Crop Utilization and Marketing

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

Project PRF 212
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Summary

In the past year, major findings for PRF-212 were in the areas of improved nutrition of sorghum grain and better understanding of fundamental grain factors for sorghum improvement. The overall aim of our research is to make sorghum and millet more competitive grains for human and animal nutrition, and for utilization in traditional and processed foods. In 2004, Betty Bugusu, a Kenyan student from KARI, obtained her Ph.D. degree. Perhaps our most notable work centers on the comparably lower starch and protein digestibilities of sorghum grain versus other cereal grains. This is somewhat an issue for animal feed use of sorghum, and is more pronounced in some cooked sorghum foods with at least the exception of fermented foods and processed extruded foods. Last year we showed that during the cooking process sorghum proteins form web- and sheet-like structures that constrain gelatinizing starch granules. This appeared to be the reason that the starch was less digestible; as such structures were not found, to any appreciable degree, in cooked maize or rice porridges. This report shows that these extended protein structures are formed due to intermolecular disulfide bonding that creates large polymers. Addition of reducing agent to break disulfide bonds, and to prevent their formation, led to formation of protein aggregates, and gelatinized starch that was more easily digested. Confocal laser scanning micrographs, before and after amylase digestion, showed a prevalence of protein-starch associated structures remaining after digestion. Normal sorghum grain apparently contains a third component that acts to promote protein polymerization that affects starch, as well as protein, digestibility.

In the area of animal feed use, starch granule properties were shown to affect raw starch digestibility rates. Specifically, amount of channels, which are found in sorghum, maize and millet starch granules, appears to affect digestion rate. The high protein digestibility mutant sorghum oddly, but consistently, has a high degree of channelization, and has somewhat enhanced starch digestion rate. Another sorghum line was identified, IS6986, with a subpopulation of abnormal "doughnut" shaped starch granules with rapid digestion properties.

A study on fundamental factors that affect sorghum flour pasting properties showed that starch amylopectin fine structure (lengths and proportions of linear chains), specifically proportion of the longest chains, highly correlated (r=0.92) to retrogradation (starch reassociation) tendency during storage. This could relate to the staling property and the comparably poor shelf life of some sorghum products (e.g., injera). Noted vari-

ability in this property among different cultivars may lead to selection of lines with improved storability.

Objectives, Production and Utilization Constraints

Objectives

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

Constraints

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

Research Approach and Project Output

Couscous and High Quality Flour Processing

As an update on our activities geared to stimulate couscous and high quality flour production in the region, with a focus on Niger, a brief overview follows. As described in previous annual reports, PRF-212 and INRAN/Niger Food Technology Laboratory set up a cereal-processing unit at INRAN to conduct research, demonstration, and testing of sorghum and millet processed products. A central goal of the project has been to optimize the processing system and products, to generate information for entrepreneurial startups, and to work with interested individuals in the private sector. Products produced by the unit include high quality flours and grits, and agglomerated products including fine couscous (or *dambou*), medium couscous, and the coarse particle-size product *degue*. In 1995, the core of the sorghum/millet processing unit was installed at INRAN; consisting of a central mechanized agglomerator designed and fabricated at CIRAD, France by 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. The initial unit was funded through the then functioning Niger InterCRSP project. Since that time, a much larger passive solar drying unit was built at INRAN to dry approximately 200 kg couscous every two days. As high quality flours are essential to make quality couscous, a commercial grain decorticator (dehuller) and hammer mill (Urpata Sahel, Dakar) were procured through PRF-212 to compete the unit. This last addition has also permitting INRAN cereal technologists to begin work on production of high quality sorghum and millet flours and other products made from them.

At INRAN/Niger, various market tests on couscous and flour produced at the unit have been completed that indicate high acceptability of the products. Current efforts, in collaboration with O. Botorou and economists, are geared towards contracting farmers for pure grain source which is critical to make consistent, acceptable products and assisting a local entrepreneur in setting up her own mechanized processing facility. A large recent achievement of the group is the fabrication of the agglomerator locally in Niamey.

In Senegal, much has been done with various donors towards stimulating domestic and some export millet processing businesses. Numerous successful partnerships between ITA (A. N'Doye) and entrepreneurs are cited. Purdue PRF-212 is now backstopping their INTSORMIL project by in-depth analysis of millet *cv.* Thialack which is superior as a composite flour for bread-making.

Fundamental Determinants of Sorghum Porridge Texture

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

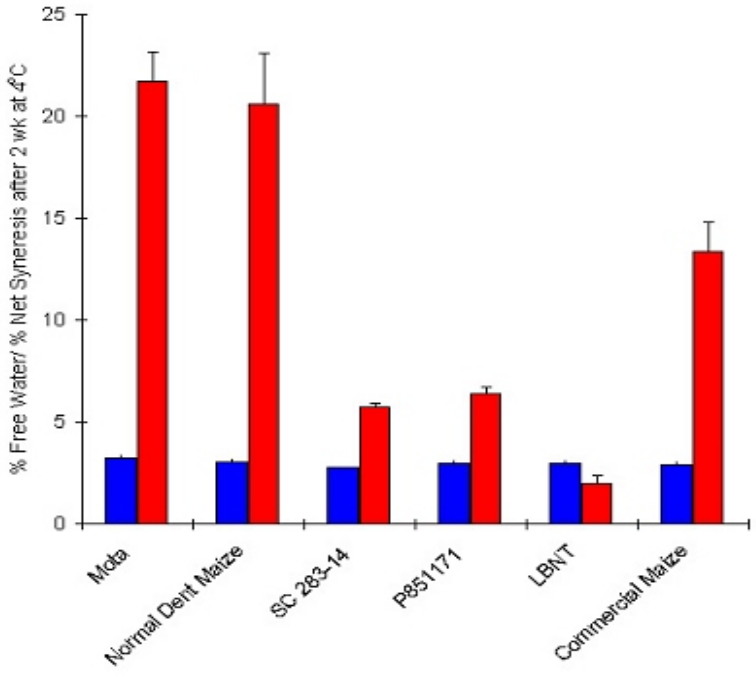
Studies conducted in the past year revealed that starch properties, particularly related to structure, largely affect properties of sorghum porridges related to paste viscosity or thickness, gel firmness, and storability (ability to retain thick paste/gel properties opposed to breaking apart and exuding water, termed syneresis). This research related sorghum starch properties to sorghum product functionality using rice and maize for comparison. In other work both in our laboratory and elsewhere, starch types and ratios, as well as structural characteristics, have been found to have a profound influence on food quality parameters. Amylose has been particularly implicated, as it is linear and smaller than amylopectin, and tends reassociate or retrograde rapidly on cooling of a cooked starchy food. Amylopectin, a much larger and highly branched molecule, also retrogrades; the rate of which depends on its structural aspects. The ultimate goal of this M.S. level project was to provide recommendations for the development and cultivation of sorghum cultivars that would produce desirable food products.

