

Crop Utilization and Marketing



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

**Project PRF 212
Bruce R. Hamaker
Purdue University**

Principal Investigator

Bruce R. Hamaker, Dept. of Food Science, Purdue University, West Lafayette, IN 47907

Collaborating Scientists

Mr. Kaka Saley, Cereal Scientist; Mr. Moustapha Moussa, Cereal Technologist; Ms. Ramatou Seydou, Chemist; Dr. Issoufou Kapran, Sorghum Breeder; INRAN B.P. 429, Niamey, Niger
Ms. Senayit Yetneberk, Cereal Scientist, EARO, Nazret Research Station, P.O. Box 436, Nazret, Ethiopia
Ms. Betty Bugusu, Cereal Scientist, KARI, Katumani Natl Dryland Farming Res. Ctr, P.O. Box 340, Machakos, Kenya
Mr. Ababacar N'Doye, Research & Development Director, ITA, B.P. 2765, Dakar, Senegal
Dr. Iro Nkama, Professor, University of Maiduguri, P.O. Box 1069, Maiduguri, Nigeria
Mr. Boniface Bougouma, Cereal Scientist, IRSAT/DTA, B.P. 7047, Ouagadougou, Burkina Faso
Dr. John Taylor, Cereal Chemist, University of Pretoria, Food Technology Department, Pretoria 0002, South Africa
Dr. Adam Aboubacar, Assistant Professor, University of Wisconsin-Stout, P.O. Box 790, Menomonie, WI 54751
Dr. Arun Chandrashekar, Cereal Chemist, CFTRI, Dept. of Food Microbiology, Mysore 570013, India
Dr. Gebisa Ejeta, Sorghum Breeder; Dr. Layi Adeola, Poultry Nutritionist; Dr. Moustapha Benmoussa, Plant Molecular Biologist, Purdue University, West Lafayette, IN 47907
Dr. Brian Larkins, Plant Molecular Biologist, University of Arizona, Tucson, AZ 85701
Dr. Tae Wae Moon, Food Chemist, Seoul National University, Seoul, Korea

Summary

The PRF-212 project at Purdue University is involved in fundamental and applied research to solve food quality and nutritional problems of sorghum and millet. In collaborative efforts in West Africa, a majority of our work focuses on the goal of commercializing high quality sorghum and millet products. The overall aim of our research is to make sorghum and millet more competitive as grains for human and animal nutrition, and for utilization in traditional and processed foods. In the past year, we continued to progress in the area of nutritional improvement of sorghum grain. In collaboration with breeders at Purdue, a modified, improved grain quality high protein digestibility/high-lysine sorghum mutant was tested in the field with promising results and a strategy was developed to further improve grain quality. Biochemical studies involving differential protein expression of the mutant showed a pleiotropic response with higher expression of a range of proteins. Consistent increases in chaperone proteins in likely response to a misfolded g-kafirin protein make this later protein a candidate mutant protein. In a related study in our group, though not funded through the INTSORMIL project, g-zein, the maize counterpart to the hard to digest g-kafirin protein, was protein engineered to be highly digestible protein, as a

recombinant *E. coli*-expressed protein. This shows that single amino acid changes can have dramatic effects on digestibility. In this case, the g-kafirin protein was previously shown to be responsible for the overall lower digestibility of sorghum protein. In related studies, we have shown that low protein digestibility of cooked sorghum is linked to its low starch digestibility, and that improvement in the former leads to higher starch digestibility. In this year, the role of the protein web-like structures that form during cooking and contain gelatinized starch was made clearer to starch digestion property. Starch associated with protein structures was less digestible than free gelatinized starch. Manipulation of starch digestion rate, both up and down, is desirable to produce more digestible sorghum foods for populations with marginal energy intake and for slowly digestible, low glycemic foods for health benefit.

Work continues on couscous and high quality flour processing in Niger with efforts to contract good, clean grain for processing competitive products. A regional effort in West Africa is underway to develop a strategy and proposal to stimulate processing of high quality sorghum and millet products

using supply chain management linking producers to processors. At Purdue, studies have been initiated on development of low-cost, quality pregelatinized flours for use in thin and thick porridges and weaning foods. Other studies showed significant grain decortication effect on porridge firmness. Starch structural aspects have been identified that influence staling properties of sorghum, and show that variability exists that can potentially be used to identify cultivars with improved food staling and keeping qualities.

Objectives, Production and Utilization Constraints

Objectives

- Determine the relationships among the physical, structural, and chemical components of grains and food to improve food and nutritional 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

Food Products

Couscous and High Quality Flour Processing

Our collaborative efforts to stimulate couscous and high quality flour production continue in Niger with more emphasis on regional strategies to commercialize sorghum and millet products. A group of food scientists/technologists with representatives from each of the six INTSORMIL-collaborating West African countries assembled in Ouagadougou in December 2004 to strategize on a regional approach to obtain funding for incubation units at the NARS food technology laboratories, to better interact with local and regional processors. This INTSORMIL regional-sponsored activity is being continued with the drafting of a proposal for funding processing activities.

As described in previous annual reports, PRF-212 and the INRAN Food Technology Laboratory have set up a cereal processing unit at INRAN/Niger 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*. The core of the sorghum/millet processing unit consists of a commercial scale grain decorticator (dehuller) and hammer mill, a central mechanized agglomerator designed and fabricated at CIRAD, France by J. Faure, a mixer for flour wetting, a couscoussiere (steamer), and a large passive solar drying unit. The ability to produce high quality sorghum and millet flours is essential for the commercial success of any flour-based product.

Various market tests have shown high acceptability of couscous and flours produced in the unit. Current work, in collaboration with O. Botorou and economists, is on contracting farmers to provide a pure, clean grain source for processed products. This is critical to make consistent, acceptable products. A recent achievement of the group (funded through IFAD, Millet and Sorghum Initiative) is the fabrication of the agglomerator locally in Niamey and assisting a local entrepreneur in setting up her own mechanized processing facility. Two contractual agreements between farmers and the INRAN food technology laboratory were implemented to obtain 10 tons of high quality sorghum grains (5 tons of *cv.* SEPON 82 and 5 tons of *cv.* MDK).

Pregelatinized Sorghum Flour Products

In this M.S. level study (M. Moussa, INRAN/Niger), a drum-drier and an unusual, and comparably low-cost, low pres-

sure, high temperature extrusion system are being used to produce pregelatinized sorghum flours for possible commercialization as instant porridge (thin or thick) and weaning food mixes. Pregelatinization is a common way of starch modification, where a starch slurry is completely cooked and dried. Pregelatinized starches have the important functional property of cold water absorption and swelling, and are used as viscosity builders in many food applications. Extrusion cooking (high temperature and pressure) and drum drying are the most common methods used to produce pregelatinized food products. The low pressure, high temperature process employed in this project produces non-expanded products that can then be ground to pregelatinized flours. Another advantage of pregelatinized products is their good shelf-life property due to decreased water activity that reduces or eliminates enzyme activity, particularly lipases and lipoxygenases that degrade residual fat.

Objectives of this study, include: 1) understanding the effect of processing methods and process variables on pregelatinized flour quality, 2) the effect of different sorghum varieties on product quality, 3) optimization of process parameters and sorghum varieties, and 4) cost analysis, and 5) sensory evaluation of foods made from the pregelatinized flour to be conducted at Purdue and in a West African community. The low pressure, high temperature extruder is used with comparison to product made from a drum-drier.

