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

Our work has continued to focus on the nutritional quality traits of sorghum grain related to protein and starch digestibility in human food and animal feed, and also fundamental aspects of the grain related to its use in food. An overall objective is to find ways to improve sorghum so that it becomes more nutritious and competitive to other major cereal grains. In Niger, work continues towards commercialization of sorghum and millet agglomerated products (couscous and other similar particle size foods) and high quality flours. While we have not worked much on millet in our U.S. studies, there is now a somewhat greater emphasis on millet research and technology at the regional level with the addition of collaborators in Maiduguri, Nigeria who work on millet hybrid development, their quality, and products made from them.

In this year, a study was expanded on factors that cause lower cooked sorghum starch digestibility (and digestion rate) compared to other cooked cereal porridges. Sorghum lines were tested that exhibited a broad range of protein digestibilities – from 23 to 76% for a one hour pepsin digestion – that included high protein digestibility mutant lines and low to high digestibility normal lines. They were compared to maize and rice. Decorticating the sorghum grain and defatting the flour significantly increased starch digestibility in all samples by a similar margin (including other cereals). Notably, protease pretreatment resulted in significant increase in starch digestibility in all samples except for the normal sorghums. The highest increase was observed in the high protein digestibility cultivars (14-19%) followed by the maize control (8%) and rice (7%). These results showed that non-starch flour components contribute to low starch digestibility and low protein digestibility seems to be the single largest contributor. The relatively high starch digestibility of the high protein digestibility mutant lines suggest that this sorghum would be beneficial for use in foods such as for weaned infants where energy and protein recovery are important. However, improvement in grain quality of the high protein digestibility mutant lines is critical for their future use.

As reported last year, grain have been identified in progeny of crosses of the mutant to hard endosperm lines that are normal in appearance and contain the abnormal protein body structure typical of the high digestibility mutant. This has now been found both in the Purdue breeding lines and those coming out of the India project funded through Mahyco Research Foundation. Yet, difficulties still exist in consistency of grain quality within a panicle and the issue of stability of the trait. We are initiating a new project this year at Purdue in breeding and chemistry to work on this problem. Two collaborator studies have been completed on feed use of the high protein digestibility sorghum. A published study on its use in chickens showed substantially higher true amino acid digestibilities in the mutant, as well as one sorghum hybrid, compared to the normal parent or maize. A study (in press) using a least-cost feed mix linear programming model to examine the benefit of high protein digestibility sorghum shows, under certain situations, potential advantage of using the sorghum in poultry feed. Combina-

tion with improved starch digestibility would make the grain even more competitive, and this is our goal.

Chemical studies on sorghum grain components have shown that sorghum starch structure appears to be somewhat different from that of maize or rice, and may begin to explain differences in the way sorghum behaves in processed foods. Sorghum amylopectin, the large branched starch molecule, was shown to have a structure such that it may retrograde (reassociate) more extensively than in rice or maize. This would lead to increased rates of staling and thick gels on cooling. This research is a step in trying to find ways, either through breeding or processing, to improve basic grain properties for traditional and processed foods.

Activities regarding the sorghum/millet processing unit in Niger and work towards commercialization of couscous and other products continued. A large market test was completed and results are currently being analyzed. Collaboration with a few local entrepreneurs has led to marketing of products in stores.

Objectives, Production and Utilization Constraints

Objectives

- Determine the relationships among the physical, structural, and chemical components of the grain that affect the 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

Couscous and High Quality Flour Processing

Work continues towards developing and marketable sorghum and millet processed products in Niger and neighboring countries, and working with local entrepreneurs to encourage commercial production. Our goal is to combine research, marketing testing, and entrepreneurial training and demonstration to stimulate the processing of high quality, competitive products for urban areas. Over the past six years INRAN/Niger Food Technology Laboratory and PRF-212 have worked together to set up in Niamey an entrepreneurial-scale agglomerated products (mainly couscous) and flour processing unit. 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 J. 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. Since that time, a much larger passive solar drying unit was built at INRAN to dry approximately 200 kg couscous every 2 days. Currently that solar drying, which is the largest of its kind in Niamey, is being improved by the addition of a better-fitting and completely waterproof top. As high quality flours are essential to make quality couscous, a small-scale commercial grain decorticator (dehuller) and hammer mill (Urpata Sahel, Dakar) were procured through PRF-212 to complete the unit. The INRAN food technology group has in the past year also developed high quality flours as commercially viable products.

