EVALUATION OF FOUR SORGHUM HYBRIDS THROUGH THE DEVELOPMENT OF SORGHUM FLOUR TORTILLAS

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ABSTRACT

With an increasing number of people with celiac disease, the need for gluten-free products is inevitable. Sorghum is a grain safe for celiac patients. Therefore, the purpose of this work was to characterize four sorghum hybrids in terms of their grain and flour; then utilize the hybrids in a wheat-free product and test for physical, chemical, textural, and sensory differences. Flour tortillas were chosen for their current popularity and the lack of research and availability for gluten-free flour tortillas.

Grain characterization included diameter, weight, and hardness as measured by the Single Kernel Characterization System and Tangential Abrasive Dehulling Device. Flour characterization included flour and starch particle size distributions, total starch, amylose content, starch pasting properties, moisture, crude protein, and ash content. Significant differences were found ($p<0.05$) among hybrids for each test except total starch.

Gluten-free flour tortillas were made from the four sorghum hybrids in addition to a commercial sorghum flour. Tortilla weight, diameter, thickness, color, pH, A_w, and moisture content were measured along with extensibility and stretchability. A descriptive panel was trained and used to analyze the five samples. Significant differences were found ($p<0.05$) among samples for color, pH, A_w, and moisture content. Significant differences were also found ($p<0.05$) among samples for extensibility and stretchability. Extensibility was a more effective test in studying quality. The sensory panel found significant differences ($p<0.05$) for grain specks, angle of bend, rancidity, sweetness, springiness, hardness, and grittiness. The commercial flour had the highest score for angle bend and springiness and was, therefore, utilized in a consumer study. When

compared to a gluten-free wrap already in the market, the sorghum flour tortilla made from this study scored significantly higher in all attributes, including overall acceptability. The commercial flour is thought to have preformed better than the other four samples due to its smaller particle size and greater starch damage allowing an increase in water absorption.

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Introduction

An estimated 1-2 percent of adults and 4-8 percent of children suffer from food allergies (Lehrer and others 2002). If an allergic person consumes their corresponding allergen, then the results can be life threatening. In August of 2004, the Food Allergen Labeling and Consumer Protection Act of 2004 was created in order to protect these individuals. The act required the labeling of eight major food allergens to be effective by January 1, 2006. The eight major food allergens are: milk, eggs, fish, Crustacean shellfish, tree nuts, peanuts, wheat, and soybeans. These allergens were chosen as they are responsible for about 90% of food allergies.

With wheat being one of the eight major food allergens, the need for wheat-free foods is obvious. Furthermore, wheat contains gluten, which poses a threat to those with celiac disease. Also known as gluten-sensitive enteropathy or celiac sprue, celiac disease is an autoimmune inflammatory disease of the upper small intestine resulting from the ingestion of gluten in genetically susceptible individuals (Case 2006). This immunologic reaction leads to damage of the absorptive surface of the small intestine.

In 2003, the University of Maryland Center for Celiac Research in Baltimore, conducted a study that found 1 out of 133 Americans have celiac disease. More recently, an estimated 1:100 Americans are affected by this disease (Case 2006). The increase in prevalence is claimed to be due to an increasing awareness and better diagnosis from physicians. With this growth, comes a demand for gluten-free products.

Sorghum is a gluten-free grain with a great deal of potential in the gluten-free food market. According to the U.S. Grain Council (2008a), grain sorghum is the fifth most important cereal crop grown in the world. In the U.S., grain sorghum is the third most important. As a continent, Africa is the largest producer of sorghum. In 2006, Nigeria was the leading producer as a country with 413.4 million bushels, followed by the United States with 393.7 million.

According to the Tortilla Industry Association, 78% of fine dining restaurants have tortillas in a menu item (Petrak 2006a). The supermarket is observing the popularity of tortillas as well with sales reaching $1 billion (Petrak 2006b). Americans are using tortillas in Mexican dishes as well as other areas. Typically called a wrap, the tortilla is being used to carry salads, sandwiches, and even breakfast items (Seiz 2006).

Sorghum has been used to replace some or all of the maize in corn tortillas where masa is formed with an alkaline-process and then made into a tortilla (Rooney and Waniska 2000). No study has been found on the use of sorghum in flour tortillas. Therefore, the objectives of this research were:

- To characterize four sorghum hybrids both as a kernel and as a flour.
- To formulate a gluten-free flour tortilla with sorghum.
- To test four flours from different sorghum hybrids in the optimized sorghum flour tortilla formula.

Chapter 1:

Literature Review

FOOD ALLERGENS

Introduction

An estimated 1-2 percent of adults and 4-8 percent of children suffer from food allergies (Lehrer and others 2002). In the United States, approximately 30,000 people require emergent care and 150 people die each year due to an allergic reaction to food (U.S. Food and Drug Administration 2004). There is currently no cure for food allergies. The individual must avoid the food they are allergic to, placing responsibility on food manufacturers.

In 1999, the FDA randomly selected foods from Minnesota and Wisconsin to review for allergens (U.S. Food and Drug Administration 2004). They found that 25% of these foods did not successfully label peanuts or eggs as ingredients. Furthermore, in 2000, the amount of recalls from unlabeled allergens rose from 35 to 121 over a decade (U.S. Food and Drug Administration 2004). As a result, the need for governmental control on these ingredients became obvious.

FDA Regulations

In August of 2004, the Food Allergen Labeling and Consumer Protection Act of 2004 was created. The act required the labeling of eight major food allergens to be effective by January 1, 2006. The eight major food allergens are: milk, eggs, fish, Crustacean shellfish, tree nuts, peanuts, wheat, and soybeans. These were chosen as they are responsible for about 90% of food allergies (U.S. Food and Drug Administration 2004; McEvoy 2007).

Before this act, ingredients in food were required to be listed by their “common or usual name” (U.S. Food and Drug Administration 2007). Studies showed many individuals were unaware that certain ingredients were derived from or contained a major food allergen. The Food Allergen Labeling and Consumer Protection Act of 2004 now requires the eight major food allergens be listed in either of the following two ways. First, the product’s label can have the word ‘contains’ followed by the name of the food source from which the major food allergen is derived. This is listed directly after or adjacent to the ingredient list in the same or larger type size. Second, the common or usual name of the major food allergen in the ingredient list is followed in parentheses by the name of the food source from which the major food allergen is derived. Unless the common or usual name uses the name of the food source or the name of the food source appears elsewhere in the ingredient list. The name of the food source from which the major food allergen is derived means one of the names described in the eight major food allergens, including the specific type or species be listed for tree nuts, fish, and Crustacean shellfish. Any food ingredient that contains the protein derived from the eight major food allergens must be listed. This excludes any highly refined oil derived from the food allergens (U.S. Food and Drug Administration 2004).

For products that may unintentionally contain the food allergens, labeling is still in effect. Cross-contact is a major concern for food allergens. If the product contains an ingredient that may have a certain allergen, then it can be listed as so. Products that are produced in the same facility as an allergen-containing product should be noted. There are five statements manufacturers currently used to note possible cross-contact of food allergens. They are: "Produced in a plant that processes...[allergen(s)];" "May contain traces of...[allergen(s)];" "May contain...[allergen(s)];" "Produced on shared equipment that processes...[allergen(s)];" and "[Allergen(s)] traces." (U.S. Food and Drug Administration 2004).

Another term currently being used in the labeling of foods is “gluten-free”, although this term has not yet been approved in the U.S. at the time of writing this document. Gluten is the storage proteins found in wheat. These proteins are a concern for people with Celiac disease, also known as gluten-sensitivity enteropathy. On January 23, 2007, the FDA publicized a proposed rule in the Federal Register (Volume 72, Number 14) for Gluten-Free Labeling of Foods. A summary of the proposed rule is stated below:

> "The Food and Drug Administration (FDA) is proposing to define the term ``gluten-free'' for voluntary use in the labeling of foods, to mean that the food does not contain any of the following: An ingredient that is any species of the grains wheat, rye, barley, or a crossbred hybrid of these grains (all noted grains are collectively referred to as ``prohibited grains''); an ingredient that is derived from a prohibited grain and that has not been processed to remove gluten (e.g., wheat flour); an ingredient that is derived from a prohibited grain and that has been processed to remove gluten (e.g., wheat starch), if the use of that ingredient results in the presence of 20 parts per million (ppm) or more gluten in the food; or 20 ppm or more gluten. A food that bears the claim ``gluten-free'' or similar claim in its labeling and fails to meet the conditions specified in the proposed definition of ``gluten-free'' would be deemed misbranded. FDA also is proposing to deem misbranded a food bearing a gluten-free claim in its labeling if the food is inherently free of gluten and if the claim does not refer to all foods of that same type (e.g., ``milk, a gluten-free food'' or ``all milk is gluten-free''). In addition, a food made from oats that bears a gluten-free claim in its labeling would be deemed misbranded if the claim suggests that all such foods are gluten-free or if 20 ppm or more gluten is present in the food. Establishing a definition of the term ``gluten-free'' and uniform conditions for its use in the labeling of foods is needed to ensure that individuals with celiac disease are not misled and are provided with truthful and accurate information with respect to foods so labeled. This proposed action is in response to the Food Allergen Labeling and Consumer Protection Act of 2004 (FALCPA)."

As of April 24, 2008, the proposed rule is still standing and no official law has been posted.

Mechanism of Actions

According to Burks (2002), an adverse food reaction can be described as an abnormal response to an ingested food or food additive. Under this term, food hypersensitivity (allergy) and food intolerance can be found. Food allergy is an immunological reaction to an ingested food or food additive. Food intolerance, on the other hand, is an abnormal physiologic response to an ingested food or food additive. Food intolerance is caused by many different factors that have not been proven to be immunological.

Although non-immunoglobulin E mechanisms exist, an allergic reaction is generally considered to be an immunoglobulin E (IgE) mechanism (Lehrer and others 2002). Upon first ingestion, the allergen, which has resisted cooking and the digestive tract, crosses the mucosal membrane. The allergen is processed and presented to IgE producing cells. The fragments are recognized by T lymphocytes and B lymphocytes are stimulated to produce IgE antibodies specific to the allergen (Lehrer and others 2002). These antibodies attach to the surfaces of mast cells. Mast cells are found in all body tissues, but are generally located in areas where allergic reactions occur. These include the nose, throat, skin, lungs, and gastrointestinal (GI) tract (National Institute of Allergy and Infectious Diseases 2007). When exposed to the allergen a second time, there is an interaction with the specific IgE antibodies on the mast cells causing a release of chemicals. A well-known example of such a chemical is histamine. Figure 1 outlines the IgE-mediated allergic reaction.

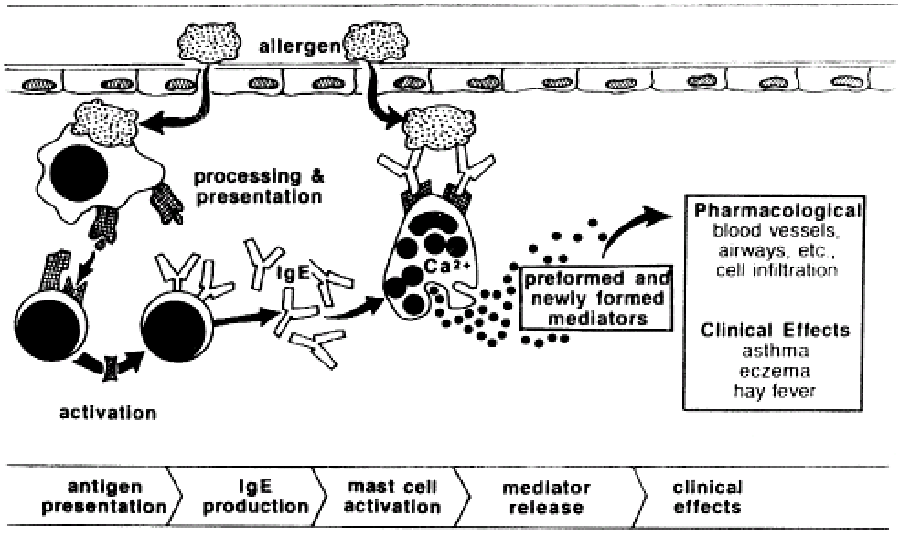

Figure 1. Mechanism of an IgE-mediated food allergy. From Lehrer and others (2002).

The type and severity of symptoms that occur from such chemicals depend on the type of chemical and tissue in which they are released. According to Madsen (2005), oral allergy syndrome includes itching and swelling of lips, tongue, palate, and throat. If the reaction is initiated in the GI tract, nausea, vomiting, diarrhea, and abdominal pain are common symptoms. Other symptoms have been associated with the skin, eyes, and respiratory system. The most dangerous of all are generalized symptoms, i.e. anaphylactic shock. This is a rapid drop in blood pressure and can be fatal if not treated promptly.

The fact that non-IgE-mediated food allergies and non-allergic food intolerances can have similar symptoms leads to a difficult diagnosis of food allergies. As mentioned before, food intolerances are caused by a variety of mechanisms and the immune system is not responsible for the symptoms. The National Institute of Allergy and Infectious Diseases (2007) provides examples of food intolerances. One example of food intolerance is food poisoning. Food contaminated with microbes and toxins create symptoms similar to allergic reactions, typically GI discomfort. Another example of food intolerance is lactose intolerance. This intolerance is due to the lack of an enzyme, lactase, which breaks down lactose. Certain food additives create food intolerance for certain people, as well. Monosodium glutamate (MSG) and sulfites are common examples. A major difference between a food allergy and a food intolerance is the concentration tolerated. Typically, a food allergy requires a minute amount for a reaction to occur, while food intolerance requires a higher concentration.

