DEVELOPMENT OF SORGHUM FOOD PRODUCTS:

POPPED SORGHUM AND INSTANT

SORGHUM MEALS

By

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TABLE OF CONTENTS

Chapter Page

LIST OF TABLES: CHAPTER III

Table | Page

Table Page

LIST OF FIGURES: CHAPTER III

LIST OF TABLES: CHAPTER IV

Table Page

LIST OF FIGURES: CHAPTER IV

Figure Page

Figure Page

CHAPTER I:

INTRODUCTION

Through plant breeders and food scientists working together the utilization of sorghum (*Sorghum bicolor* subsp. *Bicolor)* for human consumption is being improved. The United States China, India, Argentina, Nigeria, Mexico, Sudan, and Australia produce over three-quarters of the world sorghum crop that amounts to approximately 65 million tons yearly (FAO, 1995). Sorghum *S. bicolor* in the United States is primarily grown in Kansas, Oklahoma, Texas, Nebraska, and Missouri (Smith and Frederiksen, 2000). These sorghum-producing states are credited with growing 90% of the grain in the U.S. as well as exporting up to one half of its production (Smith and Frederiksen, 2000). The vast U.S. production is consumed as animal feed, with a small portion going into the food industry; although in most other less advanced countries, grain sorghum is consumed as a food product (Smith and Frederiksen, 2000).

In Nigeria, sorghum malt is utilized to produce a number of nonalcoholic beverages (Vita Malt) and dried malt extracts for use in milo. Maltabella is a ready-to-cook breakfast food made from malted sorghum in South Africa. Instant beer powder, cracked or coarsely ground malt, shelf-stable opaque beer, and a variety of meals, ricelike products, and flour from sorghum are readily available in Southern Africa. Weaning foods from extruded sorghum and soy blends are produced and used in Botswana (Smith and Frederiksen, 2000).

Sorghum flour does not contain proteins that produce the viscoelastic gluten as wheat does; therefore, acceptable yeast leavened products from 100% sorghum flour are difficult to obtain (Smith and Frederiksen, 2000). However, sorghum and wheat flour blends have been used to produce many baked products, including yeast leavened pan, hearth and flat breads, cakes, muffins, cookies, biscuits, flour tortillas, and other food products (Rooney et al., 1980, Morad et al., 1984a,b; Badi et al., 1990).

Much of the research done on sorghum has been developing ways to use it as composite flour for many of the products mentioned above. There is a present effort to rid red sorghum grain of the red pericarp that often adds an unwanted bitter flavor and color to certain products, such as sorghum starch. Instead of trying to decorticate sorghum's undesirable characteristics such as the red pericarp this research tries to use them as a benefit.

The objective of this research was to develop or improve methods of utilizing Oklahoma's sorghum in or for snack food products. Two types of processes were developed, popped sorghum and instant sorghum meal. Popped sorghum is common in India and South Africa although not within the United States. With popcorn being a popular and healthy snack food in consumer's homes, sorghum pops, a novel item due to its small size, could achieve such popularity as popcorn. Sorghum instant dried meal, was developed by using a method similar to corn masa techniques. The resulting instant meals each have their own individual pasting properties that could be beneficial to many commodity suppliers as a functional ingredient.

CHAPTER II:

REVIEW OF LITERATURE

Sorghum Chemical Composition

The pericarp is divided into three histological tissues: epicarp, mesocarp, and endocarp (Earp et al., 1982). The outermost layer, or epicarp, is generally covered with a thin layer of wax. The epicarp is two or three cell layers thick and consists of rectangular cells that often contain pigmented material. Unlike most cereal, the sorghum mesocarp contains starch granules. A thick pericarp usually contains three or four mesocarp cell layers filled with small starch granules. Pericarp thickness ranges from 8 to 60 μm and varies within an individual mature caryopsis (Blakely et al., 1982).

Commercial U.S. sorghums are generally 4 mm long, 2 mm wide and 2.5 mm thick, with a kernel weight of 25 to 35 mg, a test weight of 58 to 60 lb/bu, and density from 1.28 to 1.36 g/cm^3 (Rooney et al., 1982). The environment and genetics cause variation in the proximate composition of sorghum. The pericarp is rich in fiber, whereas the germ is high in protein, fat and ash. The endosperm contains mostly starch, some protein, and small amounts of fat and fiber. Sorghum and dent corn (*Zea Mays)*, have similar composition, with sorghum containing slightly more protein and corn containing more fat (Smith and Frederiksen, 2000).

Protein

The majority of sorghum proteins are located in the endosperm (80%), germ (16%), and pericarp (4%) (Taylor et al., 1986). The major protein fractions in sorghum are kafirins, or prolamins, and glutelins. These fractions are located primarily with in the protein bodies and protein matrix of the endosperm respectively (Warsi et al., 1973). Sorghum protein is deficient in lysine, an essential amino acid. Protein quality is critically important in developing countries where human diets consist mainly of cereals. Supplementation of sorghum-based diets with relatively small amounts of legumes can overcome the amino acid deficiency (Haikerwal et al., 1971). Sorghum lysine meets approximately 40% of the recommended level for infants. Brown and regular sorghums have similar amino acid composition; however, the high-lysine cultivars contain approximately 50% more lysine (Smith and Frederiksen, 2000).

Fiber

Cereal grains are a rich source of fiber. Dietary fiber is plant material that resists digestion by enzymes in the monogastric stomach and upper gastrointestinal track. It can be defined as "those remnants of vegetable cell walls that are not hydrolyzed by the digestive enzymes of man" (MacDonald, 1976). The major components of fiber are cellulose, hemicellulose, lignin, and pectin, which are located primarily in the pericarp, which is removed during decortication (Smith and Frederiksen, 2000). Sorghum contains 6.5 to 7.9% insoluble fiber and 1.1 to 1.23% soluble ß-glucans, which comprise most of the soluble fiber (Bach-Knudsen et al., 1985). Most of the fiber in sorghum is insoluble, 86.2% and is located in the pericarp (Smith and Frederiksen, 2000). During food processing of sorghum insoluble dietary fiber increases due to increased levels of bound protein (Bach-Knudsen et al., 1985, Serna-Saldivar et al., 1987, Bach-Knudsen et al. 1988). Sorghum bran that was parboiled and then decorticated to remove 17.5% of the weight was richer in fiber and oil than were other bran from raw grain. The insoluble and soluble dietary fiber from sorghum bran ranged from 15 to 24% and 2.7 to 3.7%, respectively (Serna-Saldivar et al. 1987).

Fedail et al. (1984) found that supplementation of sorghum bran to human subjects increase stool weigh, decreases intestinal transit time, and increases the frequency of evacuation. Klopfenstein et al. (1981) compared several sources of cereal fibers and found that sorghum bran was effective in lowering serum and liver cholesterol levels in guinea pigs. Rooney et al. (1992) decorticated white and brown sorghums to remove approximately 7.5% of the caryopsis. The resulting pericarp rich tissue (bran) contained 47.8% and 35.1% insoluble dietary fiber and 1.6 and 1.0% soluble fiber. Sorghum bran did not lower blood cholesterol levels but were excellent bulking agents in rats. Brown sorghum bran containing tannins exhibited better bulking ability than did white sorghum bran (Smith and Frederiksen, 2000)

Starch

Starch is one-half to three-fourths of the grain weight, and can affect any factors in processed sorghum, such as popping expansion ratio as well as pasting properties. Starch exits in a highly organized manner in which amylose and amylopectin molecules are held together by hydrogen bonds and are arranged radially in spherical granules or micelles (Smith and Frederiksen, 2000).

Sorghum Grain Structure

The sorghum pericarp acts as a pressure vessel, which will allow vapor pressure to build up during popping and also limit moisture loss. Popcorn with damaged pericarp does not pop well, i.e., does not expand during popping (Wu et al., 1992). Hoseney et al. (1983) found that initial breaks in the pericarp affected popped volume more radically than did subsequent breaks. Wu et al. (1992) believe that the variation of pericarp thickness in corn, in terms of pericarp yield strength, might be an important factor that caused the optimum moisture content to vary for different popcorn varieties or even with location of kernels on the ear, causing different degrees of expansion for different kernels.

Moisture Application Methods to Grain

The way in which moisture is applied to grain for tempering can have an effect on the pericarp's resulting condition. Two methods involving reconditioning corn grain are reported in the literature. Metzger et al. (1989) method applied moisture to corn grain with a spray paint gun while the popcorn tumbled in a rotating stainless steal drum. While Wu et al. (1992) rehydrated corn by spraying water on the inside wall and lid surface of an airtight glass jar. These methods limit any direct contact between water droplets and kernels. This would minimize steep moisture gradients that might induce stress cracks in the corn pericarp that could affect the expansion volume of popcorn (Wu et al., 1992, Metzger et al., 1989).

Popcorn

Popping popcorn has been around for many centuries. In 1948, archeologists found ears of popcorn in the Bat Cave in New Mexico dating back more than 5,600 years (Kische, 1977). The now common method of popping popcorn in oil has been around since the mid-1800's, and the air-popping method has been around since around 1979 (Kische, 1977). Microwave heating popcorn began in the 1940s. It has already accounted for $240 million in annual U.S. popcorn sales in the 1990s. Americans consume 17.3 billion quarts of popped popcorn each year and the average American eats about 68 quarts.

Popcorn is a one of the most familiar types of popped grain that is made from a special type of maize (*Zea mays* L.) a dent corn, but in India and parts of Africa, sorghum (*Sorghum bicolor* L. Moench) is popped to give a crunchy, porous snack with improved digestibility (Murty et al., 1995). Using traditional methods the popped sorghum is ground and made into porridge usually consumed by children and the elderly (Murty et al., 1995). Sorghum is commercially popped to produce a pre-cooked product in South Africa and can then be easily made into porridge (Parker et al., 1999). Popped sorghum has been studied for improving the feed efficiency of sorghum grain in high-concentrate livestock rations (Rooney et al., 1980). Good popping sorghum grains will be small in size, have medium thick pericarp, hard endosperm and a very low germ/endosperm ratio (Murty et al., 1983). Popcorn maize and sorghum both produce characteristic everted grains consisting of expanded endosperm foam attached to fragments of pericarp and embryo. Wheat, barley and dent corn are reported to pop to a small degree but not to the extent observed in popcorn maize or sorghum (Reeve et al., 1969, Hoseney et al., 1983).

A high expansion volume is desirable in commercial production of popcorn, since popcorn is sold on a volume basis. The effect of parameters such as kernel size and genotype (Song et al., 1991, Singh et al., 1997), moisture content (Hoseney et al., 1983, Carr et al., 1920, Song et al., 1994) and cooking temperature (Hoseney et al., 1983) on expansion volume have been investigated. Kernel structure has an important function to expansion volumes. Correlation of vitreous kernels (Hoseney et al., 1983, Pordesimo et al., 1991, Weatherwax, 1921) and undamaged pericarp (Hoseney et al., 1983, Singh et al., 1997) to high expansion volumes have been reported.

Thorat et al. (1988) reported the effect of various grain physical characteristics and their relationship with popping quality on nineteen cultivars of grain sorghum. Popping was performed at 18% moisture at 240 ± 5°C. The results indicated that there was a significant positive effect on expansion ratio due to seed hardness and bulk density. Although through the use of multiple correlation regression results indicated that none of the physical parameters had a significant effect on pop volume and expansion ratio when all the physical parameters were considered simultaneously. Only popping yield was effected by seed hardness and bulk kernel volume. Seed hardness affected the percent popping positively and the bulk kernel volume negatively affected the pop yield.

The popping process is not one big explosion but millions of tiny explosions as each starch grain expands and bursts. Apparently not only the number of starch granules but the structure of the covering of the each grain are factors in popping expansion. Some investigators have advanced the theory that the thickness or toughness of the protein matrix surrounding the starch granules holds in the moisture until sufficient steam pressure is generated to cause an explosion.

Hoseney et al. (1983) have investigated the internal structure of popped cereals. Each bubble of the endosperm foam represents an individual starch granule of the vitreous endosperm which, during the explosive popping process, becomes gelatinized and then inflated by internal steam pressure (Parker et al., 1999). The heat then dried the foam to a brittle structure (Reeve et al., 1969, Hoseney et al., 1983, Carr et al., 1920, Weatherwax, 1921). Parker et al. (1999) studied the endosperm walls after popping of yellow popcorn maize and white sorghum. By using conventional microscopy and the autoflourescent properties of cereal cell walls (Morrison et al., 1975, Harris et al., 1976, Earp et al., 1983, Glennie, 1984). The grains were popped separately in a domestic hot-air popcorn popper, but the temperature at which the grain was popped was not recorded. The vitreous endosperm and the endosperm foam of the popped popcorn and sorghum were found to be broadly similar. Additionally, the cell walls of vitreous endosperm shatter into minute fragments during the explosive process of popping. This resulted in improved accessibility of the starch and protein components of the endosperm foam to enzymes within the digestive tract. Wet cooking has been proposed to promote formation of disulfide-bonded protein polymers, amounting to a change in protein secondary structure, in sorghum (Hamaker et al., 1986) and maize (Batterman et al., 1998). Thus yielding low protein digestibility of wet cooked sorghum (Hamaker et al., 1986). Duodu et al. (year) agreed with the results found by Parker et al. (1999) concerning greater protein digestibility of popped grain (sorghum and maize corn) compared to wet cooked sorghum. Duodu et al. (1989) found from their Fourier transform infrared (FTIR) spectra that even though the same type of secondary structural change occurred in the protein by either wet cooking or popping, the increase in ß-sheet components on thermal processing occurred to a greater extent by wet cooking than by popping in both sorghum and maize. Parker et al. (1999) found evidence that partly popped grains showed some inflation of the heated starch granules of the vitreous endosperm, without the cell wall fragmenting. Parker et al. (1999) also suggested that the pericarp acted as a pressure vessel holding the initial water vapor of the heated kernel. Their observations on the relationship between experimental damage to the pericarp and popped volume (Hoseney et al., 1983, Singh et al., 1997) have shown that the intact pericarp acts as a pressure vessel which is initially able to resist the pressurized water vapor in a heated kernel.

The popcorn industry has suggested that hot-air popping requires a higher initial moisture content to obtain its maximum popping volume (Metzger et al., 1989). Ashman's (1979) study measured the popping expansion volume of maize by using small samples (<150g). Using a small sample of approximately 40g, he obtained satisfactory results of hot-air popping with the constant-volume-weight method (Metzger et al., 1989). This method used a constant volume of flakes and recorded a weight. No account was taken for popcorn moisture content during the study. Metzger et al. (1989) studied the effect moisture content has on hot-air and oil popping. The authors found similar results as other researchers in earlier reports in the literature. Lyerly (1940) observed that the maximum popping volume of oil popping maize occurs in a moisture content range from 12-14%, depending upon the variety of popcorn. The moisture content since has been narrowed to between 13 and 14.5% moisture with the optimum being 13% (Ziegler et al., 1985). It was concluded that a high moisture content was needed for hot-air popping. Metzger et al. (1989) concluded that greater moisture content is need for hot-air popping, and that hot air popping produced a larger popping volume than oil popping over the entire moisture range of 7.89-18.19% MC.

Sorghum harvesting differs from popcorn harvesting. Corn is harvested by the whole ear. The ear of corn is dried through handling during shelling or processing, and damage to the kernel by disease, rodents, or insets may lower popping expansion (Matz, 1984). However, the sorghum grain harvest process is quite different especially in other countries. For example, in West Africa the sorghum heads are cut by hand with a sickle, on a few larger farms combines are used for harvesting like in the U.S. (Smith and Frederiksen, 2000).

Pops Terminology

The term flake is used to describe the popcorn kernel after it is popped. Different varieties of popcorn and hybrids have distinctly different shapes when popped. Popped corn, which has an irregular, branched or pronged appearance (the most common type) is called butterfly; that which puffs up into an almost round ball is called mushroom. The popping expansion of mushroom type usually has a coarser hull because the varieties south American and Superb, from which this type was developed, have a coarse hull which often adheres to the popped kernel (Matz, 1984).

The mushroom-shaped flake is preferred by manufactures of confection-type popcorn products, such caramel or sugar coated corn (Matz, 1984). It is also preferred by operators of popcorn vending machines and some popcorn stands. Some of the more tender flakes are not satisfactory for central poppers because of the breakage in handling.

For home use or "on location" popcorn stands, a more tender hybrid with lighter hull is much more desirable (Matz, 1984).

Experimental work has shown that artificial drying of popcorn at temperatures not above 120°F, when the corn did not have more than 25% moisture did not lower popping volume. Some large processors follow the practice of artificially drying part of their crop on the ear in specially constructed cribs or drying binds, similar to those used by hybrid seed corn companies (Matz, 1984).

Reconditioning Process

Restoring the correct moisture content of large quantities of ear or shelled corn is a difficult problem. If stored in well-ventilated cribs, corn that has become too dry during a hot, dry spell in summer will absorb moisture during a rainy spell to then again obtain good popping conditions. Other processors have designed humidity-regulating chambers, where mist of dry air can be passed through storage bins. By regulation the flow of moisture or dry air and the speed of the corn passing through the chamber, the moisture content of the corn can be regulated quite accurately (Smith and Frederiksen, 2000).

Although popping is not restricted to popcorn, it finds its greatest expression in the form of maize. This is because popcorn is of a hard flinty structure and contains very little soft starchy endosperm. Some varieties of flint corn pop fairly well, and kernels of hard dent varieties will pop slightly. On the other hand, flour corn, which is made up entirely of soft starchy endosperm, will not pop at all. Some hard, flinty grain sorghums also pop well.

The amount of expansion is determined by the relative percent and location of hard and soft starchy endosperm in the kernel and the proper moisture content. Apparently the softer types of starchy endosperm permit the gradual escape of steam when the kernel is heated so that not enough pressure is generated to cause the sudden explosion necessary for complete popping.

Masa Processing Basics for Corn

After potato chips, corn and tortilla chips are the most popular salted snack foods in the United States (Anonymous, 1992). Retail sales for corn tortillas and tortilla chips during 1994 were more than \$5 billion (Barret, 1996). For this reason, the production of nixtamalized corn flour has expanded in this country (Lobeira et al., 1998).

Tortilla chips, corn-based tortillas and corn chips are made from a corn based dough called masa. A process known as nixtamalization is where corn is cooked in the presence of lime (calcium oxide).

In the nixtamalization, the dry grain and lime are combined in a kettle with water, and the mass is cooked with steam injection to near boiling (Strissel et al., 2002). The amount of time used to cook the grain varies depending on the product to be made. Tortilla chips require between five and ten minutes of cooking, while corn chips require 20-30 min. Tortillas require even longer cooking times.

To stop the cooking process some processors quench the corn with cold water where as others simply drain the corn. In the next step, the corn is steeped in tanks for 8-12 hours. The previous step allows for the moisture and the lime to be distributed evenly. The cooking step usually only partially cooks the kernels. The corn is ground to from masa after steeping. Finally, the masa dough is formed and fried to make corn chips; formed and baked to make tortillas; or formed, baked, cut, and fried to make tortilla chips.

Alkaline Cooking

Alkaline cooking is used in the production of corn tortillas and snack foods. In Central America and southern Mexico sorghum is used as a total or partial replacement for corn tortilla production (Bedolla et al., 1983, Serna-Saldivar et al., 1987). The physicochemical characteristics of corn and sorghum starch are similar. However, during alkaline cooking, sorghum starch is modified to a greater extent than corn starch, given similar cooking treatments (Gomez et al., 1989). Helbert et al., (1991) used lime at a 1.3% concentration in processing raw sorghum grain of varying pericarp color an thickness and varying endosperm type (waxy, nonwaxy and heterowaxy). It was found that soft, floury sorghums with thick pericarp absorbed water less rapidly than sorghums with thin pericarp and hard endosperm, similar results were also found by Khan et al. (1980).

A snack food from corn with a light crunchy texture is prepared by deep fat frying dried kernels pellets of alkaline-cooked whole white corn and is very popular in Indonesian markets (Suhendro et al., 1998). A similar product was prepared using sorghum (Jowar Crunch).

Suhendro et al. (1998) researched factors that affected the quality of alkaline-cooked pellets and fried pellets made from several sorghum cultivars. Suhendro et al. (1998) found that the degree of cooking, drying method or moisture content of pellets, and temperature of frying exhibited important and interrelated roles in the composition, structure, and quality of unfried and fried pellets.

Corn tortilla and related products are prepared from masa which is obtained through the process of nixtamalization, or alkaline cooking and steeping of corn. In this process, corn is cooked in boiling lime solution (1% lime based on corn weight) for 5-50 min and steeped over night. The steeping liquor (nejayote) is discarded. The cooked corn (nixtamal) is washed to remove excess alkali and loose pericarp tissue. Then the nixtamal is ground with a stone grinder into masa. Masa is kneaded, and then molded into a disk and baked for 30-60 s to produce a tortilla (Rooney et al., 1987).

Masa texture is determined by factors such as maize variety, endosperm texture and type, drying conditions and soundness of the corn, as well as the water uptake and degree of starch gelatinization during processing (Khan et al., 1980).

Sorghum Tortilla Processing

Various methods of processing sorghum in alkaline solutions were reported in the literature. Choto et al. (1985) processed whole and pearled sorghum into tortillas by cooking in the sorghum in an alkaline solution at 1-1.5% concentration using a steam cooker, and allowing the grain to steep for varying times (0.05, 3, and 4 hr). The cooked, steeped grain (nixtamal) was washed in cold tap water and ground into a masa with a stone grinder then cooked. Another typed of method used to process sorghum using alkaline treatment methods is explained by Helbert et al. (1991). Sorghums were boiled for various times and all steeped for 5 hr. The sorghum samples were boiled in nylon bags in a lime concentration of 1.3%. Most of the variability found in the literature in processing was in boil and steep time of the sorghum.

Pregelatinized Starch

Pregelatinized or instant starches are obtained by pouring a starch-water slurry onto a steam-heated roll or into the small space between two nearly touching and counter-rotating, steam-heated rollers, where the starch is quickly gelatinized, pasted and dried. The dry film is scraped from the roller and ground. The resulting product should contain no intact granules, except in the case of a crosslinked starch (Whistler et al., 1997).

A cross-linked starch has pasting properties that are different from a native starch. A cross-linked starch is the covalent bonding of two starch molecules to make a larger molecule (Hoseney, 1994). Usually cross-linking is done by forming a diester with phosphoric acid or by forming an ether bond. Sometimes crosslinking occurs within a large amylopectin molecule or between the molecules themselves (Hoseney, 1994). The more cross-linking that occurs the higher temperature needed for gelatinization. Highly cross-linked starches can be prepared that do not gelatinize when they are boiled in water. Hoseney (1994) stated that starch for use in food systems is generally cross-linked to a small extent. Low levels of cross-linking do not significantly change the gelatinization temperature of the starch but do materially change its pasting properties. Cross-linked starch gives a lower viscosity upon pasting. Because the starch solubilizes less, it shears less and thus gives a more viscous paste after stirring or pumping (Hoseney, 1994).

Pregelatinized starches can be used without cooking, producing dispersions without lumps if coarsely ground. Finely ground pregelatinized starch behaves similarly to a water-soluble gum, forming small gel particles and producing some graininess or pulpiness, which is desirable in some products (Whistler et al., 1997). Many pregelatinized starches are used in dry mixes such as instant pudding mixes; they disperse readily with high-shear stirring or when mixed with sugar or other dry ingredients (Whistler et al., 1997). Both chemically modified and unmodified starches can be used to make pregelatinized starches. If chemically modified starches are used, properties introduced by modifications are also exhibited by the acid, shear, and freeze-thaw cycles, are also characteristics of pregelatinized starches (Whistler et al., 1997). For example, pregelatinized, slightly crosslinked starch yields a paste of high shear strength useful in instant soup, pizza topping, and extruded snacks (Whistler et al., 1997).

During gelatinization amylose leaches out of the amylose-amylopectin complex. Amylose escapes the complex more easily because of its non-branched structure. Some leaching of amylose occurs at temperatures below gelatinization temperature due to its location on the noncrystalline regions and the fact that it is a relatively small linear molecule that can diffuse out of the starch granules (Bemiller, 1984).

Wong et al. (1996) studied the textural properties of corn masa and the importance of mixing times and the moisture content of the masa in the initial stages of producing fresh corn masa. The viscosity of fresh corn masa could be an important rheological parameter in controlling and designing equipment for the tortilla-making process. From the rheological parameters studied by Wong et al. (1996) it was found that viscosity could be very useful in predicting when the corn masa will adhere to the rollers without being sticky

Starch Gels

A gel is defined as a continuous, three dimensional network of connected molecules or particles entrapping a large volume of a continuous liquid phase (Whistler, 1997). Gels made from a network of polymer molecules or fibrils formed from polymer molecules are held together by hydrogen bonding, hydrophobic association (van der Waals attractions) ionic cross-bridges, entanglements, or covalent bonds (Whistler, 1997).

Break strength measurements are made by compressing or penetrating (puncturing) a standard gel, using a standard probe, which descends at a constant speed until the gel ruptures (Rosenthal, 1999). Although it is believed that uniaxial compression is most appropriate, since in many food processing arenas compression is likely to be used (Rosenthal, 1999).

The firmness of a gel depends on the extent of junction zone formation which can be either facilitated or hindered by the presence of ingredients such as fats, proteins, sugars and acids and the amount of water (Bemiller, 1984).