A strong and continued working relationship with the sorghum breeding program of Kapran-INRAN/ Axtell-Purdue has been important to this project. Their released hybrid, NAD-1, and now a second generation tan plant hybrid (still in the experimental phase) are being used to produce processed products. Over the last two years NAD-1 agglomerated products (fine couscous (or *dambou*), medium couscous, and the coarse particle-size product *degue*) and high quality decorticated flour have been produced by the unit in large quantities for a two part in-home consumer test and marketing study. This effort was assisted by economists C. Nelson (INTSORMIL) and J. Ndjeunga (ICRISAT/ Mali). Results from the consumer test were reported in the 2001 annual report and showed high acceptability and market potential for the products. The market test, which examined sales and pricing in three market outlets (supermarket, small store, and marketplace) is now completed and data and analysis will be reported next year. We hope that results will support making the case for sorghum/millet processing units to be placed in the commercial sector either through financing from entrepreneurs or seed funding to be sought from granting or loan agencies. An added objective of the project is to stimulate demand for sorghum hybrids through processed products sold in the marketplace. The advantage of the hybrid to a processor is a ready supply of pure source grain, which is a prerequisite to processing high quality commercial products. In an effort to extend these process technologies to interested entrepreneurs, the INRAN Cereal Technology group has formed an association with local food processors. Currently, INRAN is working with a few local entrepreneurs to distribute some products into the marketplace.

Fundamental Studies on Porridge Properties

Sorghum porridges have fundamental properties that differ somewhat from porridges made from other cereal grains. Often sorghum porridges are characterized as comparably thick pastes (this may be desirable) that may 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 behave as it does, and accordingly how these traits can be manipulated through genetics or processing.

Studies on the Fine Structure of Sorghum Starch

Because starch is the major component of sorghum grain, several studies have focused on relating its properties to the quality of sorghum food products. In most of these studies, determination of amylose content has been the only chemical test done on sorghum starch. Amylopectin, the major component of starch that is large and highly branched, has not been extensively studied to determine its relationship to nutritional quality and functionality in sorghum-based foods. Amylopectin fine structure has been shown to strongly influence the texture of food products in other cereal grains. “Fine structure” refers to the length or degree of polymerization (DP*n*) of the linear chains in the highly branched amylopectin molecule, the proportion of long, medium, and short chains in the molecule, and the resulting degree of branching. In this study, amylopectin was isolated from starch of eight sorghum genotypes and debranched with isoamylase to obtain linear chains. A trimodal distribution of chains (fractions) was obtained when isoamylase debranched amylopectins were fractionated on a Bio-gel P-10 chromatographic column. Fraction I (FrI) is a high molecular weight, long chain length component of amylopectin. The second (FrII), and third (FrIII) fractions are composed of intermediate, and short chain length molecules, respectively. The chain length of the fractions ranged from DP*n* 60 to 92, from DP*n* 40 to 49, and from DP*n* 16 to 17, for the long, intermediate, and short chain components, respectively. In our experiments, these values were somewhat higher than those reported for other cereal grains such as maize, rice, and wheat and suggest higher degree of crystallinity and tendency to retrogradation in sorghum starch. High extent of retrogradation can mean harder gels from stored pastes, more rapid staling in composite breads containing sorghum or in flatbreads, and in general poorer keeping quality of sorghum-based foods.

The proportions of the linear chains also differ among sorghum genotypes. They ranged from 8.5 to 12.3%, from 17.5% to 23.1%, and from 64.2 to 71.7%, for the long, intermediate, and short chain components, respectively. Although smaller in proportion, the long chain component of amylopectin has considerable effect on some functional properties of starch. It has been shown to affect the viscosity, pasting behavior, retrogradation tendency of starch mixtures as well as the texture of cereal foods. The differences in chain length parameters of amylopectins suggest differences in granular crystalline pattern among the starches. In future studies, we will investigate whether these differences explain at least in part why sorghum has lower starch digestibility than other cereal grains.

How can these and other fundamental studies impact the quality of sorghum-based foods? If variability exists among sorghum cultivars in amylopectin fine structure, as we have found for maize and rice, and its relationship to food quality attributes can be further established, the possibility then exists to develop cultivars with fundamentally improved quality traits. This is important to make sorghum a more utilized grain in processed as well as traditional foods for urban consumers.

Three-Component Complex Affects Paste Viscosity

Studies were completed on a unique three-component complex we identified that was found in sorghum porridge. This high molecular weight complex (in the range of 1 million Daltons) consists of starch amylose, soluble protein, and free fatty acids and was found to markedly increase the viscosity of warm (about 50^{o}C) pastes. Free fatty acids, generated from lypolysis of triacylglycerols (typical fats), were formed fairly rapidly in stored sorghum flours (1 month at 20-25^{o}C) compared to maize flour, and might be expected to be present at earlier times at higher temperatures. High paste viscosities at eating temperatures could be caused in part by incompletely decorticated flour that has been stored, and might be lessened by using only freshly ground flour or flour from well decorticated grain (with lower fat content).