CELIAC DISEASE

Introduction

Although food allergies and intolerances have been given much attention, there is another disorder that requires further awareness. This disorder is celiac disease. Approximately 1:266 people in the world have the disease, and about 1:100 individuals are affected in the U.S. (Case 2006). Also known as gluten-sensitive enteropathy or celiac sprue, celiac disease is an autoimmune inflammatory disease of the upper small intestine resulting from the ingestion of gluten in genetically susceptible individuals (Case 2006). This immunologic reaction leads to damage of the absorptive surface of the small intestine. The surface contains finger-like protrusions called villi (Figure 2) which absorb nutrients from food into the bloodstream (National Digestive Diseases Information Clearinghouse 2007). The villi are inflamed and flattened (Figure 3) during the reaction leading to malabsorption of nutrients (Case 2006).

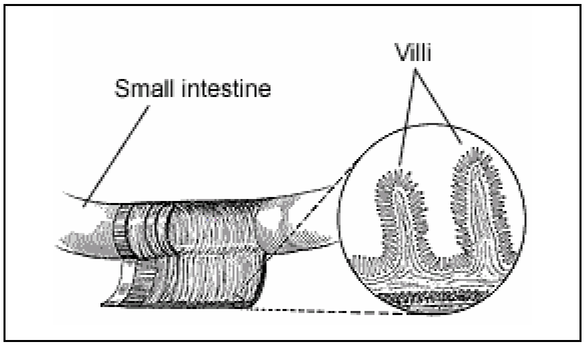

Figure 2. Villi on the lining of the small intestine.
From glutenfreeway.info/history.html

Initial damage at the first part of the small intestine creates a malabsorption of iron, calcium, and folate (Case 2006). As the damage progresses, malabsorption of carbohydrates, fats, vitamins, proteins, minerals, and sometimes water and bile salts can occur (Celiac Disease Foundation 2008).

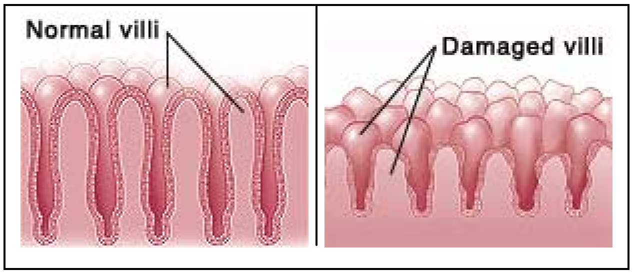

Figure 3. From left to right: normal villi and damaged villi. From Krames (2006).

Symptoms/Related Conditions

Damage to intestinal villi can create a wide range of symptoms. Each person with celiac disease is affected differently. Symptoms range from digestive to psychological. The National Digestive Diseases Information Clearinghouse (2007) lists an array of symptoms for celiac disease (Table 1).

Table 1. Symptoms of Celiac Disease

- Gas
- Recurring abdominal bloating and pain
- Chronic diarrhea
- Pale, foul-smelling, or fatty stool
- Weight loss / weight gain
- Fatigue
- Unexplained anemia
- Bone or joint pain
- Osteoporosis, osteopenia
- Behavioral changes
- Tingling numbness in the legs
- Muscle cramps
- Seizures
- Missed menstrual periods
- Infertility, recurrent miscarriage
- Delayed growth
- Failure to thrive in infants
- Aphthous ulcers (mouth sores)
- Tooth discoloration or loss of enamel
- Dermatitis herpetiformis

Note that some of the symptoms are conditions that arise from untreated celiac disease. There are some other conditions to be added to the list of symptoms that further help with diagnosis. The Celiac Disease Foundation (2008) lists long-term conditions for untreated celiac patients (Table 2).

Table 2. Long-term conditions that can result from untreated celiac disease

- Iron deficiency anemia
- Osteoporosis
- Vitamin K deficiency associated with risk for hemorrhaging
- Vitamin and mineral deficiencies
- Central and peripheral nervous system disorders
- Pancreatic insufficiency
- Intestinal Lymphomas and other GI cancers
- Lactose intolerance
- Neurological manifestations

Along with these conditions, there are a number of autoimmune disorders associated with celiac disease. These include: thyroid disease; systemic lupus erythematosus; type 1 diabetes; liver disease; collagen vascular disease; rheumatoid arthritis; Sjögren’s syndrome; dermatitis herpetiformis (National Digestive Diseases Information Clearinghouse 2007). There are other linked diseases, such as Down syndrome and Turner syndrome, but these are not as common (Celiac Disease Foundation 2008).

Diagnosis

With an exhaustive list of symptoms, conditions, and related diseases, it is often difficult to diagnose celiac disease. Symptoms similar to those of irritable bowel syndrome, iron-deficiency anemia, Chrohn's disease, and more lead to a common misdiagnosis (National Digestive Diseases Information Clearinghouse 2007).

There are a few steps in the diagnosis of celiac disease. First, a specific antibody blood test can be performed to help in the recognition of celiac disease (Celiac Disease Foundation 2008). It is important to note that a person being tested for celiac disease must continue to eat gluten. Eliminating gluten from the diet before testing may result in false conclusions. The specific antibodies tested are: IgA endomysial antibodies (EMA), IgA tissue transglutaminase (tTG), IgG tissue transglutaminase and Total IgA antibodies. If the test suggests a presence of celiac disease, then a small intestinal biopsy is performed (Celiac Disease Foundation 2008). However, since the antibody test is not 100% accurate, some people may suggest a small intestinal biopsy be performed even if the antibody test is negative (Case 2006). The biopsy is carried out with an endoscope through the mouth and stomach down to the small intestine. The procedure will confirm celiac disease and can be used to evaluate the extent of mucosal damage (Celiac Disease Foundation 2008).

With inconclusive results from the serology and biopsy, the presence of specific human leukocyte antigen or HLA genes can be tested. If the test is negative, then the chance of developing celiac disease is minimal. However, if the genes are present, this does not confirm celiac disease because this is a common gene in the general population (Celiac Disease Foundation 2008).

Treatment

If an individual is diagnosed with celiac disease, then he or she must adhere to a gluten-free diet. A gluten-free diet is the only treatment for celiac disease. To follow such a strict dietary regime is a lifelong commitment, as there is no cure for the disease. Since villi in the small intestine have usually been damaged, nutritional supplements may be given to correct any deficiencies (Celiac Disease Foundation 2008). Refraining from gluten will allow the intestine to heal and nutrients will soon be absorbed from the food. For those with celiac disease whose condition does not improve with a gluten-free diet, also known as unresponsive celiac disease, there is most likely gluten still hidden in the diet (National Digestive Diseases Information Clearinghouse 2007). Gluten can be found in some cold cuts, soups, candies, soy sauce, some low or non-fat products, and other foods (Celiac Disease Foundation 2008). However, sometimes the intestine is so damaged that it cannot heal itself. In this case, nutrients are usually given intravenously (National Digestive Diseases Information Clearinghouse 2007).

Dermatitis Herpetiformis

Dermatitis herpetiformis (DH) is a condition where the body's intolerance to gluten produces a condition on the skin instead of intestinally. A severe itching along with a blistering rash will occur around elbows, knees, buttocks, and sometimes the back, neck, and head (Case 2006). More than 85% of people with DH will have small-bowel sensitivity to gluten resulting in bloating, abdominal pain, diarrhea, and sometimes malnutrition (Case 2006). However, some will experience no bowel problems (Celiac Disease Foundation 2008). An estimated 10% of those with celiac disease have DH (Case 2006). DH is diagnosed with a skin biopsy near the infected area. Treatment is similar to celiac disease where a strict gluten-free diet must be followed. Dapsone may be prescribed to help control the rash, but this will not help replenish the damage (National Digestive Diseases Information Clearinghouse 2007). Avoiding gluten will allow the skin and intestinal areas to heal.

Gluten-Free Diet

Gluten is described as the storage proteins found in wheat. These storage proteins consist of glutenin and gliadin. Glutenin and gliadin are the specific names for wheat glutelins and prolamins, respectively. Gliadin has been known as the toxic protein to those with celiac disease and dermatitis herpetiformis. However, recent research has shown glutenin to be intolerable as well (Vader and others 2002). The prolamins in rye (secalin) and barley (hordein) are also harmful and therefore must be avoided as well. However, rice and corn prolamin, orzenin and zein respectively, are not damaging (Case 2006). The avenin prolamin in oats is still under debate for safety of consumption. The main problem seems to be contamination with wheat, rye, and barley as opposed to the actual intolerance of pure oats. However, there are a few Celiacs who cannot tolerate uncontaminated oats. Therefore, a “gluten-free” diet generally corresponds to the avoidance of wheat, rye, barley and oats in all forms. Talking to a specialist about which ingredients contain gluten is important. Items such as modified food starch, stabilizers, thickeners and binders often have hidden sources of gluten. Some binders may even be used in certain medications so it is recommended that Celiacs check with their pharmacists (Case 2006; Shepherd and Gibson 2006).

MARKET FOR GLUTEN-FREE PRODUCTS

In 2003, the University of Maryland Center for Celiac Research in Baltimore, conducted a study that found that 1 out of 133 Americans have celiac disease. More recently, an estimated 1:100 Americans are affected by this disease (Case 2006). The increase in prevalence is claimed to be due to an increasing awareness and better diagnosis from physicians. With this growth, comes a demand for gluten-free products. These products are beginning to be seen in major supermarkets instead of simply in health food stores.

The numbers can further emphasize this growth. Enjoy Life Foods, a food company specializing in gluten-free foods, had first-year sales of half a million dollars and is continuing to grow in size (Palmer 2004). Even more impressive, in 2005, Wal-mart had 982 gluten-free products listed and Whole Foods Market listed over 800 (The Associated Press 2006). From 2004 to 2005 alone, sales of gluten-free foods increased 14.6% or 77.8 million dollars (University of Chicago Celiac Disease Center 2008).

Not only is the production of gluten-free products helping those who cannot tolerate the compound, but such products are starting to create a new diet. Dr. Leo Treyzon, who specializes in gastrointestinal disorders at UCLA, stated that “the whole celiac disease problem has created a celiac fad diet” when being interviewed on the radio show NPR in May of 2007 (Aubrey 2007). People with irritable bowl syndrome describe less bloating and stomach cramping when wheat is eliminated from their diet. Others mention weight loss as well.

SORGHUM PRODUCTION

With an increasing number of people being diagnosed with celiac disease and the market for gluten-free products booming, there is a perfect opportunity to create new products using sorghum.

According to the U.S. Grains Council (2008a), grain sorghum is the fifth most important cereal crop grown in the world. In the U.S., grain sorghum is the third most important. As a continent, Africa is the largest producer of sorghum. In 2006, Nigeria was the leading producer as a country with 413.4 million bushels, followed by the United States with 393.7 million. Of the U.S. production, 89% came from the following five states in ranking order: Kansas, Texas, Nebraska, Oklahoma, and Missouri.

With the United States playing such a huge role in sorghum production, the fact that the grain is not seen more in food products may seem odd. This is partly because the U.S. does not have many uses for sorghum. Therefore, the U.S. exports half of the sorghum (Figure 3). In fact, from 2005-2006 the United States took an 89% share of the global sorghum exports, the number one customer being Mexico (U.S. Grains Council 2008a).

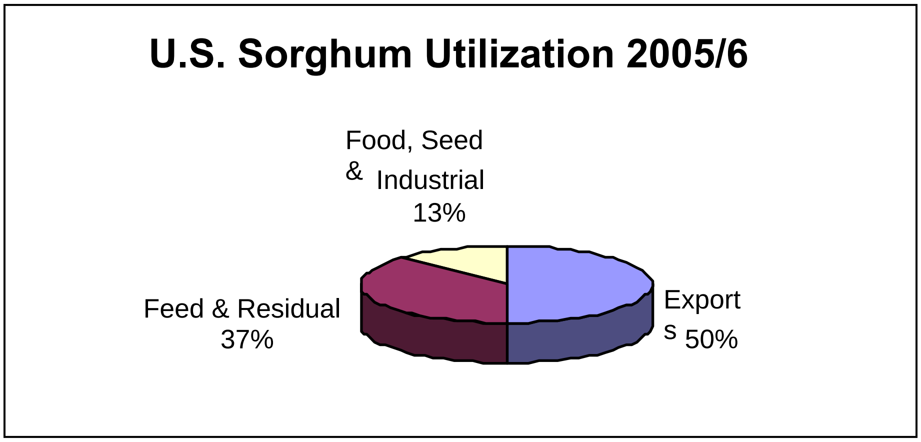

Figure 4. U.S. Sorghum Utilization for 2005 to 2006. Adapted from: U.S. Grains Council (2008a).

This exported sorghum may be used for either feed or food. In Africa and Asia, sorghum is a major food crop, whereas other continents use the grain for feed (Serna-Saldivar and Rooney 1995). An estimated 30-40% of sorghum is consumed by humans (Rooney and others 1986; Murty and Kumar 1995). The number could increase with the utilization of sorghum in gluten-free products. All sorghum varieties are gluten-free making them appealing to people with celiac disease or wheat allergies. Also, the white varieties have a neutral taste allowing them to absorb many flavors (U.S. Grains Council 2008a). Finally, sorghum is extremely drought tolerant making it easily grown in many parts of the world.

Environmental Conditions

Sorghum is considered a strong crop by being resistant to harsh conditions such as drought and high temperatures. Also, sorghum needs little irrigation and pesticides making the grain easily adaptable to the natural environment (U.S. Grains Council 2008b). Sorghums that contain a pigmented testa layer, and thus tannins, are resistant to birds, weathering, mold, and grain sprouting (Rooney and Serna-Saldivar 2000).