Specifically, this research focused on sorghum porridges, as porridge is a typical food product in parts of the world where sorghum is heavily consumed. Both isolated starch gels and flour pastes from sorghum, maize, and rice were evaluated for thermal (which in this case relates to reassociation of starch molecules following cooking) and textural changes during refrigerated storage. Analysis of starch properties including ratio of amylose to amylopectin, average molecular weights of amylose and amylopectin, and amylopectin fine structure were determined and related to textural and thermal properties of gels and pastes.

Significant differences in the rate and degree of starch retrogradation were found among starches from sorghum, maize, and rice, as well as among different sorghum cultivars. Initial starch gel texture differences were attributed to amylose retrogradation; long term changes in gel texture were attributed to amylopectin retrogradation with sorghum landrace cv. Mota Maradi showing very high retrogradation, as well as pasting properties. Likewise, syneresis, which is indicative of storability, related to amylopectin retrogradation and pasting properties. Syneresis after 2 weeks of storage at 4ºC was highly positively correlated ($r=0.99$, $p<0.01$) with a viscosity measurement relating to amylopectin retrogradation (G') measured at 25ºC after seven days of storage. Amylopectin fine structure, as represented by proportions and lengths of linear glucose-containing chains, appeared to provide the underlying basis for differences in porridge/paste properties. Proportion of the longest linear chain (100-120 glucose units long) from isoamylase debranched amylopectin was highly positively correlated with starch gel firmness (storage modulus) after 7 days at 4ºC ($r=0.92$, $p<0.01$). Analysis of initial and stored *flour* paste texture implicated starch and starch properties as the primary contributor to paste texture; native flour lipids retarded paste firming during storage.

The above results specifically showed that sorghum cultivars that have and amylopectin fine structures with a higher proportion of the longest linear chains (fraction I), as well as high amylose contents, have a much increased tendency to retrograde, which would be desirable for initial and overnight stored porridge texture. Longer-term storage of these porridges causes deterioration due to syneresis. (Figure 1)

Figure 1. Syneresis of porridges immediately after cooling (blue) and 7 days of storage at 4ºC show wide variation among sorghum cultivars (Mota, SC283, P851171 (high digestibility mutant)) with cv. Mota exhibiting poor storability.



Sorghum with High Protein Digestibility

Work has again picked up 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. 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 apparently 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. Perhaps even more useful, is a relationship reported last year where the high protein digestibility trait additionally increased starch digestibility of cooked sorghum porridges. Increasing energy utilization of staple cereals, particularly of sorghum with somewhat poor digestibility characteristics, is critical for subpopulations who have chronically low caloric intake.

Grain Quality

Aim #1 was a research focus during the latter 1990's as collaboration between our laboratory and the program of Dr. John Axtell. Upon his unexpected and sad passing in 2000, this project was not active for about three years and was again revived last year with the hiring of a post-doc (T. Tesso) shared between Drs. Ejeta and Hamaker. In the fall of 2003, Dr. Tesso was required to return to Ethiopia, however a good deal was accomplished in the nine months he was here. As shown in the 2001 INTSORMIL report, a vitreous normal-appearing kernel with mutant high digestibility protein bodies is possible, however consistency within the panicle was lacking and stability of this combination is still uncertain. In India, Drs. Murty and Chandrashekar have made progress on the grain quality question through the collaborative project (finished in 2001) funded by Mahyco Research Foundation. Their similar results showed improved quality mutant grain from crosses made with elite Indian germplasm.

In this collaborative project with Dr. Ejeta, high protein digestibility lines (screened for this trait), derived from crosses of modified mutant lines with highly vitreous parents, were first identified with well modified kernel type and seemingly good consistency within panicles. These modified endosperm types have been previously described as containing a vitreous (hard) endosperm section originating out of the interior of the kernel rather than the typical phenotype where vitreous endosperm is found at the kernel periphery radiating toward the center. In the lines chosen, the vitreous endosperm section accounted for approximately 50% or more of total area and opaque endosperm appeared encircling it with only a thin region at the kernel periphery. Stability tests are underway. 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 Mutant

Aim #2 is a research focus we have been longer-term undertaking in collaboration with A. Chandrashekar at CFTRI, Mysore, India. The following work is recent data from Purdue done by post-doctoral researcher, M. Benmoussa (partially funded through INTSORMIL), in the past year. Seed developmental studies have corroborated previous findings in India that expression of the BiP chaperone protein is much higher in the mutant grain than wild-type beginning at 20 days after pollination. This is the period that kafirin synthesis is at its highest. Moreover, 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. While it is well known that a single point mutant can cause a plietrophic response affecting many proteins, it remains possible that the chaperones may be implicated. High-resolution 2-dimension gel electrophoresis was employed to separate both the kafirin and non-kafirin classes of sorghum proteins from mutant and wild-type lines. Identification of spots differing in the mutant is currently being done.

Starch Digestibility of Cooked Sorghum Pastes

In cooked sorghum foods, as it is particularly known for porridges, starch digestibility is low compared to like foods made from other cereals and additionally appears to have a slow digesting property. We reported in the last two-year's annual reports that:

1) Starch digestibility was improved in the high protein digestibility mutant sorghum due to the fast digesting protein component. This is potentially useful, as high digestibility sorghums would be valuable in in weaning foods and other foods where high availability of macronutrients is critical. Such sorghums could find a place in diets of the marginally malnourished who do not meet UN-set requirements for protein and energy intake.