Determination of Degree of Starch Gelatinization

Khan et al. (1982) explain methods for determining starch gelatinization. Two methods explained were enzyme susceptible starch (ESS) and the amylograph peak viscosity. The ESS method was reported to be variable with insufficient sensitivity to detect differences among nixtamals and masas with considerably different characteristics.

ESS is an index of the relative amount of starch gelatinization. The amount of glucose released by enzymatic hydrolysis is measured and divided by the total of nixtamal sample weight. The amylograph peak viscosity gave reliable results. Chen et al. (2002) used differential scanning calorimetery to reflect partial and complete starch gelatinization imparted by various lime-alkaline treatments on masa flour, after undergoing heat treatment. Results were found to be slightly higher than previously reported, the reasoning behind this was that in the previous data the flour had not had any kind of heat treatment. Whistler et al. (1997) mentioned the DSC could measure both the temperature and the enthalpy of gelatinization. The idea of using the DSC for determination of gelatinization of starch granules is widely accepted. However, the interpretation of the data is still debated.

CHAPTER III

PHYSICAL AND SENSORY PROPERTIES OF POPPED SORGHUM: EFFECT OF VARYING MOISTURE CONTENTS AND MOISTURE APPLICATION METHODS

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ABSTRACT

Sorghum grain (*Sorghum bicolor* subsp. *Bicolor*) is used as animal feed in the U.S. However, sorghum food products can have a potential niche market with African heritage customers and offer an alternative selection to people with celiac disease. Sorghum can be popped and offer a potential snack food product. The uniqueness of the product's size could hold a potential place in the market for young children or serve as a functional ingredient in other snack food items. The objective of this study was to determine the effects moisture content (MC) and its application to sorghum grain popping properties such as expansion ratio, physical properties, and sensory attributes of popped sorghum.

Red and white sorghum with moisture contents of 12, 14 and 17% were obtained using two methods of moisture application (direct and indirect) and were popped using a hot air popcorn popper. Objective measurements of kernel size, bulk density, popped kernel expansion ratio, popped volume, and color was recorded. Forty-six untrained panelists evaluated the popped sorghum on appearance, size, and taste using a 9-point Hedonic scale. The same panelists were also given a paired comparison test to determine if a red or white popped kernel color was preferred.

Moisture content and moisture application method were significant factors in the popping quality and characteristics of popped sorghum. Red sorghum had increased ($p<0.05$) percent pop, expansion ratio and pop volume compared to the white popped sorghum. The indirect moisture application increased ($p<0.05$) percent pop in the white sorghum, compared to the direct method but it did not affect the percent pop level

(p>0.05) of red sorghum. White sorghum pop volume was increased (p<0.05) by the 17% level of MC compared to the 12 and 14% MC levels.

Sensory evaluation of popped sorghum indicated no significant differences (p>0.05) in the appearance scores between the 12% MC (6.5±1.7) and 17% MC (6.7±1.8) sorghum, but the commercial popcorn appearance score was significantly preferred (8.0±1.0) (p<0.05). Scores for size of the 12% MC (5.6±2.0) and 17% MC (5.6±2.2) popped sorghum were similar, but significantly (p<0.05) lower than those for the popcorn (7.9±1.0). There was no significant difference (p>0.05) in taste between the popcorn (7.1±1.5), 12% MC (6.4±1.8), and the 17% MC (6.9±1.4) popped sorghum.
Sorghum pops were 5 times smaller in size and had a bright and more vivid white color than the popcorn.

This study provides a significant basic understanding of the popping behavior of two sorghum hybrids. Because these properties are variety-dependent, other sorghum hybrids or varieties need to be compared in future studies in the utilization of sorghum as a popped product as well as further studies on the end use of the popped sorghum.

INTRODUCTION

Popping popcorn has been around for many centuries. Microwave popcorn a very common household commodity has accounted for 240 million dollars in annual U.S. popcorn sales in the 1990's (Anonymous, 1992). With Americans consuming 17.3 billion quarts of popped popcorn each year (Anonymous, 1992) there is a potential opportunity for other popping grains such as, sorghum to fall into the same profitable category as popcorn.

With today's technology many new unique "mini" products are being developed which often catch the attention of the young consumer. Many food companies are looking in the miniaturized product direction, such as Mars Mini M&M's, bite size candy bars as well as cookies such as Nabisco's Mini Oreos and Nutter Butters. An old favorite, Lunchables by Oscar Myer, contains miniaturized items such as pizzas, tacos, ham and cheese slices along with a mini drink and mini dessert. Popped sorghum, a small and unique product with similar taste to popcorn, but about 1/3 the size, just might catch the eye of American consumers who love the miniaturized world of fun food products.

Popped sorghum is a common product in parts of India and Africa although not traditionally sold commercially (Singh and Srivastava, 1993). It is popped in hot sand, ground, and eaten as porridge typically consumed by children and the elderly (Murty et al., 1995). Limited published research on popping sorghum has been done in the U.S. and a few papers published in India.

Preliminary research conducted on popping sorghum using a typical Oklahoma sorghum varieties revealed difference in popping quality characteristics. This study was designed to improve the popping percent of sorghum grain. Environment growing conditions and variety differences control the performance of cereal grains for different end-product applications. This poses some challenges in defining the optimum processing conditions for a relatively new application, popping, of sorghum grain. Two commercial sorghum hybrids with potential for food use were selected.

The objective of the research was to study the effects of varying moisture contents as well as different methods of applying moisture to the sorghum kernel had on popping characteristics such as percent pop, volume, expansion ratio, and sensory acceptability.

MATERIALS AND METHODS

Raw Materials

One of each red and white sorghum hybrids was used: red sorghum, Pioneer 8500 and white sorghum, Fontanelle 1000. Red Pioneer 8500 sorghum was harvested from Enid, Oklahoma in November of 2001. Four plots of Pioneer 8500 were harvested individually to provide four replicates, farm 1 field 1 (F1f1), farm 1 field 2 (F1f2), farm 2 field 1 (F2f1), and farm 2 field 2 (F2f2). Two separate batches of white food grade sorghum were received from Twin Valley Mills, LLC. in Ruskin, Nebraska harvested on January 2002. Due to a drought in Oklahoma in 2001, white sorghum was not harvested by Oklahoma sorghum growers therefore the white grain was supplied by a Nebraska source. Although sorghum is considered to be a drought tolerant grain, much of the 2001 harvest was damaged. The Red Pioneer 8500 sorghum was harvested about three weeks late due to constant rain. When these particular batches of grain were harvested the moisture content was abnormally high, due to recent rain conditions. In preliminary studies in 2000 sorghum grain moisture content was 7-8% at harvest. Orville Redenbacher's Gourmet Popping Corn (Hunt-Wesson, Inc. Fullerton, Ca), purchased at the local grocery store, was used as a reference.

Sorghum Grain Handling

Upon arrival the samples were placed in a -4°C freezer for a 24 hr period to kill any insect infestation. Removal of extraneous material was performed using a dockage tester (Carter Day XT5, Minneapolis, MN) with air speed 1, feed number 6, top sieve size

6 and bottom sieve size 1. After cleaning, the grain was placed back into the -4°C freezer until further needed. Moisture content was determined by Approved Method 44-15A (AACC, 1995) using the two step process upon the arrival of the grain (Table 1). A tray dryer (Proctor and Schwartz, Inc. Horsham, PA) was subsequently used to reduce the MC to the desired levels, following by tempering using the following two methods. Once the MC of the samples was achieved the samples were returned to a -4°C freezer until further needed.

Moisture Application Methods

I. Direct Method

Sorghum batches (200 g) were tempered using Approved Method 26-95 (AACC , 1995) to 12, 14 and 17% MC. The batches were tempered in plastic containers (Sho-me, Grinnell, Iowa, 4.5"diameter, 6" height). Every half-hour for the first four hours the containers were inverted ten times each. After the first four hours the containers were placed in a 4°C refrigerator. The tempering period was a total of 48 hours. Moisture content analysis was performed on the tempered grain using Approved Method 44-15A (AACC, 1995). Each sample was stored in plastic zip bags (Minigrip, ITW com. Seguin, TX) and placed into a 4°C refrigerator until further needed. Before analysis samples were equilibrated to room temperature for 24 hr.

II. Indirect Method

Batches of 200 g of sorghum were spread onto nylon mesh wood framed screens (10" X 18"). The frames were placed inside a humidity chamber (Fermentation Cabinet model 505-55, National Manufacturing , Lincoln, NE), maintained at 24 °C dry bulb and 22°C wet bulb (RH=79). To keep the mesh screen from coming into contact with the shelf the frames were raised using small plastic pedestals (3/4" height) under the corners. The grain was periodically weighed until the final weight of the grain was high enough to have reached the desired moisture content level. Once the level of moisture was achieved 12-15 g of grain was taken for moisture analysis. Each sample was stored in plastic zip bags (Minigrip, ITW com. Seguin, TX) and stored at 4°C until needed. Before analysis samples were equilibrated to room temperature for 24 hr.

Popping Procedure

A Hot Air Corn Popper (Westbend Model 82010) was used to pop the sorghum grain. An initial warming period of one minute was conducted (no grain) followed by a 50 g test batch of popcorn before the first batch of sorghum was popped. A batch of 50 g of sorghum grain was popped until no further popping occurred or until no grain remained in the popper. Unpopped kernels were separated from the popped grain using a U.S. standard sieve No. 4. Immediately after popping the weight and volume of the unpopped kernels and pops were recorded. The pops and the kernels were separately stored in zip plastic bags (Minigrip, ITW com. Seguin, TX).

Evaluation Tests

Diameter, Bulk Density and Expansion Ratio

Diameters of 25 random popcorn and sorghum kernels were measured using a vernier caliper (Table 2). Percent pop was calculated by determining each sample grain dry weight and then using the weights of the pops and the kernels on a dry weight basis (Table 3). The popped volume (cm^3) of 50 g of sorghum grain was determined by recording the volume in a 1000 ml graduated cylinder (Table 4). The expansion ratio was calculated by dividing BD of the grain by BD of popped kernels (Bedolla et al., 1983) (Table 5). The bulk density (BD) of the popped sorghum samples were calculated by using the popped sample weight divided by the popped volume (g/cm^3) (Table 6).

Color

The color of the popped sorghum was determined using a Minolta Spectrophotometer model CM-3500d (Minolfa Ltd., Osaka, Japan). The system was based on a L*C*h color space where L*=whiteness and darkness, C*=Chroma, and h=hue angle and colorization hue. Top and bottom of popped kernels were measured. Since the variation within sorghum variety and treatments were minor, measurements of one white and red popped sample were taken as well as the reference popcorn.

Sensory Evaluation

Two methods of affective testing were used on forty-six untrained panelists. In preparation for the sensory evaluation the panelists were identified by 3-digit random codes, the samples were all randomly coded as well using a random numbers table (Stone and Sidel, 1993). A balanced randomized complete block design (RCBD) was used for a three and two product test. In performing the RCBD, the numbers of subjects were taken in multiples of six, to maintain the balanced order. Each serving order appeared twice, in each serving position and preceded and followed every other product equally often (Stone and Sidel, 1993). The samples were served monadically and evaluated under florescent light. Standard procedures for affective testing (Stone and Sidel, 1993) were used. The samples were popped 30 min before the panel test and placed under food warmers at 150°F. The samples were then adequately filled into coded one-ounce soufflé cups with lids, and placed back under the food warmer.

The first test given to the panelists used a nine point hedonic scale. For analysis and interpretation, the hedonic scale was coded as follows: like extremely=9, like very much=8, like moderately =7, like slightly =6, neither like nor dislike =5, dislike slightly =4, dislike moderately =3, dislike very much =2, dislike extremely =1. During this test three products were evaluated separately: popcorn (control, Orville Redenbacher), popped red sorghum with a popping moisture content of 17%, and 12%, respectively.

The second test conducted was a paired preference test. The panelists were presented with two different samples of popped sorghum, white and red both with a popping moisture content of 17%. The panelists were asked to choose, based on appearance only, the popped sorghum that they preferred or to mark if they had no preference. The purpose of this test was to see if the panelists preferred a red or white (yellow) husk color.

Experimental Design and Statistical Analysis

Two methods of moisture application (direct and indirect) were used on each experimental unit (F1f1, F1f2, F2f1, F2f2, W1, W2, and HH). F= farm one or two of red sorghum, f= field one or two of red sorghum, W=batch of white sorghum one or two, and HH= hand harvested red sorghum. The analysis was done as a split plot with the mean units (field) in a CRD with main unit treatment (MUT) =Type and sum unit treatments (SUT) = moisture content * moisture application method. Analysis of Variance (ANOVA) was tested and its level of significance (p-value) obtained. Differences among specific treatment effects were tested with Tukey's test as well as using Proc Mixed. Statistical analyses for the sensory evaluation was done using a balanced randomized complete block design (RCBD) for a three and two product test. In performing the RCBD, the numbers of subjects were taken in multiples of six; to maintain the balanced order. Statistical analyses were performed using Statistical Analytical System software (Version 8.02, SAS Institute Inc., Raleigh, NC).

RESULTS AND DISCUSSION

Grain Diameter

Grain size varied slightly between the sorghum varieties. Grain diameter averaged 3.8 and 3.6 mm for red and white sorghum respectively. Hand harvested red sorghum grain diameter averaged 3.9 mm and popcorn grain was 7.8 mm (Table 2).

Percentage of Popped Sorghum

Table 3 gives values of the percentage of popped kernels of popcorn and popped sorghum. There was significant interaction ($p<0.05$) between sorghum type (red and white) and the treatments applied (moisture content: 12, 14, and 17% and moisture application method: direct and indirect) on the percentage of popped sorghum.

The level of moisture content of the red popped sorghum did not have a significant effect ($p>0.05$) on the percent of popped sorghum, although the NT popped sorghum was significantly higher 83.6% ($p<0.05$) (Table 3)(Fig. 1). The direct and indirect moisture application methods yielded similar ($p>0.05$) percent of popped kernels in the red sorghum.

Percent of popped white sorghum at 17% MC was significantly higher ($p<0.05$) than white popped sorghum popped at 12 and 14% MC. For white sorghum, the indirect method of moisture adjustment yielded higher popping percent (59 vs. 53% popping for indirect and direct methods, respectively)(Table 3).

The overall percentage of popped sorghum was highest ($p<0.05$) at 85.1% for the NT hand harvested red sorghum variety (Table 3). This value was 2.2% higher than the averaged NT red sorghum. This confirms the importance of integral pericarp, with no cracks or damage produced by combine harvesting, to obtain higher percentage pop.

Singh et al. (1993) found that popping percent revealed differences at different moisture levels. However, the grain moisture level at which the percent popping was the highest differed from one genotype to another. Singh et al., (1993) also concluded that suitable grain moisture for popping of sorghum varied from genotype to genotype. In general, the 12% level of grain moisture was suitable for most of the sorghum genotypes resulting in 82-86% popping rate (Sing et al., 1993).

Sorghum Popping Volume

Table (4) shows the direct volume (cm^3) of a fifty-gram sample, measurement of the red, hand harvested, white sorghum and popcorn varieties. Direct volume measurement refers to popping a recorded weight of sorghum or popcorn and measuring the volume that results. Each variety was processed by the two moisture adjustment methods (direct and indirect), and for each method three levels of MC (12, 14, and 17%) were obtained.

There were no differences ($p>0.05$) in mean popping volume due to an interaction between the red and white popped sorghum at different treatment (moisture content and moisture application method) levels.

Hot-air popping produced a maximum volume of 950.5 cm^3 (Table 4) from sorghum with no treatment (NT) at a MC of 15.5%, and the same volume for red sorghum at 17% MC with the indirect moisture application method. White sorghum had a significantly lower ($p<0.05$) popping volume of 369.6 cm^3 compared to the red sorghum (includes hand harvest) (Table 4). There are trends of increased volume for the hand harvested sorghum compared to the red or white sorghum (Fig. 2).

The volume decreased with decreasing MCs for both methods (Fig. 2). There was a significantly higher ($p<0.05$) volume for sorghum popped at 17% MC compared to 12 or 14% MC. The volume of the red sorghum variety using the indirect method at 17% MC was 50% greater than the white sorghum variety using the same method and MC. In both the red and white sorghum pops the volume was significantly increased ($p<0.05$) by the indirect moisture application method compared to the indirect. Red hand harvested popped sorghums' volume was 28% higher in all methods at all tested moisture contents except for the NT sorghum. The NT popped sorghum volume was 8% higher compared to all the other moisture and method application treatments. Metzger (1989) observed that popping volume versus moisture content shows that hot-air popping produces a larger popping volume than oil-popping over the entire moisture content range for popcorn. Lyerly (1940) observed that the maximum popping volume for oil-popping occurs in a moisture content range from 12-14%, depending upon the variety of popcorn. The moisture content range has since been narrowed between 13 and 14.5% moisture, with the optimum being 13.5% (Ziegler et al 1985). Murty (1987) studied more than 3,000 sorghum varieties from India to test their popping quality. They found that puffed product volume appeared to be mostly dependent on the grain size, although the volume of the puffed product was not measured, since they believed the variability for this trait in the cultivars selected was limited.

The large difference in popping volume from the red and white sorghum variety could be contributed to the different grain characteristics. During grain reconditioning (drying and increasing MC), the white variety showed overall slower drying or moisture absorption rates than the red sorghum. Hoseney et al. (1993) reported that the structure of the kernel is also important in popping, since high expansion volumes have been correlated with vitreous kernels. Parker et al. (1999) reported that the expanded endosperm foam of popcorn and popped sorghum originates from the vitreous endosperm. The starch granules in the small region of the floury endosperm do expand slightly but are still seen as granules, under dark field microscopy, and the cell walls do not fragment. By visual observation of red and white sorghum radially sliced kernels it was clearly seen that there was much more floury endosperm in the white sorghum than the red. Rooney (2002) described the Fontanelle 1000 variety as having a larger ratio of floury endosperm to vitreous endosperm and Red Pioneer 8500 high ratio of vitreous endosperm compared to floury. The pericarp thickness of the red and white sorghum varieties are considered thin (Dalhberg, 2002), although no actual measurement of pericarp thickness was performed. Murty (1982) found that sorghum of medium thickness of pericarp exhibited superior popping quality, and sorghum with thicker pericarp did not have as high of popping volume.

The sorghum grains that did not have any reconditioning treatments (NT) showed higher popping volumes (Fig. 2). Watson (1984) found that artificial drying of sorghum caused dryer damage and stress cracking. The drying or reconditioning of the grain influenced its popping capacity negatively by causing stress fractures to the pericarp thus lowering the pop volume as well as other results. The same principles can be expanded to the mechanical damage of kernels that affect their popping percent.

Volume of Sorghum Grain

The volume of the red and white sorghum grain averaged 49.2 and 46.9 cm^3 respectively. The hand harvested red sorghum grain volume averaged 54.1 cm^3. Thorat et al. (1988) and Murty et al. (1983) reported that grain volume had a significant negative effect on sorghum percent popping. The red hand harvest and red sorghum grain did not follow their findings. Percent popping was significantly increased ($p<0.05$) for the red hand harvest and red sorghum grain, which had a larger grain volume, similar results were found by Singh et al. (1993). The ratio of vitreous endosperm to flour endosperm was high in the red and hand harvested sorghum grain, which as discussed earlier pops better. The type of endosperm characteristics were not reported by Thorat et al. (1988) or Murty et al. (1983). The grain variety used in the sited research could have influenced their observations.

Popped Sorghum Expansion Ratio

The expansion ratio of the red popped (Table 5) sorghum and red hand harvested were significantly higher ($p<0.05$) than the expansion ratio of the white popped sorghum (7.6 and 4.6, respectively). There was no significant interaction ($p>0.05$) for the expansion ratio between the red and white popped sorghum at different treatment (moisture content and moisture application method) levels.

A significantly higher ($p<0.05$) expansion ratio was observed at 17% moisture compared to 12 and 14% (6.5, 5.5 and 5.8, respectively) (Table 5) (Fig. 3). There was no interaction ($p>0.05$) between sorghum color (red, white) and moisture application method.

A smaller expansion ratio could result from a decrease in the ability of the pericarp to withstand the initial water vapor pressure created by heating (Hoseney et al., 1983). Pericarp damage also can decrease expansion ratio due the increased rate of water vapor loss during heating. Singh et al. (1993) found that the effect of mechanical damage on popcorn seems to be two fold. First, the damaged site acts as a major pathway for the escape of water vapor from the endosperm during the heating of the kernels, decreasing the water vapor available to fuel the expansion. Low moisture contents are known to decrease expansion ratio (Song et al., 1994). Second, the damage weakens the mechanical strength of the pericarp, thus allowing the kernel to pop earlier.

Popped Sorghum Diameter

Tables 6 to 12 show measurements of 25 individual measurements of popped sorghum diameters. The popped red sorghum had a significantly larger ($p<0.05$) diameter than the white popped sorghum. Overall significantly lower ($p<0.05$) average diameter measurements (7.7mm) for sorghum popped were obtained with a moisture 12% moisture and with the indirect moisture application method compared to all other moistures and direct moisture application method.

Popped Sorghum Color

The whiteness of the foam of the popped sorghum was brighter and more vivid than the popcorn. This is shown by increased L*, C* and h values (Table 13). The popcorn showed hue values being a light yellow color (L*= 54.1, C*= 21. and h= 57.7).

The white sorghum color trends were brighter in whiteness. The color values for the husk (Table 14) side of the sorghum pops were understandably different between the red sorghum and the white sorghum since the pericarp colors are different. Popcorn husk color values were similar to the white popped sorghum. Matz (1984) reported that the starch color is very hard to change. Even by long periods of dye treatments of the raw grain the outer husk is mainly the only part changed. It takes long periods of dying or soaking the grain for the foam to have a light tint of color. In this study only water was used to temper the grain, and no color change was expected in the resulting pop foam due to moisture adjustment. The pigments in the pericarp of the red sorghum variety did not effect the color of the popped sorghum foam.

Sensory Evaluation

Hedonic Scale Test

Of the three products tested (popcorn, and two popped red sorghum samples popped at, 12 and 17% MC.) the mean appearance score for popcorn was 8.0±1.0 (liked very much). Popped sorghum appearance score for 17% MC and 12% MC were similar, 6.7±1.8 and 6.5±1.7 (mean ± standard error), respectively. The two popped sorghum products ranged from liked moderately to neither liked nor disliked averaging a liked slightly score. Overall, the appearance of the popcorn was liked significantly ($p<0.05$) more than both the popped sorghum types (Fig. 4).

The mean acceptability of the popcorn size was 7.9±1.0 which corresponds to liked very much. The mean acceptability scores for the 17% and 12%MC popped sorghum were 5.6±2.2 and 5.6±2.0, respectively, indicating that their sizes were neither like or disliked. Although with the broad standard deviation, the size acceptance ranged from liked moderately to disliked moderately. There was no difference ($p<0.05$) in the acceptably of size between the two types (12 and 17% MC) of popped sorghum. The acceptability of popcorn size was liked more ($p<0.05$) than the 12 and 17 % MC of red popped sorghum (Fig. 4).

The acceptability of taste for the three products was not significantly different from each other ($p>0.05$). Popcorn had a taste score of 7.1 ± 1.5, popped sorghum at 17% MC taste score was 6.9 ± 1.4 whereas popped sorghum at 12% MC was 6.4 ± 1.8. All products were in the range of liked slightly to liked moderately for taste (Fig. 4).

Paired Preference Test

Sensory analysis using a paired-preference test was conducted on 43 of the panelists used for the hedonic testing. Computation of the results were done by use of probability tables (Probability of X or more agreeing judgments in *n* trials (two-tailed, $p=1/2$) (Stone and Sidel, 1993). A two tailed test was used because a paired preference test is a perceptual task, there is no right or wrong answer. Using the two-tailed test, more correct decisions are necessary to achieve a statistical difference (Stone, 1993).

Paired preference results showed that 21/43 panelists preferred the red popped sorghum, 20/43 panelists preferred the white popped sorghum and 2/43 had no preference of which popped sorghum they liked best (Fig. 5). Therefore, the color of the popped sorghum did not influence ($p>0.05$) the panelist preference of the popped sorghum.

CONCLUSIONS

The hand harvested sorghum had significantly better popping quality trends than the red Pioneer 8500 or the white Fontanelle 1000 cultivar. The percent pop, volume of pops, grain volume, and expansion ratio were all higher. Considering that the grain size was larger would certainly account for the larger volume of pops and expansion ratio. The higher percentage of pop could be attributed to he difference in method of harvest. Hand harvested sorghum is presumed to have had less kernel damage. The undamaged pericarp allowed for internal steam build up and higher expansion. Another factor is the high ratio of vitreous endosperm to floury endosperm common to the red pioneer 8500 which is conducive to high popping qualities.

The white sorghum had lower popping quality characteristics than red sorghum. The size of the white kernel was smaller, than the red and typically showed a slower rate to lose or gain moisture. This was due to differences in the kernel's pericarp thickness and to a higher percentage of floury endosperm than the red sorghum. Parker et al. (1999) comment that the expanded endosperm foam of sorghum originates from the vitreous endosperm, the starch granules in the floury endosperm do expand but only slightly.

The method of moisture application does have some significant effects in sorghum popping qualities. The indirect method with more gradual moisture application method, showed an increase in percent pop ($p<0.05$). In the white sorghum, however, the method of moisture application for red popped sorghum did not influence ($p>0.05$) the level of percent pop. The volume of the pops was increased ($p<0.05$) by the indirect method in all popped sorghum samples. This supports researchers Wu et al. (1982) and Metzger et al., (1989) findings that minimizing steep moisture gradients reduce stress cracks on the pericarp resulting in higher volume of popped kernels.