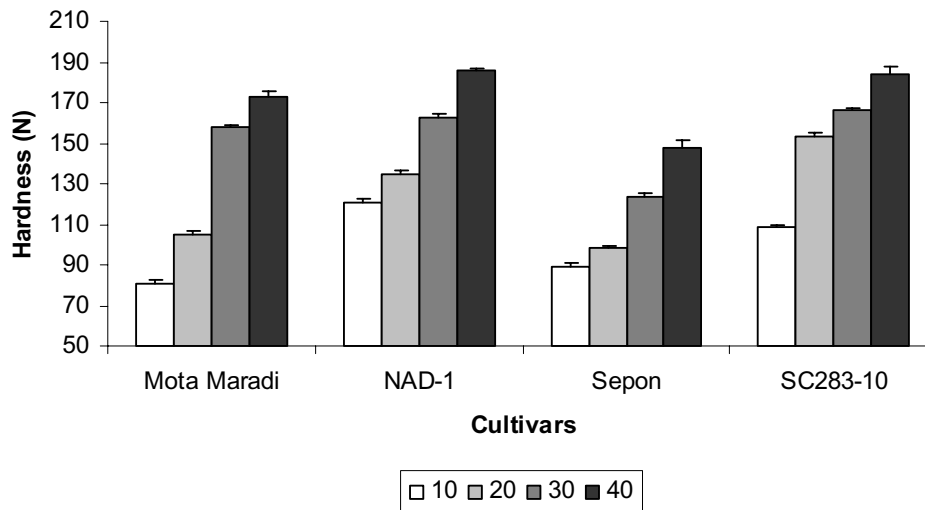
The viscosity of the paste, which is critical to its eating quality, depends to a large extent on the degree of gelatinization of the starch granules and the extent of their molecular breakdown. Initial studies have been conducted using the extruder identify good extrusion conditions and to understand these two parameters in relation to paste quality. Moisture content of the feed was the major factor determining gelatinization extent. An increase in moisture content from 12% to 40% at a working die pressure of 95 psi produced a progres-

sive decrease of Rapid ViscoAnalyzer peak viscosity, trough, and setback from 1262-517 cp, 985-396.5 cp, and 1781-336 cp, respectively; as well as an increase in final viscosity from 732.5-2766.5 cp for the various samples. Consequently, these changes indicate a transformation of the starch with lowest peak viscosity representing essentially complete starch gelatinization. Further studies will define quality in terms of molecular breakdown and other changes to optimize the process. Sensory evaluation will consider a small range of thin and thick pastes made from pregelatinized flours from the extrusion and drum-drying processes, and will be compared to control pastes using the traditional cooking process.

Effect of Decortication Level on Porridge Texture

Sorghum and millet are typically decorticated (outer kernel layer removed) prior to grinding to flours and used for thick porridges in West and East Africa. In this study, the effect of decortication on sorghum porridge texture was examined. Mean values of flour gel hardness from the decorticated samples are shown in Figure 1. Flour gels of the four cultivars increased in stiffness as flour decortication level increased from 10 to 40%. Gels made from cv's NAD-1 and SC283-14 were the hardest at all decortication levels (NAD-1: 120, 134, 163, 186 N at 10, 20, 30 and 40%; and SC283-14: 109, 153, 167, 184 N at 10, 20, 30 and 40%) followed by those made from Mota Maradi (81.1, 105, 158, 173 N at 10, 20, 30, and 40%), while those made from Sepon (89, 99, 124, 148 N at 10, 20, 30, and 40%) were the softest except at 10% kernel removal. Although having lower starch concentration, cultivar Mota Maradi had harder gels (except at 10%) than those of Sepon, indicating that some other factor such as amylopectin fine structure may have contributed. For example, another study in our laboratory (Lin et al 2002 Cereal Chem. 79:354-358) showed that the proportion of amylopectin long chains was highly and positively correlated with maize gel hardness. Correlation analysis indicated that starch concen-

Figure 1. Effect of decortication (10, 20, 30 and 40% levels) on porridge hardness.



tration is strongly associated with gel hardness within a cultivar. The correlation coefficients were 0.92, 1.0, 0.86 and 0.99 for Mota Maradi, NAD-1, Sepon, and SC283-14, respectively.

Thus, gels made from the cultivars became stiffer as decortication level increased, which is desirable since consumers have greater preference for firmer gels. These results indicate that good quality sorghum-based products or products containing sorghum flours can be obtained by adjusting milling conditions. However, economic forces lean towards greatest recovery of flour (lowest decortication level). A somewhat higher priced, highly decorticated flour, though, may be suitable for some consumers and food processes. Processing of high quality sorghum-based products is of increasing importance in sorghum-growing regions of Africa due to current emphasis on commercialization of products made from locally grown grains for sale in urban areas.

Starch Structure and Keeping Quality of Sorghum and Tef Injera

In collaboration with John Taylor and Senayit Yetneberk (then doctoral student from EARO Ethiopia) at University of Pretoria, starch properties were analyzed for several cultivars of sorghum and one cultivar of tef and related to the staling of injera, an Ethiopian fermented flat bread. Injera is a major food product for much of the population of Ethiopia. A traditional fermented flat bread, injera may be made from one or more of the following grain sources: tef, sorghum, millet, maize, barley, or wheat. The texture of injera is critical for consumer acceptance. High quality injera should be bendable and light with small air bubbles or "eyes" evenly distributed throughout the bread. A soft pliable texture is important as injera is often used as an edible utensil for consuming meat or vegetable stews. Tef is a traditionally used to make injera, however it is one of the more expensive grains found in Ethiopia and sorghum is a suitable substitute. Injera made from sorghum does not typically store well, while injera made from tef can retain a soft pliable texture for up to 3 days after baking. In the study of Yetneberk and Taylor, a range of sorghum cultivars were used to make injera with different keeping quality and were compared to tef injera.

Regarding starch characteristics, no relationship was found between the average molecular weight of amylose and amylopectin and injera staling. Chromatographic profiles of isoamylase digested amylopectin, which provides information on its fine structure, showed no significant difference in the proportions of fraction I (FrI, long chains), fraction II (FrII, intermediate chains), and fraction III (FrIII, short chains) among sorghum cultivars; while tef cultivar DZ-01-196 had a significantly higher proportion of FrI and a significantly lower proportion of FrIII compared with sorghum cultivars. Analysis of average number degree of polymerization (DP_n) for FrII indicated that sorghum cultivars with shorter DP_n for FrII produced slower staling injera compared with sorghum cultivars with longer FrII DP_n . Though there is not a clear indication of

starch molecular properties needed to improve staling, a complementary study reported last year showed a high correlation with the proportion of amylopectin long chain fraction and development of longer term gel hardness (related to staling). Variation in sorghum cultivars was noted that may offer a future way, through genetics, to develop sorghum cultivars with improved staling properties.