The complex was recreated to enable its verification and further characterization. The amounts of protein and FFA were optimized. The complex was tested for its stability under varying conditions of temperature, pH, and ionic strength. The temperature of formation of the complex was also noted. Defatted sorghum starch, corn starch, pure amylose, whey protein, and linoleic acid were used. Following complexation, the supernatant was filtered and analyzed; stability of the complex was examined by HPSEC using RI and UV detectors. The complex was monitored at room and refrigerated temperatures. It was found to be stable at room temperature for up to 10 days and at refrigerated temperatures for at least 45 days. The temperature of complex formation was observed to be between 60 and 70^0 C. The pH of the complex in solution was found to be 5.9. The pH was varied (3, 8,10), and it was found that, for freshly prepared complex, some of the complex dissociated at pH 3, but it remained intact at pH 10. The three-component complex was water-soluble, but could be precipitated by addition of NaCl (0.01, 0.1 and 1%), indicating the importance of electrostatic charges for its stability. The molar ratios of the three components (in the final mixture) were roughly estimated to be 6 amylose (corn): 2 protein:<300 FFA. Based on these studies and literature data, a model for the organization of the three-component interaction was proposed. These data show an interesting three-component interaction/complexation that occurs in sorghum and other cereal porridges that affect paste viscosity. Large viscosity changes in stored flours may be related to lipolysis and liberation of free fatty acids into the flour system.

Sorghum with High Protein Digestibility

Grain Quality

Studies have continued on the high protein digestibility sorghum mutant that we reported on first in the mid-1990's, albeit more slowly since the passing of John Axtell. 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. Our main challenge at this point is to convert the soft, floury kernel background of the mutant to a hard, vitreous kernel phenotype with a consistency of panicle grains and stability of trait for release. In last year's report, it was shown that a vitreous normal-appearing kernel with mutant high digestibility protein bodies can exist together, however consistency and stability of this combination is still uncertain. In the coming year, research with this focus will be re-initiated by Ejeta and Hamaker at Purdue. In India, 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 good quality mutant grain from crosses made with elite Indian germplasm. However, similar to the Purdue program consistency and stability are uncertain.

Cellular Responses to the Mutation

Studies done in collaboration with Dr. Arun Chandrashekar in India provide new information on cellular responses to the mutation. These data will help lead to the mutation source, which would permit more focused breeding efforts as well as understanding of the high digestibility trait. Comparisons have been made between the high protein digestibility sorghum mutant and the *floury2* maize mutant because both have abnormally shaped protein body structures. Results from these investigations reveal that the high protein digestibility sorghum mutation is likely different from that of *floury2*. *Floury2* was shown by Larkins group at University of Arizona to be caused by a gene mutation resulting in lack of cleavage of the signal peptide of some -zein storage protein. This can be visualized by an -zein protein band migrating to a higher molecular weight by SDS- polyacrylamide gel electrophoresis. The sorghum mutant did not show a similar band by electrophoresis. Studies in India showed high expression of the endoplasmic retention chaperonin, BiP, indicating a response to the unfolded structure of the protein bodies. The mutant sorghum kafirin storage protein also was found to have somewhat different solubility characteristics compared to normal sorghum grains. This may suggest either a mutation directly affecting one of the kafirin storage proteins or in a protein that assists the folding and interactions among the kafirins.

Chicken Digestibility and Growout Study

A collaborative study (see reference in publication list) was done with Dr. Robert Elkin, poultry nutritionist, to assess amino acid digestibilities and the value of the high protein digestibility sorghum on growth of broiler chickens (see publication reference below). A fairly floury mutant (P851171) was compared to its wild-type parent (P721N), a commercial hybrid (611Y), and maize. True amino acid digestibilities (TAAD) were substantially higher for the mutant and 611Y compared to either maize or P721N – mean TAAD values were 93, 93, 78, and 74%, respectively. These results confirmed the higher protein digestibility of the mutant. The commercial hybrid also had high protein digestibility and supports previous *in vitro* findings that some normal sorghum cultivars can have high protein digestibility. However, we also showed that digestibility of wild-type sorghum cultivars varied dramatically over years while the mutant remained high. Still, it must be concluded that not enough is known about variability in digestibility among wild-types.

For the growout study, mixed diets containing soy meal were prepared at optimum and suboptimum dietary crude protein levels. In this case, the high protein digestibility mutant sorghum slightly underperformed compared to the other grains in terms of feed/gain. There was, however, a confounding factor in the broiler study that made this comparison somewhat difficult. Because protein content of the other two sorghum samples was higher than the mutant and maize samples, cornstarch was added to the former diets at higher levels to make them isonitrogenous. The somewhat higher feed conversion of the normal sorghum cultivars may have been related to the added starch that is a ready source of energy for the bird. A future study should be conducted using sorghum with similar protein and starch contents which have been identified.