There are still some environmental requirements for sorghum growth. Sorghum is considered a short-day plant and can grow in rainy to semiarid areas. As far as altitude is concerned, sorghum can grow from sea level to 3000 m. Although sorghum will germinate at high temperatures (10 – 35^{o}C), the plant is killed by frost. Finally, sorghum endures soil from heavy clay to light, sandy types with a pH range from 5.0 to 8.5 (Kimber 2000).

SORGHUM GRAIN

History

Sorghum bicolor (L.) Moench is a cereal in the grasses (Poaceae) family. According to House (1995), sorghum was first domesticated around 3,000 to 5,000 years ago. The first written description of sorghum was by Pliny around 60 to 70 A.D. The next recording was not until to the 16th century where various nomenclature begins, *sorgo* (from the Latin *surrigo* meaning to grow up) and *dora* (Greek for gift) to name a few (Snowden 1936). In 1794, Moench established the genus *Sorghum* and later species were named (Clayton 1961; Snowden 1936). The three species include *S. halepense*, *S. propinquum*, and *S. bicolor* (Dahlberg 2000). This literature will focus on *S. bicolor* for this is the cultivated species.

Classification

Sorghum has many different common names around the world. Sorghum is called great millet, kafir corn or quinea corn in the Western parts of Africa. Other names are jowar (India), kaolian (China), and milo (Spain) (U.S. Grains Council 2008b). But no matter what the name, sorghum can be classified into four types based on functionality: grain, broom, grass (forage), and sweet. Grain sorghum is used as food in Asia and Africa and as feed in other continents. Broom sorghum can be made into brooms, whereas grass (forage) sorghum functions as feed and forage. For processing syrups, sugars, and alcohols, sweet sorghum is utilized (Rooney and Serna-Saldivar 2000; U.S. Grains Council 2008b).

The U.S. Department of Agriculture (1993) describes another form of classification from the sorghum market. The four market classes are: Sorghum, Tannin sorghum, White sorghum, and Mixed sorghum. This classification is best explained by the presence of a pigmented testa layer. The Sorghum grade has a low tannin content due to the absence of a pigmented testa and contains no more than 3.0% of Tannin sorghum. Sorghum grade pericarp color may appear white, yellow, pink, orange, red, or bronze. Tannin sorghums have a pigmented testa creating a high in tannin content and contains no more than 10.0% non-Tannin sorghum. The Tannin pericarp is usually brown in color. The White sorghum grade has no pigmented testa and a white or translucent pericarp. White sorghum contains no more than 2.0% of the other sorghum classes. Mixed sorghums cannot fit into the previously mentioned classes because there is a mixture of pigmented and non-pigmented testa.

Appearance and Structure

The sorghum plant can range in height between 60 and 460 cm. Long, wide leaves grow from the stalk and the seed head is located at the top with a height around 25 to 36 cm (Figure 4). The seed head contains the individual sorghum grains, or kernels, which are small and round (U.S. Grains Council 2008b). The kernels size can range from 3 to 80 mg in weight. In the U.S., commercial sorghum kernels are around 4 mm long, 2 mm wide, and 2.5 mm thick with a weight of about 25 to 35 mg and a density between 1.28 and 1.36 g/cm^3 (Serna-Saldivar and Rooney 1995).

The overall appearance and color of the kernels, or caryopses, are affected by the pericarp color and thickness, presence of pigmented testa, and endosperm color (Rooney and Miller 1982). However, the kernels' appearance can also be controlled by the plant and glume color, especially those that are damaged by the environment and insect and mold deterioration (Waniska and Rooney 2000).

Three main parts make up the sorghum caryposis: pericarp, germ, endosperm (Figure 4). The pericarp is the outer layer which begins at the ovary wall (Glennie and others 1984) and consists of three segments: epicarp, mesocarp, and endocarp (Earp and Rooney 1982). The epicarp is the outermost layer, generally covered with a thin waxy film. Unlike other cereal grain, the mesocarp (middle) in sorghum contains starch granules. The thickness of the mesocarp varies from very thin to thick with 3 or 4 cellular layers. Finally, the endocarp is the innermost layer of the pericarp and includes cross and tube cells (Waniska and Rooney 2000).

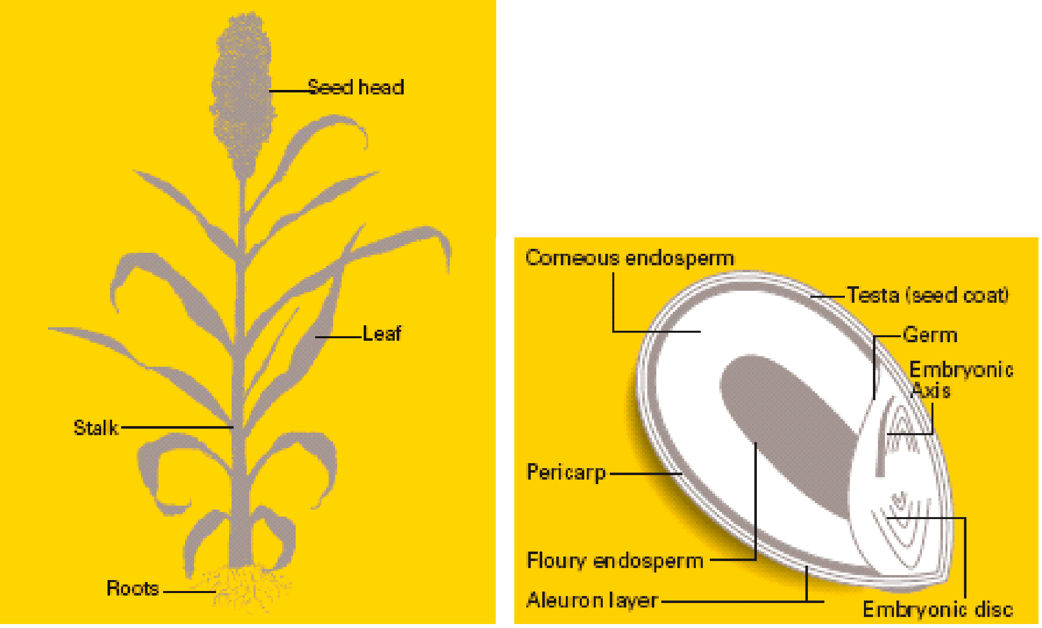

Figure 5. Left: Sorghum plant structure. Right: Sections of a sorghum seed. Source: U.S. Grains Council (2008b).

The germ is the next anatomical part, which is simply the embryo. The germ has two major parts: the embryonic axis and embryonic disc (Waniska and Rooney 2000). High levels of lysine and tryptophan can be found here (U.S. Grains Council 2008b). Finally, the endosperm is the storage organ including an aleurone layer, peripheral, corneous and floury areas (Earp and Rooney 1982). The aleurone layer contains proteins, ash, and oil (U.S. Grains Council 2008b).

The actual proportion of the three anatomical parts of sorghum varies depending on the cultivar and environment. The same goes for the chemical composition. These ranges are displayed in Table 3 (Waniska and Rooney 2000).

Table 3. Chemical Composition (%) and Anatomical Tissues of Sorghum

	Caryopsis	**Endosperm**	**Germ**	**Pericarp**
Caryopsis	100	84.2	9.4	6.5
Range	---	81.7-86.5	8.0-10.9	4.3-8.7
Protein	11.3	10.5	18.4	6
Range	7.3-15.6	8.7-13.0	17.8-19.2	5.2-7.6
Distribution	100	80.9	14.9	4.0
Fiber	2.7	---	---	---
Range	1.2-6.6	---	---	---
Distribution	100	---	---	---
Lipid	3.4	0.6	28.1	4.9
Range	0.5-5.2	0.4-0.8	26.9-30.6	3.7-6.0
Distribution	100	13.2	76.2	10.6
Ash	1.7	0.4	10.4	2.0
Range	1.1-2.5	0.3-0.4	---	---
Distribution	100	20.6	68.6	10.8
Starch	71.8	82.5	13.4	34.6
Range	55.6-75.2	81.3-83.0	---	---
Distribution	100	94.4	1.8	3.8

Source: Data from Hubbard and others (1950); L.W. Rooney and Clark (1968); Haikerwal and Mathieson (1971); Jambunathan and Mertz (1973); Hulse and others (1980); Jambunathan and others (1984); Taylor and Schussler (1986)

Table 3 exhibits the typical proximate composition of sorghum. The germ is high in protein, fat, and ash. On the other hand, the endosperm is, for the most part, starch with some protein and a small amount of fat and fiber. Of these, protein is the most variable (Serna-Saldivar and Rooney 1995). Although genetics can have an effect on protein, most variation is believed to be caused by agronomic conditions. For example, limited moisture usually produces a grain with higher protein content. Therefore, dryland sorghum will typically have a higher protein content (Waniska and Rooney 2000). Also, high-nitrogen fertilizer will increase the protein content (Warsi and Wright 1973).

Sorghum protein content is comprised mainly of kafirins. Kafirins, or prolamins, make up 50% or more of the protein. Glutelins are the second major protein fraction (Rooney and Serna-Saldivar 2000). Both of these fractions are found mainly in the endosperm. The germ, however, is rich of albumins and globulins (Waniska and Rooney 2000). The albumin, globulin, and glutelin fractions contain a rich amount of lysine, and essential amino acid (Haikerwal and Mathieson 1971; Taylor and Schussler 1986). However, with kafirins being the major protein fraction, sorghum protein is considered deficient in lysine (Taylor and Dewar 2001).

As for the carbohydrates in sorghum, starch is the primary constituent. The starch can make up to three-fourths of the grain weight (Serna-Saldivar and Rooney 1995). Typical sorghum endosperms are composed of 23-30% of amylose (Horan and Heider 1946; Ring and others 1982). The amylopectin, therefore, ranges from 70-77%. However, there are waxy type sorghums that are mostly amylopectin with only up to 5% amylose present (Serna-Saldivar and Rooney 1995).

Soluble sugars and fiber are present in smaller amounts. The soluble sugar content changes as the grain develops (Murty and others 1985). The soluble sugar content is about 1.3% on average for a mature caryopsis (Jambunathan and others 1984). Of this 1.3%, about 75% is sucrose while the rest consists of glucose, fructose, stachyose, and raffinose (Subramanian and others 1980). Sugary and high-lysine cultivars contain a higher amount of soluble sugars compared to normal sorghums (Subramanian and others 1980; Murty and others 1985).

Finally, the fiber content of sorghum is mostly insoluble and located mainly in the pericarp. Sorghum contains 6.5 to 7.9% insoluble fiber and about 1.1 to 1.23% soluble fiber (Bach-Knudsen and Munck 1985). The dietary fiber amount decreases after decortication as this amount is dependent on the degree of pericarp removal (Waniska and Rooney 2000).

Located primarily in the germ, the lipids are a minor part of sorghum. With decortication the germ is removed leading to a significant reduction in lipid content (Waniska and Rooney 2000). Sorghum oil can be compared to that of maize as the fatty acid composition is predominantly linoleic and oleic acids (Wall and Blessin 1970; Rooney 1978; Neucere and Sumrell 1980; Agullo and Rodriguez 1998).

A unique compositional part of sorghum is the phenolic compound presence. Phenolic compounds are divided into three categories: phenolic acid, flavonoids, and tannins (Chung and others 1998). All sorghums have phenols and most have flavonoids. However, tannins are present only in the cultivars with a pigmented testa (Waniska and Rooney 2000). These tannins create protection in pest-ridden areas (Waniska and others 1989), but decrease nutrient absorption (Serna-Saldivar and Rooney 1995).

SORGHUM TODAY

Current Products

As mentioned before, sorghum is a major cereal grain for food in Asia and Africa. In such areas, sorghum breads, beers, porridges, snacks and other foods are produced. Currently, more knowledge is being developed on the properties of sorghum and the effects sorghum has on food products. This understanding has led to the development of higher quality products as well as innovation using experimental research.

Since the late 1980s, sorghum has been used for malting and brewing in a commercial lager and stout (Olori and others 1996). Although originally a Nigerian product, east Africa, southern Africa, and even the USA have started brewing with sorghum (Mackintosh and Higgins 2004; Taylor and others 2006). This growth, of course, led to research for further improvement. Beta and others (2000 a,b,c) used NaOH as opposed to the previously used formaldehyde for steeping the grain in order to inactivate the tannins with a less harsh chemical. Investigation on the effects of sorghum's high gelatinization temperature (71-81^{o}C) on malt has been conducted (Chandrashekar and Kirleis 1988; Del Pozo-Insfran and others).

Another common sorghum based food is porridge. Both thick and thin porridges are produced and the difference is mainly in the flour concentration (Rooney and Waniska 2000). The porridge is made with either fermented or unfermented flour and is typically steeped in alkali, acid, or water (Anglani 1998; Rooney and Waniska 2000). A popular thick porridge consumed in Mali is "tô". According to Bello and others (1990), the quality of this porridge is affected by the endosperm hardness, amount of pericarp post-decortication, flour particle size, pH of cooking water, and nonstarch flour components. A thin porridge, atole, has been studied with differences in grain before milling and type of milling (Vivas-Rodrigues and others 1987).

Couscous is made from decorticated sorghum and differs from that made with wheat. The food may be served with milk for breakfast or with a sauce containing fish, meat, vegetables, or legumes for later meals (Anglani 1998). Although gums are typically added to improve texture, an acceptable couscous can be created with sorghum. Most sorghums, other than the waxy types, may be used. However, studies have shown preference towards white sorghums with a hard endosperm (Galiba and others 1987; Aboubacar and Hamaker 1999).