The moisture content at which the grain was popped did influence some of the popping characteristics. The white sorghum popped at a significantly higher percent and volume ($p<0.05$) at a MC level of 17% compared to 12 and 14% MC. Moisture content did not significantly effect the red or the NT popped sorghum popping characteristics.

The sensory evaluation results describe the panelists' feelings for the popped sorghum's size and appearance as liked slightly to neither liked nor disliked. The taste of the popped sorghum was liked moderately to like slightly. The score of sorghum at 12 and 17% MC was similar ($p>0.05$).

The acceptability of the popcorn in appearance, size and taste were all liked ($p<0.05$) by the panelists. Popped sorghum scored lower ($p<0.05$) in acceptability for size and appearance than popcorn but was in the acceptability range of liked slightly to neither liked nor disliked. The taste acceptability was not significantly different ($p<0.05$) between the three products, all ranging in the liked moderately to liked slightly categories. There were no significant differences ($p>0.05$) between the acceptability of (size, taste or appearance) of popped sorghum at 17 or 12% MC.

Although hand harvesting is economically impossible for any kind of profitable product it showed better popping characteristics. The red sorghum processed by the indirect method at 17% MC showed the next best popping characteristics. The popping quality of white sorghum hybrids/cultivars is related to their ratio of floury/vitreous endosperm characteristics. Preliminary studies conducted in sorghum form the crop year of 2000 revealed that the white sorghum Garst had higher vitreous endosperm than Fontanelle 1000 and had better popping quality.

FUTURE RESEARCH

To better understand the properties of popped sorghum and to continue adding value to the sorghum grain, the following suggestions are proposed:

- Generation of product innovation ideas for further value added snack food products made from sorghum pops. Examples include the use of mini-products for enhancement of textural properties.
- Include popping quality characteristics to variety, quality, and composition research on sorghum in the U.S. to look at popping.
- Determination of exact harvest time for prime popping moisture content.
- Alterations in harvesting method to ultimately cause little damage to sorghum pericarp.
- Textural differences in popped sorghum among variety types, different colors, and popping MC variances.
- Shelf life studies for packaging and resale value of popped sorghum.

TABLE 1

Moisture contents of red and white sorghum grain varieties at harvest[1].

Sample[2]	Moisture (%)
W 1	14.2
W 2	14.3
F1f1	13.3
F1f2	13.7
F2f1	14.4
F2f2	15.2
HH	15.6

[1]Refered to as no treatment (NT) sorghum sample.
[2]F= farm, f= field red sorghum,
HH= hand harvested red sorghum,
W= white sorghum.

TABLE 2

Twenty-five measurements[1] of sorghum grain hybrid diameters[2] (mm).

Grain	F1f1	F1f2	F2f1	F2f2	W1	W2	HH
1	4.10	3.40	3.80	3.50	3.50	3.90	3.30
2	3.90	4.90	3.50	3.70	3.70	3.80	3.80
3	4.20	3.80	3.80	4.00	3.40	4.20	4.00
4	4.00	3.30	3.50	3.80	3.40	3.80	4.00
5	3.90	4.20	3.20	3.80	4.00	3.40	3.90
6	3.50	3.50	3.80	3.80	3.50	3.90	3.90
7	3.90	4.10	3.80	4.10	3.90	3.80	4.10
8	3.60	3.30	3.80	4.00	3.70	3.70	4.00
9	4.10	3.70	3.90	3.90	3.50	3.40	4.00
10	3.90	3.60	3.90	4.00	3.50	3.70	3.80
11	3.70	4.00	3.50	3.90	3.00	4.00	4.00
12	3.50	3.90	3.70	3.90	3.60	3.60	4.00
13	4.60	3.50	3.60	3.80	3.70	3.70	4.00
14	4.00	4.10	3.50	3.90	3.10	3.40	3.90
15	4.00	3.80	3.90	3.60	3.60	3.60	3.60
16	3.80	3.70	3.50	4.00	3.80	3.90	4.10
17	3.60	4.00	4.00	3.80	3.40	3.30	3.80
18	3.80	4.00	4.00	3.80	3.70	3.00	4.00
19	4.10	3.20	3.70	3.50	3.20	3.60	3.80
20	4.00	3.80	3.90	4.10	3.60	3.50	3.70
21	3.70	3.80	4.10	4.30	3.70	3.80	4.10
22	3.60	3.50	3.60	3.70	3.70	3.80	3.90
23	4.10	3.60	3.50	4.30	3.30	3.50	3.80
24	3.90	3.70	4.20	4.00	4.40	3.60	3.90
25	3.90	3.40	3.90	3.80	3.80	4.00	3.50

[1]Each measurement is an individual measurement of one randomly selected piece of popped sorghum
[2]F1f1= farm 1 field 1, F1f2= farm 1 field 2 red sorghum, F2f1= farm 2 field 1, F2f2= farm 2 field 2 red sorghum, W1= white 1, W2=white 2, HH= hand harvested red sorghum.

TABLE 3

Percentage popped[1] kernels of air popped red and white sorghum hybrids and popcorn.

		Red Sorghum					White Sorghum		
Method[2]	%MC[3]	F1f1[4]	F1f2	F2f1	F2f2	HH	W1	W2	Popcorn
1	12	74.3	70.0	81.1	78.2	81.8	48.6	51.1	..
1	14	73.7	74.2	77.2	76.7	83.0	52.6	56.0	..
1	17	71.6	78.1	78.8	75.2	82.9	51.3	58.3	..
2	12	75.5	67.3	80.2	76.1	82.3	53.9	55.9	..
2	14	72.6	73.5	80.5	74.7	86.0	53.5	57.2	..
2	17	77.3	82.6	80.2	81.4	84.3	67.1	67.4	..
NT[5]	*[6]	81.6	81.9	85.1	84.1	85.1	73.8	71.9	98.0

[1]Dry weight of pops divided by dry weight of total grain before popped, shown as a percent.
[2]Method 1= direct moisture application.
Method 2= indirect moisture application.
[3]MC= percent moisture content.
[4]F= farm, f= field red sorghum, HH= hand harvested red sorghum, W= white sorghum.
[5]NT= no treatment
[6]*= moisture content as received from harvest. F1f1=13.25%, F1f2=13.67, F2f1=14.4, F2f2=15.17, HH=15.61, W1= 14.23, W2=14.3%.

TABLE 4

Volume measurements[1] (cm^3) of air popped red and white sorghum hybrids and popcorn.

		Red Sorghum					White Sorghum		
Method[2]	%MC[3]	F1f1[4]	F1f2	F2f1	F2f2	HH	W1	W2	Popcorn
1	12	528.1	443.6	633.7	528.1	813.2	211.2	211.2	..
1	14	580.9	528.1	580.9	633.7	792.1	221.8	221.8	..
1	17	549.2	580.9	633.7	602.0	792.1	232.4	274.6	..
2	12	570.3	411.9	654.8	549.2	644.2	232.4	264.0	..
2	14	559.8	528.1	612.6	580.9	823.8	242.9	264.0	..
2	17	612.6	644.2	675.9	686.5	950.5	327.4	327.4	..
NT[5]	*[6]	686.5	633.7	792.1	739.3	950.5	369.6	369.6	>1000

[1]Volume of popped grain with an initial weight of 50 g.
[2]Method 1= direct moisture application.
Method 2= indirect moisture application.
[3]MC= percent moisture content.
[4]F= farm, f= field red sorghum, HH= hand harvested red sorghum, W= white sorghum.
[5]NT= no treatment
[6]*= moisture content as received from harvest. F1f1=13.25%, F1f2=13.67, F2f1=14.4, F2f2=15.17, HH=15.61, W1= 14.23, W2=14.3%.

TABLE 5

Expansion Ratio[1] of air popped red and white sorghum hybrids and popcorn.

		Red Sorghum					White Sorghum		
Method[2]	%MC[3]	F1f1[4]	F1f2	F2f1	F2f2	HH	W1	W2	Popcorn
1	12	6.63	5.91	7.28	6.07	8.34	4.21	4.00	..
1	14	7.52	6.79	7.18	7.60	8.19	4.18	3.92	..
1	17	7.59	7.36	7.95	7.63	8.50	4.65	4.83	..
2	12	7.05	5.71	7.61	6.49	6.57	4.18	4.57	..
2	14	7.36	6.86	7.26	7.16	8.22	4.50	4.57	..
2	17	7.85	7.73	8.35	8.06	10.06	5.02	5.00	..
NT[5]	*[6]	8.05	7.41	8.81	8.06	9.78	4.98	5.16	>1000

[1]Ratio of bulk density of grain and bulk density of popped grain.
[2]Method 1 = direct moisture application.
Method 2 = indirect moisture application.
[3]MC = percent moisture content.
[4]F = farm, f= field red sorghum, HH= hand harvested red sorghum, W= white sorghum.
[5]NT = no treatment
[6]*= moisture content as received from harvest. F1f1=13.25%, F1f2=13.67, F2f1=14.4, F2f2=15.17, HH=15.61, W1= 14.23, W2=14.3%.

TABLE 6

Measurements of 25 diameters (mm) [1] of red and white popped sorghum[2] at 12% MC with a direct moisture application treatment.

	Red Sorghum					White Sorghum	
Measurement	F1f1	F1f2	F2f1	F2f2	HH	W1	W2
1	10.2	8.5	9.5	8.2	9.2	9.2	10
2	15.2	8.2	8.8	10	9	8.8	8.5
3	11.3	9.3	10.3	10.6	12.9	9.2	7.8
4	8.5	8.9	9.9	10	8.7	9.1	7.7
5	8.3	8.7	9.5	9	10.9	10.4	8
6	9.8	9.9	11.9	8.5	7.4	6.2	8.9
7	10	6.9	8.4	7.2	10.1	6.8	8.9
8	10.9	9.3	9.5	9.4	9.6	5.6	9.2
9	8.5	10.6	10	9.2	9.8	7.3	7.5
10	9.3	7.5	9.5	8.9	9.2	6.9	6.1
11	9.3	7.2	9	9.5	10.5	8.1	9.3
12	10.5	9.6	10.4	9.5	8.6	9.1	8.2
13	9.7	9.8	9.6	9.2	10.2	8.3	7.6
14	8.2	7.7	10.7	10.7	11.8	7.5	9.4
15	11.9	8.3	8.7	8.4	9.3	6.2	10.4
16	8.2	7.9	8.8	9.2	9.6	7.7	7.9
17	13.4	8.4	10	11.4	11.1	8	8.3
18	9.3	8.5	8.6	10.5	10.2	8.6	7.8
19	7.2	8.2	9.8	8.1	10	6.2	8.2
20	9.9	9.3	12.1	8.2	9.4	7.8	8.6
21	9.1	10	10	10.2	10.5	9	5
22	11	7	9	9	7.3	8	7.5
23	9.5	9.2	9.9	9.4	12.8	8.6	7.7
24	12.5	9.6	12.6	9	9.5	8.6	7.3
25	8.5	9.5	9.9	8.9	10.2	8.8	6.4

[1]Each measurement is an individual measurement of one randomly selected piece of popped sorghum
[2]F1f1= farm 1 field 1, F1f2= farm 1 field 2 red sorghum, F2f1= farm 2 field 1, F2f2= farm 2 field 2 red sorghum, W1= white 1, W2=white 2, HH= hand harvested red sorghum.

TABLE 7

Measurements of 25 diameters (mm) [1] of red and white popped sorghum[2] at 14% MC with a direct moisture application treatment.

	Red Sorghum					White Sorghum	
Measurement	F1f1	F1f2	F2f1	F2f2	HH	W1	W2
1	8.0	7.6	9.9	9.4	8.3	9.0	9.2
2	10.7	10.5	8.9	9.7	7.4	11.7	10.6
3	10.8	7.6	6.1	11.8	8.9	10.2	8.9
4	9.5	7.5	5.8	8.5	6.9	7.4	10.2
5	8.5	7.0	7.5	7.2	7.5	8.7	6.8
6	9.0	8.6	11.0	6.8	8.6	9.8	7.7
7	8.9	8.0	8.9	8.5	10.8	8.7	8.5
8	8.9	6.9	5.5	10.2	9.1	8.6	7.5
9	8.5	10.2	6.5	11.0	9.5	8.4	7.5
10	8.6	8.7	6.2	9.6	10.3	9.6	9.3
11	9.5	8.2	8.1	9.7	8.3	7.5	7.1
12	11.8	8.8	6.2	8.9	10.4	8.7	8.7
13	10.4	9.4	8.3	11.6	7.5	9.1	9.5
14	8.0	6.1	5.3	10.8	8.4	9.5	10.0
15	9.1	5.9	8.2	7.2	7.7	9.2	6.2
16	8.1	10.9	5.2	7.6	6.3	7.0	5.6
17	8.5	7.7	10.1	8.4	7.7	10.8	7.1
18	8.9	9.3	8.2	7.6	7.1	7.7	3.8
19	8.8	8.7	7.9	8.3	12.0	9.8	9.1
20	7.5	8.0	10.7	11.1	8.8	8.6	10.0
21	10.1	8.8	9.0	9.4	9.2	11.8	7.9
22	6.0	8.3	7.5	7.6	9.1	7.6	9.2
23	9.4	9.3	8.1	10.7	9.6	9.0	4.9
24	10.2	8.2	10.1	7.7	6.3	9.0	7.2
25	8.3	8.1	7.3	7.7	6.6	9.0	6.0

[1]Each measurement is an individual measurement of one randomly selected piece of popped sorghum
[2]F1f1= farm 1 field 1, F1f2= farm 1 field 2 red sorghum, F2f1= farm 2 field 1, F2f2= farm 2 field 2 red sorghum, W1= white 1, W2=white 2, HH= hand harvested red sorghum.

TABLE 7

Measurements of 25 diameters (mm) [1] of red and white popped sorghum[2] at 14% MC with a direct moisture application treatment.

	Red Sorghum					White Sorghum	
Measurement	F1f1	F1f2	F2f1	F2f2	HH	W1	W2
1	8.0	7.6	9.9	9.4	8.3	9.0	9.2
2	10.7	10.5	8.9	9.7	7.4	11.7	10.6
3	10.8	7.6	6.1	11.8	8.9	10.2	8.9
4	9.5	7.5	5.8	8.5	6.9	7.4	10.2
5	8.5	7.0	7.5	7.2	7.5	8.7	6.8
6	9.0	8.6	11.0	6.8	8.6	9.8	7.7
7	8.9	8.0	8.9	8.5	10.8	8.7	8.5
8	8.9	6.9	5.5	10.2	9.1	8.6	7.5
9	8.5	10.2	6.5	11.0	9.5	8.4	7.5
10	8.6	8.7	6.2	9.6	10.3	9.6	9.3
11	9.5	8.2	8.1	9.7	8.3	7.5	7.1
12	11.8	8.8	6.2	8.9	10.4	8.7	8.7
13	10.4	9.4	8.3	11.6	7.5	9.1	9.5
14	8.0	6.1	5.3	10.8	8.4	9.5	10.0
15	9.1	5.9	8.2	7.2	7.7	9.2	6.2
16	8.1	10.9	5.2	7.6	6.3	7.0	5.6
17	8.5	7.7	10.1	8.4	7.7	10.8	7.1
18	8.9	9.3	8.2	7.6	7.1	7.7	3.8
19	8.8	8.7	7.9	8.3	12.0	9.8	9.1
20	7.5	8.0	10.7	11.1	8.8	8.6	10.0
21	10.1	8.8	9.0	9.4	9.2	11.8	7.9
22	6.0	8.3	7.5	7.6	9.1	7.6	9.2
23	9.4	9.3	8.1	10.7	9.6	9.0	4.9
24	10.2	8.2	10.1	7.7	6.3	9.0	7.2
25	8.3	8.1	7.3	7.7	6.6	9.0	6.0

[1]Each measurement is an individual measurement of one randomly selected piece of popped sorghum
[2]F1f1= farm 1 field 1, F1f2= farm 1 field 2 red sorghum, F2f1= farm 2 field 1, F2f2= farm 2 field 2 red sorghum, W1= white 1, W2=white 2, HH= hand harvested red sorghum.

TABLE 8

Measurements of 25 diameters (mm) [1] of red and white popped sorghum[2] at 17% MC with a direct moisture application treatment.

	Red Sorghum					White Sorghum	
Measurement	F1f1	F1f2	F2f1	F2f2	Hand	W1	W2
1	10.0	11.2	6.9	7.3	12.5	6.5	6.1
2	8.9	7.9	9.0	9.5	16.6	8.2	5.5
3	9.0	9.8	9.7	12.0	10.2	7.1	6.6
4	10.0	6.0	10.6	10.9	10.8	6.6	5.4
5	10.1	12.0	6.7	8.8	10.5	8.0	7.2
6	10.1	8.5	7.0	8.8	11.2	5.1	8.0
7	8.8	7.0	7.8	8.2	10.8	3.4	7.0
8	9.9	10.0	9.0	12.4	11.8	5.5	5.6
9	9.5	7.5	8.4	11.0	12.2	4.9	7.5
10	9.5	13.5	9.3	9.4	11.6	4.6	7.0
11	7.9	11.1	9.2	8.0	11.0	6.0	6.5
12	12.1	14.6	12.3	8.0	12.1	6.5	8.5
13	10.5	8.0	8.4	10.3	10.8	5.8	6.8
14	7.6	8.8	10.5	10.9	10.9	6.9	8.6
15	12.5	13.2	10.8	12.4	10.6	4.0	7.1
16	8.6	8.0	8.5	11.0	10.9	3.2	8.0
17	10.2	13.5	10.0	8.9	10.6	5.0	3.7
18	10.2	10.5	8.5	11.1	9.0	7.7	7.8
19	11.1	9.8	10.2	12.6	10.5	7.9	4.2
20	8.1	10.1	12.3	9.3	15.5	5.6	6.4
21	9.0	10.5	9.2	7.8	11.4	7.0	4.3
22	9.1	8.9	9.1	9.1	10.5	6.7	5.6
23	10.2	10.0	6.8	6.1	12.2	4.0	4.8
24	7.8	12.3	8.6	8.7	9.5	5.1	5.4
25	8.6	7.5	9.5	7.6	8.3	5.1	5.0

[1]Each measurement is an individual measurement of one randomly selected piece of popped sorghum
[2]F1f1= farm 1 field 1, F1f2= farm 1 field 2 red sorghum, F2f1= farm 2 field 1, F2f2= farm 2 field 2 red sorghum, W1= white 1, W2=white 2, HH= hand harvested red sorghum.

TABLE 9

Measurements of 25 diameters[1] (mm) of red and white popped sorghum[2] at 12% MC with an indirect moisture application treatment.

		Red Sorghum				White Sorghum	
Measurement	F1f1	F1f2	F2f1	F2f2	HH	W1	W2
1	8.8	8.0	10.2	9.0	5.4	7.8	10.4
2	8.2	8.8	9.9	12.9	5.8	7.9	9.5
3	8.8	6.1	7.8	10.8	5.7	6.7	10.4
4	9.1	6.9	9.9	9.6	6.2	7.1	8.5
5	9.5	6.0	7.7	9.7	6.2	6.3	7.5
6	8.9	7.2	14.1	7.0	6.1	5.2	7.6
7	9.5	6.7	9.2	9.2	5.0	4.6	7.6
8	7.9	9.1	10.6	10.2	4.3	4.2	6.3
9	6.8	9.5	11.0	7.5	3.7	4.6	7.6
10	9.6	11.3	10.9	13.1	5.8	4.9	6.5
11	10.6	6.9	8.1	11.4	4.5	5.4	7.1
12	9.9	8.6	8.3	9.2	3.8	4.6	6.2
13	9.3	8.2	9.1	8.0	6.5	5.6	7.8
14	9.4	10.0	7.7	10.4	5.3	4.4	8.9
15	10.0	9.6	8.4	8.5	5.5	6.4	7.5
16	9.6	8.6	9.0	10.7	4.7	4.6	8.6
17	9.9	9.7	6.8	9.5	4.7	4.2	7.2
18	10.3	11.4	7.0	7.8	4.9	4.2	6.4
19	8.0	9.5	7.1	7.4	3.5	4.9	5.2
20	8.3	9.0	8.3	7.4	6.0	4.8	6.7
21	7.4	9.9	8.0	12.0	5.8	5.7	7.5
22	10.1	9.4	8.9	9.9	5.2	5.2	6.8
23	10.8	10.6	8.0	8.6	5.5	5.6	6.1
24	8.2	8.5	9.4	10.4	4.8	4.8	6.6
25	8.3	8.8	6.8	10.6	5.3	4.6	6.4

[1]Each measurement is an individual measurement of one randomly selected piece of popped sorghum
[2]F1f1= farm 1 field 1, F1f2= farm 1 field 2 red sorghum, F2f1= farm 2 field 1, F2f2= farm 2 field 2 red sorghum, W1= white 1, W2=white 2, HH= hand harvested red sorghum.

TABLE 10

Measurements of 25 diameters[1] (mm) of red and white popped sorghum[2] at 14% MC with an indirect moisture application treatment.

		Red Sorghum				White Sorghum	
Measurement	F1f1	F1f2	F2f1	F2f2	HH	W1	W2
1	11.5	9.5	11.5	12.9	5.9	5.6	8.8
2	13.1	11.9	6.7	9.6	6.0	7.0	7.4
3	9.7	8.8	11.1	9.5	5.2	7.2	10.3
4	10.2	9.4	11.6	8.8	5.2	7.0	9.1
5	9.2	9.7	14.9	10.5	6.3	7.7	10.9
6	10.4	10.7	10.2	8.3	7.9	6.9	10.1
7	8.5	8.6	12.0	8.6	3.6	7.6	9.3
8	8.8	10.0	10.7	10.8	5.7	8.3	10.7
9	7.6	12.2	9.3	10.0	5.5	4.3	9.5
10	10.8	9.6	7.2	11.9	8.0	4.5	9.5
11	10.0	9.9	6.8	7.4	5.2	7.7	7.6
12	6.6	8.5	11.2	9.5	4.3	6.6	8.0
13	8.9	8.4	6.8	8.4	7.3	5.0	11.2
14	9.5	9.5	8.6	10.4	6.0	7.3	11.6
15	8.9	12.5	8.7	9.1	7.2	8.0	8.3
16	10.6	11.5	11.1	8.8	5.6	5.1	10.8
17	7.7	7.5	10.0	7.0	7.8	8.4	10.9
18	8.1	8.7	9.1	7.9	5.3	7.5	9.0
19	9.8	9.5	8.8	7.8	8.2	8.4	8.2
20	13.9	11.0	9.3	11.0	7.8	5.2	10.0
21	11.0	6.1	8.7	15.0	7.3	7.6	10.0
22	11.8	7.5	10.5	8.7	7.8	6.6	11.1
23	9.9	6.7	7.6	8.7	9.6	9.2	9.8
24	8.8	6.8	8.7	10.2	7.7	7.5	11.2
25	8.6	9.4	6.9	8.7	7.9	6.2	13.2

[1]Each measurement is an individual measurement of one randomly selected piece of popped sorghum
[2]F1f1= farm 1 field 1, F1f2= farm 1 field 2 red sorghum, F2f1= farm 2 field 1, F2f2= farm 2 field 2 red sorghum, W1= white 1, W2=white 2, HH= hand harvested red sorghum.

TABLE 11

Measurements of 25 diameters[1] (mm) of red and white popped sorghum[2] at 17% MC with an indirect moisture application treatment.

	Red Sorghum					White Sorghum	
Measurement	F1f1	F1f2	F2f1	F2f2	HH	W1	W2
1	10.0	11.2	6.9	7.3	6.5	6.1	12.5
2	8.9	7.9	9.0	9.5	8.2	5.5	16.6
3	9.0	9.8	9.7	12.0	7.1	6.6	10.2
4	10.0	6.0	10.6	10.9	6.6	5.4	10.8
5	10.1	12.0	6.7	8.8	8.0	7.2	10.5
6	10.1	8.5	7.0	8.8	5.1	8.0	11.2
7	8.8	7.0	7.8	8.2	3.4	7.0	10.8
8	9.9	10.0	9.0	12.4	5.5	5.6	11.8
9	9.5	7.5	8.4	11.0	4.9	7.5	12.2
10	9.5	13.5	9.3	9.4	4.6	7.0	11.6
11	7.9	11.1	9.2	8.0	6.0	6.5	11.0
12	12.1	14.6	12.3	8.0	6.5	8.5	12.1
13	10.5	8.0	8.4	10.3	5.8	6.8	10.8
14	7.6	8.8	10.5	10.9	6.9	8.6	10.9
15	12.5	13.2	10.8	12.4	4.0	7.1	10.6
16	8.6	8.0	8.5	11.0	3.2	8.0	10.9
17	10.2	13.5	10.0	8.9	5.0	3.7	10.6
18	10.2	10.5	8.5	11.1	7.7	7.8	9.0
19	11.1	9.8	10.2	12.6	7.9	4.2	10.5
20	8.1	10.1	12.3	9.3	5.6	6.4	15.5
21	9.0	10.5	9.2	7.8	7.0	4.3	11.4
22	9.1	8.9	9.1	9.1	6.7	5.6	10.5
23	10.2	10.0	6.8	6.1	4.0	4.8	12.2
24	7.8	12.3	8.6	8.7	5.1	5.4	9.5
25	8.6	7.5	9.5	7.6	5.1	5.0	8.3

[1]Each measurement is an individual measurement of one randomly selected piece of popped sorghum
[2]F1f1= farm 1 field 1, F1f2= farm 1 field 2 red sorghum, F2f1= farm 2 field 1, F2f2= farm 2 field 2 red sorghum, W1= white 1, W2=white 2, HH= hand harvested red sorghum.