Nutritional Quality Improvements in Sorghum

We continue to work on the high protein digestibility/high-lysine sorghum mutant identified in the mid-1990's with two aims: 1) to improve grain quality (hardness) in lines that show stability over environment and consistency in panicles, and 2) to identify fundamental biochemical changes due to the mutation, and to compile information on the mutant gene responsible for the enhanced digestibility and protein quality. Also, the more recent finding by B. Bugusu in our group shows comparably high starch digestibility in mutant flour sorghum pastes. As described in previous reports and publications, 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 also causes over expression of certain cytoplasmic proteins that concurrently result in elevated lysine content. Practical advantages of the high protein digestibility trait are for improved protein nutritional value for people who have margin protein intake and for livestock where high protein feed meals are expensive relative to sorghum. Increasing energy (starch) utilization of staple cereals, particularly of sorghum with somewhat poor digestibility characteristics, is additionally critical for subpopulations that have chronically low caloric intake.

Collaborative work on digestibility aspects of sorghum was carried out in the 1990's with J. Axtell (deceased), and has recently been renewed with G. Ejeta.

Grain Quality

High protein digestibility lines with a previously reported intermediate, and unique in nature, modified hard endosperm trait are currently being tested for stability over environments. In another study, genotypes were developed to understand whether a dosage effect would be present regarding the high protein digestibility trait. Results show that, in fact, when copies of the mutant genome are reduced from 3 to 2 to 1, digestibility decreases concomitantly. This may offer a strategy to obtain a compromise in improved digestibility with good grain quality.

Biochemical Changes in the High Protein Digestibility/High-Lysine Mutant

Through an understanding of the biochemical changes that occur due to the high protein digestibility/high-lysine mutation, an approach can be identified to identify the mutant gene,

as well as develop ways to alter protein digestibility and quality characteristics of sorghum. Seed developmental studies in our laboratory have supported and expanded previous findings in India (collaboration with A. Chandrashekar) that expression of the BiP chaperone protein is much higher in the mutant grain than wild-type beginning at 20 days after pollination; the period that kafirin synthesis is at its highest. Two other chaperone-type proteins, heat-shock protein 70 (HSP70) and protein disulfide isomerase (PDI), were found to be present in higher amount at early stages of seed development for HSP70 and later stages of development for PDI. Taken together, this indicates that misfolding of the protein body in the high protein digestibility mutant causes repair or chaperone protein expression to be enhanced, but at different times.

In the past year in a study in our laboratory by M. Benmoussa (partially funded through INTSORMIL), total proteins (kafirins and non-kafirins) from wild and mutant-type lines were separated by a high resolution 2-dimension gel electrophoresis, stained and analyzed by PDQuest software to determine differential protein expression (Figure 2). Spots differing in the mutant were identified by Maldi-TOF mass spectrometry. Data analysis resulted in the identification of the differing spots in the sorghum mutant as GTP-binding protein, chaperonin hsp 70 Kd, ribosomal protein S2, protein disulfide isomerase precursor (PDI), luminal binding protein (BiP) 75, 70 and 45 Kd, plastid-localized – maize 50S ribosomal protein, glyceraldehyde 3-phosphate dehydrogenase, triosephosphate-isomerase, malate dehydrogenase, chloroplast 30S ribosomal protein S7, S-adenosylmethionine synthetase 2, RNA polymerase I, maturase, actin, actin depolymerising

like protein, chloroplast inner envelope protein, and flavonoid 3',5'-hydroxylase.

Thus, there was a pleiotropic response in protein expression caused by the point mutation for the high protein digestibility/high-lysine phenotype. Results showed that the expression of many proteins was affected in the mutant. Flavonoid metabolism was affected due to the mutation. Most evident, again, were the high expression of a number of chaperone proteins. Enhanced expression level of chaperon proteins is apparently in response to a misfolded kafirin protein, perhaps g-kafirin making it a candidate gene for mutational analysis. Cytoskeleton-related proteins were also affected; in particular the expression of actin was reduced. (Figure 2)

Related Study on Maize g-Zein Digestibility

Improving nutritional availability of prolamins is of interest in food, feed and biofuel applications. g-Prolamin, g-kafirin in sorghum and its counterpart g-zein in maize, has been shown in previous studies in our laboratory to determine the overall digestibility of prolamins due to their location at the protein body periphery and their hard-to-digest characteristic. These proteins additionally influence digestibility of starch. In a related study from our laboratory (though not funded through INTSORMIL), we recently showed that a protein engineering approach can be successfully used to increase g-prolamin digestibility.

Work done by S.H. Lee (doctoral student in our laboratory) tested hypotheses that certain single amino acid changes

Figure 2. High resolution 2-dimension gels of total protein extracts from wild-type and high protein digestibility mutant sorghum seeds.

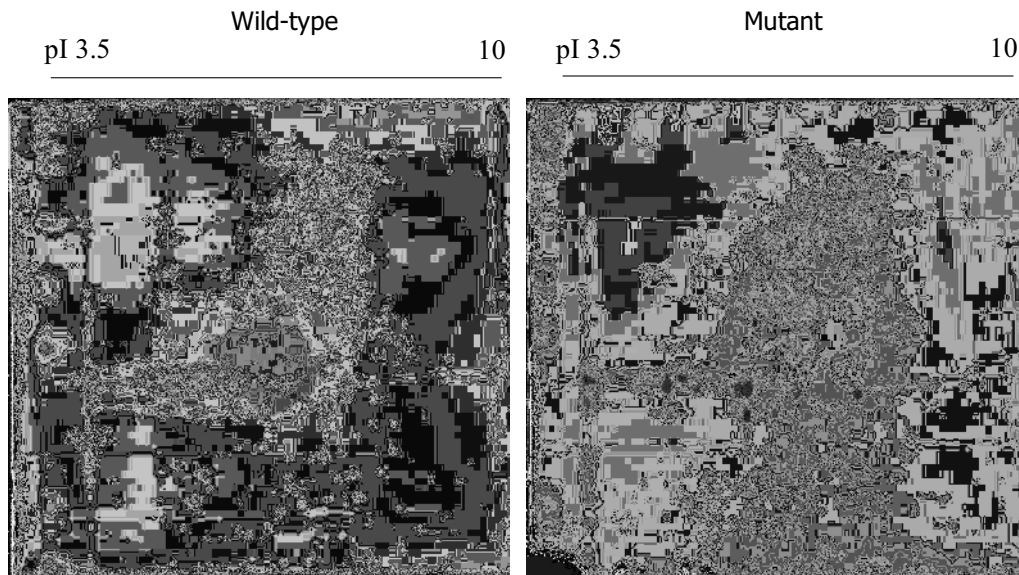


Figure 3. Western blot of time-course pepsin digestions of expressed recombinant γ -zein proteins by pET-24a(+) indicated by the arrow. Note the rapid digestion of the Cys mutant protein.