Economic Analysis

In a study (see reference in publication list) done by Purdue agricultural economist, Channing Arndt, and his student, the value of the high protein digestibility trait in sorghum was estimated relative to regular sorghum for market broilers. A least-cost feed mix linear programming model was used to optimize rations for starting and grown-for-market broilers in poultry production for three age categories: zero to three weeks, three to six weeks, and six to eight weeks. From amino acid digestibility parametric analysis, it was found that a premium for high protein digestibility sorghum increases essentially linearly with improvements in digestibility over the zero to 10 percent range. Concomitant increases in starch digestibility, if possible, would likely give this sorghum a real advantage for use in animal feed.

Sorghum Starch Digestibility

Factors Causing Low Starch Digestibility in Cooked Sorghum Porridges

The starch digestibility of cooked sorghum porridges is relatively low compared to other cereal flours such as maize (Thorne et al., 1983, American J. Clin. Nutr. 38:481). However, the digestibility for isolated sorghum starch is similar to that of maize in raw and in cooked forms. This implies that other flour components such as protein, anti-nutritional factors, dietary fiber, and lipid or complexation of starch with some of these components contribute to low sorghum starch digestibility. A nutritional study of children fed a sorghum-based diet showed that approximately 21% of calories consumed were recovered in feces compared to 13% for maize and 7% for rice (MacLean et al., 1981, J. Nutr. 111:1928). The overall objective of this research was to identify the fundamental factors causing lower starch digestibility in cooked sorghum flour compared to other cereals. Knowledge from this research will be used to optimize the use of sorghum as an energy source for human food.

Initial studies, reported last year, were conducted to determine the effect of some of the various flour components (antinutritional factors, fat and protein) on starch digestibility. Two sorghum cultivars, a normal (MR732) and high protein digestibility mutant (P851171) were used with maize and rice as the controls. Cooked sorghum porridges were significantly ($p<0.001$) less digestible than rice and maize. There were no significant differences in starch digestibility between the normal and the high protein digestibility sorghum cultivars before pepsin pretreatment. Decorticating and defatting significantly increased starch digestibility in all samples by a similar margin. Pepsin pretreatment resulted in significant increase in starch digestibility in all samples except for the normal sorghums. The highest increase was observed in the high protein digestibility cultivars (14 to 19%) followed by the maize control (8%) and rice (7%). These results show that non-starch flour components contribute to low starch digestibility and low protein digestibility seems to be the single largest contributor.

Subsequent studies in the past year were conducted using a wide range of samples as follows: high protein digestibility sorghum mutant lines - #222, P721Q, P851171 and #4; normal sorghums - MR732, P721N, #181, #30; controls – rice and maize. The samples were analyzed for protein and starch content and protein digestibility (Table 1). Similar results were obtained as in the initial study - no significant differences in starch digestibility among the sorghums and significant increase in starch digestibility in high protein digestibility sorghums after pepsin pretreatment (Figure 1). This was a consistent feature of all mutant lines. In conclusion, it has been shown that low starch digestibility in sorghum could be attributed to the low protein digestibility. This fact is further proven by the high increase in starch digestibility among the high protein digestibility mutants after protease pretreatment. A correlation of 0.97 was observed between starch digestibility and protein digestibility of sorghum cultivars when protease treatment preceded amylase digestion. High digestibility sorghums could have a useful impact in weaning foods and other foods where high availability of macronutrients is critical. Such sorghums could also find a place in diets of the marginally malnourished who do not meet UN-set requirements for protein and energy intake.

Starch Digestibility in Raw Grain

Studies have also begun on starch digestibility of sorghum with the aim of identifying ways to increase availability of grain starch for livestock and poultry. Results suggest

Table 1. Chemical composition, *in vitro* protein and starch digestibility of decorticated flours samples

Sample	Starch content (%)[a]	Protein content (%)[1]	Protein digestibility (%)	Starch digestibility (mg maltose)[2]
Rice	87.9	8.2	69.1	7.9
Maize	82.5	9.6	70.1	7.4
#222	74.7	11.7	75.5	6.5
P721Q	71.9	12.7	73.8	6.5
#4	74.6	10.9	75.7	6.6
P851171	74.9	10.2	73.0	6.5
MR732	83.5	9.0	53.8	6.2
P721N	77.6	10.7	22.6	6.3
#181	78.1	11.0	28.4	6.6
#30	75.1	13.3	27.3	6.2

[1] values reported on dry weight basis
[2] reducing sugar content values after 2 h digestion with -amylase

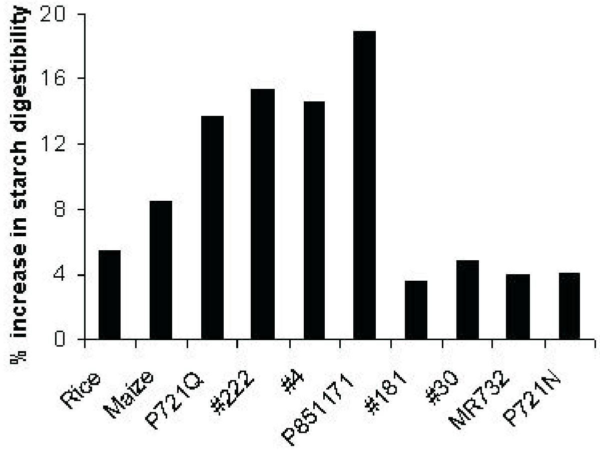

Figure 1. Percent increase in starch digestibility due to protease pretreatment.