TABLE 12

Measurements of 25 diameters[1] (mm) of red and white popped sorghum[2] with no treatment[3].

	Red Sorghum					White Sorghum	
Measurement	F1f1	F1f2	F2f1	F2f2	HH	W1	W2
1	10.20	10.90	14.70	12.70	10.10	6.70	12.20
2	9.00	9.30	11.50	12.70	8.30	7.00	9.40
3	12.30	9.80	10.70	7.50	11.20	5.50	7.20
4	9.50	8.80	10.90	7.10	9.40	5.80	12.70
5	12.30	8.10	10.80	9.60	7.30	7.00	9.70
6	11.90	10.60	11.40	9.10	6.50	5.50	16.30
7	10.60	10.60	10.40	12.70	5.10	6.50	9.30
8	13.00	9.10	9.90	9.90	5.80	10.00	8.30
9	10.10	10.90	10.30	9.90	5.30	8.80	11.20
10	7.20	7.00	8.30	8.90	7.50	8.10	8.80
11	10.00	10.90	8.20	7.60	5.20	5.90	11.90
12	11.40	9.00	12.50	11.70	12.70	8.00	11.50
13	8.60	11.00	12.90	10.30	8.20	8.40	10.80
14	10.50	10.00	8.40	10.20	7.60	7.00	15.00
15	10.50	8.50	13.60	8.00	8.90	9.10	9.50
16	13.30	10.10	12.10	9.20	7.20	8.00	11.90
17	9.10	8.10	9.30	7.90	8.10	9.20	10.00
18	11.30	8.40	10.90	8.80	6.50	12.50	8.80
19	9.00	7.20	12.30	8.80	5.20	9.30	13.10
20	11.20	8.60	10.30	7.50	5.90	9.60	8.60
21	8.50	10.90	8.90	8.00	6.70	7.30	12.80
22	9.00	8.60	9.40	10.20	6.70	11.20	9.70
23	10.00	7.20	11.80	10.10	8.70	7.10	13.10
24	11.00	9.80	10.70	10.70	6.00	10.30	11.10
25	11.80	10.80	7.70	8.60	10.40	10.90	8.20

[1]Each measurement is an individual measurement of one randomly selected piece of popped sorghum
[2]F1f1= farm 1 field 1, F1f2= farm 1 field 2 red sorghum, F2f1= farm 2 field 1, F2f2= farm 2 field 2 red sorghum, W1= white 1, W2=white 2, HH= hand harvested red sorghum.
[3] moisture content as received from harvest. F1f1=13.25%, F1f2=13.67, F2f1=14.4, F2f2=15.17, HH=15.61, W1= 14.23, W2=14.3%.

TABLE 13

Color values[1] on the foam side of air popped red and white sorghum hybrids with 12% direct moisture content and popcorn.

Sample[2]	L*	C*	h
F1f1	68.5	4.9	87.9
F1f2	77.7	4.0	89.3
F2f1	83.4	3.1	88.9
F2f2	73.6	3.5	83.5
HH	72.3	2.4	82.6
W1	80.8	2.9	84.1
W2	81.6	3.5	89.0
Popcorn	54.1	2.1	57.7

[1] Measurements made in triplicate. Reported values are the mean of three measurements.

[2] F= Farm, f= field red sorghum, W= white sorghum, HH= hand harvested red sorghum.

TABLE 14

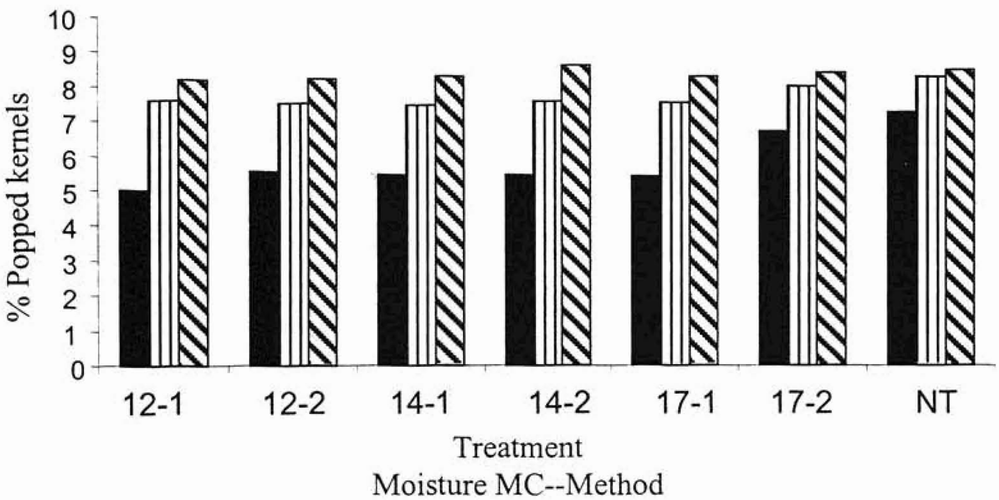
Color values[1] on the husk side of air popped red and white sorghum hybrids with 12% direct moisture content and popcorn.

Sample[2]	L*	C*	h
F1F1	27.3	15.0	50.9
F1F2	34.4	23.4	58.3
F2F1	25.2	20.5	58.3
F2F2	22.4	10.8	52.5
HH	29.7	4.1	64.8
W1	26.7	16.8	73.9
W2	36.8	22.3	78.2
Popcorn	25.8	9.5	83.5

[1] Measurements made in triplicate. Reported values are the mean of three measurements.
[2]F= farm, f= field, W= white, HH= hand harvested red sorghum.

FIGURE 1

Percent popped kernels[1] of red and white popped sorghum[2] at varying moisture contents[3] and methods[4].



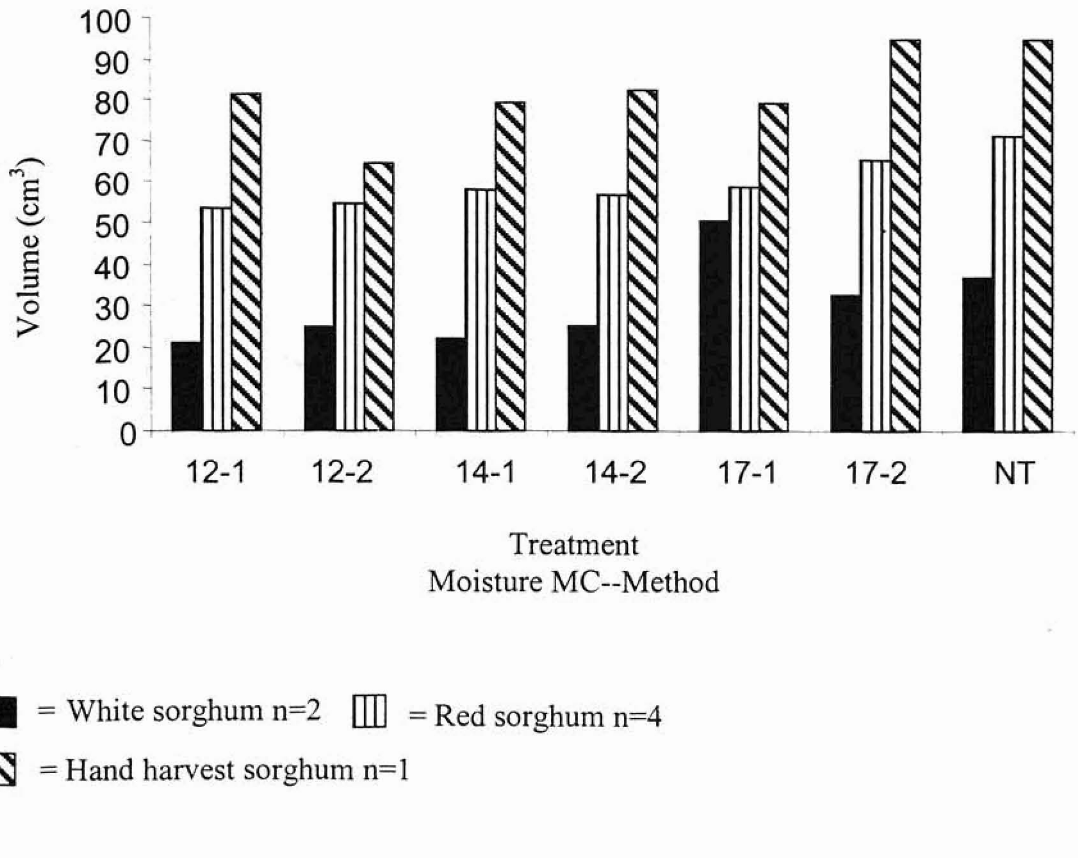
■ = White sorghum n=2 ▥ = Red sorghum n=4

▧ = Hand harvest sorghum n=1

[1]Dry weight of pops divided by dry weight of total grain before popped, shown as a percent.
[2]White sorghum = mean of white 1 and white 2, red sorghum = mean of farm 1 and 2 and field 1 and 2, hand harvest = one observation.
[3]Moisture contents = 12, 14 and 17%, NT= no treatment with MC's of red = 14.2%, HH=15.61%, W= 14.2%
[4]Method 1 = direct moisture application.
Method 2 = indirect moisture application.

FIGURE 2

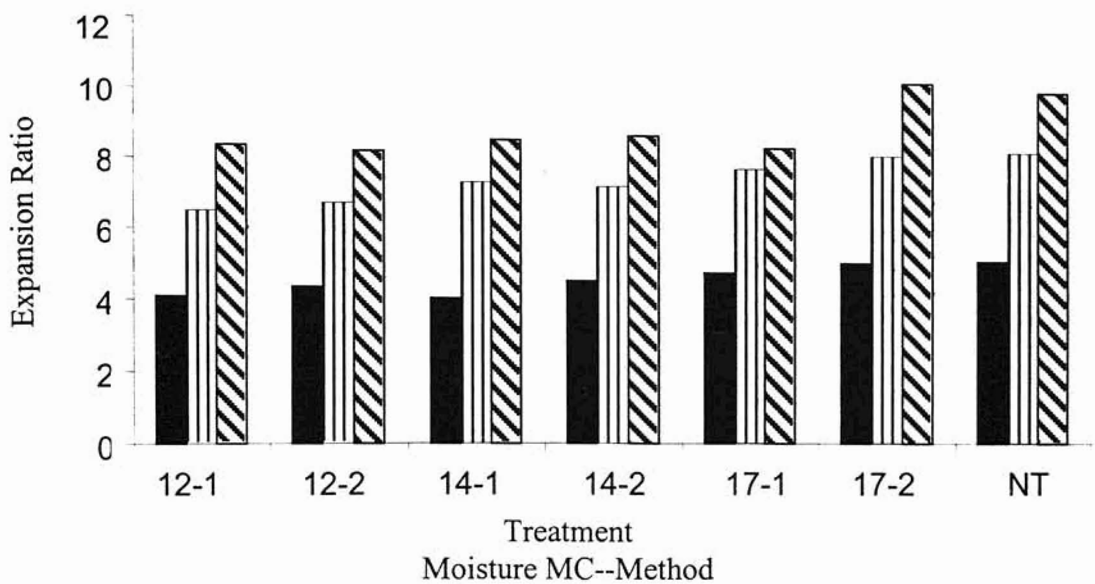
Volume[1] (cm^3) of red and white popped sorghum[2] at varying moisture contents[3] and methods[4].



[1]Volume of popped grain with an initial weight of 50 g.
[2] White sorghum = mean of white 1 and white 2, red sorghum = mean of farm 1 and 2 and field 1 and 2, hand harvest = one observation.
[3] Moisture contents = 12, 14 and 17%, NT= no treatment with MC's of red = 14.2%, HH=15.61%, W= 14.2%
[4]Method 1 = direct moisture application.
Method 2 = indirect moisture application.

FIGURE 3

Expansion ratio[1] of red and white popped sorghum[2] at varying moisture contents[3] and methods[4].



= White sorghum n=2 = Red sorghum n=4

= Hand harvest sorghum n=1

[1]Ratio of bulk density of grain and bulk density of popped grain.

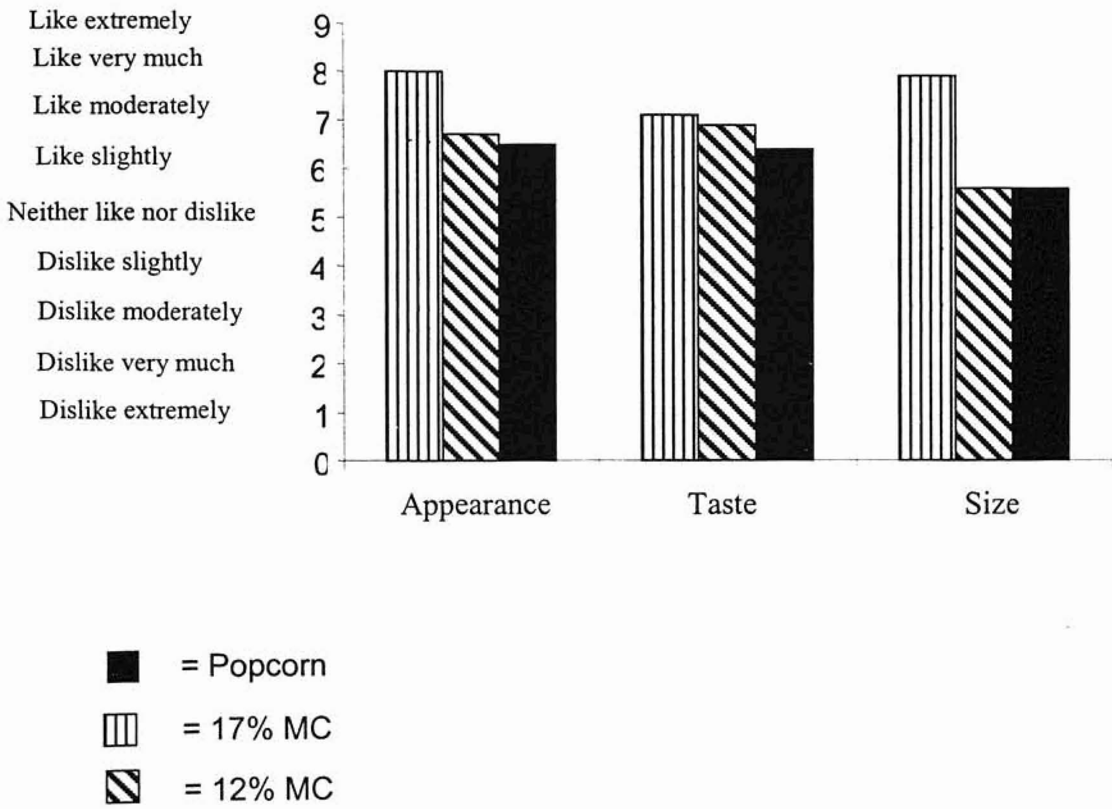
[2] White sorghum = mean of white 1 and white 2, red sorghum = mean of farm 1 and 2 and field 1 and 2, hand harvest = one observation.

[3] moisture contents = 12, 14 and 17%, NT= no treatment with MC's of red = 14.2%, HH=15.61%, W= 14.2%

[4]Method 1 = direct moisture application.
Method 2 = indirect moisture application.

FIGURE 4

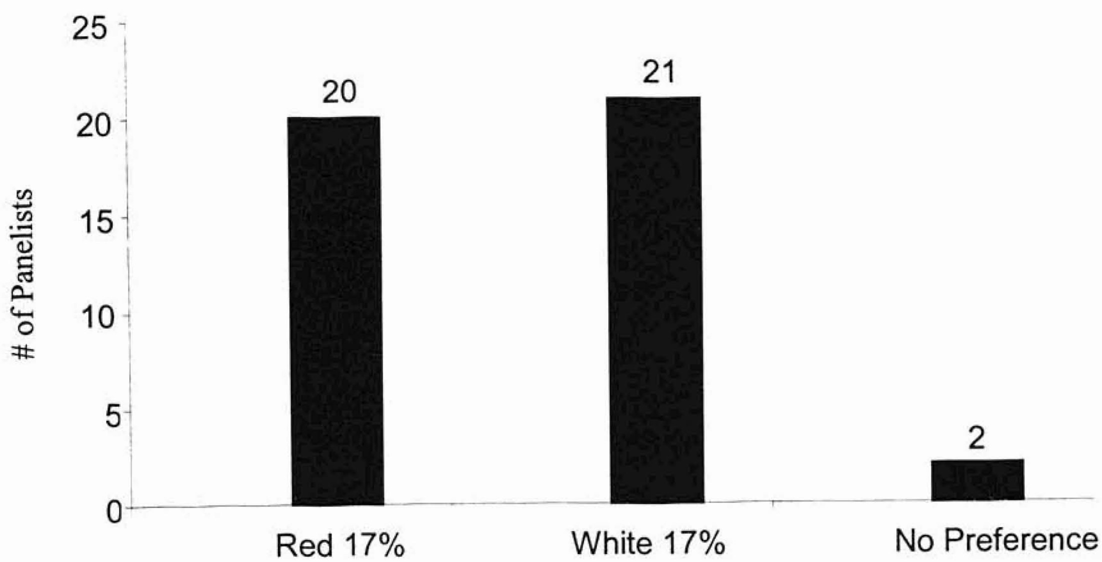
Sensory evaluation[1] scores evaluating popcorn and red popped sorghum popped at 12 and 17% MC, on a nine point hedonic scale, on appearance, taste and size.



[1] Sensory evaluation conducted on 46 untrained panelists. Scores are a mean of the 46 panelists.

FIGURE 5

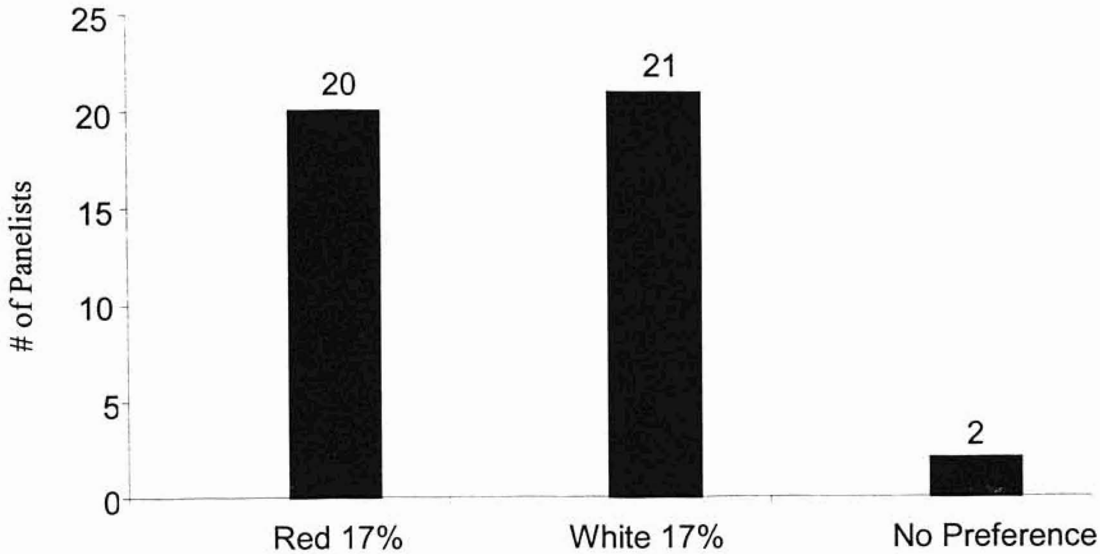
Paired preference[1] testing results[2] comparing red popped sorghum at 17% MC and white popped sorghum popped at 17% MC.



[1] Untrained panelists were asked to chose which popped sorghum sample they preferred.
[2] Sensory evaluation conducted on 43 untrained panelists.

FIGURE 5

Paired preference[1] testing results[2] comparing red popped sorghum at 17% MC and white popped sorghum popped at 17% MC.



[1] Untrained panelists were asked to chose which popped sorghum sample they preferred.
[2] Sensory evaluation conducted on 43 untrained panelists.

APPENDIX A

BULK DENSITY OF POPPED SORGHUM AND POPCORN

TABLE 15

Bulk density[1] of popped sorghum and popcorn.

Sample[2]	Bulk Density (g/cm^3)
F1f1	0.41
F1f2	0.41
F2f1	0.41
F2f2	0.40
HH	0.37
W1	0.43
W2	0.43
Popcorn	0.89

[1] Popped sorghum volume measured using a 1000ml graduated cylinder with a 9.61cm diameter. Calculated by dividing air popped sample weight by air popped volume (g/cm^3).
[2] F= Farm, f= field, W= white, HH= Hand harvested sorghum.

APPENDIX B

INITIAL AND FINAL MOISTURE CONTENTS OF SORGHUM GRAIN

TABLE 16

Direct water application method to red and white sorghum varieties at 12% moisture.

Sample[1]	Initial Wt.[2] (g)	Water Added[3] (g)	Final Moisture[4] (%)
W 1	11.07	1.59	11.60
W 2	11.23	1.31	11.89
F1f1	8.43	6.09	11.75
F1f2	9.26	4.67	11.92
F2f1	8.87	5.34	11.93
F2f2	9.35	4.52	11.90
HH	10.29	2.91	11.98

[1]F= farm, f= field red sorghum, HH= hand harvested red sorghum, W= white sorghum.
[2] Initial weight (g) of grain before reconditioning.
[3]Amount of water added to sorghum grain (g) during conditioning.
[4]Final percent moisture of sorghum grain.

TABLE 17

Direct water application method to red and white sorghum varieties at 14% moisture.

Sample[1]	Initial Wt.[2] (g)	Water Added[3] (g)	Final Moisture[4] (%)
W 1	7.80	18.90	14.01
W 2	7.50	21.02	13.89
F1f1	6.77	19.27	13.79
F1f2	7.37	18.34	14.20
F2f1	7.69	20.44	13.89
F2f2	7.23	19.68	13.90
HH	6.97	40.70	14.00

[1]F= farm, f= field red sorghum, HH= hand harvested red sorghum, W= white sorghum.
[2] Initial weight (g) of grain before reconditioning.
[3]Amount of water added to sorghum grain (g) during conditioning.
[4]Final percent moisture of sorghum grain.

TABLE 18

Direct water application method to red and white sorghum varieties at 17% moisture.

Sample[1]	Initial Wt.[2] (g)	Water Added[3] (g)	Final Moisture[4] (%)
W 1	7.80	27.71	17.00
W 2	7.50	28.61	16.77
F1f1	6.77	30.81	16.71
F1f2	7.37	29.01	16.89
F2f1	7.23	28.04	16.65
F2f2	7.69	29.43	16.97
HH	6.97	30.21	16.97

[1]F= farm, f= field red sorghum, HH= hand harvested red sorghum, W= white sorghum.
[2] Initial weight (g) of grain before reconditioning.
[3]Amount of water added to sorghum grain (g) during conditioning.
[4]Final percent moisture of sorghum grain.

TABLE 19

Moisture content values of sorghum grain varieties using the indirect moisture application method with a final moisture of 12%.

Sample[1]	Initial Wt.[2] (g)	Final Wt.[3] (g)	Initial Moisture[4] (%)	Gained Moisture[5] (%)	Final Moisture[6] (%)
W 1	150.0	152.5	11.07	1.67	12.74
W 2	150.0	152.8	11.23	1.87	13.10
F1F1	150.0	155.7	8.43	3.80	12.23
F1F2	150.0	153.2	9.26	2.13	11.39
F2F1	150.0	155.8	8.87	3.87	12.74
F2F2	150.0	154.7	9.35	3.13	12.48
HH	250.0	262.2	6.97	4.88	11.85

[1]F= farm, f= field red sorghum, HH= hand harvested red sorghum, W= white sorghum.
[2]Weight (g) of grain before reconditioning.
[3]Weight (g) of grain after conditioning.
[4]Moisture content of grain after harvest.
[5]Percent of moisture gained during conditioning.
[6]Final percent moisture.

TABLE 20

Moisture content values of sorghum grain varieties using the indirect moisture application method with a final moisture of 14%.

Sample[1]	Initial Wt.[2] (g)	Final Wt.[3] (g)	Initial Moisture[4] (%)	Gained Moisture[5] (%)	Final Moisture[6] (%)
W 1	187.0	209.2	7.80	6.5	14.30
W 2	185.0	205.3	7.50	7	14.50
F1F1	250.0	270.6	6.77	7.1	13.87
F1F2	250.0	272.2	7.37	6.63	14.00
F2F1	250.0	270.0	7.69	6.79	14.48
F2F2	250.0	268.0	7.23	7.20	14.43
HH	164.0	175.4	6.97	6.95	13.92

[1]F= farm, f= field red sorghum, HH= hand harvested red sorghum, W= white sorghum.
[2]Weight (g) of grain before reconditioning.
[3]Weight (g) of grain after conditioning.
[4]Moisture content of grain after harvest.
[5]Percent of moisture gained during conditioning.
[6]Final percent moisture.

TABLE 21

Moisture content values of sorghum grain varieties using the indirect moisture application method with a final moisture of 17%.