Rice-like foods have been made using sorghum. The genotype and environment of the sorghum affects the cooking characteristics (Subramanian and others 1982). However, white sorghums can produce an acceptable product. Decorticated sorghum that is parboiled, called sori, has an increased yield, reduced breakage, increased firmness and reduced stickiness (Young and others 1990).

Sorghum noodles can be made with decorticated sorghum flour. Suhendro and others (2000) simply added sorghum flour, water, and salt to create sticky, soft noodles. Heterowaxy sorghum was correlated with inferior quality. A better quality noodle was produced with finer flour making flour particle size a critical factor.

Some snack foods have been developed by means of sorghum. The sorghum kernels can be deep fried after an alkaline-cooking to create a popcorn-like product called Jowar crunch (Suhendro and others 1998). Certain sorghum varieties are popped and eaten in India (Rooney and Waniska 2000). Tortilla chips have been successful made with food-grade sorghum using a lime solution and cooking similar to the maize product (Taylor and others 2006).

Aside from tortilla chips, tortillas have been made with sorghum in many Central American countries (Rooney and Waniska 2000). With sorghum having such a similar composition to maize, replacement of some or all of the maize in corn tortillas with sorghum has been seen. Choto and others (1985) found a 25 percent replacement of maize for sorghum produced the best tortillas.

Sorghum baked goods ranging from cakes to cookies have been studied. Eggs added to cakes help in creating an acceptable sorghum cake. However, these cakes typically have a lower volume and poor texture due to the lack of glycol- and phospholipids and the high gelatinization temperature of sorghum (Glover and others 1986). Cookies have been made with 100 percent sorghum flour, but the texture is gritty and hard and the cookie lacks spread and surface cracking (Badi and Hoseney 1976). According to Badi and Hoseney (1976), these problems can be fixed with the addition of soy lecithin, soaking and drying the flour, and lowering the pH of the dough. However, Morad and others (1984) found contrasting results with a large spread from sorghum cookies suggesting that particle size and extraction rate of the flours are critical factors.

Finally, sorghum bread has played a major role in the sorghum foods category. Some countries produce fermented sorghum breads, such as injera, kisra, and dosa (Murty and Kumar 1995). These breads are in a thin, pancake-like form. When looking at traditional loaf bread, there has been some success with the use of sorghum flour. Several successful studies used composite breads, meaning sorghum flour is added to wheat flour to produce an acceptable bread (Hulse 1980; Dendy 1995; Cauvain 1998; Carson and others 2000). This method can create a typical bread dough and fairly nice loaves, but is not suitable for people with celiac disease. When sorghum flour is used alone, the doughs tend to be more fluid and give lower loaf volumes (Schober and others 2006). Hart and others (1970) developed a sorghum bread and tested different additives, such as gums, starches, enzymes, emulsifiers and shortenings. The study concluded that a more traditional dough was not as sufficient in rising as the more batter-like doughs. Olatunji and others (1992) had success with a combination of sorghum flour, gelatinized cassava starch, and raw cassava starch in a 70/20/10 ratio, respectively, and water, emulsifier, and fat.

PRINCIPLES OF FLOUR TORTILLA PRODUCTION

Market

Flour tortillas may have started as an ethnic food being used in burritos, tacos, and fajitas, but the United States is stretching the tortilla in other areas as a bread replacement. McDonald's and Arby's are examples of restaurants that utilize tortillas on their menus (Petrak 2006a). Typically called a wrap, the tortilla has been used to carry salads, sandwiches, and even breakfast items (Seiz 2006). According to the Tortilla Industry Association, 78% of fine dining restaurants have tortillas in a menu item (Petrak 2006a).

The supermarket is seeing the popularity of tortillas as well with sales reaching $1 billion (Petrak 2006b). Part of this popularity comes from important innovation with whole grains and omega-3 fatty acids being used in a normally plain product (Seiz 2006). With tortillas going mainstream, sales doubled in the past decade (Petrak 2006b).

Process

There are three different methods for flour tortilla production: hot press, hand stretch, and die-cut (Qarooni 1993). Hot press is the most common method among commercial production (Bello 1991). Each of these operations may use different formulas, as well as different steps in preparing the dough. Typical formulas for each operation can be seen in Table 4.

Table 4. Typical Formulas for Different Operations of Flour Tortillas

Process	Water %	Fat %	Salt %	Preservative %	Gums %	Reducing Agents %
Hot Press	50	10-14	2.0	0.2 propionate	variable	variable
Hand Stretch	50	8-12	2.0	0.2 propionate	variable	variable
Die-cut	54	6-10	1.33	0.3 sorbate	0.5 guar	0.25 SSL + bisulfite

From Serna-Saldivar and others (1988) and Waniska and Clements (1986).

The processing steps for each of these operations vary. A flow chart of the process for flour tortillas can be seen in Figure 5. Each step is crucial in producing a consistent, quality tortilla.

Dough Mixing

Dough mixing is the first important step in tortilla production. There are two ways to mix the ingredients: the ingredients are mixed at the same time or in a three step procedure. The three step procedure mixes the dry ingredients first, then the shortening is added and mixed, and finally the water is added and mixed until the dough develops (Qarooni 1993). Flour tortilla studies tend to use the three step procedure (Serna-Saldivar and others 1988; Bello and others 1991; Waniska and others 2004).

The amount of water, mixer's speed, and mixing time influence the dough during mixing. Water amount ranges from 47-55% (Qarooni 1993). The level of water can be determined with the 750 Farinograph consistency line (Bello and others 1991). Warm water ranging from 38 to 52^{o}C (Bello and others 1991; Waniska and others 2004) is used to produce a dough temperature around 30-36^{o}C (Cepeda and others 2000).

The mixing speed and time are important in ensuring the dough is developed to optimum. Bello and others (1991) mixed the dry ingredients for 2 minutes at slow speed, then added shortening and mixed for another 8 minutes, finally water was added and mixed for 1 minute at low speed and at medium speed until the dough was developed (about 5 min.). Waniska and others (2004) used a similar process, but the shortening was mixed for 6 minutes instead of 8.

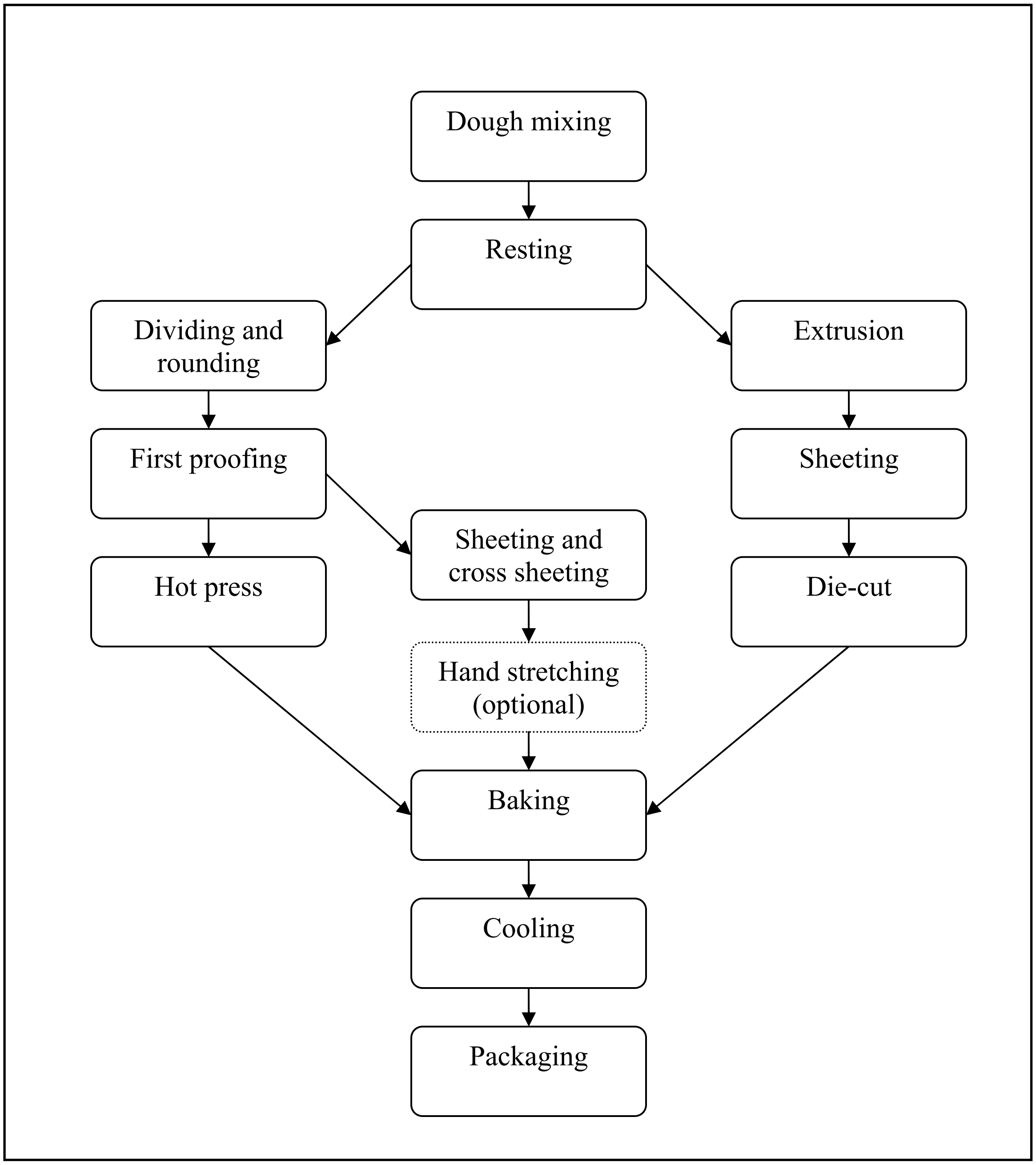

Figure 6. Flour tortilla process. Adapted from Qarooni (1993).

Resting

Once the dough is mixed, it will rest for about 5 minutes and then placed in a divider to create dough balls varying in size from 25 to 60g (Anonymous 1991). These dough balls are transferred to a proofing cabinet with a temperature of 30-36°C and relative humidity between 65 and 75% (Serna-Saldivar and others 1988). This is a short resting period and is important for dough relaxation and prevention of skin formation or excess moisture (Qarooni 1993).

Sheeting/Pressing

After resting, there are differences between the three methods. For the hot press operation, the proofed dough pieces are placed on a heated conveyer and a hydraulic press sheets each piece into a flat disc. The temperature and pressure of the press ranges from 177 to 237°C and 278 to 758 N/cm^2 respectively (Janson 1990). This process creates a skin that essentially seals the tortilla restricting the amount of steam and carbon dioxide released during baking. Therefore, the tortilla will puff.

The hand stretched method passes the relaxed dough pieces through two sheet rollers creating a round disc. These discs are then further stretched by hand (Janson 1990). With such intense labor and sanitation issues, the hand stretch method is rare (Serna-Saldivar and others 1988).

Finally, in the die-cut process, the dough is extruded and then gradually sheeted. This dough sheet is passed under a die-cut cylinder to create uniform discs (Janson 1990). Stronger doughs must be used in order to pass through such harsh processing conditions. Therefore, die-cut tortillas tend to be less elastic, have low moisture content, and crack easily. These tortillas are best for frying to create hard taco shells, chimichangas, and other products. (Serna-Saldivar and others 1988).

Baking

A three-tier gas oven is typically used for baking flour tortillas. The conveyor belt moves at an opposite direction at each level. At the end of each level, the tortilla flips ensuring even baking. The temperature and bake time can very between 191-260°C and 17 to 40 seconds, respectively (Janson 1990; Anonymous 1991). Bello and others (1991) produced hot press tortillas using a total bake time of 40 seconds and oven temperatures of 232°C for the top and bottom tiers and 273°C for the middle tier.

Cooling and Packaging

Tortillas are cooled on a similar type of conveyor used in the oven. There can be 3 to 11 tiers and the dwell time ranges from 5 to 9 minutes (Serna-Saldivar and others 1988; Qarooni 1993). Once the tortillas cool, they are packaged utilizing paddle bagging or horizontal form-fill-seal systems (Qarooni 1993). Twist ties and clip sealing have been common in the past, but resealable type packaging is becoming more familiar.

Ingredients

Flour

The most important ingredient in flour tortillas is of course the flour. The flour is typically enriched, bleached hard-wheat flour. However, all purpose flours and soft-wheat flours have been used (Serna-Saldivar and others 1988). Waniska and others (2004) studied the effects of flour properties on tortilla quality by studying sixty-one commercial tortilla flours. They found that a protein content between 10.0 and 12.0%, intermediate protein quality, and lower levels of starch damage yielded good quality tortillas.

Water

The next crucial ingredient in tortillas is water. Water provides an intermediate for the ingredients to be integrated and distributed. Water is also necessary for gluten development and activation of leavening agents. (Serna-Saldivar and others 1988). Water can effect the dough handling properties and the diameter, texture, layering, and color of tortillas (Qarooni 1993). The temperature of the water is generally warm in order to create an optimum dough temperature. A farinograph or mixograph can be used to determine the amount of water to add, but 45 to 55% is typical. Flour, shortening, processing, and other variations will affect the amount of water used. (Serna-Saldivar and others 1988).