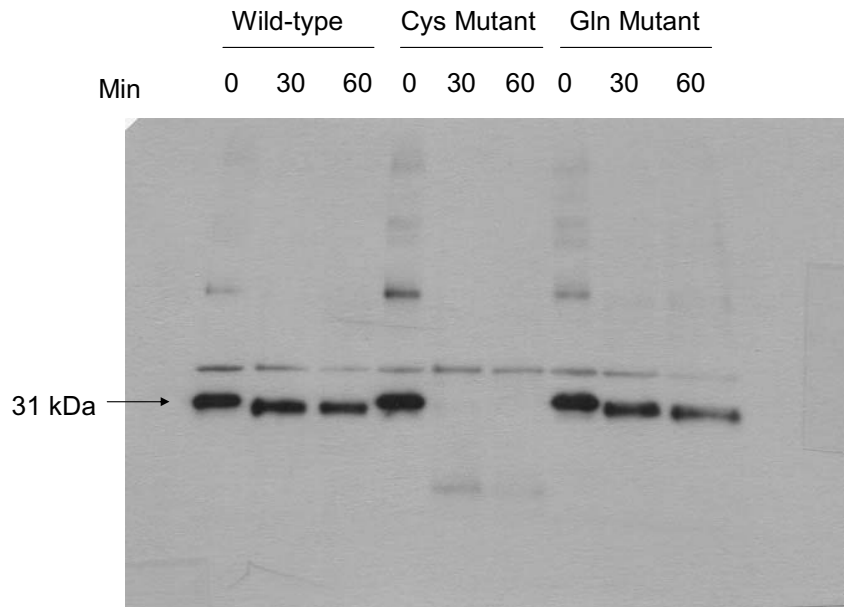
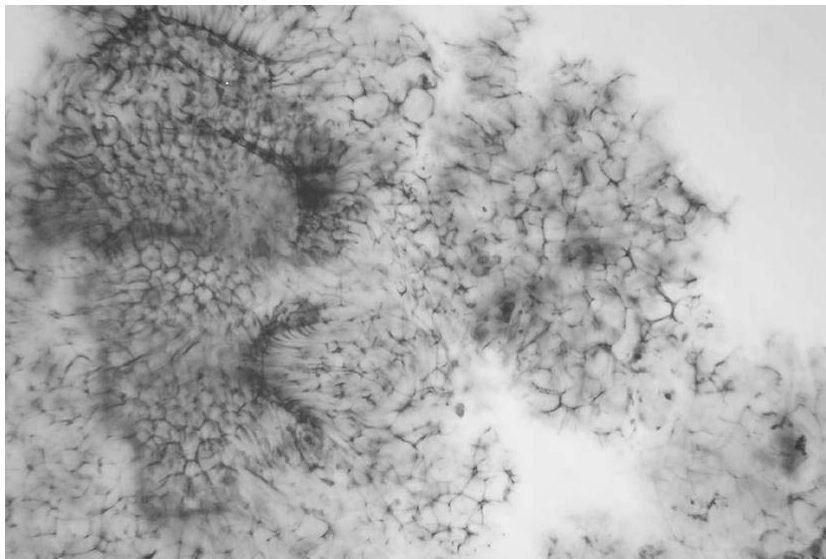


Figure 4. Cooked sorghum (P721N) paste with dual staining (protein – Gelcode (blue/dark); starch – periodic acid staining (pink/light) showing containment of much of the gelatinized starch in a 3-dimensional protein web-like structure. Evidence shows that starch digestion is slowed in these structures, particularly with hard to digest protein.



would improve overall digestion properties of g -zein. Due to the high sequence homology between g -zein and g -kafirin, one could expect a similar response to amino acid alterations in g -kafirin. A g -zein clone (originally from B. Larkins group) was subjected to site-directed mutagenesis using the QuickChange™ site-directed mutagenesis kit (Stratagene, CA)

with two specifically designed oligonucleotides shown above following manufacturer's protocol. Obtained mutated plasmids ligated with the expression vectors, pET-30a(+) and pET-24a(+), were transformed into Rosetta-gami™ 2(DE3) bacterial cells, followed by screening positives on LB agar plates containing kanamycin and induction with IPTG. Two mutants,

Cys and Gln, were chosen for digestion experiments. Proteins were digested with pepsin, trypsin, or chymotrypsin. Figure 3 shows results of pepsin digestion of the wild-type, Cys mutant, and Gln mutant recombinant expressed proteins. By changing one Cys residue to Ala, pepsin digestibility increased dramatically. This convincingly shows that compact folding of the protein causes its hard-to-digest character, and that the unfolded protein digests very quickly.

This protein engineering approach, therefore, holds promise as a way of improving digestibility through transformation of such mutated gene clones into maize and sorghum plants. Because the g-prolamin has poor digestibility and surrounds the more digestible a-kafirin major storage protein, its improvement in digestibility conceivably could positively affect overall protein digestibility, as well as starch digestibility. This could confer a nutritional improvement of the grain for animal feed and human food, and possibly for biofuels. This approach, however, does imply a “genetic modification” that must be considered in its application.

Starch Digestibility of Cooked Sorghum Foods

Our work on starch digestion properties of cooked sorghum foods has a two-fold application. Both derive from the comparably low starch digestibility, or slowly digestible starch property, that characterizes many sorghum foods. In poor, high sorghum-consuming regions, populations not meeting UN-set requirements for energy intake would benefit from more highly digestive sorghum varieties, while in over-consuming, obese-prone populations in developed, and some urban areas of developing countries, would gain from sorghum’s slower digesting property. Our research has addressed both aspects of starch digestibility of sorghum-based foods.

As previously reported, starch digestibility was found to be improved in the high protein digestibility mutant sorghum due to the fast digesting protein component. In a larger sense, though, this suggests that normal sorghum varieties that inherently have higher protein digestibility would likewise have higher starch digestibility. Highly digestibility sorghums would be valuable in weaning foods and other foods where high availability of macronutrients is important.

Secondly, sorghum proteins were previously reported to form web- and sheet-like structures that constrain swelling of the gelatinized granules and reduce starch digestion rate and overall digestibility. Figure 4 shows a light micrograph of such web-like structures in cooked sorghum porridge (double-stained with protein in the darker network and starch in dispersed within). Following digestion up to 60 minutes with α -amylase, remaining starch was found associated with the protein network; gelatinized starch initially outside the confines of the protein network was digested first. This shows that protein contained starch has a slower digesting property than does free starch, and explains why sorghum-based foods are less digestible than other cereals such as rice where proteins ag-

gregate on cooking. Maize was found to behave somewhat similarly to sorghum, but faster digesting proteins of cooked maize foods likely, in turn, expose starch for more ready digestion. We believe that the high protein digestibility/high lysine sorghum mutant has higher starch digestibility in cooked porridge due to rapid protein digestion that releases gelatinized starch from this dense protein network. Ability to manipulate this trait from high to low starch digestibility would be quite useful in sorghum and other grains.

Networking Activities

In November 2004, Dr. Hamaker traveled to Bamako, Mali to participate in a meeting on the contracting and marketing regional project of J. Sanders and O. Botorou.

Dr. Hamaker traveled to Ouagadougou in December 2004 to participate in a West African regional crop utilization group meeting. This group is charged with developing a proposal to stimulate sorghum and millet processing in the region.

In February 2005, Dr. Hamaker traveled to Reno, Nevada to attend an INTSORMIL Technical Committee meeting and the following biennial sorghum meetings.