2) Sorghum proteins form web- and sheet-like structures that appear to constrain swelling of the gelatinized granules and, in a manner that is yet clear, reduces starch digestion rate and overall digestibility. As is the cause for the relatively low

protein digestibility of sorghum, intermolecular disulfide bonding among proteins that is promoted by the cooking process seems to be responsible for formation of large polymeric web-like protein structures. As shown in Figure 2, large web-like protein structures form on normal cooking of sorghum flour to porridge that are related to the lower starch digestibility of sorghum. Addition of reducing agent prevents formation of the large polymeric structures resulting in protein aggregates and higher starch digestibility.

Further work showed the actual effect of the protein web- and sheet-like structures in sorghum porridge on starch digestibility. An experiment was designed to determine the relative degree of starch-protein associated structures in cooked samples after 30 min of a-amylase digestion to digest away free, highly susceptible starch. If starch-protein associated structures were truly less digestible, then a concentration of such structures would appear in sorghum digests compared to maize or rice. Rice, maize, and normal sorghum samples were used. Confocal micrographs showed that the microstructure of cooked sorghum and maize pastes were more similar than that of rice showing a protein structure embedded in the mass of gelatinized starch. In cooked rice, the proteins aggregated away from the gelatinizing starch. After 30 min a-amylase digestion, sorghum still had a lot of gelatinized starch associated with the protein structures and some of it still encapsulated, while in maize most of the starch was digested and in rice almost all the starch was digested. Clearly the formation of the starch-protein structures caused retarded digestion of the associated starch.

Betty Bugusu completed her Ph.D. thesis on this topic in 2004. Overall, it was concluded that the transformation that sorghum proteins undergo during cooking have a dramatic effect on starch digestibility, although it is unclear exactly how such protein-starch associated structures affect amylase digestion. a-Amylase inhibitors present in the cereals samples were heat-labile and, thus, are not a major concern in cooked porridges. We believe that sorghum protein forms resilient web-like and sheet-like structures that encapsulate starch, resulting in reduced accessibility of starch by amylases. Maize and rice protein form aggregates and collapsed web-like structures that allow release of gelatinized starch. The protein component does not seem to affect the degree of gelatinization of starch granules. The greater increase in starch digestibility for the high protein digestibility mutant sorghums (compared to normal sorghum cultivars) after pepsin treatment could be attributed to the high protein digestion rates that result in the destruction of the protein microstructure, and hence the exposure or release of starch for amylase digestion. Practical aspects of this work center on increasing or decreasing digestion rate of sorghum starch through processing treatments. Long-term, this work should lead to knowledge of how to genetically manipulate starch digestion properties of cooked sorghum foods.

Starch Digestibility in Animal Feed Grain

For animal feed usage, low tannin or tannin-free sorghum grain is competitive with other feed grains, though in most studies is somewhat low in starch and protein digestibilities, with the former more pronounced. In fact, in other feed grains, such as maize, there is also interest in ways to improve starch digestibility for increased feed efficiency. In the U.S., sorghum grain is often, and in some cases always, processed to improve starch availability. Therefore, investigations into finding ways to increase starch digestibility are pertinent to the sorghum industry both in the U.S. and abroad. In our studies on how to improve starch digestibility of sorghum grain for animal feed, we have investigated the effect of endosperm protein matrix, starch molecular fine structure, and starch granule structures on digestibility. Our previously reported *in vitro* study on the effect of the fast protein-digesting mutant on starch digestibility showed no obvious relationship between protein and starch digestibilities. Last year we reported on a study that suggests that fine structure of sorghum amylopectin, specifically the comparably longer length of the short chains of the molecule, leads to a lower digestion property of the starch, hypothetically through greater starch crystallinity. Our initial work on granule structure and digestibility follows.

Implication of Starch Granule Structure - morphology and channels

Sorghum and maize starch granules are similar in the respect that they both have interior channels leading from pores on the granule surface to the central cavity of the granule. Accordingly, in animal digestion starch granules are corroded from the inside out, as amylases travel down the channels and digest the less crystalline central parts of the granule preferentially. A hypothesis pursued was that sorghum cultivars with higher amounts of channels may have somewhat higher starch digestibility. In a screening of different sorghum lines, mutant high protein digestibility/high lysine lines showed starch granules with high degree of channelization (Figure 3, arrows show pores, native and digested, leading to interior channels). *In vitro* digestibility testing showed that isolated starch from the mutant was digested at a somewhat faster rate than its wild-type relative. While a more extensive study is needed to confirm this trend over a wider range of genotypes, this approach appears to hold promise as a way to enhance starch digestion rate.

Other studies in our laboratory revealed that sorghum and maize starch granule channels are lined with proteins and a subsequent effort has been made to identify the proteins both to better understand the nature of the channels and to give clues on how to manipulate amount of channels to affect digestibility. Protein in channels was shown using a dye, 3-(4-carboxybenzoyl)quinoline-2-carboxaldehyde (CBQCA), that only fluoresces when covalently attached to protein and confocal laser scanning microscopy. Using a proteomic approach, maize channel proteins were separated on by 2-D gel electrophoresis and major proteins identified by MALDI-TOF mass spectrometry and identified as actin, tubulin, enzymes important in starch synthesis (ADP-glucose pyrophosphorylase, granule bound starch synthase), and brittle-1protein (a membrane

Figure 2. Confocal micrographs showing protein (labeled with CBQCA) in cooked sorghum flour pastes in water (left) and water + reducing agent (right). Web-structures in normal pastes are implicated in lower starch digestibility while reduction of disulfide bonds breaks up webs and increases digestibility.