Figure 2. Microwave popped sorghum.

that high protein digestibility sorghums, either the high digestibility mutant or normal cultivars with comparably high digestibility, also have more digestible starch. However, more work must be done to verify and better understand this relationship. In another study on this topic, the comparative rate of digestion of the two starch molecules, amylose and amylopectin, was performed. Quantification was done by measuring peak areas of size-exclusion chromatograms over a time-course digestion with -amylase. Amylopectin was found to digest at a significantly faster rate than amylose. Studies are in progress using other approaches to achieve higher starch digestibility in sorghum grain.

Microwave Popped Sorghum

A team composed of an undergraduate (Lindsey Kirleis) and graduate (Betty Bugusu, Agung Tandjung) students entered the product development competition at the American Association of Cereal Chemists annual meeting with a microwave popped sorghum product. Axtell's selections of popped sorghum (through assistance from Terry Lemming) were compared for popping volume, flake size, and number of unpopped kernels. An optimal line was chosen and preparation and conditions for a microwaveable popped sorghum bag were optimized to give maximum fill of bag. The team placed third in the national competition (Figure 2).

Networking Activities

Hamaker traveled to Manhattan, Kansas in July 2001 to present a talk to representatives of Japanese cereal processing companies at the Grain Sorghum Utilization Workshop. The meeting was sponsored by the US Grain Council and Kansas State University.

Publications and Presentations

Abstracts

Huang, C.P. and B.R. Hamaker. 2001. Protein bodies and immunolocalization of alpha- and gamma-kafirins of developing wild type and high protein digestibility mutant sorghum lines. American Association of Cereal Chemists annual meeting, Charlotte, NC, October.

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Dissertations and Theses

Maladen, M. 2002. Characterization and carrying capacity of a soluble three-component complex. M.S.

Food and Nutritional Quality of Sorghum and Millet

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Summary

In Mali, an entrepreneur successfully produced N'Tenimissa, a white tan sorghum under identity preserved (IP) marketing procedures. The grain was used successfully by a large baking company to produce cookies.

When the government subsidized wheat flour, the entrepreneur found an alternative profitable market for decorticated white sorghum. The urban consumers liked the ready-to-cook product with substantial sales to expatriate Malians.

We hope these activities will expand. New more efficient 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.

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. Value-enhanced white food sorghums have been used by the Japanese food industry to market snacks and several other products.

In Central America, white food sorghums are used in pan dulce, breads, cookies and other products as a substitute for wheat or maize flour.

Several mills 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 Celiacs.

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.

New commercial sorghum hybrids with tan plant white pericarp color were released by commercial hybrid seed companies. Several parental sorghum lines released from our program are used in commercial food hybrids. ATX 635 hybrids have outstanding milling food properties.

Sorghum milling yields must be calculated on the basis of flour or grit yields adjusted to a common color value, i.e., an L of 67 for grits and 85 for flour where color attributes are important.

Antifungal proteins are related to grain mold resistance in sorghum. An improved faster assay was developed.

Near infrared equipment was calibrated and used for whole grain analysis of sorghums successfully. Calibrations for starch, protein and moisture for whole kernels of sorghum were developed.

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

Two M.S. students completed their degree. Both joined the food industry.

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 Identity Preserved (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.

Factors affecting food quality, processing properties, and nutritional value of sorghum and millet are critically important. If the grain cannot be processed and consumed for food or feed, then the agronomic and breeding research has been wasted. This project relates quality to measurable characteristics that can be used to select for sorghum and millet 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

Sorghum and millet grains grown locally and from various areas of the world were analyzed for physical, chemical, structural, and processing properties. Various food and feed products were prepared to test the quality of the different grain samples. It became apparent early in our program that 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 is lacking and is difficult to put in place. Progress is happening but it is slow.

Significant Accomplishment

Applications of Technology in Mali

Work in Mali continues to demonstrate the value of new, white, tan plant sorghum varieties in food systems. During the past two 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 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 type sorghums into rice-like products that he sold for a profit. Thus, the concept has been proven by Malian personnel. New value enhanced food sorghums from the Malian sorghum breeding program will likely improve productivity and improve 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 is that farmers growing the white tans 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 Japanese food companies (Figure 1). They are marketing flour,

Figure 1. Cookies containing white sorghum flour that are marketed in Japan.

meal, grits, and decorticated sorghum sold as a rice-like product. 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 less developed areas that sorghum is a good food ingredient. Similar findings in Mali and other countries of West Africa demonstrate that sorghum of good quality is necessary for value added products. The same is true in Central America and Mexico.