Sample[1]	Initial Wt.[2] (g)	Final Wt.[3] (g)	Initial Moisture[4] (%)	Gained Moisture[5] (%)	Final Moisture[6] (%)
W 1	250.0	274.7	7.80	9.88	17.68
W 2	250.0	274.9	7.50	9.96	17.46
F1f1	184.0	202.7	6.77	10.16	16.93
F1f2	188.0	207.1	7.37	10.16	17.53
F2f1	177.0	197.0	7.69	9.30	16.98
F2f2	175.0	193.2	7.23	10.40	17.63
HH	71.0	76.2	10.29	6.60	16.89

[1]F= farm, f= field red sorghum, HH= hand harvested red sorghum, W= white sorghum.
[2]Weight (g) of grain before reconditioning.
[3]Weight (g) of grain after conditioning.
[4]Moisture content of grain after harvest.
[5]Percent of moisture gained during conditioning.
[6]Final percent moisture.

APPENDIX C

RAW DATA OF HEDONIC RATING SCORES

TABLE 22

Raw data: Hedonic rating scores of popped sorghum and popcorn given by a panel of assessors.

Panelist	prod code[1]/ serving order	appearance	size	taste	Panelist	prod code/ serving order	appearance	size	taste
1	2	5	4	7	7	3	4	4	4
1	1	5	6	4	7	1	8	8	7
1	3	5	4	6	7	2	4	4	4
2	3	7	7	5	8	2	7	7	8
2	1	9	8	9	8	1	7	6	8
2	2	8	8	6	8	3	7	7	6
3	2	9	9	8	9	1	8	8	7
3	3	9	9	7	9	3	3	3	5
3	1	5	5	6	9	2	3	2	5
4	2	8	7	5	10	3	8	9	8
4	1	8	8	2	10	1	9	8	9
4	3	6	5	3	10	2	9	8	8
5	1	8	8	7	11	3	7	8	8
5	3	4	5	6	11	2	8	8	8
5	2	4	3	5	11	1	8	7	7
6	1	8	8	4	12	3	8	8	8
6	3	3	3	3	12	2	9	8	8
6	2	4	2	4	12	1	9	9	8

TABLE 23

Raw data cont: Hedonic rating scores of popped sorghum and popcorn given by a panel of assessors.

Panelist	prod code[1]/ serving order	appearance	size	taste
13	3	9	9	8
13	1	8	8	8
13	2	9	9	8
14	1	8	8	6
14	2	9	9	7
14	3	9	9	7
15	2	7	4	8
15	3	7	4	8
15	1	7	8	6
16	3	8	4	8
16	1	9	9	8
16	2	8	3	7
17	1	8	8	7
17	2	8	7	6
17	3	8	7	6
18	3	8	7	8
18	2	8	8	8
18	1	9	9	9

Panelist	prod code/ serving order	appearance	size	taste
19	1	8	7	8
19	2	4	3	6
19	3	3	3	4
20	2	6	4	8
20	3	6	5	7
20	1	9	9	8
21	3	9	7	7
21	2	9	6	4
21	1	9	9	9
22	2	7	6	8
22	1	8	6	7
22	3	5	7	7
23	3	5	4	4
23	2	4	4	5
23	1	8	8	6
24	1	8	7	6
24	2	7	4	5
24	3	7	4	6

TABLE 24

Raw data cont: Hedonic rating scores of popped sorghum and popcorn given by a panel of assessors.

Panelist	prod code[1]/ serving order	appearance	size	taste
25	1	8	8	6
25	3	6	7	4
25	2	7	7	7
26	3	8	7	6
26	1	9	9	7
26	2	8	7	7
27	2	7	8	7
27	1	8	7	8
27	3	7	8	7
28	1	9	9	9
28	3	8	7	8
28	2	7	7	8
29	3	8	4	9
29	1	8	8	7
29	2	8	4	9
30	1	8	8	7
30	2	4	4	7
30	3	4	4	7

Panelist	prod code/ serving order	appearance	size	taste
31	1	8	8	7
31	2	5	7	7
31	3	5	7	7
32	2	8	8	9
32	3	8	8	9
32	1	9	9	9
33	3	7	4	7
33	1	8	8	8
33	2	7	4	7
34	3	8	4	6
34	1	7	8	8
34	2	8	6	6
35	2	6	4	7
35	1	7	7	9
35	3	6	4	5
36	1	9	9	9
36	3	7	6	9
36	2	7	8	8

TABLE 25

Raw data cont: Hedonic rating scores of popped sorghum and popcorn given by a panel of assessors.

Panelist	prod code[1]/ serving order	appearance	size	taste
38	2	7	3	8
38	3	6	6	7
38	1	9	8	8
39	1	8	8	8
39	3	7	7	9
39	2	7	7	8
40	3	7	7	7
40	1	6	6	5
40	2	7	7	8
41	1	7	6	6
41	2	2	1	4
41	3	3	1	3
42	2	7	4	7
42	1	8	8	6
42	3	6	3	4
43	3	7	6	8
43	1	9	9	7
43	2	7	7	7

Panelist	prod code/ serving order	appearance	size	taste
44	2	7	4	7
44	3	6	4	5
44	1	7	8	6
45	2	8	2	8
45	3	8	3	9
45	1	9	9	5
46	1	8	9	7
46	2	6	7	7
46	3	6	5	4

Appendix D

Hedonic and Paired Preference Score Sheets

<u>Consumer Acceptance Test</u>

Popped Sorghum

Panelist Code ________ Sample Code______ Test Date: _______________

We would like to have your honest opinion and any specific comments you have about this product. Please make a mark beside the answer best describing your response to the attribute at the top of the column. Please rinse your mouth between samples. Use the expectorant cup provided if you do not want to swallow the samples.

Directions:

1) Please rinse your mouth with water.
2) ***Observe*** a few pieces of the sample, and check or make an X in the box, which best describes your feelings about the product's appearance and size.
3) ***Chew*** a few pieces of the sample and check or make and X in the box, which best describes your feeling about the product's taste.

Responses	**Appearance**	**Size**	**Taste**
Like extremely			
Like very much			
Like moderately			
Like slightly			
Neither like, nor dislike			
Dislike slightly			
Dislike moderately			
Dislike very much			
Dislike extremely			

How many times per month do you eat popcorn? [ ] Zero [ ] 1-4 [ ] 5-8 [ ] 9-15 [ ] 16 or more

Paired Preference Test

Panelist Code_______________ Date_________________

Please do not eat sample.
Observe both products starting from the left. Check the box for the product you prefer.
Please make a choice.

_______ ☐ _______ ☐ No preference ☐

CHAPTER IV

INSTANT SORGHUM MEAL AND ITS UNIQUE PASTING PROPERTIES THAT ARE ATTRIBUTED TO DIFFERENT SOAKING TREATMENTS

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ABSTRACT

The objective of this study was to characterize the effect of different soaking treatments on the rheological properties of the resulting instant sorghum meal and gels. Three cooking/soaking treatments H_2O, $Ca(OH)_2$ and $CaSO_4$ (1.3% w/v) and two sorghum types, white sorghum Fontanelle 1000 and red sorghum Pioneer 8500, were used. The sorghum was boiled in the three solution treatments at 98 °C for 10 min and soaked for 10 hr. The samples were drained, rinsed and ground into a masa like-product and drum dried. The final product was instant dried sorghum meal. The pasting properties of the products were determined using a Rapid Visco Analyser with a short (15 min) and a long (90 min) RVA ramp. Gel firmness was measured using Texture Profile Analysis after a 24 hr resting period of the 90 min RVA paste.

Peak viscosity values were higher ($p<0.05$) for the $Ca(OH)_2$ treatment than the H_2O or $CaSO_4$ treatments. However, viscosity during cooling of the paste for the treated meals were lower ($p<0.05$) than the non treated sorghum meal. Thus producing a sorghum meal gel with unique pasting characteristics. The cooking/soaking treatments will produce a functional ingredient that will contribute to different textural properties for gels or a variety of cereal based products. The precooked dried sorghum meal has the potential to be used in combination with other products or alone in the manufacture of snacks or breakfast cereals. The initial viscosity, intermediate (during cooling) and final viscosities obtained can be used as a basis for tailored cooking/soaking and drying treatments for target characteristics of the precooked/retrograded meal.

INTRODUCTION

Sorghum grain is commonly used in formulations in animal feed. In Oklahoma, 90% of sorghum goes toward the animal food supply (Suhendro et al., 1998). However sorghum used as or in food products could have a potential niche market with African heritage consumers and offer an alternative grain selection to people with celiac disease.

Although the use of sorghum in feedlots is effective it has potential for increased economic return when processed as a value-added food product or ingredient. Typically sorghum meal is used at low levels in combination with higher levels of wheat or corn flour, used to make breads, or muffins in countries such as India and Africa. Sorghum is sometimes used as a complete replacement for corn for tortilla making when the price of corn is to high for consumers to buy. (Smith and Frederiksen, 2000).

The process of making corn tortillas is done by alkaline cooking of the grain. During the cooking and steeping process sorghum starch is modified (Gomez et al., 1989). Under normal circumstances the cooked grain is ground into a masa and formed into tortillas or chips. Different soaking treatments of the masa in combination with a drum drying process can affect the degradation of the starch even further.

The objective of this study was to characterize the effect of different soaking treatments on the rheological properties of the resulting instant sorghum meal and gels. The instant sorghum meal could be used in conjunction with other products to give a desired texture or consistency during or after processing such as snacks and savory crackers.

Materials and Methods

Raw Materials

Two sorghum hybrids were used, vitreous red sorghum Pioneer 8500 and floury white sorghum Fontanelle 1000. Red Pioneer 8500 sorghum was harvested from Enid, Oklahoma in November of 2001. Four plots of Pioneer 8500 were harvested individually to provide four replicates, Farm 1 field 1 (F1f1), Farm 1 field 2 (F1f2), Farm 2 field 1 (F2f1), and Farm 2 field 2 (F2f2). Two separate batches of white food grade sorghum were received from Twin Valley Mills, LLC. Ruskin, Nebraska, in January 2002. Due to a drought in Oklahoma in 2001, white sorghum was not harvested by Oklahoma sorghum growers, therefore the white grain was supplied by a Nebraska source. Although sorghum is considered to be a drought tolerant grain much of the 2001 harvest was damaged. The Red Pioneer 8500 sorghum was harvested about three weeks late due to constant rain. When these particular batches of grain were harvested the moisture content was abnormally high (15%), due to recent rain conditions. In preliminary studies in 2000 sorghum grain moisture content was 7-8% at harvest.

Sorghum Grain Handling

Upon arrival the samples were placed in a -4°C freezer for a 24 hr period to kill any infestation. Removal of extraneous material was performed using a dockage tester (Carter Day XT5, Carter Day International, Minneapolis, MN) with air speed 1, feed number 6, top sieve size 6 and bottom sieve size 1. After cleaning, the grain was stored at -4°C until further needed. Grain moisture content (MC) was determined upon receiving the sorghum using Approved Method 44-15A (AACC, 1995) (Table 3). A tray dryer (Proctor and Schwartz, Inc. Horsham, PA) was subsequently used to reduce the MC to the desired levels to then be rehydrated using the following two methods. Once the MC of the samples was achieved the samples were returned to a -4°C freezer until further needed.

Proximate Analysis

Crude protein (N x 6.25) was determined by method 2001.11 using block digestion and steam distillation into boric acid (AOAC 1998) using a 2300 Kjeltec Analyzer Unit (Tecator, Foss North America Inc, Enden, Pairie, MN). Fat determination was done using method 922.06 (AOAC 1998). Moisture content was determined using Approved Method 44-15A (AACC, 1995) (Table 28).

Sorghum Grain Preparation

Three 900 ± 0.1 g batches of each sorghum sample were weighted and placed in perforated (36 holes/cm^2) nylon sacks (12.0 X 12.0 in). Three steam- jacketed kettles (Model DC-6, Crown Food Service Eq. LTD. Toronto, ON) were filled with 20 L of water. Three treatments were used, water and 1.5% of each $CaSO_4$ (Allied Custom Gypsum. Lindsay, OK) and $Ca(OH)_2$ (Ball Pickling Lime, Muncie, IN). The three kettles were brought to a gentle boil (98°C). In each of the three boiling kettles three 900 g sample nylon bags were added and brought back to a boil. A ten-minute boil was then timed. The steam was then turned off and the sorghum was soaked for 10 hr at a cooling rate of 1°C/min. The bags of grain were drained by shaking the bags by hand. The grain was removed from the bags and weighed. The grain was rinsed in cold tap water in large rectangular buckets. Loose pericarp was removed manually by rubbing the grains and rinsed three times. Nylon mesh wood framed screens (10" X 18") were used to catch the rinsed grain. The grain was weighed again to account for the amount of pericarp removed during the soaking and steeping process. The soaked grain was immediately ground. Figure 11 is a flow chart depicting the sorghum grain cooking/soaking procedure.

Sorghum Grain Grinding

Each batch was ground for 1 min in a Stephan UMC5 Electronic mixer (Stephan Machinery Corp. Columbus, OH). Water (200 ml) was added to the grain and mixed for 1 min. The mixture was then divided into three equivalent parts. Each part was mixed in a blender (Osterizer, grind mode) with the addition of 250 ml water to each part. The three mixtures where combined. The blended mixture was drum dried (Blaw-Knox.Co., Buffalo, NY) with a 7" diameter stainless steel drum at 1 mm gap, 2.4 rpm and 275-285°F. The resulting sheets of sorghum instant masa meal were further dried (Table 29) in a custom made batch tray dryer with variable air circulation (Proctor and Schwartz, Inc. Horsham, PA) for 24 hr with no heat and only air circulation (fan speed setting #5). The dried product was ground using a coffee grinder (Braun House Hold Type, 4041, Model KSM2(4), Minneapolis, MN) with an end meal particle size of U.S. mesh #100. Samples were placed in plastic zip bags (Minigrip, ITW co. Seguin, TX). Control meal was raw sorghum (no treatment) ground using a breakmill (Brabender, Hackensack, NJ) and then a coffee grinder was used to obtain similar particle size to the treated meal.

Pasting Properties

Pasting properties were determined as a function of grain treatment of sorghum samples, using 3.5 g of meal (14% mb) in a 28 g total suspension, using a Rapid Visco Analyser (Newport Scientific). Water was added to the meal and the mixture was manually stirred with a spatula for 30 sec to produce a slurry. The slurry was immediately placed in the RVA for analysis, using two ramps, short 15 min and a long 90 based on Bello (2001). The respective profiles of time (min) and temperature (°C) were short profile; 0:50, 2:50, 7:95, 11:95, 15:50; long profile; 0:30, 40:90, 50:90, 90:30.

Gel Firmness

Gel firmness was measured using a Texture Analyser TA-XT2i (Texture Technologies Corp, Scarsdale, NY) and texture profile analysis (TPA) after a 24 hr rest period of gels obtained from the 90 min RVA analysis (Bhattacharya, 1997). The meal paste was immediately poured after the 90 min RVA analysis into a cellulose casing (Ez-Peel Cellulose 25mm, Devor-Teepak, Lisle, IL). Each end of the casing was knotted and placed in a plastic zip bag (Minigrip, ITW Co. Seguin, TX) to prevent any drying of the gel and stored at room temperature for 24 hr. The casing was then gently cut away from the gel. The ends were trimmed to a flat surface using a knife and cut into two pieces (37 mm) for replicate evaluations on the TPA. A standard two-cycle program was used to compress the gels for a distance of 10 mm (27% compression) at a crosshead speed of 30 mm/min using a 7 mm cylindrical probe with a flat end.

Starch Gelatinization Measurement

The degree of starch gelatinization was determined using a Differential Scanning Colorimeter (DSC) Model DSC 7 (Perkin Elmer, Norwalk, CT) connected to a computer via a TAC 7/DX Thermal Analysis Instrument Controller and Pyris Software for Windows. Samples (2-3 μg) of instant sorghum meal were weighed in aluminum pans (Kit No. 0219-0041). Distilled water (11-12 μg) was added with a micropipette and covered with a lid (Kit No. 0219-0041). After equilibration for 30 min at room temperature, the sample was analyzed by heating from 25 to 120°C at a rate of 10°C/min based on Chen et al. (2002).

Statistical Analyses

All four soaking treatments (H_2O, $CaSO_4$, $Ca(OH)_2$ and control) were performed on each experimental unit (F1f1, F1f2, F2f1, F2f2, W1, and W2), where F= farm one or two of red sorghum, f= field one or two of red sorghum, and W= batch of white sorghum one or two. In one kettle of each soaking treatment was a nylon bag of F1f1, F1f2, and W1 (day one). The experiment was replicated with F2f1, F2f2, and W2 the following day (day two). The pasting properties of the instant sorghum meal were analyzed using a split-plot experimental design with the main units in a completely randomized design. Analysis of Variance (ANOVA) was tested and its level of significance (p-value) was obtained. Differences among specific treatments effects were tested with Tukey's test as well as using Proc Mixed. Statistical analysis was performed using Statistical Analytical System software (Version 8.02, SAS Institute Inc., Raleigh, NC).

Results and Discussion

Meal Pasting Characteristics

Peak Viscosity

Peak viscosity (PV) is an indication of maximum viscosity the instant sorghum meal was able to achieve prior to the cooling stage of the test ramp during RVA analysis. It is an indication of the degree of gelatinization of starch or cook for processed products (Walker et al., 1992). As seen in figures 1 to 4, representative tracings of pasting curves of white and red sorghum meals plus the control (NT), are compared for each soaking treatment. The tracings show PV is reached during the holding time at 95°C, typically peaking at 5-6 min. Figure 5a PV for a 15 min RVA cycle, on red and white sorghum instant and control (NT) meals. For the 15 min treated sorghum meals, $Ca(OH)_2$, $CaSO_4$, and H_2O had significantly lower ($p<0.05$) PV values (Table 1) compared to the NT sorghum meals. PV values for the treated red sorghum meals are 73.5, 66.5 and 54.9 RVU and 114.5, 82.8 and 74.8 RVU, respectively for white sorghum (Table 1). Suhendro et al. (1998) reported that raw sorghum kernels have the highest peak viscosity because the starch in raw flour was more available for gelatinization and produced a higher peak than that in the cooked products. PV values (Table 1) for NT red and white sorghum meals ranged from 233.3 to 162.6 RVU. Figure 5b shows PV values of red sorghum and white sorghum for each soaking treatment during the 90 min RVA cycle. Trends in PV values (Table 2) were similar for the 90 min RVA cycle compared to the 15 min RVA cycle.

Trough

The trough (TR) shows how much the starch molecule ruptured as the temperature was held at a constant high temperature (95°C short cycle, 90°C long cycle). TR viscosity values are determined by the difference between PV and breakdown where breakdown is the minimum viscosity that occurs after the first peak. Figures 1 to 4 show 15 and 90 min RVA profile tracings for the NT, red and white treated instant sorghum meals. The trough can be seen after the initial peak viscosity (PV) begins to decrease. The NT (white and red) sorghum meal TR values (Table 1) (124.1 and 146.9 RVU, respectively) were significantly higher ($p<0.05$) than the treated meals with TR values ranging from 50.1 to 67.3 RVU. TR viscosity values of the red and white H_2O treated grain (50.2 and 72.9 RVU) were significantly lower ($p<0.05$) than $Ca(OH)_2$ treated grain with TR values of 73.5 and 114.5 RVU, respectively. The 90 min RVA analysis followed opposite trends as the 15 min cycle (Fig. 6). TR values (Table 2) for red and white 90 min NT sorghum meals were lower (8.3 and 6.3 RVU, respectively) and then only slightly increasing in TR for the red and white treated meals TR values ranging from 11.9-12.9 RVU (there was no color by soak interaction). During the 90 min test lower differences in the energy level of the meal are explained by lower heating rate compared to the 15 min test. Thus the viscosities formed by the sorghum meal molecules were lower. The higher the TR value, the more change the sample has undergone during the heating/shearing test. In the 15 min test all treated meals showed lower TR values than NT meaning that the viscosity during the heating at 95°C was less stable than the NT. The low TR values for the treated sorghum in the 15 min cycle analysis are an indication that the cooking treatment in combination with the drum drying caused gelatinization of the starch granules there by showing only small changes in between PV values and breakdown values.

Pasting Temperature

The pasting temperature is defined as the temperature at which gelatinization starts (Walker et al., 1998). The pasting temperatures for the instant sorghum meals during the 15-min cycle all ranged between 70 and 93°C (Fig. 7). The white sorghum showed a significantly lower ($p<0.05$) pasting temperature for $Ca(OH)_2$ (72.4°C) compared to the NT, H_2O and $CaSO_4$ treated sorghum meals (Table 1). Red sorghum pasting temperatures were also lower ($p<0.05$) for $Ca(OH)_2$ compared to NT (72.4° and 85.7°C, respectively) (Table 1). Lower pasting temperatures suggest that the starch molecules in the $Ca(OH)_2$ treatment are more hydrophilic and absorbed water easier.

Peak Time

Peak time is the time at which the peak viscosity occurred from the start of the test, expressed in minutes as defined by Walker et al. (1998). There were no significant differences ($p>0.05$) in peak times for the 15-min or the 90-min RVA cycle (Table 1 and 2). Figures 8a and 8b depict the differences in peak time for the different soaking treatments at 15 and 90 min RVA cycles. Peak time for the 90-min cycle for NT sorghum meals (red and white) ranged from 40.5 to 41.3 min. The three other grain soaking treatments $CaSO_4$, $Ca(OH)_2$ and H_2O averaged from 37.1 to 40 min. An early peak usually indicates a higher degree of gelatinization (Walker et al., 1998). The presence of $CaSO_4$ and $Ca(OH)_2$ in the processed meal delayed the onset of swelling and gelatinization of starch (in all treatments except for F1fl, 15 min RVA) as well as compete with starch for the water (Fig. 1 to 4). Even though the meals were gelatinized, the residual molecules from $Ca(OH)_2$ and $CaSO_4$ delayed peak time. Starch that is not partially or completely gelatinized (such as the NT sorghum meal) has a delayed peak viscosity development (Suhendro et al. 1998). The overall trend of peak time in the two RVA cycles (15 vs. 90 min) (Fig. 8a and 8b) were different, due to the slower heating rate in the 90 min cycle, peak viscosity was not reached until the heating temp reached 90 °C. The 90 min cycle showed opposite trends than the expected, shorter peak time with the NT sorghum meal. The delayed peak viscosity and peak time development is explained in part to the residual $Ca(OH)_2$ and $CaSO_4$ in the samples.

Setback

Upon cooling some starch molecules begin to reassociate (Whistler, 1997) forming a precipitate or gel and increase in viscosity (Hoseney, 1994). Reassociation of starch decreases the potential for starch solubilization or dispersion (Waniska and Gomez, 1992). This process is called retrogradation or setback (SB). SB is calculated as FV-PV, it is a good value to understand how the meal (starch) is going to behave during cooling. The viscosity in most cases will rapidly increase due to a decrease in energy in the system therefore allowing more hydrogen bonding between starch chains producing an increased viscosity.

The SB occurred when cooling from 95 to 50°C (9°C decrease/ min) during the 15 min RVA cycle, and from 90 to 30°C during the 90 min RVA (1.5°C decrease/min). figures 1 to 4 visually show SB for red and white sorghum, NT and treated sorghum meals for the 15 and 90 min RVA analysis. The SB (15 and 90 min) for the three treated grains for both the red and white sorghum meals were significantly lower ($p<0.05$) than the NT meals (there was no color by treatment interaction)(Table 1 and 2). Lower SB values as seen in Fig. 9a and 9b are due to the decrease in hydrogen bond capacity of the meals after the cooking and drum drying treatments. The lower SB values were a direct result of gelatinization, degradation, and fine structure of the starch molecules.

The sorghum meal gels formed during the SB period were strong with numerical values similar to PV (Tables 1 and 2). The SB values were almost 100% higher for the NT red and the white sorghum (red PV= 233 and SB= 223; white PV=162 and SB=211) compared to the treated sorghum meals.

Final Viscosity

At the end of the cooling cycle is the final viscosity of the meal paste. During cooling the starch molecules begin to move closer together. The absence of heat reduces the starch molecule movement due to the energy being lost by the starch molecules. Hydrogen bonding is able to take place easier which would increase the paste FV. The FV values for the 15 and 90 min cycles are shown in tables 1 and 2 and are seen in graph form in Figures 1 to 4. NT red sorghum meal FV was significantly higher ($p<0.05$) than the three treated $Ca(OH)_2$, $CaSO_4$ and H_2O) sorghum meals (there was no color by treatment interaction). Overall, the patterns of FV values in the two testing cycles (15 and 90 min) were similar. Trends of higher FV values were observed in the 90 min test (Fig. 10a and 10b).

Degree of Starch Gelatinization

Table 3 shows the values onset temperature (T_o), peak temperature (T_p), enthalpy (ΔH) values obtained from differential scanning colorimetry (DSC) on non treated (NT) red and white sorghum meals. The NT meals showed T_o in the range of 54.5-69.9°C, and T_p 65.9 to 75.7°C. The T_p values were within the reported ranges (66°C to 76°C) by Sweat et al. (1984). The endothermic enthalpy of gelatinization ranged from 7.6 to 26.9 J/g. The ΔH values of the sorghum meals are within range of the values reported for isolated sorghum starch (6.8 to 11.1 J/g) by Beta and Corke (2001).

The ratio of endothermic peak of the raw vs. processed samples has been used as an indication of degree of starch gelatinization. The DSC endotherms showed complete starch gelatinization for all the treated instant sorghum meals obtained from the red and white sorghum hybrids studied (Fig. 11 and 12). The flat endotherms with no peak of $Ca(OH)_2$, $CaSO_4$ and H_2O meals revealed no energy consumed by the meal thus no endothermic transition. Chen et al. (2002) used the DSC to show the degree of starch gelatinization in masa meal that had additional heat treatment during the drying process of the meal. These authors reported that no endothermic peak was an indication of a high degree of starch gelatinization.