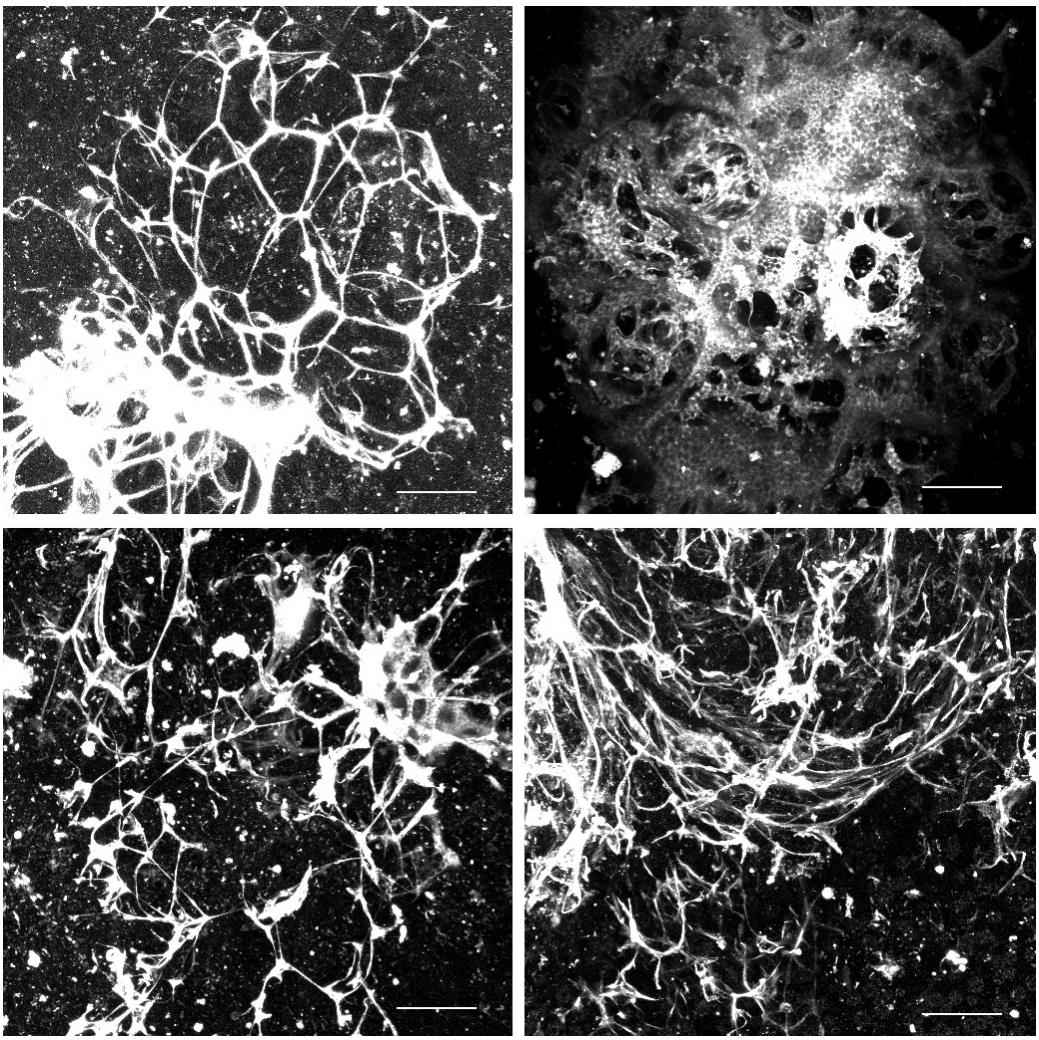


Figure 3. Scanning electron micrographs of starch granules from a high protein digestibility/high lysine mutant sorghum line showing surface pores that reveal interior channels leading to the central cavity (right – native granules, left – amylase-treated granules). High degree of channelization of mutant lines suggests faster starch digestion rate.

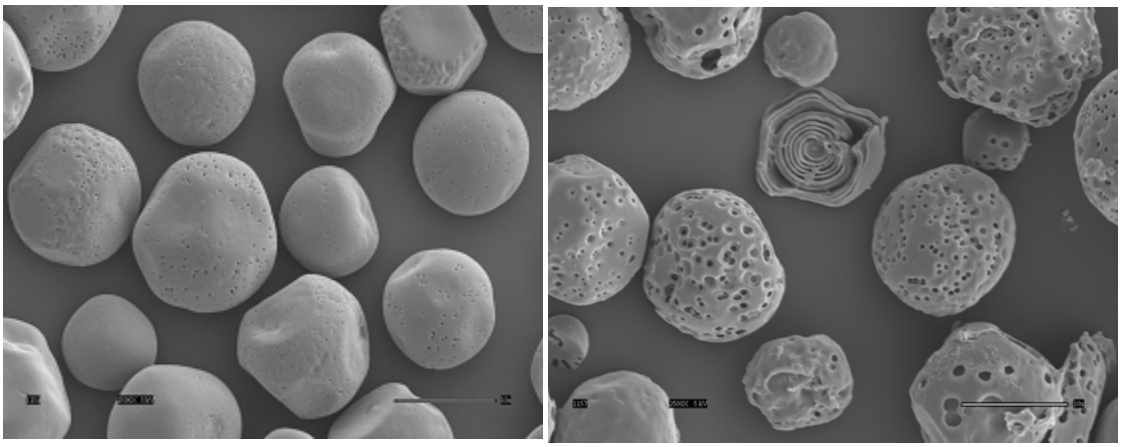
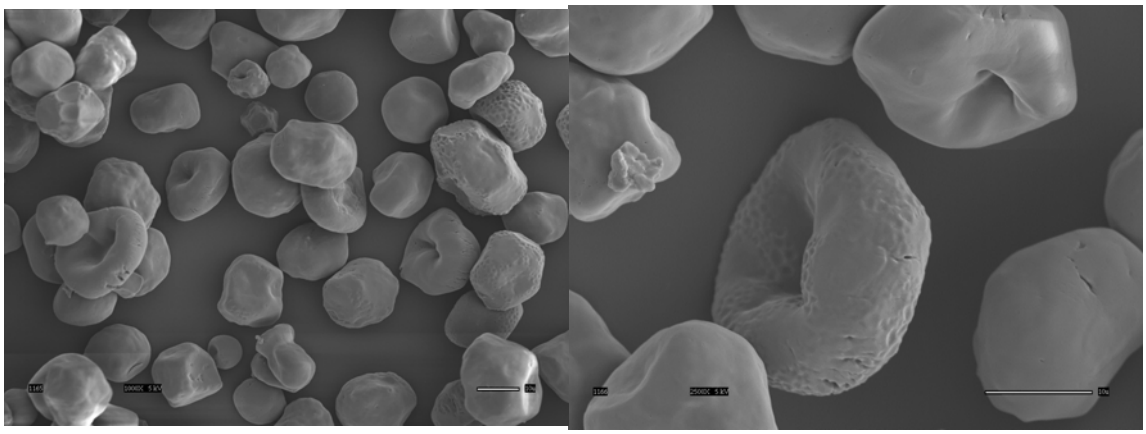


Figure 4. Sorghum *cv.* IS6986 containing a subpopulation of starch granules with abnormal "doughnut" shapes that are highly digestible.



protein involved in transport of ADP-glucose). The finding, in particular, of actin and tubulin residing in the channels implies that they are microtubules and that manipulation at the genetic level might be possible for digestibility improvement.