Publications and Presentations

Abstracts

- Woo, H.D., Choi, S.J, Ha, H.J., Hamaker, B.R. and T.W. Moon., In vitro protein and starch digestibility of sorghum in the presence of sodium bisulfite, Institute of Food Technologists annual meeting, Las Vegas, July.
- Han, X.Z., BeMiller, J.N. and Hamaker, B.R., Channels in starch granules affect extractability of granule-bound starch synthase, Institute of Food Technologists annual meeting, Las Vegas, July.
- Benmoussa, M., Suhendra, B., Aboubacar, A. and Hamaker, B.R. Effects of starch granule morphology on sorghum starch digestibility, American Association of Cereal Chemists annual meeting, San Diego, September.
- Bugusu, B.A. and Hamaker, B.R.. Effect of protein microstructure on starch digestibility of cooked sorghum porridge, American Association of Cereal Chemists annual meeting, San Diego, September.
- Benmoussa, M., Chandrashekar, A. and Hamaker, B.R., Profiling endosperm protein expression of a high protein digestibility sorghum mutant, American Association of Cereal Chemists annual meeting, San Diego, September.
- Barth, A.M. and Hamaker, B.R., Effect of starch properties on sorghum product functionality, American Association of Cereal Chemists annual meeting, San Diego, September.
- Hamaker, B.R. and Bugusu, B.A., Comparably low starch digestibility of sorghum foods and its health implications, American Association of Cereal Chemists annual meeting, San Diego, September.

Journal Articles

Han, X.Z., Benmoussa, M., Gray, J.A., BeMiller, J.N. and Hamaker, B.R. 2005. Detection of proteins in starch granule channels. *Cereal Chem.* 82(4):351-355.

Dissertations and Theses

Barth, A.M. 2004. Role and proposed mechanism of starch retrogradation in determining sorghum porridge texture. M.S.

Food and Nutritional Quality of Sorghum and Millet

Project TAM 226

L.W. Rooney

Texas A&M University

Principal Investigator

Lloyd W. Rooney, Professor, Food Science & Agronomy, Cereal Quality Lab, Soil & Crop Sciences Dept., Texas A&M University, College Station, Texas 77843

Cooperator: Ralph D. Waniska, Professor, Food Science, Cereal Quality Lab, Texas A&M University, College Station, Texas 77843

Collaborating Scientists

Dr. A. Touré, Sorghum Breeder, Institute Economic Rurale, Bamako, Mali

Dr. G. Peterson, Texas A&M Ag Research and Extension Center, Lubbock, TX 79401

Drs. W.L. Rooney and D. Hays, Texas A&M University, Soil & Crop Sciences, College Station, TXs 77843-2474

Drs. Mitch Tuinstra, Dept. of Agronomy, and Joe Hancock, Dept. of Animal Sciences and Industry, Kansas State University, Manhattan, KS 66506-5506

Dr. Sergio Serna-Saldivar, Professor and Head, Food Science, ITESM de Monterrey, Monterrey, Mexico

Professor John R.N. Taylor, Head, Food Technology Dept., University of Pretoria, Pretoria 0002, South Africa

Ms. Ruth Vilma Calderon, Food Technologist, and Ing. René Clará, Sorghum Breeder, CENTA, Km 331/2 Carretera a Santa Ana, San Andrés, La Libertad, El Salvador

Ms. Eliette Palacio, Seed Technologist, INTA, Managua, Nicaragua

Dr. Javier Bueso, Associate Professor, Escuela Agrícola Panamericano, Zamarano, Honduras

Dr. John Sanders, Professor, Agriculture Economics, Purdue University, W. Lafayette, IN 47907-2056

Summary

New, more-efficient, higher-yielding white tan photosensitive varieties from the IER breeding program in Mali have excellent properties for food processing. They escape significant weathering/ molding that adversely affects earlier insensitive white tan sorghums which led to their failure. Farmers were pleased with the grain quality for their own food and appreciated the opportunity to sell the grain at a potential premium. The principle of supply chain management from seed to food products has been demonstrated; however, more work to obtain wide-spread participation is required.

Similar situations exist in El Salvador where small farmers have vertically integrated and sell their own white tan sorghums in the form of baked products. There are some significant successes in this area.

United States value-enhanced white food sorghums developed in part by this project and promoted by the U.S. Grains Council in Japan continued to be used by the Japanese food industry to market snacks and several other products. The white sorghums are color sorted, decorticated, and used as an ingredient in a wide variety of foods including brewing. The cost of value-added white sorghums is competitive with domestic Japanese rice.

Several small 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 and ethnic groups. Other food companies are developing new food products and preparing mixes for special markets.

Special sorghums with high levels of phenols and antioxidants were extruded to produce snacks with high levels of antioxidants. The extruder is a low-cost, short-barrel friction type that could be used by small companies in targeted countries, i.e., Central America. The extrudates are high in dietary fiber as well as antioxidants. We found that whole, cracked and decorticated sorghums produced a wide variety of extrudates. The extruded whole grain products have significant appeal as health foods. Bread machine mixes with sorghum bran, gluten, flax and barley flour produced good-quality bread with a natural dark color and improved nutritional value.

We continue to monitor the quality of new food-type sorghums in special sorghum nurseries grown in the sorghum belt by collaboration with Drs. Tuinstra, Rooney, Peterson and others. The IFSAT trials consisting of advanced food sorghums of potential value in host countries is evaluated for quality

annually in several locations. 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. Red tan plant hybrid sorghums have excellent milling properties compared to red purple plant sorghums.

Tannin and other special sorghums have excellent levels of antioxidant power, high dietary fiber and impart attractive dark natural color to baked products. They can be incorporated into a wide variety of products. Small quantities of tannin sorghum bran were an effective preservative for ground beef patties.

Workshops on food sorghums and special tannin sorghums as health foods were presented in South Africa, Central America, Mali and to technical conferences and industry personnel in the USA.

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 need new 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. Profit for all from the seed to the processor is necessary.

Significant Accomplishments

Profitable Food and Feed Markets for Sorghums and Millet

We believe strongly that supply chain management is the way to improve adoption of new technologies from new cultivars to other management practices provided there is a profitable market for the grain produced. This is an emerging situation that occurs only when sufficient margins are available to produce increased profits for all parties in the supply chain. Successful development of this system is difficult and requires patience and practical programs to educate key managers, farmers and processors.

Several extruded salty snacks and milled products based on identity preserved U.S. white food sorghums continue to be sold by Japanese food companies. South Korea and other countries are interested in using white food sorghums. Utilization of sorghum in these highly developed countries helps 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 purchased by consumers provided convenience, good taste, appearance and consistent quality is available at competitive prices.

White sorghum for brewing beer is gaining momentum since South African Breweries (SAB) initiated contracting for white sorghum. The supply chain management is a key component of their program that is occurring in several Southern

and East African countries. In South Africa, interest in white food sorghum is increasing especially in the small holder areas of Limpopo State.

New second generation value-enhanced food sorghum cultivars from the Malian sorghum breeding program have improved productivity and profitability as indicated by farmers who planted them. They like the grain yields, agronomics, the improved grain quality for their own food processing and potential premium prices. It is important to recognize that these farmers still have this attitude even though they had a bad experience with grain traders who defaulted on the initial contracts.

In Central America, a similar situation exists where farmers prefer tortillas made from white tan sorghum varieties instead of the native Criollos, which have purple glumes. The varieties Sureño, Soberano, Dorado and others with white tan plant color are used for tortillas, rosquillos, rosquettes and other products. In El Salvador, sorghum flours from white tan plant varieties are used in small bakeries to produce pan dulce, muffins, bread, rosquettes, 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 identify preserve food sorghums for processing is necessary for consistent success. The opportunities exist to stimulate use of white food sorghums in Central America since a source of grain is available, but inexpensive technologies that can be used to decorticate sorghum and mill it into flour or meal are required along with supply chain management.