Applications in Honduras and El Salvador

Our research on sorghum has been applied in Honduras and El Salvador. The variety Sureño, and others with white tan plant color are used in Central America for tortillas, rosquillos, and rosquettes. 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 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.

Sorghum Phenols and Catechins as Antioxidants

Additional brown and black sorghum samples evaluated confirmed that brown high tannin sorghums have outstanding antioxidant activities. The ORAC values are comparable to blueberries and other fruits that are known to contain high levels of antioxidants. The antioxidants are concentrated in the pericarp and pigmented testa and can be easily processed into bran fractions Moreover, the bran is high in dietary fiber, phytates and natural brown or black pigments that impart attractive color 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.

Additional studies to produce highly nutritious multigrain breads and cookies are nearing completion along with a bread mix for bread machines. Black sorghum bran gave breads with appearance, texture, color, and specific volume (cm3/g) similar to commercial specialty or dark rye breads.

Ms. Linda Dykes, a Ph.D. student, has joined our efforts to characterize the phenols and tannins using HPLC and other techniques. Mr. J. Awika from Kenya continues his research on antioxidants in sorghum for his Ph.D.. His last year of study is supported by a Tom Slick Graduate fellowship which allowed us to leverage TAM-226 funds for other student activities.

Another student is nearing completion of her M.S. on the development of a bread mix containing brown or black sorghum bran with flax seed, gluten, and wheat flour. These breads have good flavor and color similar to variety breads.

Extrusion

Low-cost extrusion using friction produced excellent products from whole kernels of sorghum. 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 infra structure does not permit use of higher cost more sophisticated extruders and processes. Thus, the ability to produce snacks directly from whole clean grain would be a distinct advantage.

The evaluation of sorghum as an ingredient in extrusion of snacks and breakfast foods was initiated to compare its properties with corn and rice. This information is of interest to potential users of sorghum around the world. Rice produces extrudate with white, bland flavor and excellent crispness. Sorghum can be as effective but the price may be significantly reduced.

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. It is possible to produce expanded sorghums directly from whole ground undecorticated sorghum from white or brown grains. The color and flavor of the extrudates varied significantly. The brown sorghums after extrusion still had significant quantities of extractable antioxidants. Additional studies will demonstrate the use of extrusion to process the bran from brown and black sorghums into acceptable nutraceutical products.

Sorghum Starch, Malting and Brewing Studies

Dr. Serna-Saldivar, ITESM, Monterrey, Mexico, is continuing to collaborate on sorghum research especially with students working on sorghum for brewing, industrial films and as a source of antioxidants. 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.

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 Celiacs 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 (Figure 2). These activities especially for special dietary requirements and ethnic foods are continuing to expand as more products are made available.

Figure 2. Commercial food products containing sorghum sold in the United States.

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.

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. 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 (Table 1). The protein content of the food sorghums was significantly higher than that of the commercial sorghum samples. The white food type sorghums had significantly improved milling yields when adjusted to a common L value of 67. The red pericarp contributes significant color to the decorticated grain. The method we use to assess the relative color and decorticated grain yields provides a sensitive test to distinguish among sorghum cultivars. The effect of weathering and molds on decorticated grain yields is significant and white food types maturing or exposed to high humidity and heat after maturation have significantly reduced yields of acceptable products. The purple or red plant color sorghums are the most sensitive to these conditions.

Tan Plant Food Type Hybrid Performance and Quality Trials

Several new tan plant food hybrids were entered into uniform performance nurseries grown at five locations in Texas, two in Kansas and one in Nebraska. The tan plant hybrids were competitive with maturity comparable to traditional purple plant hybrids. The availability of short season tan plant hybrids is limited. More of them are required to encourage food sorghum production in drier, shorter season environments. Grain weathering and molds are limiting factors affecting food sorghum production. For example, in South Texas this year, the white food sorghums have been severely damaged by molds.

Grain samples from international food quality nurseries and hybrid trials are evaluated to monitor new materials in the pipeline and to encourage private seed companies to develop new improved value-enhanced hybrids. The grain industry in the U.S. is changing to a value-enhanced IP marketing system that fits into our long-term goal of improving sorghum quality for food and feeds.

Improved Methods of Analysis

Near infra-red 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.

Table 1. Summary of Quality Data for Food and Commercial Sorghums Grown in 2001.