Fat

Shortening is more commonly used, but oil can be used in die-cut and hand stretch operations. The shortening influences dough machineability and the tortilla texture by reducing dough stickiness and improving shelf-life. (Serna-Saldivar and others 1988).

Salt

Salt is important for flavor enhancement as well as dough strengthening. Salt affects the water activity of the tortilla, which in turn affects the shelf-life.

Leavening agents

The most common type of leavening in tortillas is chemical leavening, instead of yeast leavening (Waniska 1999). Baking powder, consisting of sodium bicarbonate, starch, and leavening acids, is a common leavening agent in tortillas. However, some formulations use sodium bicarbonate with the addition of leavening acids creating more control over the leavening (Cepeda and others 2000). The leavening affects the amount of air bubbles released during processing. These air bubbles influence the tortilla quality in terms of flexibility, opacity, thickness, and even flavor (Cepeda and others 2000).

Emulsifiers

Emulsifiers, such as sodium stearoyl-2-lactylate (SSL) and mono/diglycerides, are added for dough conditioning. Emulsifiers improve the dough machineability and shortening levels can be reduced when emulsifiers are added. Tortillas have better texture and tearing quality. (Qarooni 1993; Serna-Saldivar 1988)

Gums

Gums, or hydrocolloids, bind large amounts of water affecting the tortilla dough and the finished product. Guar gum, carboxymethyl cellulose, xanthan gum, and gum arabic are common gums used in flour tortillas. Gums improve dough machineability and stickiness. Gums decrease moisture loss improving rolling and folding properties of the tortilla and delaying staling. (Qarooni 1993; Serna-Saldivar 1988)

Preservatives and Acidulants

Extending the shelf-life of tortillas is important in the United States since same day consumption is rare (Cepeda and others 2000). Preservatives and acidulants act as mold inhibitors. Examples of preservatives are sodium and calcium propionate and potassium sorbate. Fumaric and citric acid are examples of acidulants used in flour tortillas. (Qarooni 1993). The pH is important to note when preservatives and acidulants are added as adjustments to leavening agents may be needed (Serna-Saldivar and others, 1988).

Reducing Agents

Reducing agents break disulfide bonds in gluten and can impact protein properties. Disulfide bonds affect dough recovery and stretching. When reducing agents are added the dough is more extensible and less elastic improving dough machineability (Serna-Saldivar and others 1988). L-cysteine, sodium bisulfites, and sodium metabisulfites are common reducing agents (Qarooni 1993).

Oxidizing Agents

Die-cut operations may add oxidizing agents to increase the mixing stability as dough is reworked. Ascorbic acid and potassium bromate are examples of oxidizing agents for die-cut flour tortillas (Serna-Saldivar and others 1988).

Structure Development

Gluten Functionality

Among cereal flours, wheat flour is the only flour that can form a strong, cohesive dough with gas retention capabilities. This viscoelastic property is what sets wheat apart from the other cereal flours. The source of this function is essentially from hydrated gluten (Pyler 1988).

Isolated gluten is about 80% protein and 8% lipids on a dry basis, with the residual 12% being ash and carbohydrate (Hoseney 1994a; Pyler 1988). The gluten proteins are believed to be responsible for the cohesive, viscoelastic characteristic as well as gas retention. The two proteins in gluten are gliadin and glutenin, each at approximately half the total composition (Hoseney 1994a).

Gliadin, which is a prolamin characterized by being soluble in aqueous alcohols, has a molecular weight between 30,000 to 100,000 (Pyler 1988). When gliadins are isolated and hydrated, a viscous, fluid mass is produced.

Isolated glutenins, on the other hand, produce a very tough, rubbery mass when hydrated. The extensibility (i.e., ability to stretch without breaking) of a wheat dough is affected by the total amount of glutenin in the flour (Macritchie 1992). Glutenins are often classified as glutelins as they are insoluble in aqueous alcohols, but are soluble in dilute acetic acid. The molecular weight ranges from 100,000 to several million. This large tertiary structure is due to the presence of inter-molecular disulfide bonds.

These disulfide bonds have created an area of study in gluten development known as the disulfide-sulfhydryl interchange reaction. The function of this interchange reaction in gluten development continues to be a controversial topic. Effects on the rheological properties of dough have been observed when using disulfide bond reducing agents, sulfhydryl oxidizing agents, and sulfhydryl blocking agents (Macritchie 1992). However, the purpose of sulfur-containing amino acid residues in dough development has not been successfully explained through experimental research (Bloksma and Bushuk 1988; Pomeranz 1988).

Although the intricate bonding that takes place in gluten is extremely important in discussing functionality, the glass transition temperature must be taken into account. A glass transition is a large change in modulus at a certain temperature for a particular material. At the right temperature, the polymers go from a leathery state to a rubbery state. Gluten with 16% water has a glass transition temperature at room temperature. This property explains gluten’s ability to form a unique dough while mixing. Other cereals, such as corn and sorghum, are not able to reach the glass transition without elevated temperatures. The addition of enough plasticizers can bring the glass transition temperature down, but the product would be inedible (Hoseney 1994b).

Gluten Development

Flour tortillas are a gluten-structured product (Waniska 1999). Hydrated proteins form a gluten network that surrounds hydrated starch granules and small air bubbles (Serna-Saldivar 1988). The amount and size of these air bubbles affects the opacity and is therefore important in creating an acceptable tortilla. A small number of bubbles means less diffraction of light and the tortilla will appear translucent. Since a more opaque tortilla is desired, manufactures strive to generate many small air bubbles during mixing and hopefully retain these bubbles during baking (Adams and Waniska 2005). This creates a proper opacity and desirable layering and texture.

McDonough and others (1996) studied the microstructure changes in wheat flour tortillas during mixing and baking. The proofed dough was found to have large lenticular and small spherical starch granules held together by a gluten matrix. This gluten matrix formed during mixing and hydration creating an elastic-type layer to grasp the starch granules such as in a bread system (He and Hoseney 1991). The gluten matrix resembled a continuous network covering the starch granules in the dough.

The McDonough and others (1996) study further found that hot pressing creates a sealing film on the surface of the tortilla disc. When the tortilla reaches the oven, the air bubbles enlarge and carbon dioxide develops forming puffed areas. The fluffy texture of the final baked tortilla is dependent upon the retention of steam and leavening gases. The gluten matrix can hold some of the steam and gas, but some enlarged air bubbles form blisters that collapse after cooling.

Quality Assessment

Flour quality is important for producing an acceptable tortilla. The protein content, ash content, starch damage, and moisture absorption of flours are typically analyzed (Qarooni 1993). Color and particle size distribution can also help assess the flour (Waniska and others 2004). Waniska (1999) claims the protein content alone is not suitable in determining flour quality since protein contents ranging from 9.5 to 12.5% have been found successful. The protein quality must also be taken into consideration.

Tortilla dough can be subjectively assessed for dough machineability and stickiness (Bello and others 1991). Waniska and others (2004) used softness and toughness scales to evaluate the doughs visco-elastic properties. Also, the dough mixing properties were assessed using a mixograph.

The quality of the baked flour tortilla can be assessed subjectively and objectively. Subjective characteristics include: toast spots, flexibility, puffing, streaks, mouth-feel, layering, symmetry, aroma and flavor, and opaqueness (Bello and others 1991; Qarooni 1993; Cepeda and others 2000; Adams and Waniska 2005). Objective attributes include: weight, diameter, thickness, moisture content, color and pH (Bello and others 1991; Qarooni 1993; Cepeda and others 2000; Adams and Waniska 2005).

A final important assessment of flour tortilla quality is shelf-life. A shelf-life evaluation may include an objective and/or subjective test. Objectively, tortillas are evaluated utilizing a texture analyzer with extensibility being a typical test. The rollability method is used for subjective assessment. The tortilla is rolled around a 1-cm dowel and rated for breakage on a scale from 1 to 5. A score of 1 is typically associated with “unrollable or breaks easily”, whereas a score of 5 is “rollable and no breaking. Both the objective and subjective methods are performed over a certain period of time, for example, 1, 4, 8, and 12 days of storage (Adams and Waniska 2005).

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Chapter 2:

Grain and Flour Characterization of Four Sorghum Hybrids

Abstract:

With an increasing number of people with celiac disease, the need for gluten-free products is on the rise. Sorghum is a grain tolerated by celiac patients which can be used in gluten-free foods. The grain and flour of four sorghum hybrids were characterized through physical and chemical means. Hybrids included: Fontanelle-625 (F-625), Fontanelle-1000 (F-1000), ATx631xRTx2907 (NE#20), and 5040C. Grain characterization included Single Kernel Characterization System (SKCS) and abrasive hardness index. Flour characterization included flour and starch particle size distributions, total starch, amylose content, starch pasting properties, moisture, crude protein, and ash content. Significant differences were found ($p<0.05$) among hybrids for each test except total starch. The average SCKS hardness indexes and abrasive hardness indexes ranged from 72.1 (5040C) to 82.7 (NE#20) and from 8.4 (5040C) to 12.7 (F-625), respectively. NE#20 had the largest particle diameter at each volume for both flour and starch. F-1000 had significantly higher starch damage at 3.0 ($p<0.05$) compared to the other three hybrids. Amylose content (%) ranged from 20.2 (NE#20) to 27.3 (F-1000). F-625 had a significantly higher moisture content (15.00%) than the other hybrids. The lowest moisture content coincided with NE#20 (11.44%). Crude protein values and ash content (%db) ranged from 8.61 (F-1000) to 10.53 (NE#20) and 1.20 (F-1000) to 1.45 (F-625), respectively. These characterizations can be used to find differences among sorghum hybrids which could help predict sorghum flour quality for use in gluten-free products.

Introduction:

An estimated 1-2 percent of adults and 4-8 percent of children suffer from food allergies (Lehrer and others 2002). There are eight major food allergens responsible for about 90% of food allergies. The eight major food allergens are: milk, eggs, fish, Crustacean shellfish, tree nuts, peanuts, wheat, and soybeans (U.S. Federal Department of Agriculture 2004). With wheat being one of the major food allergens, the need for wheat-free foods has been observed. Furthermore, wheat is a gluten-containing grain that poses a threat to those with celiac disease. Celiac disease is an autoimmune inflammatory disease of the upper small intestine resulting from the ingestion of gluten in genetically susceptible individuals (Case 2006).

In 2003, the University of Maryland Center for Celiac Research in Baltimore, conducted a study that found that 1 out of 133 Americans have celiac disease. More recent estimates are 1:100 Americans are affected by this disease (Case 2006). The increase in prevalence of celiac disease has caused a bigger demand for gluten-free products. From 2004 to 2005 alone, sales of gluten-free foods increased 14.6% or 77.8 million dollars (University of Chicago Celiac Disease Program 2006).

With an increasing number of people being diagnosed with celiac disease and the market for gluten-free products thriving, there is a perfect opportunity to create new products using sorghum. Sorghum is a gluten-free cereal grain grown world-wide. According to the U.S. Grains Council (2008), grain sorghum is the fifth most important cereal crop grown in the world. In the U.S., grain sorghum is the third most important. In 2006, the United States produced 393.7 million bushels of sorghum. Of the U.S.

production, 89% came from the following five states in ranking order: Kansas, Texas, Nebraska, Oklahoma, and Missouri.

With sorghum being such an available product, there is a great deal of logic to use the grain to produce gluten-free foods. However, there needs to be an understanding of different hybrids. Physical and chemical characteristics are important factors in determining the quality of grain and flour. Therefore, the objective of this study was to compare chemical and physical characteristics of the grain and flour from four sorghum hybrids.

Materials and Methods:

Sorghum Hybrids

Four sorghum hybrids were obtained from collections at the Grain Marketing and Production Research Center (GMPRC) of the United States Department of Agriculture in Manhattan, KS. The four hybrids were: Fontanelle-625 (F-625), Fontanelle-1000 (F-1000), ATx631*RTx2907 (NE#20), and 5040C. F-625and F-1000 are white sorghums. NE#20 is a heterowaxy white sorghum. 5040C is a red sorghum.

Grain Characterization

Single Kernel Characterization System (SKCS):

Prior to analysis, the grain was cleaned by sieving about 500 kernels over a No. B-P 5/64” inscribed circles (0.0781”) and triangle (8/64” TRI) PRECISION sieves with an E bottom pan all manufactured by Seedburo (Chicago, IL) to rid the grain of dirt and dust. Large pieces of contaminants that did not fall through the sieve were picked out by hand.

The cleaned grain was then analyzed using the Single Kernel Characterization System (SKCS) 4100 (Perten Instruments, Inc., Springfield, IL) as described in Bean and others (2006). Averages and standard deviations of 300 kernels are reported for all measurements.

Kernel Abrasive Hardness:

A tangential abrasive dehulling device or TADD (Venebles Machine Works, Saskatoon, Canada) was used to determine the abrasive hardness of the kernels for each of the four hybrids as described in Oomah and others (1981). An 80-grit abrasive, supplied by the manufacturer, was used.

Flour Characterization

Starch Isolation:

This procedure used sonication to isolate the starch similar to that done by Park and others (2006). Prior to the four hybrids, practice run throughs were achieved with Twin Valley Mill sorghum flour (Twin Valley Mills, LLC, Ruskin, NE) to ensure proper isolation.

The flours were prepared with the decorticated grain from the abrasion hardness experiment. The decorticated grain was milled with a Cyclone sample mill (Udy Corporation, Fort Collins, CO) and collected into sealable plastic bags.

In preparation for starch isolation, 500ml of pH 10 buffer was made. First, 50ml of 12.5mM sodium borate pH 10 was prepared with 0.21g of boric acid and 1.1g of borax in 50ml of distilled water. This solution was then diluted to 500ml with distilled water and 2.5g SDS and 2.5g of sodium metabisulfite were dissolved in the mixture. The solution was placed on a hot plate on low heat while being stirred to speed up the dissolving of particulates.