In a related study on relationship between sorghum starch granule structure and digestibility, a line, IS6986, was identified containing a subpopulation of starch granules that are abnormal in shape (doughnut-shaped) with a highly digestible characteristic (Figure 4). I was unclear what internal properties of the granule lead to faster digestion.

Networking Activities

In August 2003, Dr. Hamaker traveled to Burkina Faso and Niger to meet with INERA and IRSAT staff in Ouagadougou, and INRAN staff in Niamey to discuss ongoing research.

In September 2003, Dr. Hamaker traveled to West Africa for the External Evaluation Panel review of the eastern and western regional programs. Because of the proposed change to merge the programs into one West Africa regional program and the likelihood that Dr. Hamaker would take the role of U.S. coordinator, he accompanied the panel in Senegal, Niger, and Mali. In Niamey, Nigerian PIs attended the meetings.

Dr. Hamaker traveled to Ouagadougou in April 2004 for the West Africa Regional Planning meeting; a three and one half day meeting and workshop for strategic planning for the merged six country regional program, workplan development and submission, and new project development. There were 60 participants, 48 African PIs and 12 U.S. PIs and administrative personnel.

Publications and Presentations

Abstracts

Aboubacar, A. and Hamaker, B. Investigation of the structures of cereal starches attacked by alpha-amylase, American Association of Cereal Chemists annual meeting, Portland, October.

Bugusu, B.A. and Hamaker, B.R. Role of the protein component in low starch digestibility of cooked sorghum porridges, American Association of Cereal Chemists annual meeting, Portland, October.

Choi, S.J., Kim, H.J., Jung, S.H., Hamaker, B.R. and Moon, T.W. The relationship between sorghum digestibilities and their protein-starch interaction, Institute of Food Technologists annual meeting, Chicago, July.

Hamaker, B.R. and Rooney, L.W. INTSORMIL activities on grain-source preserved value-added sorghum/millet urban foods, Institute of Food Technologists annual meeting, Chicago, July.

Journal Articles

Miklus, M.B. and Hamaker, B.R. 2003. Isolation and characterization of a soluble branched starch fraction from corn masa associated with adhesiveness. *Cereal Chem.* 80:693-698.

Shin, S.I., Choi, H.J., Chung, K.M., Hamaker, B.R., Park, K.H. and Moon, T.W. 2004. Slowly digestible starch from debranched waxy sorghum starch: preparation and properties. *Cereal Chem.* 81:404-408.

Dissertations and Theses

Bugusu, B.A. 2004. Understanding the basis of the slow digestion characteristic of sorghum porridges and how to manipulate starch digestion rate. Ph.D.

Food and Nutritional Quality of Sorghum and Millet

Project TAM 226

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Ms. Etienne Palacios, Seed Technologist, INTA, Nicaragua (English language training and potential M.S. in FSTC)

Summary

New more efficient higher yielding white tan varieties are near release from the IER breeding program in Mali. The photosensitive types escape significant weathering/molding that adversely affects earlier insensitive white tan sorghums and led to their failure. These photosensitive value-enhanced sorghums provide improved grain quality for identity-preserved (IP) marketing of sorghums. The grain produced excellent food products because it was not discolored by insects and molds. Farmers were very excited with these white tan plant sorghum varieties because they liked the agronomics and grain yields. They were pleased with the grain quality for their own food consumption and appreciated the opportunity to sell the grain at a potential premium. This was especially significant in view of the fact that some of them had a bad experience the previous year with a grain trader who defaulted on a promised premium price. The principle of supply chain management from seed to food products has been demonstrated; however, a great deal of work to obtain widespread 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 containing sorghum flour. There are some significant successes in this area.

Dakar, Senegal has a significant and growing number of small processors producing packaged pearl millet products ranging from yogurt containing pearled millet to extruded snacks, flours, meals and various couscous products. There is a growing interest in securing improved quality grains for processing. This project has collaborated with Dr. Sander's project to further the marketing of these grains. A position paper was authored with other INTSORMIL PIs and Dr. Ouendeba Botorou regarding the development of a supply chain management system in targeted areas such as Senegal, Mali, Burkina and Niger.

United States value-enhanced white food sorghums developed in part by this project and promoted by the U.S. Grains Council in Japan are used by the Japanese food industry to market snacks and several other products. The white sorghums are color sorted, pearled to a very white color, 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. More production of white food sorghum is needed.

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.

Special sorghums with high levels of phenols and antioxidants were extruded to produce snacks with high levels of anti-

oxidants. 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 would 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.

The high antioxidant sorghums had effective antioxidant properties in processed meat systems. A patent disclosure was developed on the use of sorghum bran in processed meats.

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 are 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. ATx635 hybrids have outstanding milling and food properties. Red tan plant hybrid sorghums have excellent milling properties compared to red purple plant sorghums.

Antifungal proteins (AFP) are related to grain mold resistance in sorghum. An improved faster assay for antifungal protein detection was developed. When exposed to warm, humid environments and mold attack, sorghums that have higher levels of AFP have the highest resistance to molds. It is not really the level, but the ability of the sorghum to retain the AFP.

One Ph.D. and two M.S. students completed their degrees with thesis or dissertations on sorghum. In addition, two M.S. students had experience with sorghum but their theses were on QPM maize and tortilla quality. They are employed in the food industry in Mexico, the U.S. and by EARO in Ethiopia. The Ph.D. was Ms. Senayit Yetneberk who worked with Dr. John Taylor at the University of Pretoria.