Some producers process their own sorghum into flour and sell baked products in local village markets. These operators plant Dorado, harvest, store and process the grain into baked products. These activities apparently support the family since two or three daughters are involved along with the father who produces and stores the sorghum. According to CENTA personnel there are many examples of these small processors marketing sorghums in food products. There is significant interest in the larger formal baking industry in San Salvador to use white sorghum flour. Ms. R. Vilma Calderon, Food Technologist, CENTA, has worked with a rice miller to process white food sorghum into flour and decorticated products. The flour is acceptable to bakers in San Salvador.

Compatible Technology Incorporated, an NGO located in St. Paul, Minnesota, has developed an Omega VI grinder that provides an opportunity to grind decorticated sorghum into flour or meal in an economically effective way. The mill can be locally manufactured and may be an effective method of grinding decorticated grain into flour. These mills can be locally manufactured and are significantly more effective than the current grinders used for sorghum by the molineros. They can be operated by hand or by using a motor. Ms. Vilma Ruth Calderon, M.S. graduate student from El Salvador is evaluating

the mill and CTI is modifying it for grinding sorghum into flour. Work will continue.

There is real potential for use of the meal and other components in snacks via extrusion where a light color, bland flavor would be desirable (Figure 1). The concepts proven successful in Japan apply directly to use of the white sorghums in Central America and elsewhere. Bland flavor sorghum flour has an advantage over corn flour as a substitute for wheat flour and in producing certain types of snacks, i.e., extruded fried potato sticks. This affords an opportunity to utilize sorghum in popular food items.

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 by small hillside producers. The technologies developed in El Salvador can be utilized in Nicaragua; a workshop in Managua featured presentations by CENTA personnel and a commercial Salvadoran baker who demonstrated to Nicaraguan bakers the use of white sorghum flour.

Health Foods from Special Sorghums

The potential to produce healthy foods from sorghum is quite high. A team of graduate students won first prize in the American Association of Cereal Chemistry International Meeting for producing "Vita Bread" containing sorghum bran, flax seed, gluten and other ingredients. The bran is high in dietary fiber, antioxidants and natural brown or black pigments that impart attractive colors to baked products such as cookies and multigrain breads. Ms. Lindsey Hines, M.S. student, has developed combinations of sorghum bran, wheat gluten, flax and beta-glucans into mixes for bread machines following up previous research in our laboratory (Figure 2). A bread that contains modest levels of high tannin sorghums as a source of antioxidants is currently being sold by a commercial bakery.

The effect of tannins and cooked sorghum on glycemic index is being measured by a new graduate student. This is an effort to demonstrate another healthy feature of sorghum. In related studies, rat feeding trials are underway to evaluate tannin and special black sorghums that contain tannins and anthocyanins in high levels. Our interactions with the sorghum breeding program has led to different sorghums with significant variation in total phenols, antioxidant levels, color and potential applications as healthy food ingredients.

Gluten Free Breads for Celiacs

Ms. Lindsey Hines, M.S. student, also developed a gluten free bread for gluten intolerant people based on a blend of starches, xanthan gum, tannin sorghum bran, inulin and flax seed which produced excellent bread. The inulin improved loaf volume and softened the bread crumb significantly over the control bread while the dark color of the sorghum bran improved appearance and enhanced nutritional value significantly.

Figure 1. Extruded snack product prepared from white sorghum, coated with a savory flavoring. White sorghum provides a bland substrate that does not interfere with the flavors.

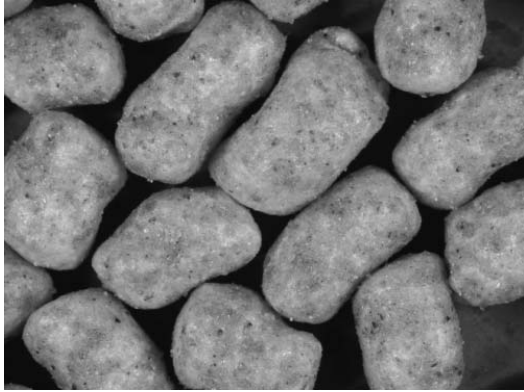
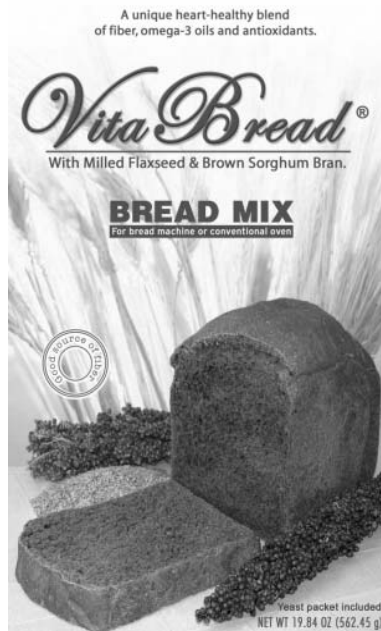


Figure 2. VitaBread mix, a prototype bread machine mix with high levels of antioxidants from brown sorghum and good nutritional factors including flaxseed. The mix is one of several prototype products showing the successful and tasty use of brown tannin sorghums in common food products.



This information was presented to Disney World chefs in Orlando Florida who are very interested in baked products without gluten for special diets. A five-member team made a wide variety of gluten-free foods and demonstrated them.

Extrusion Processing

It is possible to produce expanded sorghums directly from whole or ground white or tannin sorghum grains using low-cost friction extruders. These smaller extruders are used in

areas where infrastructure limits costly sophisticated processes. Thus, the ability to produce snacks directly from whole clean grain is a distinct advantage for sorghum. Extrudates of 100% whole tannin sorghums would have excellent nutritional properties. More work is needed to document their properties.

White sorghum samples prepared by combining four decortication levels (0, 10, 20 and 30%) and three particle sizes were extruded in a Maddox single screw friction-type extruder. A commercial yellow corn meal 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, crisper 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 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 affect expansion ratio, crispiness and bulk density.

Mr. Alejandro Perez, M.S. graduate student, demonstrated that whole grain, cracked whole grain and decorticated grain of waxy, heterowaxy and nonwaxy sorghums had significantly different extrusion properties which can lead to snacks and ready to eat breakfast cereals with different degrees of expansion and texture. For example, waxy whole grain extrudates had a softer texture with less expansion than nonwaxy or heterowaxy extrudates. These sorghums have different levels of amylose and have potential for use in numerous products.

Sorghum Starch, Malting and Brewing Studies

Dr. S.O. Serna-Saldivar, ITESM, Monterrey, Mexico, is continuing to collaborate on sorghum research, especially with graduate students 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 projects in El Salvador and Nicaragua and was a key speaker in the Nicaraguan white sorghum utilization workshop.