					Chemical composition (dry basis)					Grain yield		
Sample Type	Moisture (%)	Test Weight (lb/bu)	True Density (g/cm^3)	1,000 Kernel Wt. (g)	Protein (%)	Starch (%)	Oil (%)	Ash (%)	Fiber (%)	Dec.[1]y ield (%)	Dec.[2] (L=67) (%)	Hardness index
White FoodType												
Count	21	18	21	21	21	21	21	21	21	21	12	21
High	14.6	62.6	1.39	30.0	14.0	77.5	4.9	1.8	2.3	86.0	96.0	109.3
Low	7.4	56.5	1.34	18.3	8.7	71.4	2.5	1.1	1.6	71.3	77.0	60.9
Average	11.0	60.5	1.37	25.2	11.5	74.9	3.5	1.5	2.1	80.3	86.7	85.2
Std. Dev.	1.89	1.65	0.01	3.41	1.48	2.05	0.74	0.19	0.14	3.8	5.3	13.16
Commodity / Elevator												
Count	11	11	11	11	11	11	11	11	11	11	11	11
High	13.2	60.6	1.38	26.5	10	77.5	2.9	1.5	2.4	75.8	66.0	82.0
Low	12.7	59.7	1.37	24.7	9.3	76.5	2.5	1.4	1.9	72.5	52.0	6.2
360Average	12.9	60.2	1.37	25.6	9.5	77.0	2.7	1.5	2.0	74.0	58.5	78.6
Std. Dev.	0.19	0.31	—	0.54	0.27	0.35	0.14	0.02	0.14	1.0	4.8	1.60

[1] Decorticated Grain Yield (%) = 100 - % pericarp removed
[2] Decorticated Grain Yield (%) adjusted to comparable lightness values (L= 67)

A single kernel hardness characterization system used for wheat kernel hardness was modified slightly for sorghum kernel hardness, diameter, and moisture measurements. Unfortunately , the single kernel hardness value was not significantly correlated with the TADD decorticated grain yields of a set of 32 sorghum samples. This must be confirmed for a larger set of samples. At this time the abrasive milling procedure appears to be necessary especially if one wants to compare yields vs. color of the decorticated grain.

Grain Molds/Deterioration

Grain deterioration caused by molding is a major problem that significantly affects grain quality for sorghum utilization in most regions of the world. Grain molds and weathering reduce processing quality significantly and can totally destroy the value of the grain for humans. This often happens in the kharif sorghum crop in India and is common in the gulf coast areas of the U.S. and Mexico. In Mali, photo insensitive sorghum varieties are totally destroyed by the combination of head bugs followed by molds, which render the kernels soft, floury and easily pulverized. The grain cannot be decorticated to mill into flour. Thus, farmers grow photosensitive types.

Many factors affect the molding of sorghum and none of them in themselves account for tolerance. The kernel structure, especially endosperm hardness, pericarp surface wax covering, presence of a pigmented testa, phenolic compounds, plant height, glume characteristics, antifungal proteins, and many unknown factors affect grain mold tolerance. Our research over the years has identified some of them but with the exclusion of the high-tannin sorghums no factor appears dominant.

Role of AFP in Minimizing Grain Molding of Sorghum

An improvement in the analysis procedure was implemented last fall (2001) for the sorghum samples collected in 2001. Threshed, hand-cleaned, and Udy-mill ground sorghum samples were mixed for 1 hr with the extraction buffer with agitation, followed by centrifugation, and the supernatant was collected. The Western blotting procedure was replaced with a “dot” blotting procedure. Protein extracts were directly loaded into nitrocellulose membrane using a 96-well, dot-blotting apparatus. The membranes with the proteins were then blocked, incubated with the antibodies and then visualized as in the Western blotting procedure. With this procedure, the gel formation, electrophoresis, gel handling, and protein transfer steps were skipped. Hence, analyses are now completed more efficiently and about three times more samples can be analyzed in the same time period. The results of the traditional Western and dot blotting procedures do not yield the same values but the trends and cultivars identified as being responsive and resistant are similar.

The sorghum growing environments in 2000 and 2001 did not attain mold rating greater than “2” or low incidence of deterioration at 50 days after anthesis. This indicates these sorghums were grown in environments that were not very mold conducive. The sorghum growing environments in 2002 already has more precipitation during and after anthesis and during caryopsis development than the previous two years combined. Raul Rodriguez previously demonstrated that in mold-conducive environments, grain-mold resistant sorghums respond with more AFP; and in non-mold-conducive environments this correlation was not significant. Samples are now being collected to verify this relationship in about 55 elite sorghum lines and 25 commercial hybrids. Significant molding has occurred this crop year.

We have made progress in a collaborative study with Dr. Louis Prom, USDA plant pathologist, concerning the virulence of *Fusarium thapsinum*, *Curularia lunata,* and their mixture on eight sorghums varying in resistance to grain molding. A manuscript was submitted for publication: “Response of eight sorghum cultivars inoculated with *Fusarium thapsinum*, *Curvularia lunata*, and a mixture of the two fungi” by Louis K. Prom, Ralph Waniska, Kollo Abdourhamane Issoufou, and William Rooney.