Once the buffer was made, 7.5g of flour and 150ml of buffer were added to a beaker making a 1:20 ratio. The mixture was stirred to ensure no lumps. The beaker was then placed in ice water and sonicated for 100 seconds in a VCF-1500 ultrasonic processor (Sonics & Materials, Inc., Newton, CT). The ice water was used to keep the solution cool as the sonication creates heat. After sonication, the mixture was poured into centrifuge bottles and centrifuged for 10 minutes at 4000rpm. The remaining liquid was decanted. Using 40ml of distilled water, the solid was washed and carefully pushed through a 62µm screen on top of a funnel placed in another centrifuge tube. The suspension was placed in the centrifuge for 5 minutes at 4000rpm and the liquid again decanted. The solid was resuspended in 40ml of distilled water and centrifuged for 5 minutes at 4000rpm and decanted. The solid was resuspended again in 40ml of distilled water and centrifuged for 5 minutes at 4000rpm. After the liquid was decanted, the dry pellet containing sorghum starch was freeze dried with a Labconco Freezone 6 Freeze Dryer (Labconco Corporation, Kansas City, MO)

Flour Particle Size Distribution:

A Beckman Coulter LS™ 13 320 Laser Diffraction Particle Size Analyzer (Beckman-Coulter, Inc., Miami, FL) was used to determine the particle size distribution of the four flour hybrids. A dry procedure was utilized. The flour was poured into the canister until reaching about 2/3 full. The canister was then placed in the instrument and the measurements were taken.

Starch Particle Size Distribution:

A Beckman Coulter LS™ 13 320 Laser Diffraction Particle Size Analyzer (Beckman-Coulter, Inc., Miami, FL) was used to determine the particle size distribution of the starches isolated from the four hybrids. The Universal Liquid Module (Beckman-Coulter, Inc., Miami, FL) was used with a wet procedure to help suspend such small particles. The freeze-dried starch samples were ground in a coffee grinder (Mr. Coffee, Shelton, CT) before being placed into a microfuge tube. 0.01g of starch was hydrated in 1% sodium azide for 1.5 days to prevent clumping.

Total Starch:

The total starch content of the four commercial flours was determined using Megazyme Total Starch Assay kit, K-TSTA 05/06 (Megazyme International Ireland Ltd., Co. Wicklow, Ireland). This is the amyloglucosidase/α-amylase method (AOAC Method No. 996.11). This enzymatic procedure uses thermostable α-amylase for solubilization. The dextrins are hydrolyzed to glucose by amyloglucosidase. Since sorghum starch can have high levels of resistant starch, a pretreatment with dimethyl sulphoxide (DMSO) was performed.

Starch Damage:

Starch damage was determined on the commercial flour of each variety using Megazyme Starch Damage Assay kit, SDA 11/01, AACC Method 76-31 (Megazyme International Ireland Ltd., Co. Wicklow, Ireland). This enzymatic procedure first hydrates and hydrolyzes the damaged starch granules with purified fungal α-amylase. Sulphuric acid stops the reaction and amyloglucosidase is added for complete degradation of dextrins to glucose.

Amylose/Amylopectin:

The amylose and amylopectin content of each starch was found using Megazyme Amylose/Amylopectin Assay Kit, K-AMYL 04/06 (Megazyme International Ireland Ltd., Co. Wicklow, Ireland). Dimethyl sulphoxide (DMSO) and heat help disperse the starch at the start of this enzymatic test. Ethanol is added to remove lipids and the amylopectin is precipitated with concanavalin A (Con A). Amylose is hydrolyzed with a glucose oxidase/peroxidase reagent and the samples are compared to the total starch sample.

Starch Pasting Properties:

A Rapid Visco Analyser (Model 4, Newport Scientific, Australia) was used to find the paste viscosity profiles of the starches from the four hybrids. The RVA was turned on and allowed to warm up for 30 minutes. After a control was run, distilled water (25.2g) was weighed into a new canister to achieve 14% moisture basis. The starch (3.32g) was weighed out in a weighing boat and poured onto the water surface. Then, the paddle was placed into the canister and pumped up and down 10 times and stirred 20 times to ensure no lumps are on the surface or the paddle. After mixing, the paddle was set in the canister and the canister is placed into the RVA instrument. The motor tower was pushed down and the measurement cycle began.

A pasting curve is given as the end result along with the values for pasting temperature, peak viscosity, time to peak, breakdown, minimum viscosity, setback and final viscosity. The pasting curve is a result of the starch slurry being subjected to an increase in temperature. The temperature starts at 50^{o}C and rises to 95^{o}C where it is held for a certain period of time. The temperature then decreases back down to 50^{o}C and is held again.

Moisture Content:

The moisture contents of the starches and flours were determined using an infrared moisture analyzer, IR-100 Power Module (Denver Instrument Company, Arvada CO). Between 2 and 3 grams of starch or flour were placed on the machine and measurements taken.

Crude Protein Content:

The crude protein of each flour was determined using a LECO FP-528 instrument (Leco Corporation, St. Joseph, MI). The AACC approved method 46-30 (10th edition) was followed.

Ash Content:

The ash content was found using an adoption of the AACC approved method 08-01. Modifications were as followed: 3 to 4 g of flour, 21 hours at 1000°F, cool for 1 hour in desiccator and weigh.

Statistical Design

Four treatments of sorghum flour were evaluated for grain and flour characterizations. For grain characterization, two replications were performed. For flour characterization, two replications were performed for particle size distributions, total starch, starch damage, amylose content, and pasting properties. Triplicate readings were taken for moisture, protein, and ash content.

All data were analyzed using SAS, Software Release 9.1 (SAS, Institute Inc., 2003). When treatment effects were found significantly different, the least square means with Tukey-Kramer groupings were used to differentiate treatment means. A level of significance was observed at $\alpha = 0.05$.

Results and Discussion:

Grain Characterization

Single Kernel Characterization System (SKCS):

Significant differences were found among the four hybrids ($p<0.05$) for hardness index, kernel weight, and kernel diameter (Table 1). F-625 and NE#20 had higher hardness index averages that were significantly higher than F-1000 and 5040C. The average hardness indexes ranged from 72.1 (5040C) to 82.7 (NE#20). F-625 had the lowest average kernel weight (23.1mg) and NE#20 the highest average kernel weight (29.5mg). Significant differences were found among the hybrids, but F-1000 and NE#20 were not significantly different from each other in terms of kernel weight. Kernel diameter averages were the highest for NE#20 (2.44mm) and F-1000 (2.41mm). NE#20 and F-1000 were significantly different from F-625 and 5040C. Kernel moisture values (not shown) ranged from 13.8 (F-625) to 14.9 (F-1000). These values were not studied as the SKCS is not an accurate predictor of sorghum kernel moisture (Bean and others 2006).

Since 1994, the single kernel characterization system (SKCS) has been available for commercial use (Lyford and others 2005). The function of SKCS is established mainly throughout the wheat industry for end-use quality identification. However, Pedersen and others (1996) and Bean and others (2006) found that the SKCS can be used to successfully measure sorghum grain attributes.

Kernel hardness, weight and size are considerable factors used when evaluating sorghum grain quality (House 1985). According to Bean and others (2006), grain hardness is an important attribute related to grain quality and the end-use quality of grain products. Grain hardness can also be related to the defense mechanism of the plant (Chandrashekar and Mazhar 1999). Sorghum cooking quality such as adhesion and cooked grain texture have been associated with grain hardness (Cagampang and Kirleis 1984). In specific products, sorghum porridge and couscous quality have also been related to grain hardness (Rooney and others 1986; Aboubacar and Hamaker 1999). Grain hardness is also an important factor in milling quality (Rooney and Waniska 2000).

Kernel Abrasive Hardness:

Significant differences were found ($p<0.05$) for the averages of abrasive hardness index (AHI) shown in Table 1. F-625 had the highest average AHI (12.7) and 5040C had the lowest average AHI (8.4). Significant differences were found among the hybrids, but F-1000 and NE#20 were not significantly different from each other in terms of AHI.

Abrasive dehulling is important in removing the fiber and tannin content (Deshpande and others 1982). Appearance, texture, and cooking quality are improved by abrasive dehulling (Kon and others 1973). Kernel hardness is important in end-use properties and milling yield (Stenvert 1972). The abrasive hardness of a kernel demonstrates hardness without destroying the grain, unlike the crushing hardness used in SKCS. F-625 and NE#20 were significantly different in terms of AHI, but not significantly different in terms of the SKCS hardness index. This suggests that different factors influence AHI values compared to those which influence the SKCS hardness index values. Factors effecting AHI are kernel shape, kernel size, and pericarp thickness (Kirleis and Crosby 1982; Lawton and Faubion 1989).

Table 1. Comparison of kernel hardness index, weight, and diameter using Single Kernel Characterization System and abrasive hardness index using Tangential Abrasive Dehulling Device for four sorghum hybrids*

		SKCS[1]		TADD[2]
Sample	**Hardness Index**	**Kernel Weight (mg)**	**Kernel Diameter (mm)**	**AHI[3]**
F-625	81.1 ± 0.8^{a}	23.1 ± 0.4^{c}	2.09 ± 0.03^{b}	12.8 ± 0.2^{a}
F-1000	75.0 ± 0.6^{b}	29.4 ± 0.4^{a}	2.41 ± 0.03^{a}	12.2 ± 0.1^{b}
NE#20	82.7 ± 0.7^{a}	29.5 ± 0.7^{a}	2.44 ± 0.06^{a}	12.3 ± 0.1^{b}
5040C	$72.1 \pm 1.5.^{b}$	27.0 ± 0.7^{b}	2.12 ± 0.01^{b}	8.4 ± 0.1^{c}

*Means with different superscripts in columns indicate significant differences among treatments ($p<0.05$)

1 Single Kernel Characterization System

2 Tangential Abrasive Dehulling Device

3 Abrasive Hardness Index

Flour Characterization

Flour Particle Size Distribution:

Table 2 shows the average flour particle diameter (µm) for each sample at five different volume percents: 10, 25, 50, 75, and 90. Significant differences were found ($p<0.05$) at each of the five volume percents. The average flour particle diameters ranged from 27.9µm to 33.9µm , 83.8µm to 101.8µm, 154.4µm to 191.8µm, 244.3µm to 299.6µm, 320.5µm to 367.1µm for 10, 25, 50, 75, and 90 volume percents, respectively. NE#20 had the largest particle diameter at each volume. F-625 had the smallest particle diameter at each volume, except at 10% in which 5040C had the smallest. All four hybrids produced a sigmoidal distribution.

Schober and others (2007) found lower values for sorghum flour particle size compared to the values found in this study. The particle diameter (<µm) was 21.7µm, 118.6µm, and 276.6µm for 10, 50, and 90 volume percents, respectively.

Flour particle size distribution has been related to the functional properties in different ways. For cowpea flour, a higher fraction of small particles produces poor performance in *akara*, a fried cowpea paste (McWatters 1983). Nixtamalized corn (masa) flour requires different particle size distributions depending on the end product. Fried corn chips need a coarse particle size for crispiness (Montemayor and Rubio 1983). Corn tortillas, on the other hand, require a fine particle size for flexibility and cohesiveness (Montemayor and Rubio 1983). Gomez and others (1987) reported smaller particle size in masa to be generally related to more water uptake, cohesiveness, plasticity and smoothness.

Table 2. Comparison of flour particle size distributions for four sorghum hybrids*

	Volume % (Diameter <µm)				
Sample	10	25	50	75	90
F-625	28.6 ± 0.6^{c}	83.8 ± 1.1^{c}	154.4 ± 0.8^{d}	244.3 ± 0.9^{c}	320.5 ± 1.7^{b}
F-1000	31.5 ± 0.3^{b}	88.8 ± 1.5^{b}	163.1 ± 1.2^{c}	250.2 ± 0.0^{c}	324.6 ± 1.0^{b}
NE#20	33.9 ± 0.3^{a}	101.8 ± 0.7^{a}	191.8 ± 3.4^{a}	299.6 ± 3.7^{a}	367.1 ± 4.5^{a}
5040C	27.9 ± 0.8^{c}	88.9 ± 0.5^{b}	177.8 ± 1.9^{b}	278.1 ± 2.1^{b}	356.7 ± 5.0^{a}

*Means with different superscripts in columns indicate significant differences among treatments ($p<0.05$)

Starch Particle Size Distribution:

The average starch particle diameters (µm) for each sample were found at five different volume percents: 10, 25, 50, 75, and 90 (Table 3). Significant differences were found ($p<0.05$) at each of the five volume percents. The average starch particle diameters ranged from 6.2µm to 7.3µm , 11.7µm to 13.7µm, 17.6µm to 20.8µm, 24.5µm to 28.7µm, 31.7µm to 37.1µm for 10, 25, 50, 75, and 90 volume percents, respectively. NE#20 had the largest particle diameter at each volume, except at 10% in which F-1000 had the largest. F-625 had the smallest particle diameter at each volume. All four hybrids produced a sigmoidal distribution.

Starch particle size can impact processing and end-product quality. Wheat starch contributes functional qualities in food such as volume, texture, appearance, and retrogradation with firming and syneresis (Wilson and others 2006). Small (B-type) starch granules in wheat have been associated with water absorption and bread loaf volume (Hoseney and others 1971). Morikawa and Nishinari (2002) found that rheological behavior of chemically modified potato starch dispersions is strongly influenced by granule size and distribution.