Tannins and Phenols

Ms. Linda Dykes, Ph.D. candidate, has documented the antioxidant level, tannin content and easily extractable phenols in a large number of sorghum samples from special studies of U.S. cultivars of known genetics compared to sorghums from West African countries including Niger, Mali, Burkina Faso and Senegal. She confirmed that sorghums containing B1B2S₁ genes had the highest levels of phenols, tannins and antioxidant activity. Sorghums with dominant B1B2s₂ had signifi-

cantly lower levels of tannins and antioxidant activity. She confirmed that sorghums without a pigmented testa did not have detectable levels of condensed tannins using HPLC and the vanillin assay with blanks subtracted to remove background noise.

The HPLC analysis of procyanidins (condensed tannins) indicated that tannin 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 might 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.

West African sorghums (140 plus samples) were evaluated for presence of pigmented testa using the chlorox bleach method; those testing positive were analyzed with the vanillin-HCl method. Most West African sorghums did not contain tannins in the grain; however, those cultivars that did contain tannins had low levels of tannins. Most had only the B1B2 genes which give low levels of tannins. Other samples were blends of tannin and tannin free grains. Overall, the incidence of tannins in sorghum grown in those four West African countries is low and does not significantly affect sorghum value for livestock feeds. Education of buyers and producers will alleviate the production of tannin sorghums except in special locations where they are needed.

Many myths about tannins that negatively affect the perception of sorghum as a feed exist; information from these studies should provide clear signals that sorghums are excellent feed for livestock as well as human foods. Dr. Sanders (PRF 205) and his colleagues are providing leadership to overcome these problems. A brochure on "Myths About Tannins" is in preparation and will be provided to the food, feed and related industries. The lack of understanding regarding tannins creates significant reluctance toward the use of sorghum by feeders and human nutritionists. Workshops in Central American, West Africa and Southern Africa spoke to this issue. More efforts are required to overcome the myths about tannins in sorghum because the confusion leads to poor acceptance of sorghum as food or feeds.

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. This work was in collaboration with Drs. Tuinstra, Peterson and W.L. Rooney who conducted the evaluation trials. Red and white sorghum hybrids grown at several locations in Texas and Kansas were evaluated for hardness using a SKHT (single kernel hardness tester), decortication properties using TADD (tangential abra-

sive dehulling device), TKW (thousand kernel weight), color (L, a, b), test weight, density, proximate composition and relative mold damage. 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. 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. However, the TADD or barley pearler more effectively predicts commercial decortication since the principles are similar to those used in large scale decorticators. 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 red tans might be useful for decortication and produce better food and poultry feed than the white tan sorghums currently being grown.

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.

Mold Resistance of Sorghum: Effect of Antifungal Proteins and Other Grain Properties

We presented the results of our work "Biochemical and Physical Traits Associated with Sorghum Grain Mold Resistance" in September 2004 at American Association of Cereal Chemists (AACC) Meeting in San Diego, California. This presentation was based on the evaluation of sorghums collected in 2003 from TAES Field Plantation in College Station. Sorghums (44 elite lines and hybrids) included 31 with red pericarp and 13 with white pericarp. Chitinase and sormatin in caryopses of sorghum at 30 and 50 days after anthesis (DAA) were determined. Mold resistance was more consistently related to the retention of antifungal proteins (AFP) from 30 to 50 DAA, than on seed physical traits such as seed density and color.

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

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

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

*SKHT = Single Kernel Hardness Tester.

Table 2. Sorghum traits and mold response among hybrids and parents.*

Sorghum Attribute	Hybrid	Female Parent	Male Parent	LSD ($\alpha=0.05$)
Mold Rating Score (1-5)	2.8 b	3.3 a	3.4 a	0.3
Germination Rate (%)	80 a	75 a	57 b	7
Chitinase Retention (%)	-2 a	-23 b	-28 b	8
Sormatin Retention (%)	0 a	-30 b	-28 b	10
Seed Density (g/cm ³)	1.370 a	1.342 c	1.356 b	0.013

*means in the same row with the same letter are not significantly different.

Sorghums (93 lines and hybrids) were grown in 2004 in the TAES Plantation in College Station under ambient conditions (not inoculated, no additional misting). Sorghums (52 red and 41 white) were sampled at physiological (30 DAA) and combine harvest maturity (50 DAA). The percentage loss in chitinase and sormatin from 30 to 50 DAA was referred to as the retention rate. Gain mold rating, germination rate, phenol content, seed density, hardness and seed color (L, a and b values) were also measured.

Grain mold rating and germination rate were significantly correlated with both chitinase and sormatin retention but not with phenol content and SKHT hardness. Seed density was correlated with grain mold rating but not with germination rate. Thus, sorghums that are more resistant to molds retain more chitinase and sormatin from 30 to 50 DAA than those which are susceptible. On the other hand, the study did not show a relationship between mold resistance and phenol content or seed hardness. Clearly, chitinase and sormatin contribute to limit mold damage of sorghum (Table 1).

From the sorghums evaluated in 2004, a subset comprising 33 hybrids and their respective male and female parents were evaluated to look into the inheritance pattern of antifungal proteins as it relates to mold resistance. The hybrids had improved mold resistance, germination, density and increased retention of chitinase and sormatin when compared to their parents (Table 2).

Our studies have shown that antifungal proteins significantly contribute to mold resistance in both red and white varieties. We found that hybrids had increased retention of antifungal proteins as compared to either of the parents as they mature in the field. Consequently, mold resistance of the hybrids was enhanced. However, mold resistance in sorghums is a complex interaction of various physical and chemical properties of the grain including antifungal proteins. All of these are affected by genetics of the plant and environmental conditions.

Networking Activities

Southern Africa

Graduate students in the Food Science Department at the University of Pretoria from many African countries participate in a Regional Program conducted jointly between CSIR and University of Pretoria. INTSORMIL's interaction with Professor Taylor and his colleagues at the University of Pretoria informs many future African food industry leaders of the potential role of sorghum and millets as food and industrial ingredients. Several workshops and related research projects have been mutually beneficial to all parties.

In October 2004, the University of Pretoria, INTSORMIL and the South African Sorghum Forum jointly sponsored a workshop on white sorghums for food with participants from Southern Africa and graduate students from the University of Pretoria. The University of Pretoria hosted the workshop which filled the auditorium with feed, food and seed industry personnel along with small entrepreneurs and major sorghum users in the malting and brewing industries. Both feed and food potentials were discussed and progress was made to determine actions required to promote use of sorghum in profitable food and feed applications. There is significant interest by South African Breweries and many smaller companies to access improved quality sorghums for use in lager beer.

Significant progress was made but investment in development of sorghum varieties and hybrids with improved processing properties is required for the long-term with practical demonstrations of its use in the short term. It is important to understand that sorghum use is decreasing in brewing of opaque beer but increasing in decorticated meals for porridges in spite of a 14% value-added tax on sorghum in South Africa. The current strong interest in white sorghums for brewing into Lager beer may influence policy to develop improved sorghum hybrids for Southern Africa.

Ms. Nomusa Ngwenya-Dlamini, Bulawayo, Zimbabwe, is working on a Ph.D. in food science at Texas A&M University and the University of Pretoria. She was awarded a Fulbright Fellowship to complete her Ph.D. program at TAMU. Professor J.R.N. Taylor, University of Pretoria, is a coadvisor on her Ph.D. dissertation involving antioxidants from sorghum. She taught food science courses at the National University of Zimbabwe in Bulawayo. She is on schedule to complete requirements in 18 months or more because she had already done some research on antioxidants in traditionally processed sorghums in South Africa. Professor Taylor will be in the U.S. to participate in her Ph.D. examination and orals this September.