Objectives, Production, and Utilization Constraints

Objectives

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

Constraints

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

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

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

Research Approach and Project Output

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

Significant Accomplishments

Applications of Technology in Mali

Work in Mali continues to demonstrate the value of new white, tan-plant photosensitive sorghum varieties in food systems. During the past few years, progress to develop an effec-

tive IP production scheme to produce sorghum of good quality for processing into value-added flour and meal was demonstrated.

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 and the grain quality for their own food processing. In addition, they appreciated the potential to secure a premium price for processing. Some of these farmers had contracted to grow N'Tenemissa last year (2002) but the grain trader defaulted on the contract. Nevertheless, the farmers still were willing to grow the newer photosensitive white tan cultivars from IER since they thought that they had high yields and improved quality. It is fairly impressive and the concept of growing improved quality sorghums has been demonstrated provided the agronomics and grain yields are competitive with the best locals and that is apparently true.

Another positive development is that farmers growing the white tan sorghums prefer the porridge and other foods 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 (TAM 226) has interacted with the Malian program since 1979. We believe that significantly faster progress will continue now that the principles have been demonstrated quite well and Malian business people are involved.

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 will occur only when sufficient margins are available to support all parties in the supply chain by sharing the profits. Successful development of this system is difficult and requires patience and practical programs to educate key managers, farmers and processors.

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. 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 acceptable and purchased by consumers provided convenience, good taste, appearance and consistent quality is available at competitive prices.

In South Africa, significant quantities of Mabella meal are consumed even though the price is significantly higher than mealy meal (maize) because a 14% value-added tax is assessed to sorghum-processed products. Botswana is an example where maize consumption is decreasing while sorghum consumption is increasing even though red or brown sorghum must be imported from South Africa. Professor Taylor and L.W. Rooney are chairing a white food sorghum workshop in Pretoria for the Southern African area in October 2004. White food sorghums may find significant niche markets in South Africa.

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, 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 IP food sorghums for processing must be developed for consistent success. The opportunities exist to stimulate use of white food sorghums in Central America since a source of grain is available, but technologies that can be used to decorticate sorghum and mill it into flour or meal are required along with production of a consistent supply of IP grain**.**

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 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 formal baking industry to use white sorghum flour but a large quantity of flour is unavailable to test the market. The costs of sorghum flour are reduced in the country while it would be higher in San Salvador due to transport into San Salvador.

Ms. R. Vilma Calderon, food technologist, CENTA, has been working with a large rice miller to process white food sorghum into flour and decorticated products. These are being supplied to bakers. A large snack food company in El Salvador is interested in using white food sorghum in extrusion because they saw our pilot plant sorghum extrusion results.

Health Foods from Special Sorghums

The HPLC analysis of procyanidins (condensed tannins) indicated that tannin or brown sorghums had a large number of oligomers that comprised the condensed tannins. The processing of tannin sorghums using extrusion significantly reduced the polymer size of the procyanidins. The increased percentages of oligomers with less than 10 units may positively affect the biological significance of the antioxidants. The type of pro-

cessing is important since similar changes did not occur when the brans were mixed into cookie and breads. The potential to produce healthy foods from sorghum is quite high.

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

Ms. Crystal Rudiger completed her M.S. thesis and developed a bread mix containing brown or black sorghum bran with flax seed, gluten, barley and wheat flour. The bread has excellent flavor, texture and outstanding levels of dietary fiber, antioxidants, ligans and omega 3 fatty acids with a natural brown color. Black sorghum bran in breads resulted in appearance, texture, color and specific volume (cm3/g) similar to commercial specialty or dark rye breads without the use of caramel coloring. Ms. Lindsey Wortham, M.S. student, has developed combinations of sorghum bran, wheat gluten, flax and beta-glucans into mixes for bread machines in some follow up research.

Ms. Linda Dykes, Ph.D. student, continues to characterize sorghum phenols and tannins using HPLC and other techniques. She is specifically evaluating the effect of different combinations of B1B2S and pericarp colors on tannin and anthocyanin contents. She is also studying the changes that occur in the tannins during maturation of the sorghum kernel. The levels of antioxidants and phenols are measured as well to determine the best combinations of genes to secure the highest levels of antioxidants. Ms. Lisha Xu, M.S. student, is evaluating the effect of extrusion on changes in the tannins using HPLC and also in the levels of antioxidants. The extrusion includes whole grain special sorghums and addition of up to 30 % bran to the whole or cracked grains. This research is to confirm what Turner found during extrusion of high bran levels. It may be possible to change the antioxidant activities and biological value by processing these special sorghums. Some of this work uses USDA funds. We are working with Dr. S. Bean at the Grain Marketing Lab in Manhattan, KS. His group will provide mass spectrometer data to aid in identifying the compounds.

Extrusion

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

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

White sorghum samples prepared by combining 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 cornmeal and polished rice were extruded as controls. The extrusion conditions were held constant for all samples. The expansion ratio, bulk density, color and texture of the extrudates were significantly affected by both particle size and decortication level. As the decortication level increased, the extrudates were whiter, more expanded, less dense, 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 both rice and corn, and had similar bulk density and texture characteristics. With increasing decortication level, whiter, more expanded, stronger and crispier, bland flavored extrudates were produced. The decortication level and particle size can be used to vary expansion ratio, crispiness and bulk density.

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

Sorghum Flour in Specialty Products

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

Sorghum Starch, Malting and Brewing Studies

Dr. Serna-Saldivar, ITESM, Monterrey, Mexico, is continuing to collaborate on sorghum research, especially with 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. He has consented to participate in seminars we are planning to have in Central America this next year. We hope to utilize his expertise.

Central American Use of Sorghum

Ms. R. Vilma Calderon, working with CENTA in El Salvador, has conducted trials in local bakeries showing that sorghum can be used effectively in baking of rosquettes, sweet breads and many other products as well. She and others are working with a large rice milling company to decorticated white sorghum for use in foods. The product appears to be acceptable and is being tried by some of the local bakeries. Technically the project will be successful but the economics must be determined and higher value products developed. 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. The concepts proven to be successful in Japan apply directly to use of the white sorghums in Central America. 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 by small producers in the Hillsides.