Table 3. Comparison of starch particle size distributions for four sorghum hybrids*

	Volume % (Diameter <µm)				
Sample	10	25	50	75	90
F-625	6.2 ± 0.3^{b}	11.7 ± 0.7^{b}	17.6 ± 0.6^{c}	24.5 ± 0.8^{b}	31.7 ± 1.4^{b}
F-1000	7.3 ± 0.1^{a}	13.2 ± 0.1^{a}	19.5 ± 0.0^{ab}	26.2 ± 0.1^{b}	32.3 ± 0.2^{b}
NE#20	7.1 ± 0.2^{a}	13.7 ± 0.2^{a}	20.8 ± 0.3^{a}	28.7 ± 0.7^{a}	37.1 ± 1.3^{a}
5040C	6.3 ± 0.1^{b}	12.5 ± 0.0^{ab}	18.7 ± 0.1^{bc}	25.4 ± 0.5^{b}	32.9 ± 0.6^{b}

*Means with different superscripts in columns indicate significant differences among treatments (p<0.0

Total Starch:

The total starch content of the sorghum flour was not significantly different among hybrids ($p<0.05$) (Table 4). Total starch ranged from 66.6 % (F-1000) to 72.6% (NE#20) on a dry basis. Buffo and others (1998) reported an average starch content of 73.12 ± 2.73 (% db) for sorghum grain.

Starch Damage:

F-1000 had significantly higher starch damage at 3.0 ($p<0.05$) compared to the other three hybrids. F-625, NE#20, and 5040C were not significantly different from each other (Table 4). Physical effects of milling cause starch damage (Stasio and others 2007). Starch damage affects water absorption, mixing properties, and end-product quality. There is a positive correlation between damaged starch and water absorption (Evers and Stevens 1985). Damaged starch also affects rheology and fermentation of leavened wheat products (Stasio and others 2007). In bread making, too much starch damage can produce slack dough, but too little starch damage causes low bread volumes and heavy texture (Mao and Flores 2001). In maize starch pastes, Han and others (2002) showed that an increase of starch damage caused a decrease in elastic properties.

Amylose/Amylopectin:

Amylose content (%) ranged from 20.2 (NE#20) to 27.3 (F-1000). Significant differences were found ($p<0.05$) (Table 4). NE#20 was significantly lower than the other hybrids. This was expected as NE#20 is a heterowaxy sorghum. Waxy grains contain lower amylose content compared to their counterpart. The amylose/amylopectin ratio is a property of cereal starches that affects the end product by varying gelatinization, gelation, solubility, resistant starch formation, and textural characteristics (Juliano 1971; Berry and others 1988; Sievert and Pomeranz 1989; Tester and Morrison 1990; Leloup and others 1991). Park and Baik (2004) reported amylose content effecting water absorption, lightness (color), fat absorption, cooking time, and texture properties of cooked instant noodles. In bread making, waxy and partial waxy wheat flour have greater resistance to retrogradation during storage (Sasaki and others 2000). Park and Baik (2007) observed a greater crumb moisture content and softer crumb texture in French bread when using flours with 15.4 to 16.6% amylose content. In rice, the amylose content is an important attribute for determination of eating and cooking quality (Tan and Corke 2002).

Table 4. Comparison of total starch, starch damage, and amylose content of four sorghum hybrids*

Sample	Total Starch (% db)	Starch Damage	Amylose %
F-625	72.5 ± 2.2^{a}	2.7 ± 0.1^{b}	$25.6 + 2.3^{ab}$
F-1000	66.6 ± 8.6^{a}	3.0 ± 0.1^{a}	27.3 ± 0.6^{a}
NE#20	72.6 ± 1.6^{a}	2.8 ± 0.1^{b}	20.2 ± 0.7^{c}
5040C	71.5 ± 2.6^{a}	2.8 ± 0.1^{b}	24.1 ± 1.4^{b}

*Means with different superscripts in columns indicate significant differences among treatments ($p<0.05$)

Starch Pasting Properties:

Significant differences were found ($p<0.05$) at each parameter of the Rapid Visco Analyser (RVA) curve, except the final viscosity and set back. F-1000 had the highest peak viscosity (428.7 RVU) and breakdown (380.4 RVU). The lowest peak viscosity (380.1 RVU) and breakdown (296.1 RVU) were from NE#20.

Since starch can express differences in properties from even the same plant cultivar and species (Fujita and others 1996), analyzing and understanding the pasting properties of each variety or hybrid is important. In rice, the pasting properties and amylose content play important roles in eating and cooking quality (Tan and Cork 2002; Allahgholipour and others 2006). Juliano (1985) reports that the paste viscosity is an important difference revealed among rice varieties with similar amylose contents. The protein content and liberation of free fatty acids during storage of whole grain sorghum flour creates different pasting properties during cooling (Zhang and Hamaker 2005). These differences could cause variation in cooking quality, such as thick porridge made from sorghum flour in certain African regions (Aboubacar and others 1999). In alkaline cooking of corn, RVA viscosity values have been correlated to grain floatation, hardness and cooking parameters (Almeida-Dominguez and others 1997).

Table 5. Comparison of starch pasting properties from four sorghum hybrids using a Rapid Visco Analyser*

Sample	Peak Viscosity (RVU)	Trough (RVU)	Breakdown (RVU)	Final Viscosity (RVU)	Setback (RVU)	Peak Time (min)	Pasting Temp (^{o}C)
F-625	428.7 ± 2.7^{b}	85.5 ± 1.8^{a}	324.3 ± 0.2^{b}	236.5 ± 5.6^{a}	151.0 ± 7.4^{a}	3.78 ± 0.00^{bc}	70.50 ± 0.00^{b}
F-1000	476.8 ± 4.36^{a}	77.5 ± 1.6^{b}	380.4 ± 1.8^{a}	255.3 ± 0.9^{a}	177.9 ± 0.6^{a}	3.81 ± 0.00^{b}	71.60 ± 0.28^{ab}
NE#20	380.1 ± 8.6^{c}	84.0 ± 1.1^{a}	296.1 ± 7.5^{c}	266.5 ± 5.0^{a}	182.5 ± 4.0^{a}	4.14 ± 0.00^{a}	72.15 ± 0.57^{a}
5040C	417.8 ± 3.5^{b}	83.5 ± 1.9^{ab}	318.5 ± 3.2^{b}	256.8 ± 13.1^{a}	173.3 ± 15.0^{a}	3.77 ± 0.02^{c}	71.33 ± 0.04^{ab}

*Means with different superscripts in columns indicate significant differences among treatments ($p<0.05$)

Moisture Content:

F-625 had a significantly higher moisture content (15.00%) than the other hybrids. The lowest moisture content coincided with NE#20 (11.44%). Buffo and others (1998) found unground sorghum seeds to have a moisture content from 13.80 to 13.95%.

Crude Protein Content:

Table 6 shows the crude protein contents of the four sorghum hybrids. Significant differences were found among the four hybrids ($p<0.05$). The values ranged from 8.61 (% db) to 10.53 (% db) with F-1000 having the lowest and NE#20 having the highest protein content. F-625 and 5040C were not significantly different from each other.

The protein content for cereal grains is important not only for nutritional purposes, but also for functional reasons. In wheat breadmaking, Pomeranz and others (1976) found that variations in protein content within a variety described 96% of loaf volume variability. Aamodt and others (2003) related the effects of protein content on hearth loaves to the amount of glutenin polymers. Sorghum-wheat composite doughs produce higher tensile strength and increased loaf volumes when zein (maize prolamin) is added (Bungusu and others 2001). Similar results could take place if kafirin, the sorghum prolamin encapsulated in protein bodies of the endosperm, could be made available during dough formation (Bugusu and others 2001).

Ash Content:

Ash content (%db) ranged from 1.20 (F-1000) to 1.45 (F-625) (Table 6). All hybrids were significantly different from each other except NE#20 and 5040C ($p<0.05$).

Ash content is an indication of the amount of bran and germ contamination in milling (Kim and Flores, 1999). A flour mill uses different flour streams in order to create a flour of a specific ash content (Shellenberger and Ward 1967). In terms of flour quality, ash content is an important indicator of flour color (Kim and Flores 1999) and bakers continue to look at ash content as a factor of flour grade.

Sorghum couscous quality was related to ash in a study by Aboubacar and Hamaker (1999). They reported that sorghum cultivars have high couscous yields when the flour has a low ash content and high proportion of course particles. Suroso and others (2000) used ash content of sorghum grits as a factor in determining bran contamination. The lower ash content was thought to have more potential for utilization in human food.

Table 6. Comparison of moisture, protein, and ash content of four sorghum hybrids*

Sample	Moisture Content (%)	Protein (% db)	Ash (% db)
F-625	15.00 ± 0.12^{a}	9.85 ± 0.08^{b}	1.45 ± 0.01^{a}
F-1000	11.91 ± 0.14^{bc}	8.61 ± 0.05^{c}	1.20 ± 0.00^{c}
NE#20	11.44 ± 0.19^{c}	10.53 ± 0.05^{a}	1.40 ± 0.02^{b}
5040C	12.45 ± 0.38^{b}	9.87 ± 0.05^{b}	1.41 ± 0.01^{b}

*Means with different superscripts in columns indicate significant differences among treatments ($p<0.05$)

Conclusions:

This study has shown that sorghum hybrids can differ in kernel and flour properties. Although not enough studies were found on the implications of these findings in the production of sorghum based foods, similar findings in other grains would indicate potential correlation of sorghum grain hybrids to sorghum foods. The results could help predict sorghum flour quality for the purpose of gluten-free products. Based on this conclusion, our next step was to formulate a gluten-free flour tortilla and evaluate the impact of different hybrids on the quality of the tortilla.

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Chapter 3:

Evaluation of Four Sorghum Hybrids through the Development of Sorghum Flour Tortillas

Abstract

Gluten-free flour tortillas were made with five different sorghum flours to evaluate flour quality. Four sorghum hybrids were used along with a commercial sorghum flour. The four hybrids were: Fontanelle-625 (F-625), Fontanelle-1000 (F-1000), ATx631xRTx2907 (NE#20), and 5040C. The tortilla weight, diameter, thickness, color, pH, A_w, and moisture content were measured along with extensibility and stretchability. A descriptive panel was trained and used to analyze the five samples. Significant differences were found ($p<0.05$) among samples for color, pH, A_w, and moisture content. Significant differences were also found ($p<0.05$) among samples for extensibility and stretchability. Extensibility was a more effective test in studying quality. Extensibility force and distance values ranged from 534.94g (TVM) to 664.68g (F-625) and 0.39mm (F-1000) to 0.52mm (F-625), respectively. The sensory panel found significant differences ($p<0.05$) for grain specks, angle of bend, rancidity, sweetness, springiness, hardness, and grittiness. The commercial flour had the highest score for angle bend (12.92) and springiness (3.50) and was, therefore, utilized in a consumer study. When compared to a gluten-free wrap already in the market, the sorghum flour tortilla made from this study scored significantly higher in all attributes, including overall acceptability with an average score of 5.94. The commercial flour preformed better than the other four samples due to its smaller particle size and greater starch damage allowing an increase in water absorption.

Introduction:

Flour tortillas may have started as an ethnic food being used in burritos, tacos, and fajitas, but the United States is stretching the tortilla in other areas as a bread replacement. Typically called a wrap, the tortilla is being used to carry salads, sandwiches, and even breakfast items (Seiz 2006). According to the Tortilla Industry Association, 78% of fine dining restaurants have tortillas in a menu item (Petrak 2006a).

The supermarket is seeing the popularity of tortillas as well with sales reaching $1 billion (Petrak 2006b). Part of this popularity comes from important innovation with whole grains and omega-3 fatty acids being used in a normally plain product (Seiz 2006). With tortillas going mainstream, sales doubled in the past decade (Petrak 2006b).

But, there are some people who are not able to contribute to such a growth. Approximately 1:266 people in the world have celiac disease, and about 1:100 individuals are affected in the U.S. (Case 2006). Also known as gluten-sensitive enteropathy or celiac sprue, celiac disease is an autoimmune inflammatory disease of the upper small intestine resulting from the ingestion of gluten in genetically susceptible individuals (Case 2006). Gluten is a protein found in wheat, barley, and rye. These grains are found in common foods like bread, ready to eat cereal, and of course flour tortillas. The development of flour tortillas with gluten-free grains would allow celiac patients to remain included in the growth and cultural development of food products.

Sorghum is a world wide gluten-free grain. According to the U.S. Grains Council (2008), grain sorghum is the fifth most important cereal crop grown in the world. In the U.S., grain sorghum is the third most important. In 2006, the United States produced 393.7 million bushels of sorghum. Of the U.S. production, 89% came from the following five states in ranking order: Kansas, Texas, Nebraska, Oklahoma, and Missouri. Most of the grain is either exported or used for feed.

In Africa and Asia, sorghum is a major food crop (Serna-Saldivar and Rooney 1995). An estimated 30-40% of sorghum is consumed by humans (Rooney and others 1986; Murty and Kumar 1995). The number could increase with the utilization of sorghum in gluten-free products. All sorghum varieties are gluten-free making them appealing to people with celiac disease or wheat allergies. Also, the white varieties have a neutral taste allowing them to absorb many flavors (U.S. Grains Council 2008). Finally, sorghum is extremely drought tolerant making it easily grown in many parts of the world.

The objectives of this study were to develop an acceptable sorghum flour tortilla and evaluate the physical, chemical, textural, and sensory effects of different sorghum variety flours utilized in the sorghum flour tortilla.

