Africa. April 2-4, 2003. Pretoria, South Africa.

Rooney, L.W. 2002. Constraints to utilization of sorghum/millet in value-added foods. In INTSORMIL Project Investigators Conference, November 18-20, 2002. Addis Ababa, Ethiopia.

Rooney, L.W. and F. Herrera. 2002. Central American utilization of sorghum for food. In INTSORMIL Project Investigators Conference, November 18-20, 2002. Addis Ababa, Ethiopia.

Rooney, L.W. 2002. White food sorghum utilization properties and advantages for extrusion. US Grain Council Japanese Trade Team, September 19-21, College Station, Texas, U.S.

Dissertations and Theses

Awika, Joseph. 2003. Antioxidant properties of sorghum. Ph.D. dissertation. Texas A&M University, College Station, Texas.

Bueso, Javier. 2003. Staling of corn tortillas. Ph.D. dissertation. Texas A&M University, College Station, Texas.

Maranphal, Nitit. 2003. Direct expanded snacks from sorghum. M.S. thesis. Texas A&M University, College Station, Texas.

Rudiger, Crystal. 2003. The formulation of a nutraceutical bread mix using sorghum, barley, and flaxseed. M.S. thesis. Texas A&M University, College Station, Texas.

Miscellaneous Publications

U.S. Grains Council. 2002. 2001-2002 Value-Enhanced grains quality report, US Grains Council, Washington, D.C. http://www.vegrains.org/documents/2002veg_report/veg_report.htm, 142 pp.

Rooney, L.W. 2002. Food and nutritional quality of sorghum and millet, Project TAM-226 INTSORMIL Annual Report 2002, University of Nebraska, N.E. Pp. 88-95.

Rooney, Lloyd W. and C. McDonough. 2001. PROFIT Annual Report: Near infrared analysis for marketing of sorghum. http://sorghum.tamu.edu/report_database/files/rep17/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/rep34/2001tphtreport.pdf

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/rep9/WaniskaProfit01Report.html

Abstracts

Acosta, D., M. Barron, M. Riaz, R. Waniska, and L. Rooney. 2003. Decortication level and particle size effect on direct-expanded white sorghum extrudates. 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 Research and Utilization Conference, p. 36. Albuquerque, New Mexico, U.S.

Acosta, D., M. Riaz, R.D. Waniska, and L.W. Rooney. 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 Research and Utilization Conference, p. 119. Albuquerque, New Mexico, U.S.

Awika, J.M., L.W. Rooney, X.L. Wu, R.L. Prior, and L. Cisneros. 2003. Antioxidant properties of sorghum measured by three methods. 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 Research and Utilization Conference, p. 34. Albuquerque, New Mexico, U.S.

Bejosano, F.P., W. L. Rooney, R. R. Klein, L. W. Rooney, and R. D. Waniska. 2003. Antifungal proteins in commercial hybrids and elite 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 Research and Utilization Conference, p. 38. Albuquerque, New Mexico, U.S.

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 Research and Utilization Conference, p. 39. Albuquerque, New Mexico, U.S.

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 Research and Utilization Conference, p. 37. Albuquerque, New Mexico, U.S.

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 Research and Utilization Conference, p. 35. Albuquerque, New Mexico, U.S.

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 Research and Utilization Conference, p. 32. Albuquerque, New Mexico, U.S.

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 Research and Utilization Conference, p. 33. Albuquerque, New Mexico, U.S.

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

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

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

Maranphal, N., M. Barron, L. Rooney, R.D. Waniska, and M.N. Riaz. 2002. Extrusion properties of sorghum for third generation snacks. http://www.aaccnet.org/meetings/2002/abstracts/a02ma347.asp. Montreal, Quebec