The interactions of the principal grain molding fungi, the sorghum genotype, and the environment on the level of grain mold severity and seed germination were determined. Grain mold is considered a complex disease associated with several genera of fungi. The synergistic interaction of fungi did not markedly increase the levels of grain molding, except on 98LB650 in 2000. The effect of F. thapsinum and C. lunata in combination was similar to the individual pathogen that produced the highest grain molding on many cultivars in this study. Therefore, in screening for resistance against grain molding, inoculation with a mixture may not be as effective as inoculating with the individual fungi that are the most prevalent. Also, fungal treatments significantly reduced seed germination more than it increased seed deterioration as measured by the threshed grain mold rating.

Networking Activities

Southern Africa

Several graduate students are conducting research on aspects of sorghum utilization with Professor Taylor, Food Science Department, University of Pretoria. Ms. Leda Hugo, Mozambique, is a Ph.D. student at University of Pretoria working on the effect of malting sorghum on its use in composite breads. She is a professor at University of Eduardo Mondlane University and completed her M.S. at Texas A&M University. Lloyd Rooney serves on her Ph.D. committee. She will complete her Ph.D. in August 2002.

Ms. S. Yetneberk from Ethiopia has started her Ph.D. program and L. Rooney is a co-director of her committee. Her project is related to determination of factors affecting the quality of injera from sorghum cultivars present in Ethiopia.

Graduate students in the Food Science Department at the University of Pretoria are from many other African countries. Many participate in the Regional Master of Science program which consists of joint programs between CSIR and the University of Pretoria. Thus, INTSORMIL 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 can provide significant assistance to the region by involvement in these programs.

Mr. J. Awika from Kenya completed his Ph.D. written and oral preliminary examinations. He is working on nutraceuticals from sorghums. He received several scholarships from national and local sources due to his outstanding academic performance. He was partially supported by INTSORMIL but was awarded a competitive Tom Slick Research Fellowship from TAMU which supports his last year of Ph.D. research.

Mr. Hoffman of Namibia conferred with INTSORMIL project leaders regarding pearl millet research and development activities. We provided support for conferences with commercial milling equipment companies in our area.

Honduras, Salvador, Mexico and South America

Rene Clara, Sorghum Breeder, El Salvador and sorghum breeders from Nicaragua spent time in the cereal quality lab. Dr. L. 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.

L.W. 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 Ph.D. 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.

Mr. Bueso, Honduras, is nearing completion of his PhD and is supported this last year by a Tom Slick Graduate Fellowship from Texas A&M University. His research is on tortillas and related products.

Mali

Dr. A. Toure presented a Faculty of Food Science special seminar that summarized current progress in utilization and breeding research in Mali where significant progress continues to develop identity preserved production and use of the new white plant photosensitive sorghum varieties. I have not visited Mali recently but the work we initiated continues and is on the verge of being successful and is supported by other agencies including ROCARS and ICRISAT. Thus our long term efforts accompanied by many setbacks are now being pursued actively in Mali. 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. This has been demonstrated in Niger and many other places where poor quality grain produced unacceptable products that consumers will not buy.

North America

Several papers were presented at the annual American Association of Cereal Chemists Conference, Charlotte, N. Carolina. L.W. Rooney presented sorghum quality/utilization discussions to the Texas Sorghum Producers Board Members and panels and the U.S. Grains Council sponsored visitors and reported on value-added conferences in Japan.

Lloyd Rooney was a key speaker at a KSU Feed and Food Grains short course on Value Added Food Sorghum which had more than 25 participants from Asia, Mexico and Central America.

Lloyd Rooney completed a two year research project which was funded (100K+) by the Texas Advanced Technology Research program to evaluate special sorghums for antioxidant potential and use in nutraceuticals. Sorghum bran fractions contained from 20-400+ ORAC units compared to 80-200+ ORAC units for blueberries which are considered excellent sources of antioxidants

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

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 Lloyd 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 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 was presented at U.S. Grain Council sponsored value-enhanced market development work shops in the United States and Japan.

Training, Education and Human Resource Development

At the Monterrey Institute of Technology, our collaboration with Dr. Serna-Saldivar, Head, Food Science Department, ITESM, Monterey, Mexico has lead to completion of six Master of Science degrees. These young scientists have positions in the Mexican food industry which transfers the technology directly to industry. Dr. Serna-Saldivar participated in the Central American Regional planning workshop in Managua, Nicaragua this spring. He summarized his work on sorghum utilization.

Three graduate students from Mexico and one from Honduras 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. J. Awika from Kenya is a Ph. D. candidate. We have assisted in training two students from Africa who are enrolled at U of Pretoria working under Professor John Taylor at the University of Pretoria.

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