Tan Plant Food-type Hybrid Performance and Quality Trials

Attributes of sorghums that produce light colored meals, flour and grits with bland flavors were evaluated under different environments in uniform yield trials with 40 entries. This work was in collaboration with Drs. Tuinstra and William Rooney, who conducted the evaluation trials. Red and white sorghum varieties grown at locations in Texas, Kansas and Nebraska from 1999-2003 were evaluated for hardness using a SKHT (single kernel hardness tester), decortication properties using TADD (tangential abrasive dehulling device), TKW (thousand kernel weight), color (L, a, b), test weight, density, proximate composition and relative mold damage. Environment and hybrids significantly affected composition, physical and processing properties. White tan sorghum (WT) hybrids were harder, more dense and lighter in color than white purple (WP) hybrids or red hybrids (Figure 1). 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 would more effectively predict commercial decorticating 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 problem of molding and staining is decreased with tan plant sorghums that have straw colored glumes. For example, the Kharif sorghums of India become black with mold damage and sell for 50-60% discount. This is rapidly reducing sorghum production in India during the rainy season. The red tans might be useful for decortication and produce better food and poultry feed than the white sorghums currently being grown. The Kharif hybrids sell for significantly less money than the rabbi or dry, post rainy season sorghum called maldandi. Similar problems occur in much of Africa except the Sudan, Ethiopia and others where sorghum matures in the very dry season.

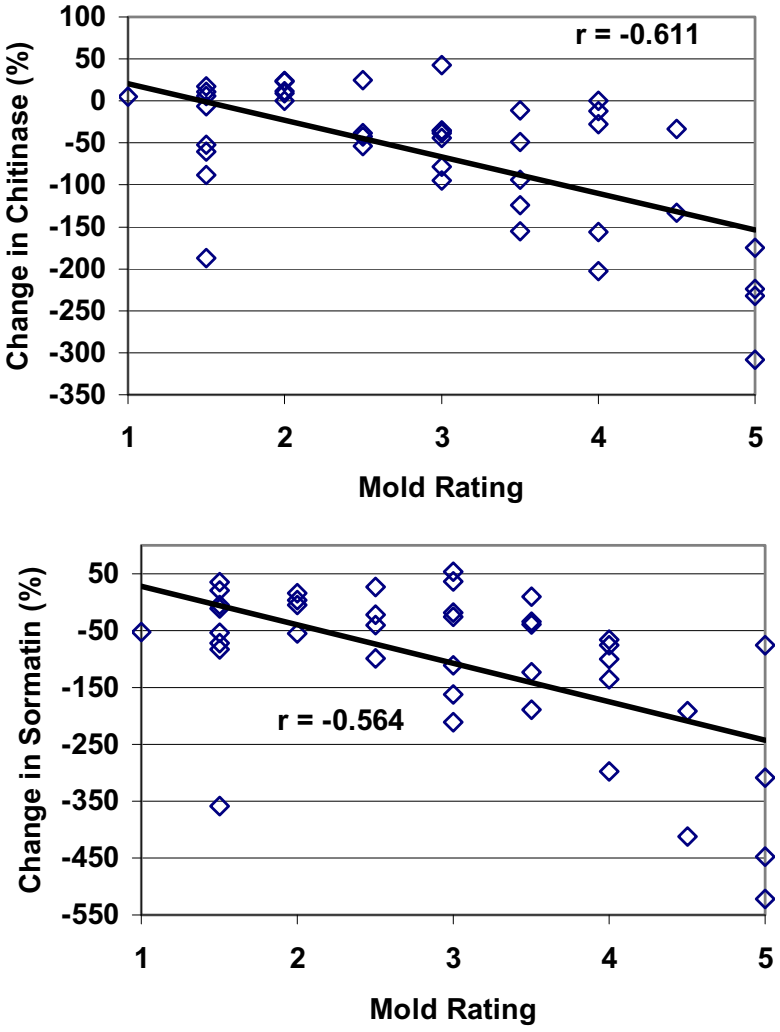
Improved Methods of Analysis

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.

In our previous reports, we have shown that when considerable mold infection occurs, there were statistically significant correlations between the severity of mold infection and the amount of AFP in sorghums. Higher levels (at 50 DAA) and greater retention (% change from 30 to 50 DAA) of AFP reduced molding of sorghums (Figure 1). Sorghums are likely to be more resistant to fungal invasion if they are able to retain good amounts of AFP from physiological to combine harvest maturity. In contrast, if they lose a lot of AFP during that period, they become more susceptible to molds. This indicates that AFP provides sorghums with an effective defense mechanism against fungal infection.

Another set of samples was collected and analyzed in 2003 and results of this study will be presented in the 2004 annual meeting of the American Association of Cereal Chemists (AACC) in September. All sorghums were grown at the Texas A&M University Farm, College Station, Texas. It comprised

Figure 1. Effect of AFP retention on grain mold rating of 2002 sorghums: Chitinase (top); Sormatin (bottom).



of 31 red and 13 white sorghum cultivars. Grain mold ratings at 50 DAA were assessed in the field by visually estimating severity, based on a 1 to 5 scale. Other grain quality attributes such as seed density, seed color, germination rate and total phenols were measured. Sorghum AFP (chitinase and sormatin) at 30 and 50 DAA were determined using the dot-blot immunoassay. The percentage change in AFP content from 30 to 50 DAA was calculated and used to measure degree AFP retention for each cultivar.

In order to determine the factors that influence sorghum's response against mold invasion, considerable molding should occur in the field as in 2002. The average mold rating for the 2003 sorghums was 2.1 which were less than that in 2002 (mold rating = 3.0). Nevertheless, differences in mold response among the cultivars were still observed. In the 2002 experiment, only AFP contents and mold ratings were measured. In the 2003 collection, sorghums were also analyzed for other physical and chemical properties in order to know if such attributes play some role in grain mold resistance.

Correlations between different sorghum variables for all the 44 cultivars of varying seed colors were determined. Mold rating score (MS) and germination rate (GR) were significantly correlated with each other. Visual assessment of molding in colored-seeded sorghums can be difficult. Hence, although not a direct measure of mold infection, the germination rate test was used to compliment the mold rating scores.