Gel Texture Analysis

The hardness of a gel is defined as the maximum force that occurs at any time during the first compression cycle. It may occur when the gel initially breaks or later on when the sample is flattened or deformed (Rosenthal 1999). Figures 12 and 13 are representative curves of the two compression tests for gels made from red and white sorghum meals. Distinct tracing are observed for each sorghum sample with the same order for the first peak. A fracturability peak is observed in all red sorghum samples earlier than the maximum peak (Fig. 12) unlike the white sorghum where the fracturability peak comes after the maximum peak. $Ca(OH)_2$ treatment formed firmer gels compared to the other three samples (Table 4). This suggests that this meal has the potential to contribute to texture attributes when firmer products are desirable. (Bemiller, 1997).

Peak force and springiness values are shown in table 4 for treated ($Ca(OH)_2$, $CaSO_4$, H_2O) red and white sorghum instant meals and the NT meals. The peak force values for each red and white instant sorghum meal were higher for the $Ca(OH)_2$ treated sorghum meals than the other treatments (Fig. 12 and 13). Peak force (firmness) of $Ca(OH)_2$ treated meals of red sorghum farm 1 (mean of F1f1 and F2f1), farm 2 (mean of F2f1 and F2f2), and white sorghum (mean of W1 and W2) were, 173., 212, and 307 (g) respectively (Table 4).

In the white sorghum sample, ionic and hydrogen bonding between $Ca(OH)_2$ and H_2O produce a strong structure allowing the gel to withstand more force, thus producing firmer gel. Water molecules form hydrogen bonding with the starch chains. When a starch paste is cooled, the starch chains become less energetic and the hydrogen bonds become stronger, giving a firmer gel (Whistler, 1997). Storage of a gel gives time for more interaction between the starch chains and crystals will eventually form. Retrogradation is the crystallization of starch chains in a gel. The data suggest inherently different properties of the sorghum meals form the two hybrid types studied.

CONCLUSIONS

The cooking/soaking and drum drying treatments produced completely gelatinized sorghum meals. Overall, peak, trough and final viscosities of the sorghum meals were lower than the NT sorghum. Stable paste viscosities were obtained for all the meals during the RVA analysis.

$Ca(OH)_2$ and $CaSO_4$ treatments produced similar viscosities except for white sorghum meal peak and setback which were higher than the red sorghum. The more stable paste structures formed by the white sorghum during cooling suggest more hydrogen bonds and less retrograded starch. This was supported by the higher FV and gel firmness of white to the red sorghum. The setback viscosity of red sorghum decreased 3.5 times with $Ca(OH)_2$ treatments compared to NT sample meals. The low setback viscosities could be beneficial during pumping or filling operations. The white sorghum (Fontanelle 1000) had a floury endosperm where the red (Pioneer 8500) was vitreous. Floury sorghum has higher water absorption during moisture adjustment (conditioning) than vitreous sorghum (Khan et al., 1980). This suggests differences in the physical properties of the endosperm types. These differences could have affected the changes occurring in every processing step. The resulting lower final viscosity and gel firmness of the vitreous red sorghum suggest a more degraded meal with limited hydrogen bonding between the micelles of the meal and in particular starch molecules. Although the meal of both sorghum types were gelatinized, differences in the fine structure of the starch and adhesion of starch granules and protein bodies in the endosperm could have accounted for the different final paste viscosity and gel firmness observed. More studies are needed to describe the retrogradation kinetics for the processed meals (not isolated starch) from both sorghum types.

Retrogradation is considered a staling phase that takes place after gelatinization. The amylose leaches out forming aggregation of chains and thus causing crystallization to take place. Reassociation of amylose chains reduces its capability to absorb water, therefore reducing viscosity or swelling of the starch granule. Apparently, the different starch structure of red and white sorghum can cause retrogradation at different degrees. The white sorghum starch appeared to be less retrograded hence the observed higher PV and SB values (Schiraldi and Fessas, 2001).

Starch gelatinization and denaturing of the proteins and retrogradation of starch were the main reason for the RVA profiles for the treated sorghum meals. The precooked sorghum meal paste gel had unique pasting characteristics and textural properties with potential to be used in combination with other products or alone. A products' initial viscosity, intermediate (during cooling) and final viscosities can be manipulated by combinations of cooking/soaking and drying treatments and subsequent levels of retrogradation. The different characteristics of the meals could affect the functionality of a product such as a snack food.

The resulting treated meals reported can further be used as the basis for obtaining types of "designer" textural attributes. Alternatives include, processing of red sorghum (Pioneer 8500) to enhance retrogradation and contribute to the textural properties of a snack product.

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FUTURE RESEARCH

To better understand the properties of sorghum meals and to contribute to adding value as potential ingredient, the following suggestions are proposed:

- Monitor RVA profiles on masa before drum drying to observe the extent of gelatinization that takes place during the soaking treatments.
- Vary the concentrations of the soaking treatments to see if there is any further extended gelatinization. Whistler et al. (1997) reported that soaking starches in salts have little effect on gelatinization or gel formation. This is true until their concentrations reach a point at which they begin to lower water activity by uptake of large amounts of water, thus lowering the amount of water available for hydration of starch molecules, or by exerting antiplasticizing effect.
- Investigate the effects of a wet stone mill grinder to obtain the meal. Hoseney (1994) stated that the grinding appears to be an important step. Stone mills are generally thought of to be necessary to produce good masa. This is related to the particle size distribution that is produced.
- Use the developed instant meals in a series of product development. Whistler et al. (1997) mentioned good uses for pregelatinized starches could be used in dry mixes such as instant soup, pizza topping, and extruded snacks. Product development using the meal in an extruded product could be a unique way of utilizing the developed instant meal for a snack food product.

TABLE 1

Effect of steeping treatments[1] on mean pasting properties[2] of sorghum meal from two cultivars[3], during a 15 min time ramp.

Cultivar	Control	H_2O	$CaSO_4$	$Ca(OH)_2$
Red Sorghum				
PV	158.5c*	54.9b	66.5ab	73.5a
TR	120.1c	50.2b	59.0ab	67.3a
FV	326.5c	93.4b	116.4ab	126.8a
SB	208.9b	42.7a	57.3a	59.5a
P_{time}	5.6a	6.4a	6.5a	5.0b
P_{temp}	83.7a	86.8a	85.8a	82.9a
White Sorghum				
PV	237.3c	74.8a	82.8a	114.5b
TR	135.3c	72.9b	77.9ab	92.6a
FV	362.4c	135.6b	157.0ab	202.8a
SB	237.5d	62.8a	79.1ac	110.3b
P_{time}	5.6a	6.9a	6.4a	5.8a
P_{temp}	79.7b	81.7b	81.1b	72.4a

[1] H_2O, $Ca(OH)_2$ (1.5%), $CaSO_4$ (1.5%), Control (no soaking treatment).
[2] PV = peak viscosity, TR = trough, FV = final viscosity,
and SB = setback (FV-PV) measured in Rapid Visco Analyser units (RVU).
P_{time} = time (min) to PV and P_{temp} = temperature (°C) at PV.
[3]F= Farm, f= field red sorghum, W= white sorghum.
*Values followed by the same letter in the same row are not significantly different (P>0.05)

TABLE 2

Effect of steeping treatments[1] on mean pasting properties[2] of sorghum meal from two cultivars[3], during a 90 min time ramp.

Cultivar	Control	H_2O	$CaSO_4$	$Ca(OH)_2$
Red Sorghum				
PV	151.6b	49.4a	54.5a	89.4c
TR	8.3a	12.6a	12.5a	11.9a
FV	334.0a	161.9b	176.9b	256.8a
SB	250.9a	149.3a	164.5a	245.0a
P_{time}	41.3a	38.9b	39.4b	38.6b
White Sorghum				
PV	201.2b	70.4a	68.0a	117.2c
TR	6.7b	12.5a	10.7a	16.7a
FV	397.0b	231.0a	240.5a	295.9b
SB	266.4b	218.5a	229.8a	279.2b
P_{time}	40.5a	39.0b	39.8b	37.9b

[1] H_2O, $Ca(OH)_2$ (1.5%), $CaSO_4$ (1.5%), Control (no soaking treatment).
[2] PV = peak viscosity, TR = trough, FV = final viscosity,
and SB = setback (FV-PV) measured in Rapid Visco Analyser units (RVU).
P_{time} = time (min) to PV and P_{temp} = temperature (°C) at PV.
[3]F= Farm, f= field red sorghum, W= white sorghum.
*Values followed by the same letter in the same row are not significantly different ($P<0.05$)

TABLE 3

Differential scanning calorimeter characteristics for the first endothermic transition of non-treated red and white sorghum meal.

Sorghum Sample	T_0[1] (°C)	T_p[2] (°C)	ΔH[3] (J/g)
F1[4]	62.7	74.5	26.7
F2	54.5	65.9	13.5
W1	69.9	75.7	7.6
W2	60.9	70.5	10.3

[1]T_0 = onset temperature; [2]T_p = peak temperature; [3]ΔH = enthalpy.
[4]F= red sorghum (F1fl, F2fl) and W= white sorghum sample one and two.

TABLE 4

Gel firmness[1] and springiness of control and instant sorghum meal[2] gel of red and white sorghum.

Treatment	Gel Firmness (g)			Springiness		
	Red Sorghum		White Sorghum	Red Sorghum		White Sorghum
	F1	F2	W	F1	F2	W
Control	79.03	71.33	55.77	0.41	0.54	0.51
$CaOH_2$	79.13	54.61	76.95	0.3	0.59	0.61
$CaSO_4$	75.63	61.88	63.20	0.41	0.51	0.46
H_2O	71.24	57.29	61.34	0.45	0.54	0.51

[1]Maximum force of the first compression (n=4)
[2]F= farm, f= field red sorghum, HH= hand harvested red sorghum, W= white sorghum.

FIGURE 1

Representative RVA graphs of 15 min F1f1 red instant sorghum meal samples for each of the three treatments (H_2O, $Ca(OH)_2$, $CaSO_4$) and the control (NT).

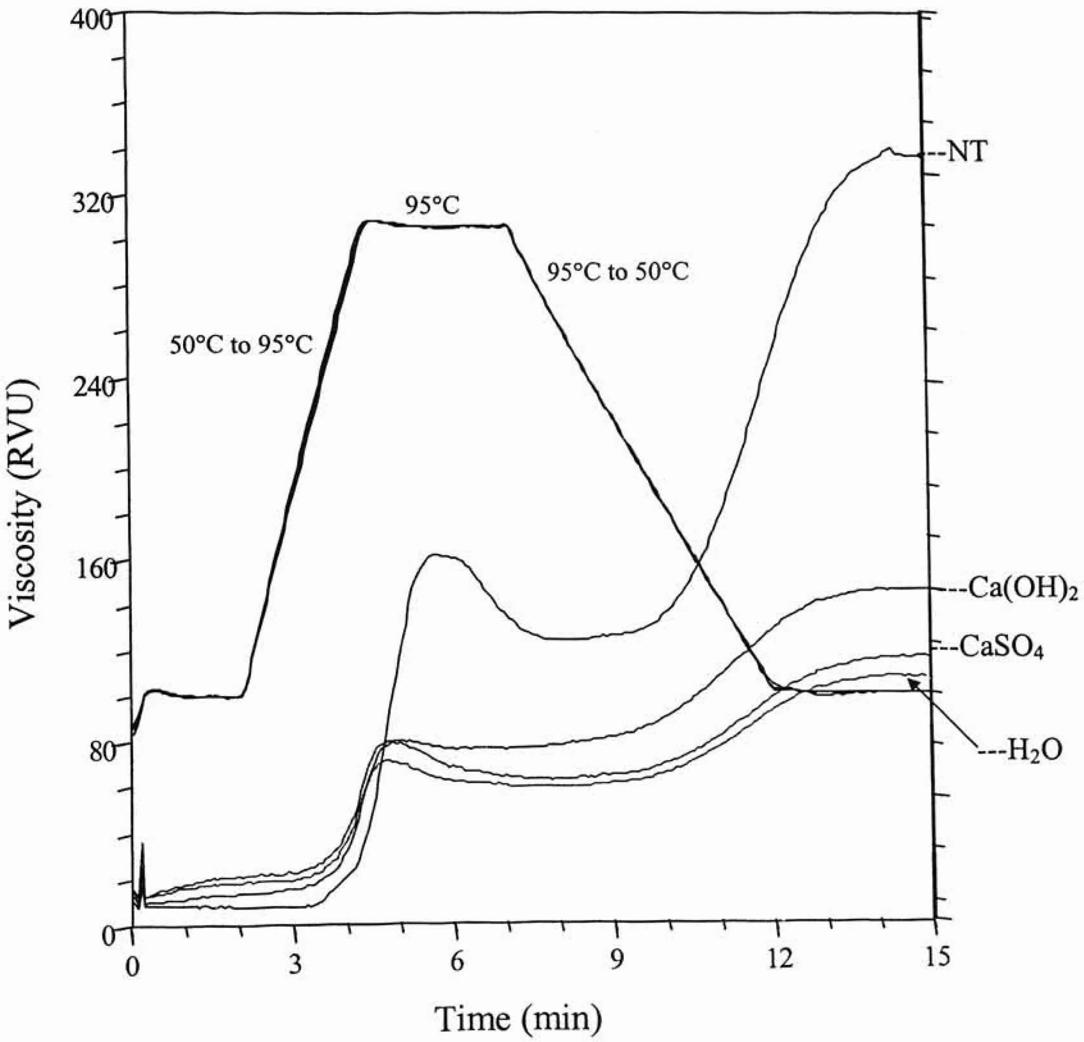


FIGURE 2

Representative RVA graphs of 90 min F1f1 red instant sorghum meal samples for each of the three treatments (H_2O, $Ca(OH)_2$, $CaSO_4$) and the control (NT).

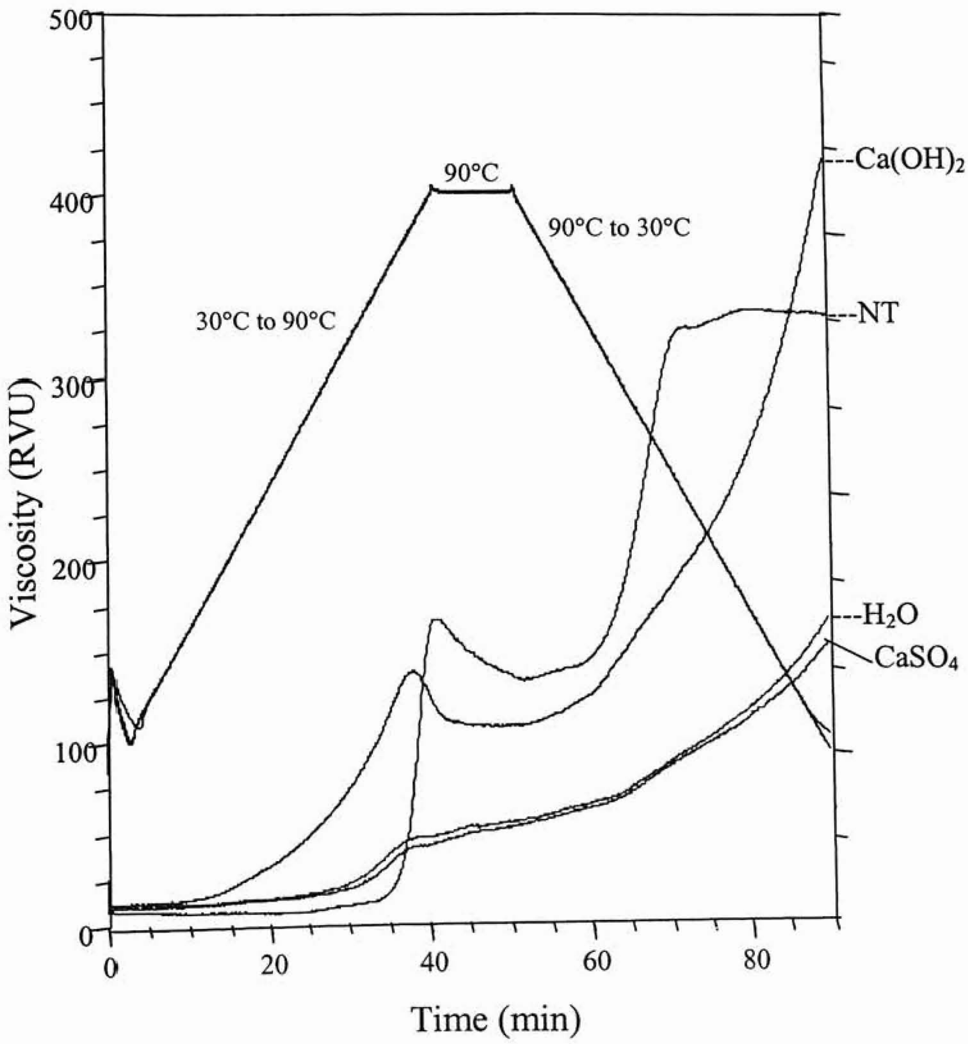


FIGURE 3

Representative RVA graphs of 15 min white instant sorghum meal samples for each of the three treatments (H_2O, $Ca(OH)_2$, $CaSO_4$) and the control (NT).

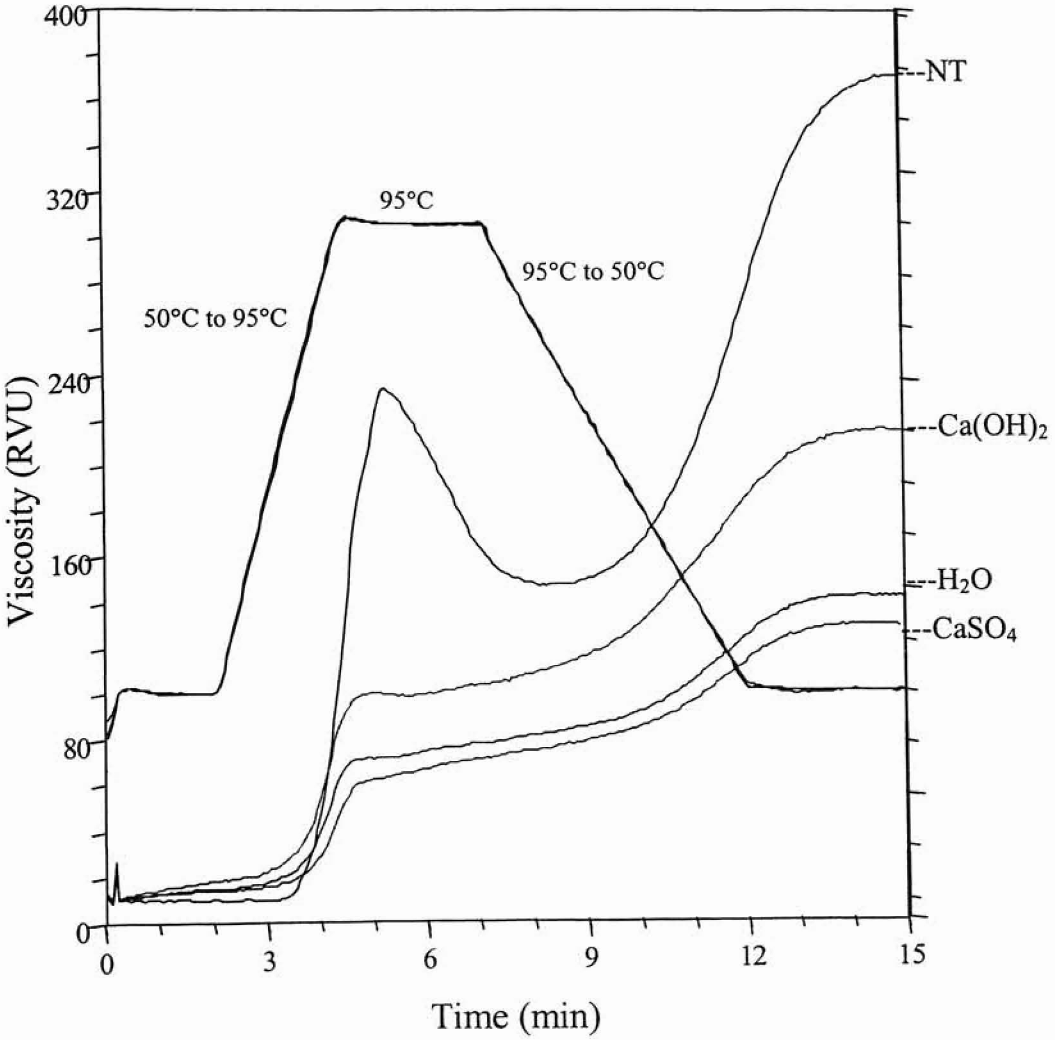
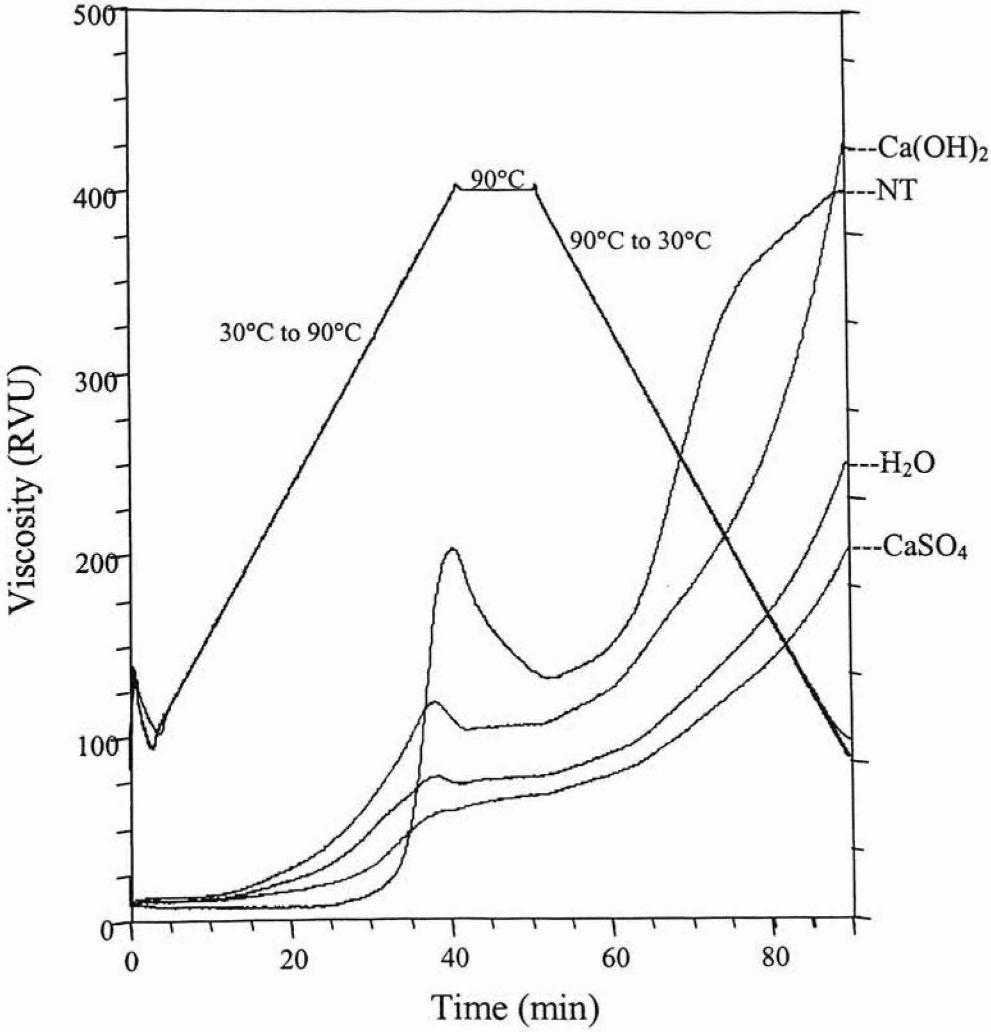
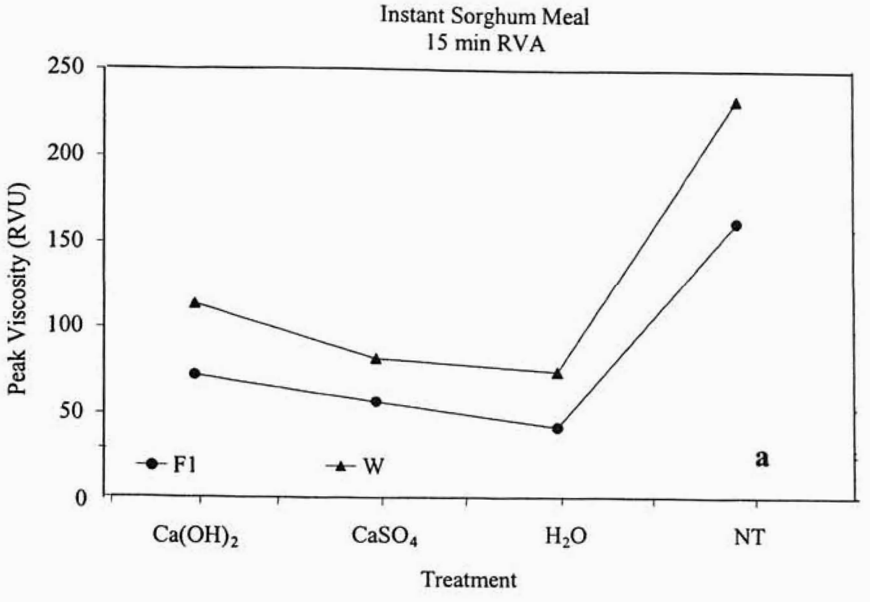


FIGURE 4

Representative RVA graphs of 90 min white instant sorghum meal samples for each of the three treatments (H_2O, $Ca(OH)_2$, $CaSO_4$) and the control (NT).