Professor Taylor's research program is optimizing processes using local equipment for dry milling of sorghum and millet. For example, Mr. M. Kabile of Botswana is evaluating dry milling of sorghum as his Ph.D. research at the University

of Pretoria. Dr. Lloyd Rooney participates on these advisory committees.

Publications related to injera production by Dr. S. Yetneberk, Ethiopia who completed her Ph.D. at University of Pretoria were completed this past year and she returned to Ethiopia to work on sorghum quality.

Central America, Mexico and South America

Dr. L.W. Rooney traveled to Managua, Nicaragua to develop collaborative research plans and to participate in a workshop on utilization of sorghum for human and animals which was jointly sponsored by INTA, AMPROCESSORS and INTSORMIL. Collaborators in El Salvador (CENTA) and Dr. J Bueso, Associate Professor, EAP, Zamorano Honduras were key participants. In addition, Dr. Serna Saldivar, Professor and Head of the food technology department at Monterrey Institute of Technology summarized his research on sorghum utilization in brewing. The workshop included a commercial baker from El Salvador who made pan dulce and other products from composites of white sorghum and wheat flours. Personnel from CENTA and EAP in Central America presented excellent papers and demonstrations of sorghum food use. Drs. Sanders, Rooney and Hancock presented information on economics, food processing and practical feeding value of sorghum. Myths about sorghum tannins were discussed.

Dr. L.W. Rooney has long-term cooperative projects with Dr. S. Serna-Saldivar, Professor and Head, Food Science, Instituto Tecnológico 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 Ph.D. and subsequent post doctorate experience in our laboratory was partially funded from INTSORMIL.

We currently have five graduate students from Central America and Mexico partially funded on TAM 226. We are able to leverage our INTSORMIL funds by using additional research funds from private industry, TAMU graduate fellowships 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.

Ms. Vilma Ruth Calderon, food technologist, CENTA, joined our laboratory in January 2005 for a M.S. program in food science and technology. Ms. Y. Eliette Palacio, seed technologist, INTA was admitted to TAMU for a M.S. program but could not enroll because of health problems. She likely will enroll at ITESM in Monterrey Mexico for a M.S. program jointly with Texas A&M. Dr. Saldivar, Professor, ITESM will be her major professor.

Two scientists from Central America are scheduled for training.

West Africa

Ms. Yara Koreissi, Food Scientist, IER, Mali and Mr. Luis Sandoval, undergraduate student at EAP in Honduras were short-term trainees in the Cereal Quality Laboratory. Ms. Koreissi completed her M.S. in public health at Tulane University and is currently participating in a three-month training program to gain experience in cereal technology and processing. She will return to the food technology lab in the IER in Bamako. Mr. Sandoval returned to EAP to complete his B.S. program.

Mr. Joseph Gayin, Assistant Research Scientist, Food Research Institute, CSIR, Accra, Ghana, was a Borlaug Fellowship participant in our laboratory from September 1-30, 2004 where he gained experience in cereal technology and processing quality of sorghum and maize.

Dr. Lloyd Rooney participated in a workshop in Bamako, Mali on utilization and marketing of sorghum and millet feed and food products. He summarized current information on sorghum tannins and how they can be determined in market channels and how they affect quality for humans and animals. He is also participating in the West African project on marketing by providing information and analysis of West African sorghums for tannins. The information indicates that there are some sorghums containing condensed tannins produced in West Africa but the cultivars that have tannins do not have large quantities of tannins and do not reduce feeding value significantly. Only a few cultivars were found with high levels of tannins. A chlorox bleach test was used to distinguish the tannin types in market samples. Research on analysis of tannins and other phenols in sorghum continues since these compounds are considered health promoters.

A brochure to provide facts on tannins and debunk misinformation about sorghum has been drafted and will be made available to policy makers and potential users of sorghum.

North America

Several papers were presented at the American Association of Cereal Chemists Conference, San Diego, California and the Institute of Food Technologists Conference. We presented information on the utilization of whole grain sorghums for special dietary foods and whole grain products. Participants included many small and large food companies interested in diversifying products. Special sorghums for use in baked and extruded products were of interest to several companies. Some trials were made and interest continues with supply chain management a key need to secure adequate supplies of grain.

A special seminar and demonstration of gluten free products from white sorghum was presented to 52 Disney World chefs. The program organized by the National Sorghum Producers Association created interest and currently some small companies are trying to meet Disney's specifications for sorghum based bakery mixes.

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 one-week 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. Lloyd Rooney contains information on food sorghum. Participants (44) from all over the world (14 countries represented) 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.

Training, Education and Human Resource Development

Five graduate students currently work on INTSORMIL related research in our laboratory, with partial financial support while several others are supported from non-INTSORMIL funds. Inflation continues to significantly reduce the number of graduate students that can be supported.

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.

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Entrepreneurship and Product Development in East Africa: A Strategy to Promote Increased Use of Sorghum and Millet.

Project UNL 220
David S. Jackson
University of Nebraska – Lincoln

Principle Investigator

Dr. David S. Jackson, University of Nebraska - Lincoln, Dept. of Food Science & Technology, 256 Food Industry Bldg, Lincoln, NE 68583

Collaborating Scientists

Ms. Jill Gifford, University of Nebraska, Food Processing Center, Lincoln, NE 68583

Dr. Joseph J. Mpagalile, Sokoine University of Agriculture, Dept. of Food Science and Technology, P. O. Box 3006, Morogoro, Tanzania

Ms. Joan Scheel, University of Nebraska, Food Processing Center, Lincoln, NE 68583

Dr. Curt Weller, University of Nebraska, Dept. of Biological Systems Engineering, Lincoln, NE 68583

Summary

This new project was initiated on March 10th, 2005 and is designed to promote increased use of sorghum and millet by establishing an entrepreneurship education/training program coupled with follow-up technical and business support services. This training program is being coordinated and offered through the Sokoine University of Agriculture's (SUA) Department of Food Science and Technology. It is anticipated that new individual and village/cooperative ventures will be established that use sorghum and millet grain and ingredients in food products to be sold locally and in urban markets. Draft entrepreneurship training materials were adapted from those developed by the University of Nebraska's Food Processing Center with the on-site collaboration between UNL's Entrepreneurship Program coordinator Ms. Gifford and Dr. Mpagalile (who was in Nebraska through May 2005). After his return to Tanzania, Dr. Mpagalile has further coordinated

material refinement and localization by including local product photographs, Tanzania Food and Drug Agency (TFDA) regulations and Tanzania Bureau of Standards (TBS) specifications. A project coordinator was hired by SUA; the individual has a B.S. degree in agricultural economics and agribusiness with a wide experience in entrepreneurship and business incubator programs in Tanzania. The first *Entrepreneurial Workshop* is scheduled for September 20th, 2005; 19 entrepreneurs (or entrepreneurial groups) have been identified as initial workshop participants prior to any advertising. It is anticipated that approximately 15 individuals will attend the first workshop, which will serve as a prototype for future efforts. As part of the workshop, participant's efforts to further develop (or initially develop) their businesses will be supported by business and technical assistance provided by a network of SUA and UNL specialists.