Consistent with our previous findings, the results prove that AFP is a significant factor that determines the resistance of sorghums against fungal invasion. Chitinase retention was significantly correlated with MS and GR, while sormatin retention was correlated to GR only. Seed color measurements (L, a and b values) were consistent with total phenols, showing that colored seeded sorghums contain more phenolic compounds than white sorghums. Total phenols were significantly correlated with MS but not with GR. Seed density was not correlated with MS or GR.

Previous studies have explained the role of phenolic compounds against molds which may be consistent with the results of this study. However, while total phenols were significantly correlated with MS, it was not with GR. It appears that the amount of phenolic compounds in sorghum alone does not guarantee mold resistance, as there are mold susceptible red sorghums and mold resistant white varieties. However, mold resistance attributed to AFP retention is more consistent and applies to both red and white sorghums.

We previously mentioned the possibility of AFP as mechanism for mold resistance in sorghums being an inherited trait. Thus, seven sorghum hybrids and their parents were measured of their mold response as well as the various factors that may have contributed to such response. Traits from parents were compared to those of the hybrids. The degree of chitinase retention in hybrids appears to be inherited from their parents. Most hybrids showed improved chitinase retention and consequently, higher mold resistance than their parents. Among the attributes being linked to mold resistance, chitinase retention appears to be more consistent than the others. However, this is only a preliminary study and did not strictly follow the inheritance study methodology used by plant geneticists. Thus, we will be asking the help of plant geneticists to come up with a better experimental design that would test this hypothesis.

We are currently in the processes of collecting samples from this year's crop. We have chosen to collect from 87 cultivars of which 46 are red and 41 are white sorghums. As in 2003, we will analyze for AFP as well as other physical and chemical grain attributes that are implicated in grain mold resistance. This will validate the conclusions we came up in the 2003 study. (Figure 1)

Networking Activities

Southern Africa

The PI, Lloyd Rooney, made three trips to Central America, one trip to Mexico and one trip to Mali to develop collaboration and present information on sorghum food and feed quality

INTSORMIL's interaction with the University of Pretoria informs many future African food industry leaders of the potential role of sorghum and millets as food and industrial ingredients. Graduate students in the Food Science Department at University of Pretoria are from many African countries. Many participate in the Regional Master of Science program, which consists of joint programs between CSIR and University of Pretoria. INTSORMIL is providing significant assistance to the region by involvement in these key programs.

Dr. S. Yetneberk from Ethiopia completed her Ph.D. program at University of Pretoria under Dr. John Taylor. She made excellent progress to determine major factors affecting the quality of injera from sorghum cultivars grown in Ethiopia. She found the addition of emulsifying agents appears to improve quality and prolong shelf life of injera from sorghum. Some hard white cultivars have acceptable injera quality. She has returned to the Ethiopian National Sorghum Improvement Program where she is developing improved sorghums for injera.

Mr. Steve Barrion, M.S. candidate, University of Pretoria, is working on milling of pearl millet from Namibia. Commercial milled products from a major millet variety were produced and analyzed for components and physical properties. This project will provide useful information relative to commercial milling of pearl millet compared to traditional milling.

Ms. Nomusa Ngwenya-Dlamini, Bulawayo, Zimbabwe, is working on a Ph.D. in food science at the University of Pretoria, involving antioxidants from sorghum. She teaches food science courses at the National University of Zimbabwe in Bulawayo. She was granted a Fulbright Fellowship to complete a Ph.D. program which will be done at Texas A&M University and the University of Pretoria where she has already made progress on antioxidants from sorghum and the effect of processing on them. Professor Taylor and Dr. L.W. Rooney will work together to co-advise her on her Ph.D. program.

Honduras, Salvador, Mexico and South America

Dr. Rooney traveled to San Salvador, El Salvador and Managua, Nicaragua to develop collaborative research plans and to evaluate the current status of value-added sorghum in food processing. A one day seminar on Sorghum Utilization in Feeds and factors affecting its value especially tannins was presented in Nicaragua and El Salvador. Dr. J Bueso, Associate Professor, EAP, Zamarano Honduras was the interpreter for Professors Joe Hancock (KSU 220) and Lloyd Rooney. In April, Dr. Lloyd Rooney participated in the PCCMCA conference in San Salvador by giving a presentation to the sorghum and rice sessions. While there, meetings with potential processors and CENTA personnel furthered the use of white food sorghums in snacks and other products. Dr Bueso just completed his Ph.D. at TAMU as part of the TAM 226 INTSORMIL project.

Experience obtained in Japan applies quite well to the situation in Salvador and elsewhere in Central America. A small Central American food company has initiated use of modest amounts of sorghum in their extruded snacks as the result of participation in our snack foods short course.

Dr. Lloyd 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.

We are actively recruiting a graduate student from El Salvador (Ruth Vilma Calderon) and Nicaragua (E. Palacio) to develop skilled personnel for those programs in Central America where food science personnel related to crop improvement programs are unavailable. Ms. Palacios is in language training using World Bank Funds. Ms. Calderon is a food scientist at CENTA who is conducting research on the milling of sorghum into flour using a large rice mill. This appears promising.

Mali and West Africa

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

The products were of excellent quality overall; processors realize they need improved quality and consistency of grain and are willing to pay more for it. The organization of farmers to produce higher quality grain and supply chain management and sharing in profits by all parties are the next steps toward more efficiency. These developments are the results of long-term efforts on the part of numerous international agencies that assisted ITA and other organizations to lay the groundwork for these entrepreneurs. The time is ripe to develop a supply chain to provide value-enhanced grain for increased profits for all participants from seed producers through to the consumer. A supply chain for improved quality grain will make delivery and adoption of new cultivars much easier and will permit processors to expand production to meet market demands that appear to exist.

North America

Several papers were presented at the annual American Association of Cereal Chemists Conference, Portland, Oregon. Dr. Lloyd Rooney presented sorghum quality/utilization discussions to Texas Sorghum Producers Board Members and panels and U.S. Grains Council sponsored trade teams.

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 (48) from all over the world (18 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

Two M.S. theses were completed. 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.

Publications and Presentations

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