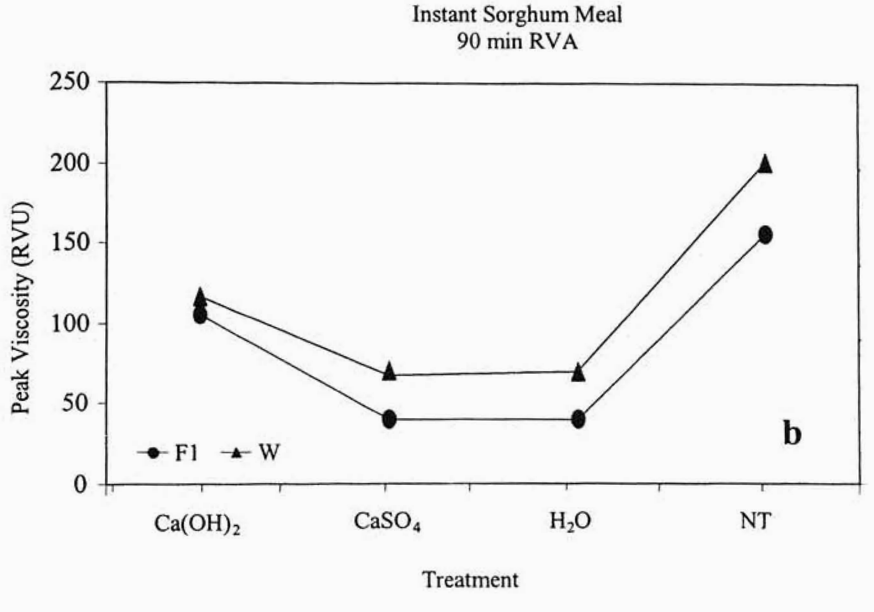
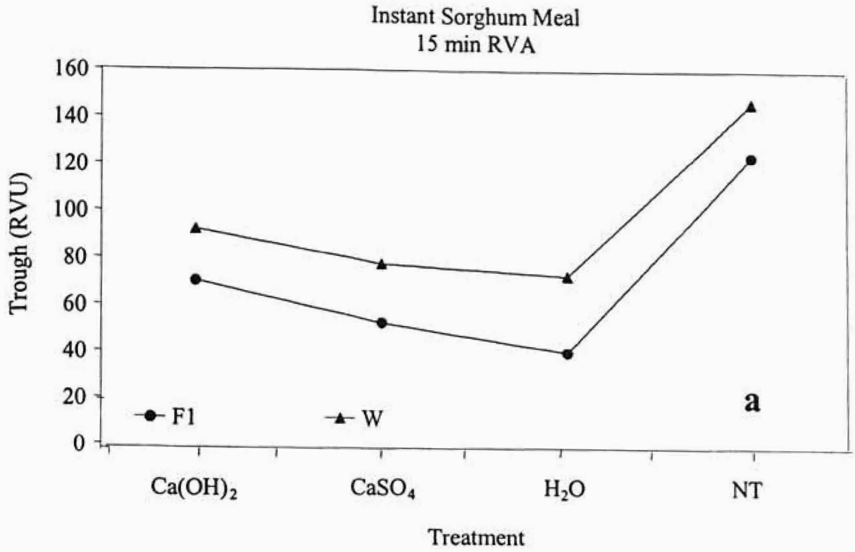


FIGURE 5.
Peak viscosity as a function of meal treatment of sorghum samples using 3.5g meal, (14% mb) in 28g total suspension. Rapid Visco Analysis performed at 15 (a) and 90 (b) min time ramps. F1= mean of farm 1 and 2, field 1 and 2 red sorghum (Mean of four independent replications), W= mean of white sorghum 1 and white sorghum 2. Treatments were 1.3% $Ca(OH)_2$, and $CaSO_4$; NT= no treatment (Mean of two independent replications).



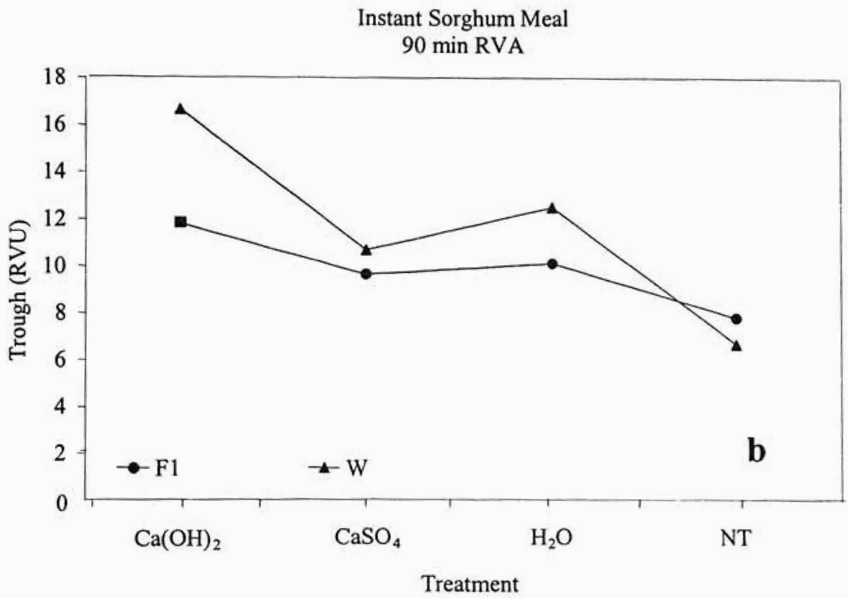


Figure 6.
Trough as a function of meal treatment of sorghum samples using 3.5g meal, (14% mb) in 28g total suspension. Rapid Visco Analysis performed at 15 (a) and 90 (b) min time ramps. F1= mean of farm 1 and 2, field 1 and 2 red sorghum (Mean of four independent replications), W= mean of white sorghum 1 and white sorghum 2. Treatments were 1.3% $Ca(OH)_2$, and $CaSO_4$; NT= no treatment (Mean of two independent replications).

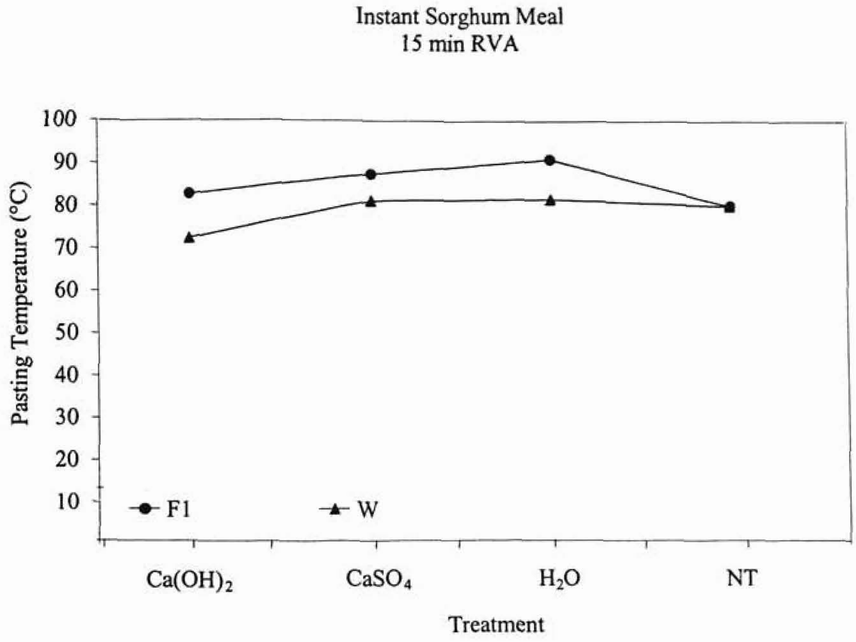


FIGURE 7.
Pasting temperature as a function of meal treatment of sorghum samples using 3g meal, (14% mb) in 28 g total suspension. Rapid Visco Analysis performed on a 15 time ramp. F1= mean of farm 1 and 2, field 1 and 2 red sorghum (Mean of four independent replications), W= mean of white sorghum 1 and white sorghum 2. Treatments were 1.3% $Ca(OH)_2$, and $CaSO_4$; NT= no treatment (Mean of two independent replications).

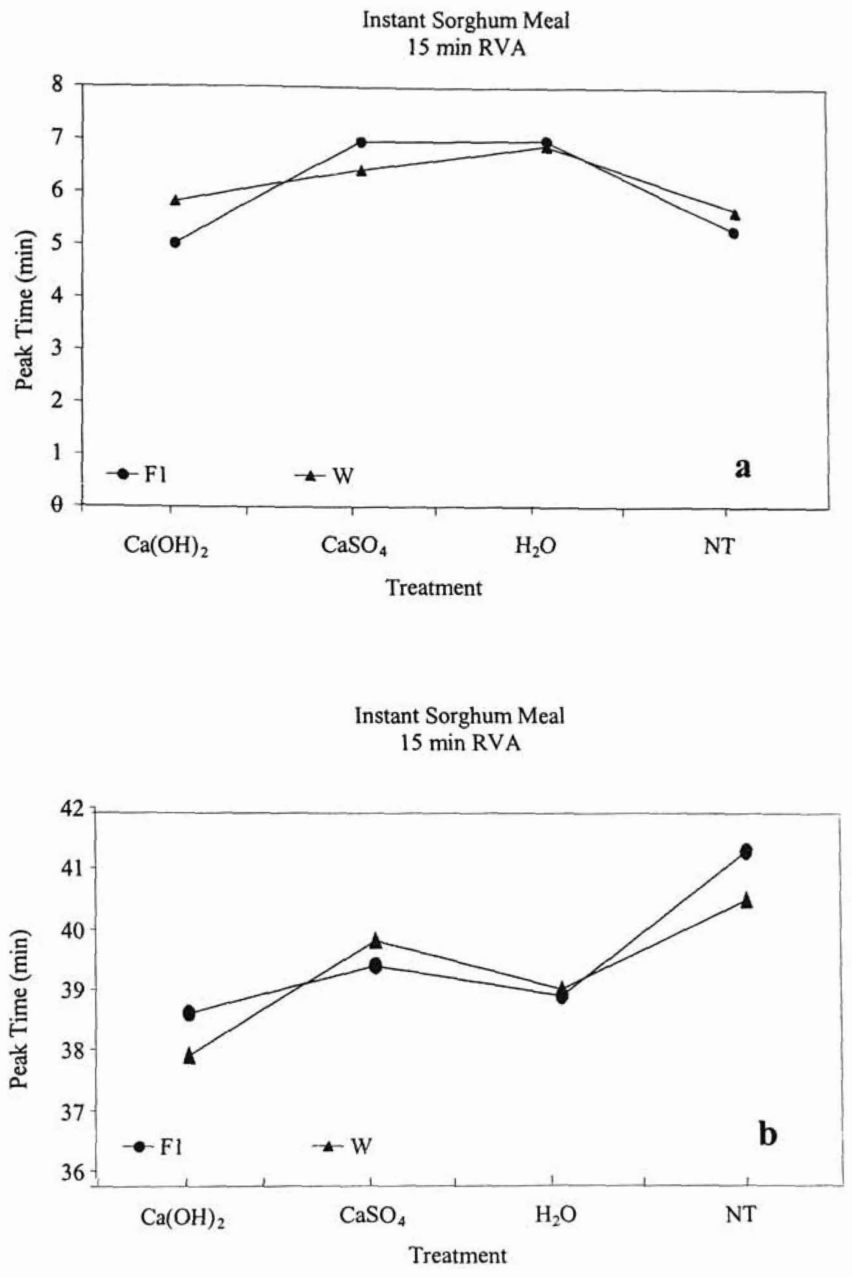
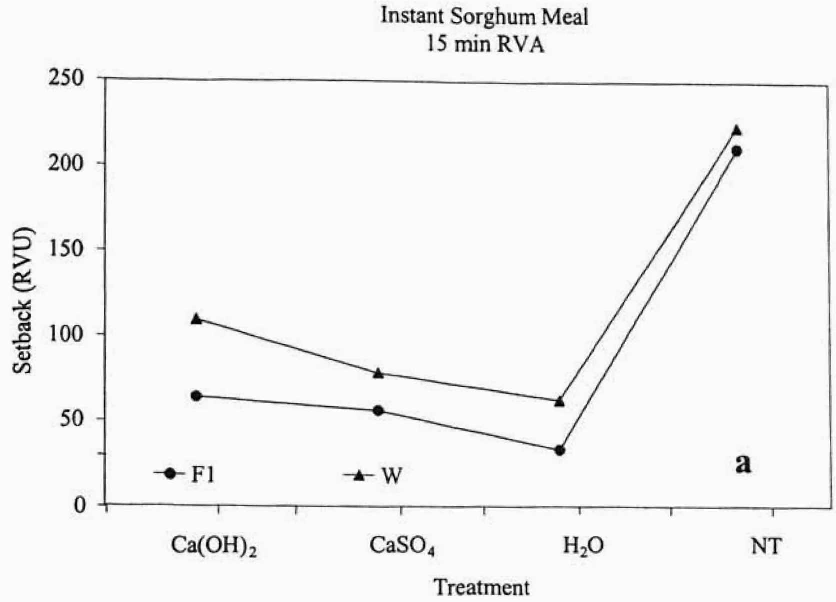


FIGURE 8.
Peak time as a function of meal treatment of sorghum samples using 3.5g meal, (14% mb) in 28 g total suspension. Rapid Visco Analysis performed at 15 (a) and 90 (b) min time ramps. F1= mean of farm 1 and 2, field 1 and 2 red sorghum (Mean of four independent replications), W= mean of white sorghum 1 and white sorghum 2. Treatments were 1.3% $Ca(OH)_2$, and $CaSO_4$; NT= no treatment (Mean of two independent replications).



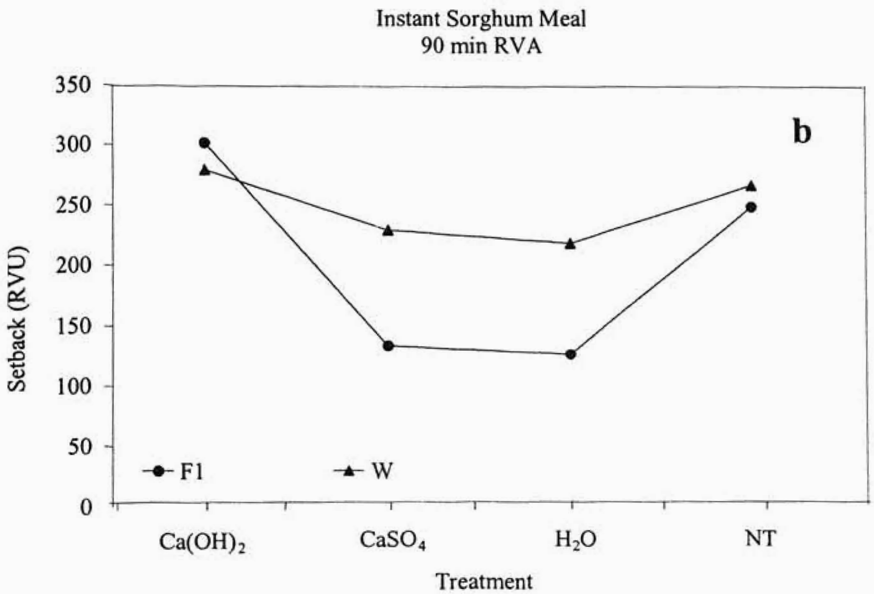
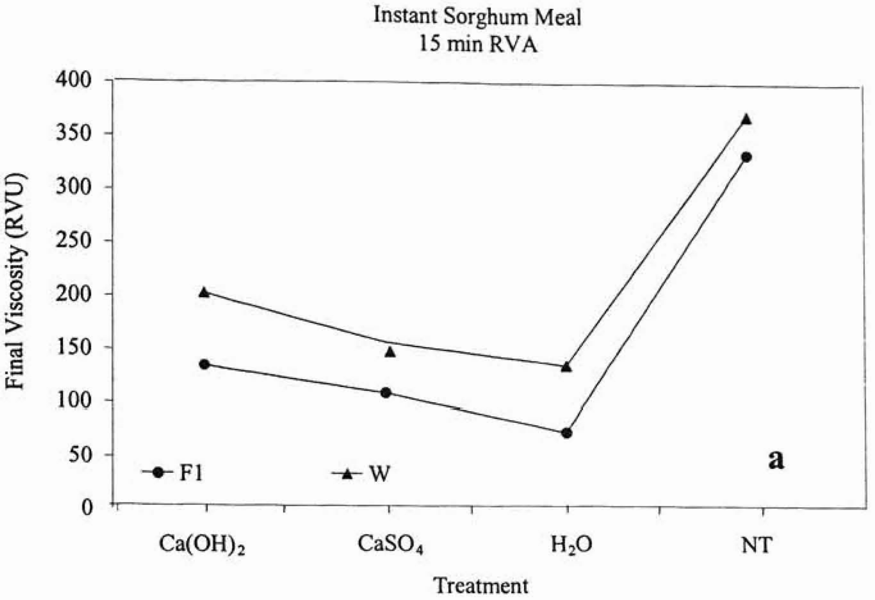


FIGURE 9.
Setback viscosity as a function of meal treatment of sorghum samples using 3.5g meal, (14% mb) in 28 g total suspension. Rapid Visco Analysis performed at 15 (a) and 90 (b) min time ramps. F1= mean of farm 1 and 2, field 1 and 2 red sorghum (Mean of four independent replications), W= mean of white sorghum 1 and white sorghum 2. Treatments were 1.3% $Ca(OH)_2$, and $CaSO_4$; NT= no treatment (Mean of two independent replications).



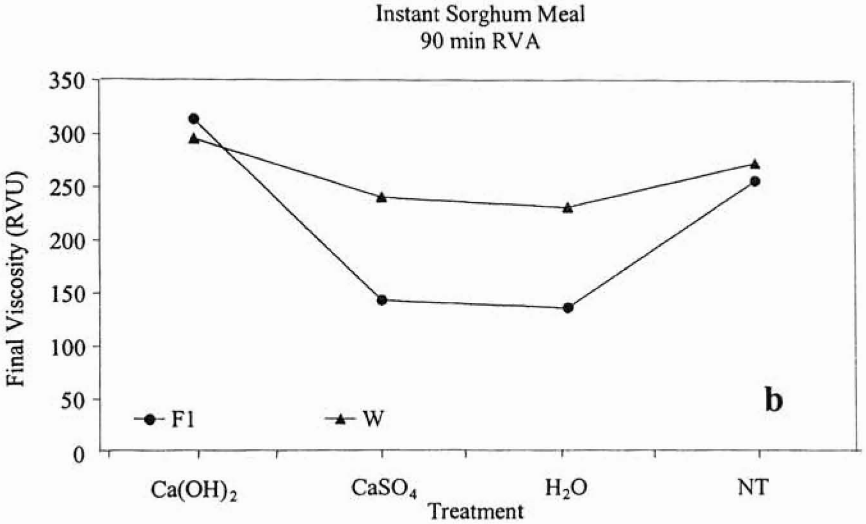
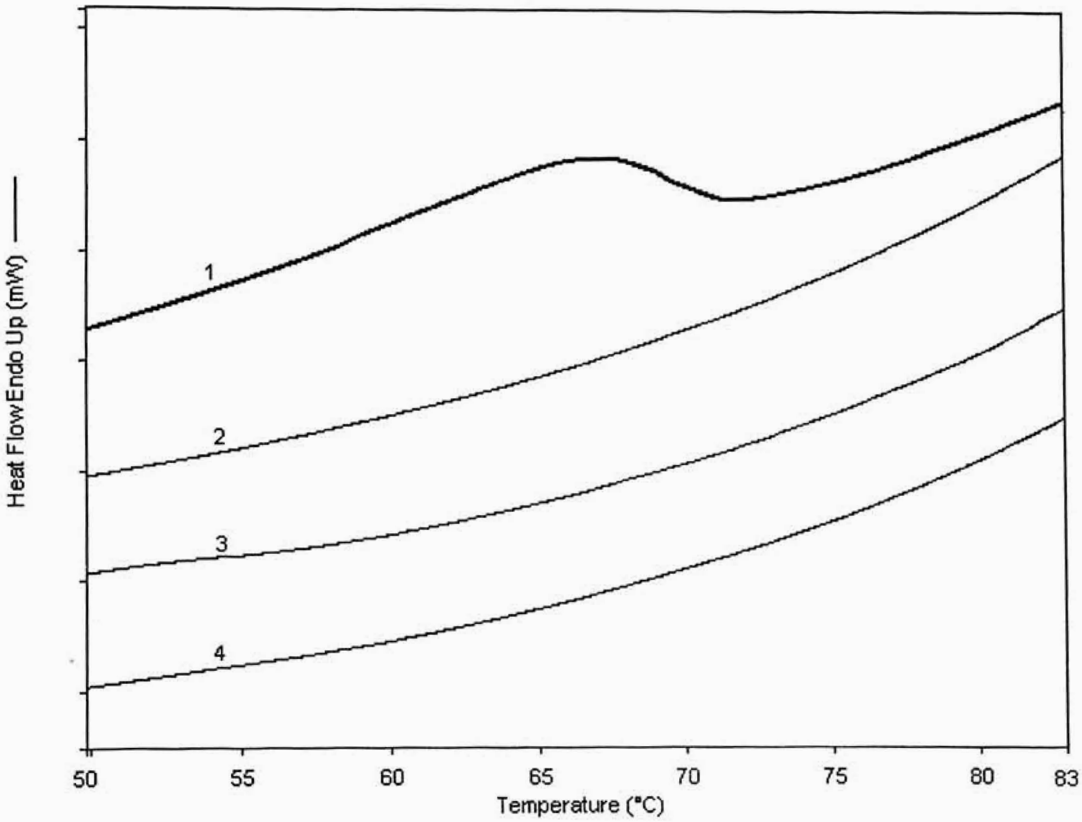


FIGURE 10.
Final viscosity as a function of meal treatment of sorghum samples using 3.5g meal, (14% mb) in 28 g total suspension. Rapid Visco Analysis performed at 15 (a) and 90 (b) min time ramps. F1= mean of farm 1 and 2, field 1 and 2 red sorghum (Mean of four independent replications), W= mean of white sorghum 1 and white sorghum 2. Treatments were 1.3% $Ca(OH)_2$, and $CaSO_4$; NT= no treatment (Mean of two independent replications).

FIGURE 11

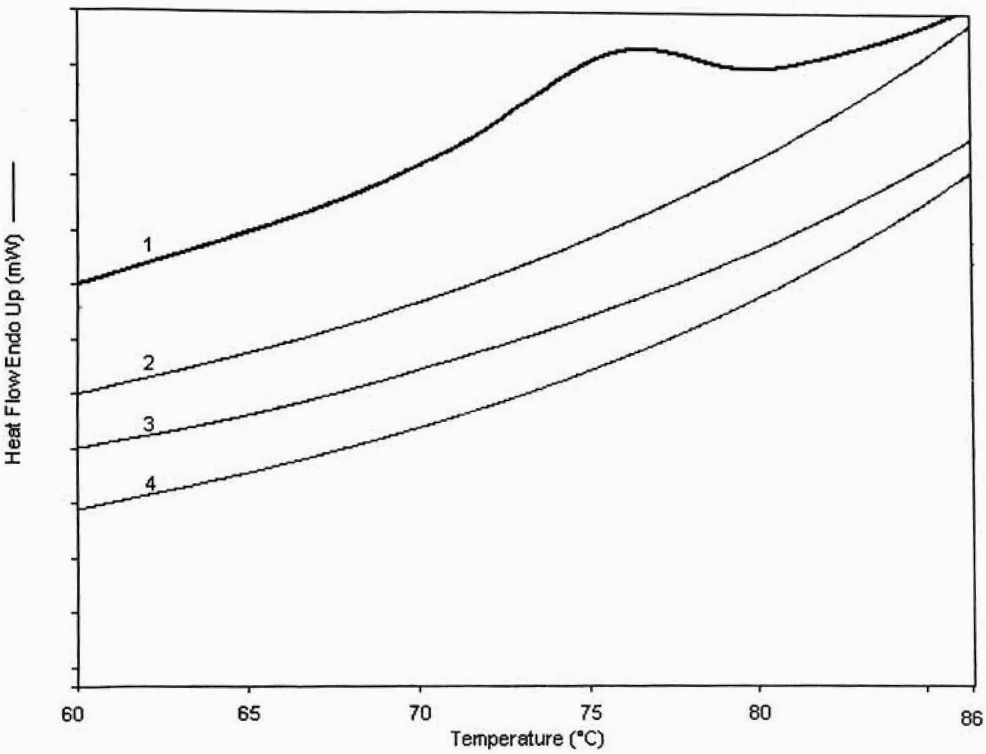
Endothermic peaks of red instant sorghum meal for each soak treatment of farm1 field 1.



1= Control no treatment, red sorghum Farm 1 field 1.
2= $CaOH_2$ soak treatment, red sorghum Farm 1 field 1.
3= $CaSO_4$ soak treatment, red sorghum Farm 1 field 1.
4= H_2O soak treatment, red sorghum Farm 1 field 1.

FIGURE 12

Endothermic peaks of white instant sorghum meal for each soak treatment.



1= Control no treatment, red sorghum Farm 1 field 1.
2= $CaOH_2$ soak treatment, red sorghum Farm 1 field 1.
3= $CaSO_4$ soak treatment, red sorghum Farm 1 field 1.
4= H_2O soak treatment, red sorghum Farm 1 field 1.

FIGURE 13

Representative, texture analysis graphs of red instant sorghum meal obtained from cooking/soaking and drum drying treatments - control (NT), $CaSO_4$, $Ca(OH)_2$ and H_2O.

Red Sorghum

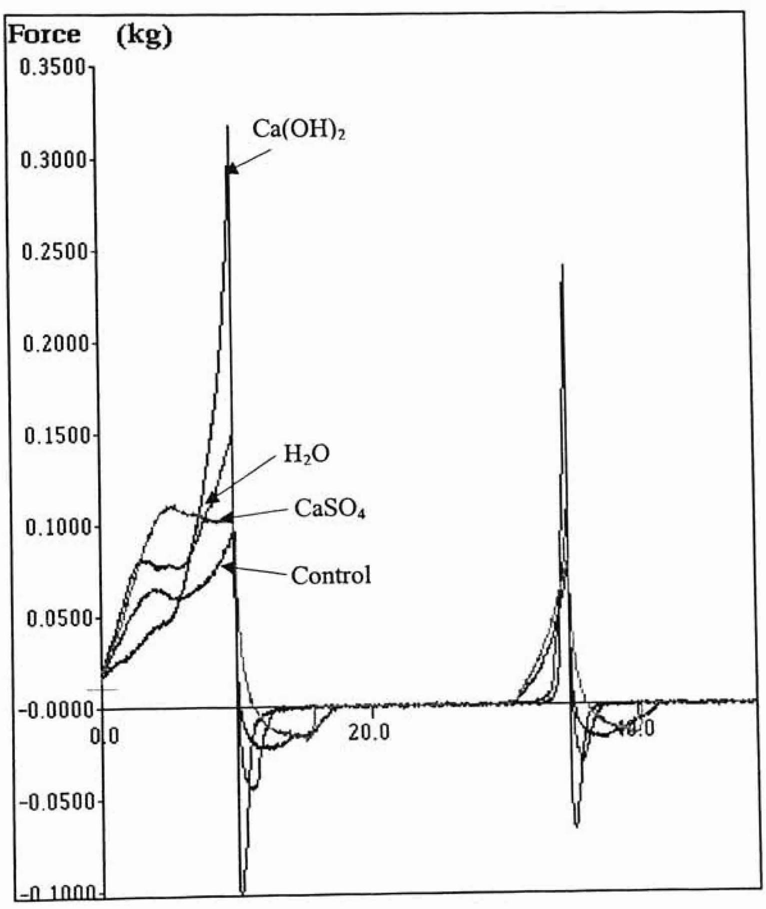
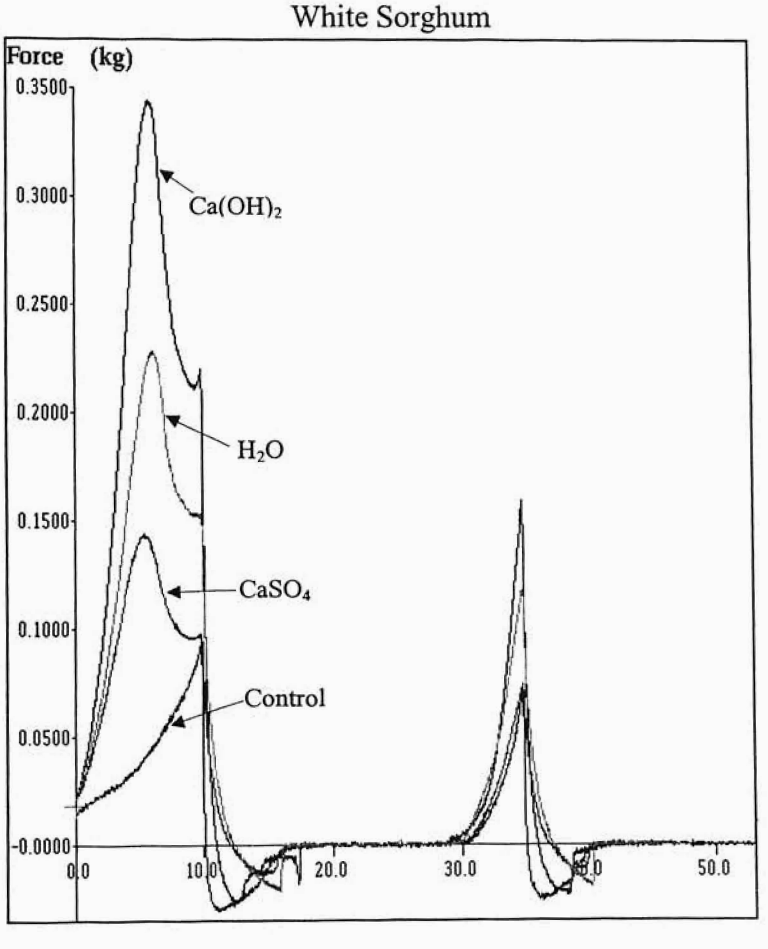


FIGURE 14

Representative, texture analysis graph of white instant sorghum meal obtained from cooking/soaking and drum drying treatments-control (NT), $CaSO_4$, $Ca(OH)_2$, and H_2O.



APPENDIX A

Raw Data of RVA Analysis

TABLE 5

Chemical composition of red and white sorghum meal[1].

Sample	Moisture (%)	Protein (%)	Fat (%)
W 1	12.59	8.38	3.62
W 2	12.25	8.32	3.84
F1F1	13.73	12.13	4.54
F1F2	13.24	12.38	4.21
F2F1	14.48	11.52	4.19
F2F2	14.46	11.80	4.15
HH	10.93	12.25	4.68

[1]F= Farm, f= field red sorghum, W= white sorghum, HH= hand harvest red sorghum.

TABLE 6

Percent moisture content in treated red and white sorghum meal[1].

Sample	Moisture (%)			
	Control	H_2O	$Ca(OH)_2$	$CaSO_4$
W 1	17.20	6.90	7.14	11.43
W 2	17.20	6.45	10.17	6.90
F1F1	17.20	7.69	6.90	15.15
F1F2	17.20	3.23	3.57	6.67
F2F1	17.30	7.14	3.85	3.57
F2F2	17.10	3.33	13.79	6.45

[1]F= Farm, f= field red sorghum, W= white sorghum, HH= hand harvest red sorghum

TABLE 7

Effect of steeping treatments[1] on pasting properties[2] of sorghum meal from two cultivars[3], during a 15 min time ramp.

Treatment	PV	TR	FV	SB	P_{time}	P_{temp}
H_2O						
F1f1	52.2	49.3	92.8	43.5	7.0	89.0
F1f2	32.6	30.9	54.7	23.8	7.0	93.0
F2f1	70.9	59.8	107.4	47.6	4.7	79.5
F2f2	64.1	62.8	118.9	56.1	6.8	85.8
W1	72.0	70.9	129.4	58.5	6.9	84.2
W2	77.6	74.8	141.8	67.0	6.9	79.1
$CaOH_2$						
F1f1	78.1	74.6	142.8	68.2	5.1	83.6
F1f2	68.1	66.4	127.1	60.7	4.9	81.9
F2f1	63.3	60.2	112.2	52.0	5.0	84.0
F2f2	84.7	67.8	125.1	57.3	4.9	81.9
W1	125.6	86.0	191.1	105.1	4.7	70.7
W2	103.3	99.2	214.6	115.4	7.0	74.1
$CaSO_4$						
F1f1	76.0	69.1	151.9	82.8	7.0	85.1
F1f2	38.7	36.6	67.1	30.5	6.9	89.7
F2f1	70.7	66.4	130.1	63.7	7.0	84.1
F2f2	80.5	64.1	116.3	52.3	4.9	84.2
W1	94.9	89.1	185.3	96.3	5.9	78.0
W2	70.6	66.8	128.8	61.9	7.0	84.3
Control						
F1f1	162.6	124.1	335.2	211.1	5.3	80.1
F1f2	156.4	123.5	332.6	208.2	5.4	82.4
F2f1	158.4	111.2	320.1	208.7	5.7	86.5
F2f2	156.6	121.3	318.2	207.4	5.8	85.2
W1	233.2	146.9	370.8	223.8	5.7	80.1
W2	241.2	123.6	353.9	251.2	5.4	79.3

[1] H_2O, $Ca(OH)_2$ (1.5%), $CaSO_4$ (1.5%), Control (no soaking treatment).

[2] PV = peak viscosity, TR = trough, FV = final viscosity, and SB = setback (FV-PV) measured in Rapid Visco Analyser units (RVU). P_{time} = time (min) to PV and P_{temp} = temperature (°C) at PV.

[3] F= Farm, f= field red sorghum, W= white sorghum.

TABLE 8

Effect of steeping treatments[1] on pasting properties[2] of sorghum meal from two cultivars[3], during a 90 min time ramp.

Treatment	PV	TR	FV	SB	P_{time}
H_2O					
F1f1	35.26	11.17	168.00	156.83	38.9
F1f2	31.33	9.08	104.92	95.83	39.9
F2f1	66.75	17.00	172.83	155.83	38.1
F2f2	64.08	13.25	201.92	188.67	38.7
W1	62.42	15.00	209.92	194.92	39.5
W2	78.42	10.08	252.08	242.00	38.5
$CaOH_2$					
F1f1	138.8	12.58	419.50	406.92	38.3
F1f2	71.6	11.08	207.58	196.50	38.9
F2f1	63.3	10.50	191.67	181.17	38.7
F2f2	83.9	13.25	208.58	195.33	38.5
W1	115.1	23.25	339.67	316.42	37.7
W2	119.2	10.08	252.08	242.00	38.1
$CaSO_4$					
F1f1	43.4	9.92	154.25	144.33	40.0
F1f2	37.8	9.42	132.50	123.08	39.9
F2f1	62.0	10.75	244.58	233.83	39.5
F2f2	74.8	19.83	176.42	156.58	38.0
W1	76.5	11.08	277.17	266.08	39.8
W2	59.4	10.33	203.83	193.50	39.7
Control					
F1f1	155.42	7.25	333.50	326.50	41.1
F1f2	150.3	8.42	329.41	329.40	41.3
F2f1	148.2	9.58	345.2	315.70	40.8
F2f2	152.4	7.83	328.00	319.23	41.8
W1	201.7	6.08	393.75	393.75	40.4
W2	200.6	7.33	400.33	398.26	40.5

[1] H_2O, $Ca(OH)_2$ (1.5%), $CaSO_4$ (1.5%), Control (no soaking treatment).
[2] PV = peak viscosity, TR = trough, FV = final viscosity, and SB = setback (FV-PV) measured in Rapid Visco Analyser units (RVU). P_{time} = time (min) to PV.
[3]F= Farm, f= field red sorghum, W= white sorghum.

TABLE 9

Peak one and peak two of red and white instant sorghum meal[1] gels after a 24 hour rest period during texture profile analysis.

Sample ID	Peak 1 Force (g)	Peak 2 Force (g)	Sample ID	Peak 1 Force (g)	Peak 2 Force (g)
F1f1 $Ca(OH)_2$	318.47	250.49	F1f2 $Ca(OH)_2$	97.23	73.43
	*190.89	154.31		85.67	69.82
F1f1 $CaSO_4$	107.37	78.62	F1f2 $CaSO_4$	76.25	59.40
	111.12	81.07		117.16	91.92
F1f1 H_2O	128.46	102.14	F1f2 H_2O	81.72	57.99
	153.81	111.93		84.45	52.11
F1f1 Control	96.30	76.58	F1f2 Control	120.72	94.84
	102.11	82.25		115.56	89.57
F2f1 $Ca(OH)_2$	191.80	102.24	F2f2 $Ca(OH)_2$	232.36	123.94
	193.36	122.65		230.05	111.23
F2f1 $CaSO_4$	135.44	82.66	F2f2 $CaSO_4$	227.98	100.34
	154.21	104.44		221.24	165.38
F2f1 H_2O	169.75	96.54	F2f2 H_2O	205.89	117.76
	136.15	80.57		204.71	114.50
F2f1 Control	154.94	104.45	F2f2 Control	155.44	110.12
	145.86	115.60		157.94	107.10
W1 $Ca(OH)_2$	264.47	141.85	W2 $Ca(OH)_2$	345.70	163.05
	245.23	129.57		309.59	214.94
W1 $CaSO_4$	133.10	90.00	W2 $CaSO_4$	227.20	122.36
	71.36	54.93		215.13	120.06
W1 H_2O	112.35	89.98	W2 H_2O	145.29	75.73
	180.89	100.57		118.28	79.63
W1 Control	100.62	61.61	W2 Control	94.99	74.27
	94.09	67.85		60.24	51.21

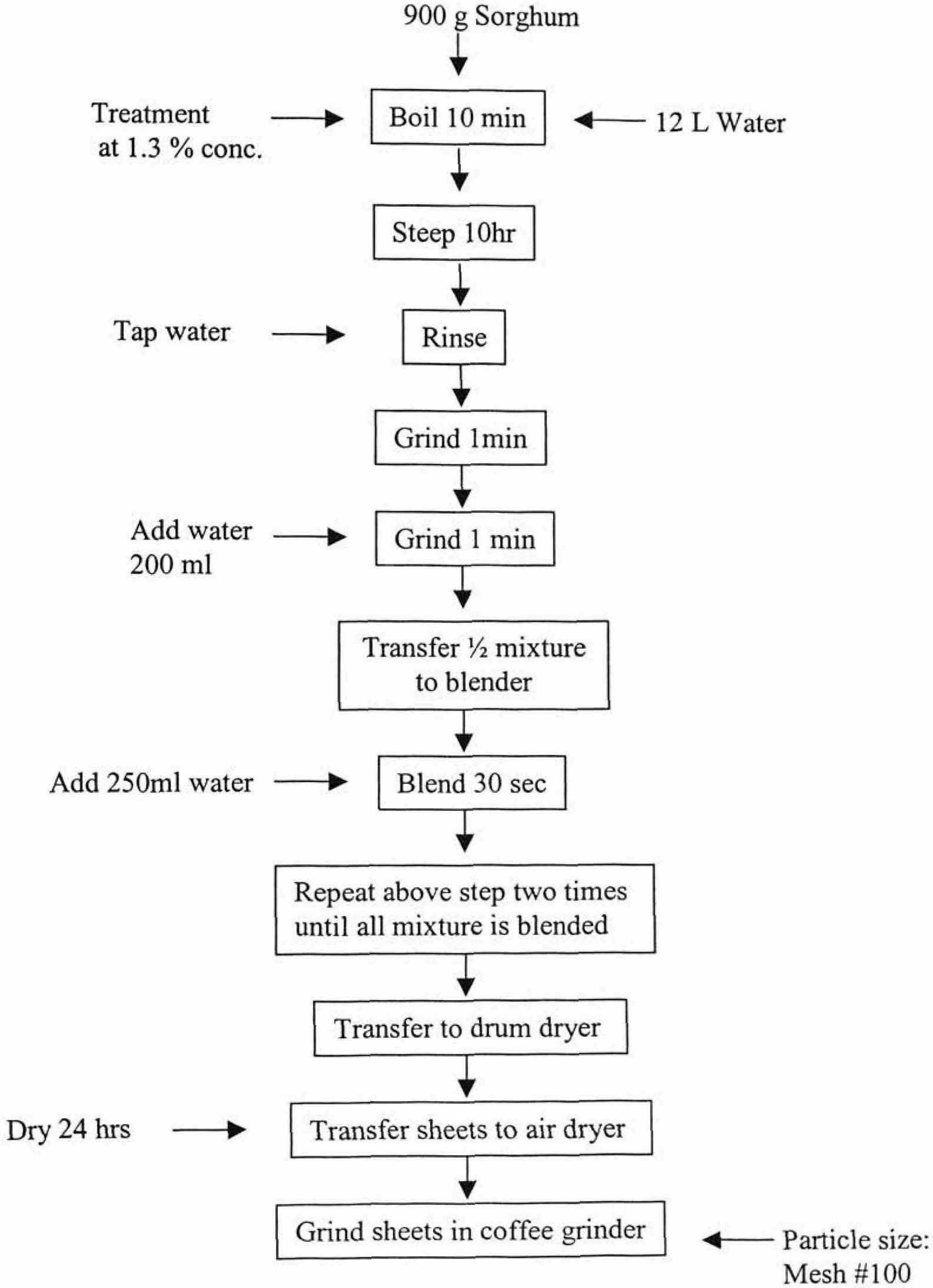
[1]F= Farm, f= field red sorghum, W= white sorghum.
*duplicate.

APPENDIX B

INSTANT SORGHUM MEAL PROCEDURE

FIGURE 15

Flow chart for processing instant sorghum meal.



APPENDIX C

ANOVA TABLES FOR RVA ANALYSIS

TABLE 10

Analysis of variance of peak viscosity during a 15 min RVA cycle, shown for red and white instant sorghum meal at different soaking treatments.

Source Variation	df	Mean Square	F ratio	Pr >F
Color	1	8091.99	24.6	.0077
Error a	4	329.00	2.63	.0873
Soak	3	19999.01	159.72	<.0001
Color * Soak	3	1096.04	8.75	.0024
Error b	12	125.21	125.21	
Corrected Total	23			

Analysis of variance of trough during a 15 min RVA cycle, shown for red and white instant sorghum meal at different soaking treatments.

Source Variation	df	Mean Square	F ratio	Pr >F
Color	1	2221.84	13	.0227
Error a	4	170.95	1.41	.2883
Soak	3	4717.52	39	<.0001
Color * Soak	3	25.09	.21	.8893
Error b	12	120.97		
Corrected Total	23			

TABLE 11

Analysis of variance of breakdown during a 15 min RVA cycle, shown for red and white instant sorghum meal at different soaking treatments.

Source Variation	df	Mean Square	F ratio	Pr >F
Color	1	36.09	.53	.5069
Error a	4	68.06	1.18	.3687
Soak	3	120.83	2.09	.1547
Color * Soak	3	101.36	1.76	.2091
Error b	12	57.75		
Corrected Total	23			

Analysis of variance of final viscosity during a 15 min RVA cycle, shown for red and white instant sorghum meal at different soaking treatments.

Source Variation	df	Mean Square	F ratio	Pr >F
Color	1	12643.49	18.06	
Error a	4	700.06	1.35	
Soak	3	58706.77	113.26	
Color * Soak	3	453.77	.88	
Error b	12	518.34		
Corrected Total	23			

TABLE 12

Analysis of variance of setback during a 15 min RVA cycle, shown for red and white instant sorghum meal at different soaking treatments.

Source Variation	df	Mean Square	F ratio	Pr >F
Color	1	4894.26	22.13	.0093
Error a	4	221.16	1.15	.3812
Soak	3	32773.72	169.98	<.0001
Color * Soak	3	265.93	1.38	.2964
Error b	12	192.81		
Corrected Total	23			

Analysis of variance of peak time during a 15 min RVA cycle, shown for red and white instant sorghum meal at different soaking treatments.

Source Variation	df	Mean Square	F ratio	Pr >F
Color	1	0.60	1.12	0.3495
Error a	4	0.53	0.76	0.5723
Soak	3	2.04	2.90	0.0788
Color * Soak	3	0.23	0.33	0.8051
Error b	12	0.70		
Corrected Total	23			

TABLE 13

Analysis of variance of pasting temperature during a 15 min RVA cycle, shown for red and white instant sorghum meal at different soaking treatments.

Source Variation	df	Mean Square	F ratio	Pr >F
Color	1	194.01	31.04	0.0051
Error a	4	6.25	0.47	0.7602
Soak	3	46.52	3.46	0.0510
Color * Soak	3	12.10	0.90	0.4693
Error b	12	13.43		
Corrected Total	23			

TABLE 14

Analysis of variance of peak viscosity during a 90 min RVA cycle, shown for red and white instant sorghum meal at different soaking treatments.

Source Variation	df	Mean Square	F ratio	Pr >F
Color	1	4169.02	14.42	0.0191
Error a	4	289.07	0.76	0.5683
Soak	3	15919.49	42.1	<0.0001
Color * Soak	3	322.27	0.85	0.4918
Error b	12	378.21		
Corrected Total	23			

Analysis of variance of trough during a 90 min RVA cycle, shown for red and white instant sorghum meal at different soaking treatments.

Source Variation	df	Mean Square	F ratio	Pr >F
Color	1	0.6417	0.03	0.8649
Error a	4	19.50	1.71	0.2123
Soak	3	44.25	3.88	0.0377
Color * Soak	3	12.57	1.10	0.3863
Error b	12	11.41		
Corrected Total	23			

TABLE 15

Analysis of variance of breakdown during a 90 min RVA cycle, shown for red and white instant sorghum meal at different soaking treatments.

Source Variation	df	Mean Square	F ratio	Pr >F
Color	1	0.0117	0.04	0.8535
Error a	4	0.3021	1.24	0.3451
Soak	3	2.4900	10.23	0.0013
Color * Soak	3	0.0479	0.2	0.8965
Error b	12	0.2434		
Corrected Total	23			

Analysis of variance of final viscosity during a 90 min RVA cycle, shown for red and white instant sorghum meal at different soaking treatments.

Source Variation	df	Mean Square	F ratio	Pr >F
Color	1	11479.67	1.87	0.2438
Error a	4	6155.28	1.32	0.3181
Soak	3	8606.15	1.84	0.1929
Color * Soak	3	853.37	0.18	0.91
Error b	12	4666.64		
Corrected Total	23			

TABLE 16

Analysis of variance of setback during a 90 min RVA cycle, shown for red and white instant sorghum meal at different soaking treatments.

Source Variation	df	Mean Square	F ratio	Pr >F
Color	1	11308.96	1.97	0.2329
Error a	4	5734.42	1.23	0.3508
Soak	3	8845.82	1.89	0.1850
Color * Soak	3	880.92	0.19	0.9023
Error b	12	4678.06		
Corrected Total	23			

Analysis of variance of peak time during a 90 min RVA cycle, shown for red and white instant sorghum meal at different soaking treatments.

Source Variation	df	Mean Square	F ratio	Pr >F
Color	1	0.3333	0.88	0.4006
Field (color)	4	0.3775	1.12	0.3939
Soak	3	7.59	22.42	<0.0001
Color * Soak	3	0.467	1.38	0.2964
Error	12	0.3383		
Corrected Total	23			

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Oklahoma State University
Institutional Review Board

Protocol Expires: 3/28/03

Date: Friday, March 29, 2002 IRB Application No AG0230

Proposal Title: SNACK PRODUCTIN AND FLOUR PARTICLE SIZE OF SORGHUM GRAINS

Principal
Investigator(s):

Patricia Rayas Duarte
107 FAPC
Stillwater, OK 74078

Jennifer Mitchum
107 AG
Stillwater, OK 74078

Reviewed and
Processed as: Exempt

Approval Status Recommended by Reviewer(s): Approved

Dear PI :

Your IRB application referenced above has been approved for one calendar year. Please make note of the expiration date indicated above. It is the judgment of the reviewers that the rights and welfare of individuals who may be asked to participate in this study will be respected, and that the research will be conducted in a manner consistent with the IRB requirements as outlined in section 45 CFR 46.

As Principal Investigator, it is your responsibility to do the following:

1. Conduct this study exactly as it has been approved. Any modifications to the research protocol must be submitted with the appropriate signatures for IRB approval.
2. Submit a request for continuation if the study extends beyond the approval period of one calendar year. This continuation must receive IRB review and approval before the research can continue.
3. Report any adverse events to the IRB Chair promptly. Adverse events are those which are unanticipated and impact the subjects during the course of this research; and
4. Notify the IRB office in writing when your research project is complete.

Please note that approved projects are subject to monitoring by the IRB. If you have questions about the IRB procedures or need any assistance from the Board, please contact Sharon Bacher, the Executive Secretary to the IRB, in 203 Whitehurst (phone: 405-744-5700, sbacher@okstate.edu).

Sincerely,

Carol Olson

Carol Olson, Chair
Institutional Review Board

VITA 2

Jennifer A. Mitchum

Candidate for the Degree of

Master of Science

Thesis: DEVELOPMENT OF SORGHUM FOOD PRODUCTS: POPPED SORGHUM AND INSTANT SORGHUM MEALS.

Major Field: Food Science

Biographical:

Personal Data: Born in Little Rock, Arkansas, on October 7, 1977, the daughter of Ronald and Jane Mitchum.

Education: Graduated from Hilliard High School, Hilliard, Ohio in June of 1996; received Bachelor of Science degree in Animal Science with emphasis in Food Science from Oklahoma State University, Stillwater, Oklahoma in July 2000. Completed the requirements for the Master of Science degree with a major in Food Science at Oklahoma State University in August, 2002.

Experience: Employed by Oklahoma State University, Food and Agricultural Products Research and Technology Center as an undergraduate (1998-2000) and as a graduate research assistant (2000-2002); Oklahoma State University, Food and Agricultural Products Research and Technology Center, 2000 to 2002. Employed as a Starch Application Scientist by Midwest Grain Products Inc. in Atchison, KS, 2002-present.

Professional Memberships: American Association of Cereal Chemists and Institute of Food Technologists.