Materials and Methods:

Preliminary Work

Preliminary experimental work was performed in order to optimize a sorghum flour tortilla formula. Being able to produce a basic wheat flour tortilla seemed necessary before further testing was done with sorghum. The United States Department of Agriculture's Grain Marketing and Production Research Center (GMPRC) in Manhattan, KS provided a wheat tortilla formula. After following the methods, a satisfactory flour tortilla was made. Using the GMPRC formula, sorghum flour was 100% substituted for wheat flour. Xanthan gum, gelatin, and egg powder were tested along with variations in shortening and water levels.

Then, two batter-type formulas were tested. One was from a gluten-free cookbook (Hagman 2000) and the other from a gluten-free website (Wheat-Free.org 2006). Both formulas were gluten-free tortillas or wraps that utilized starches, such as tapioca, corn starch, and bean flour, and eggs. The cookbook formula called for xanthan gum.

Finally, a gluten-free tortilla formula was developed using a dough-type formula. The formula originally consisted of sorghum, rice, and potato flour as well as many functional ingredients. Different ratios of the flours were tested to increase the amount of sorghum flour. Once sorghum was the only flour, each of the functional ingredients was assessed at varying types and levels to determine optimums. The ingredients were categorized into three groups by their affect on structure, texture, and taste. Prototypes were informally evaluated by a panel of faculty and students at Kansas State University as well as employees from GMPRC. Panelists looked at appearance, taste, and rollablity.

The procedure was also optimized. Mixing times, mixing speeds, water temperatures, press time and temperatures, and griddle time and temperatures were all studied. Parchment paper was necessary to place on the press plates to avoid sticking and for easy transfer of the tortilla to the griddle. Samples were evaluated in the same way as with ingredient optimization.

Factors Affecting Structure

Dried egg whites were initially utilized to help hold the dough together. However, when the egg white was removed from the formula the flexibility of the tortilla increased. This is probably due to the egg protein creating a rigid gel. The cooled gel was constricting the tortilla from rolling.

After testing four different types of gums, the tortilla was found to work best with xanthan gum alone at a level of 1.0% (based on 100% flour). Guar gum also worked, but the dough was sticky and usually fell apart while trying to get on the griddle. Both carboxymethylcellulose (CMC) and hydroxypropylmethylcellulose (HPMC) produced a dough that was too soft to get a tortilla.

Figure 1. Guar gum at 0.375% (100% Flour Basis)

Acid modified starches did not seem to improve the tortilla quality. National Starch Struct-sure 20, an acid modified corn starch, created a tortilla that cracked easier. Xpandex modified tapioca starch was advertised as a gluten-free baking necessity. However, there was no noticeable difference found in the tortilla.

Factors Affecting Texture

Leavening agents were necessary to test. Double-acting baking powder, sodium bicarbonate, and ammonium bicarbonate all produced tortillas with similar puffing and layering. Although there was sufficient puffing and layering at levels of 4% (100% Flour Basis), the tortilla lost rollability. Baking powder gave the best taste and rollability at 0.75% (100% Flour Basis).

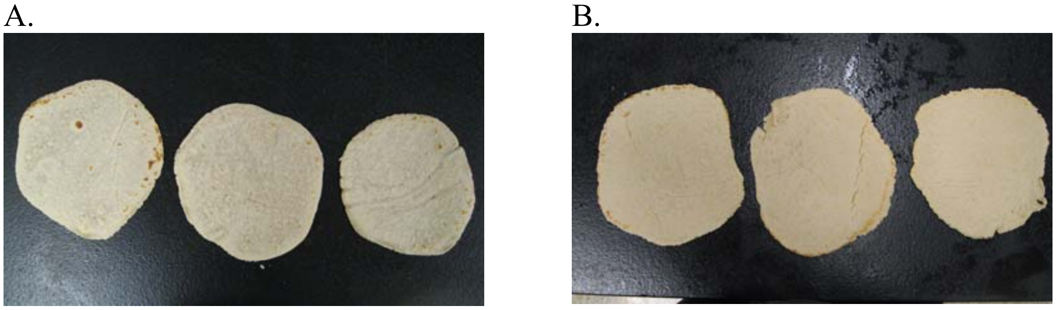

Figure 2. A. Baking Powder at 0% (100% Flour Basis); B. Baking Powder at 4% (100% Flour Basis)

Emulsifiers were found to improve the dough and tortilla quality. Glycerin and monoglycerides were found to help with the machineability of the dough and rollability of the tortilla. Both were used at slightly higher levels than usual in order to replace the functionality of gluten.

No noticeable difference was found with alpha-amylase addition. The enzyme was diluted (1:10) with sorghum flour for ease of measuring. The dough was allowed to rest for enzyme activation.

Factors Affecting Taste

Shortening was found to be more effective than oil. Oil seemed to help with rollability, but the dough handling properties were poor. When shortening levels were at 20% (100% Flour Basis) the dough was oily and the tortilla was hard after cooking. A level of 11.5% (100% Flour Basis) shortening was found to be optimum.

Salt and citric acid levels were agreeable to flavor. The sugar level, 15% at 100% Flour Basis, is high for a tortilla formula, but is necessary to mask the bitter taste of sorghum flour.

Procedure

Mixing the dry ingredients, then adding the shortening and glycerin and mixing, and finally adding the water produced the best results. The mixing times were shorter than a typical tortilla process. Over-mixing made the dough too soft. There is no gluten development, so the mixing was mainly for ingredient incorporation and dispersion.

Warm water (38°C) proved to be the best temperature. Allowing the warm dough to rest did not show any differences. The purpose of resting the dough in wheat tortilla procedures is for the gluten structure to relax (Serna-Saldivar 1988). Since gluten is not an issue in sorghum flour tortillas, resting should not be required.

The tortillas had the best rollability when pressed at 230°C for 6 seconds. Two pieces of circular parchment paper were used in the press to avoid sticking. One piece was placed on the lower plate and the dough ball set on top of the paper. The second piece of parchment paper was placed on top of the dough ball and then moved into position for pressing.

Once the tortilla was pressed, one side of the parchment paper was removed and the dough side placed down on the griddle. The second piece of paper was then removed and the tortilla cooked for 30 seconds on each side at 350°F. This was the time and temperature for the best rollability. The tortilla still has some doughy characteristics after cooking this long. But when cooked longer to get rid of this doughy trait the tortilla becomes hard.

Samples

Four sorghum hybrids were obtained by GMPRC of Manhattan, KS. The sorghum was milled by a Bliss Hammermill and the final sift was with a Great Western box sifter through a #120 screen. The four hybrids were: Fontanelle-625 (F-625), Fontanelle-1000 (F-1000), ATx631xRTx2907(NE#20), and 5040C. F-625and F-1000 are white sorghums. NE#20 is a waxy white sorghum. 5040C is a red sorghum.

After finding that these four flours did not work properly in the formula developed in the preliminary work, the flour used to optimize the formula was added as a fifth flour. This flour is a commercial sorghum flour from Twin Valley Mills.

All five flour samples were tested in the following formulation and procedure three times.

Tortilla Preparation

The formulation for the sorghum flour tortillas is shown in Table 1. Ingredients used were: sorghum flour, iodized salt (Kroger, Cincinnati, OH), Xanthan gum (Grindsted® Xanthan 200, Danisco USA, Inc., New Century, KS), double acting baking powder (Clabber Girl, Terre Haute, IN), citric acid (Gold Coast Ingredients, Inc., Commerce CA), granulated sugar (Extra Fine, Great Value, Wal-mart Stores, Inc., Bentonville, AR), monoglycerides (Dimodan® PH 300 K-A, Danisco USA, Inc., New Century, KS), all-vegetable shortening (Crisco, J. M. Smucker Company, Orrville, OH), glycerin (Kosher Superol Glycerine USP, Procter & Gamble Chemicals, New Milford, CT), and water. The amount of water for each flour varied. The amounts were 70, 82, 85, 78, and 130 grams for F-625, F-1000, NE#20, 5040C, and TVM, respectively. The dry ingredients (sorghum flour, salt, xanthan gum, baking powder, citric acid, sugar, and monoglycerides) were mixed for 1 minute and 30 seconds on speed 1 in a KitchenAid mixer (KitchenAid, St. Joseph, MI. Shortening and glycerin were added and mixed for 45 seconds at speed 1. The sides were scraped down with a spatula. The ingredients were mixed for another 45 seconds at speed 2 until no clumps were visible. Warm water (38^{o}C) was slowly added while mixing at speed 1 and increasing to speed 3 for a total mixing time of 1 minute and 30 seconds.

Table 1. Formulation for sorghum flour tortillas.

Ingredient	**Amount (g)**
Sorghum	200.0
Salt	5.0
Xanthan	2.0
Baking Powder	1.5
Water	variable
Glycerin	13.5
Vegetable Shortening	23.0
Citric Acid	1.0
Sugar (granulated)	30.0
Monoglycerides	4.5
TOTAL	280.5

The dough was kneaded for 30 seconds and then placed in a sealed container in order to retain moisture. Being careful to keep the dough in the container, 25 grams of dough were weighed out and rolled into a smooth ball by hand. Each dough ball was kept in the sealed container during preparation.

For pressing, a TXA-SS DoughXpress (Perten Instruments, Inc. Springfield, IL 62707) was used with settings of 230°C and a 6 second press time. Two pieces of parchment paper were used to avoid sticking. One sheet was placed on the bottom plate and the dough ball set on top of the paper. The second sheet was then laid on top of the dough ball and pressed. The tortilla was then placed on a DoughPro griddle (Model TW1520, Proprocess Corporation, Paramount, CA) set at 350°F by removing the top piece of parchment paper, laying the tortilla on the griddle, and removing the second piece of parchment paper. The tortilla cooked for 30 seconds on each side. The tortilla was then put on a cooling rack for 2 minutes before being stored in a sealable bag.

Physical and Chemical Measurements

After the tortillas rested in the bags for 4 hours, physical and chemical measurements were taken. Each measurement was taken in triplicates, with the exception of pH and water activity in which duplicates were taken. All measurements were recorded at room temperature which averaged 23.0°C at 24% relative humidity.

Weight

The tortillas were weighed on an A&D HF scale (A&D Company, Limited) one at a time. The values were recorded in grams to the nearest 100th decimal.

Diameter

The diameter of each tortilla was measured with a ruler in centimeters to the nearest 10th decimal. Two values were taken for each diameter measurement. After the first recording, the ruler was turned 90 degrees for a second reading.

Thickness

A caliper was used to determine the thickness of the tortillas. Each tortilla was measured one at a time and the values were recorded in millimeters to the nearest 10th decimal.

Rollability

Rollability scores were obtained using a 1 centimeter dowel. The tortilla was wrapped around the dowel and cracking and breaking was evaluated. A scale from 1 to 5 was used with 1 meaning broke immediately or unrollable and 5 meaning no cracks or breakage. This procedure was used by Waniska and others (2004) in the evaluation of wheat tortilla quality.

Extensibility

Extensibility of each tortilla was tested using a TA.XT.plus Texture Analyzer (Texture Technologies Corp., Scarsdale, NY). The TA-96 tensile grips (Texture Technologies Corp., Scarsdale, NY) were used with the following settings: pre-test speed of 1.00 mm/s, test speed of 1.00 mm/s, post-test speed of 5.00 mm/s, distance of 25.000 mm, and force of 5.0 g.

For each tortilla, two pieces were cut out of the center using a carving knife and a template measuring 3.5 by 3.7 centimeters. Each piece was placed in the tensile grips with the longer side in the vertical direction (Figure 3). The grips were tightened by hand as tight as possible and the test ran. As the test ran, the tortilla piece was pulled up vertically. The maximum peak force values and distance values were recorded.

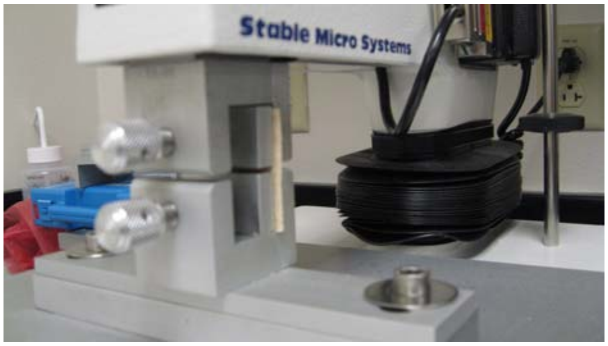

Figure 3. Extensibility test for flour tortillas

Stretchability/Flexibility

The puncture test on a texture analyzer can be used to show the stretchability and flexibility of a tortilla. Each tortilla was tested using a TA.XT.plus Texture Analyzer (Texture Technologies Corp., Scarsdale, NY). The American Institute of Baking provided a standard procedure for flour tortilla stretchability/flexibility measurement to determine the breaking point and rupture force. The TA-108 Tortilla/Film Fixture (Texture Technologies Corp., Scarsdale, NY) and TA-108a 18mm diameter probe w/ rounded edge (Texture Technologies Corp., Scarsdale, NY) were used with the following settings: pre-test speed of 6.00 mm/s, test speed of 1.70 mm/s, post-test speed of 10.00 mm/s, distance of 30.000 mm, force of 20.0 g, and acquisition of 200 pps.

The tortilla was placed in the fixture and pushed through the four screws. The tortilla was screwed in using the bolts. As the test ran, the probe pushed through the center of the tortilla. The maximum peak force values and distance values were recorded.


Figure 4. Stretchability/Flexability test
for flour tortillas

Color

A HunterLab MiniScan (Model MS/S-4000S, Hunter Associates Laboratory Inc., Reston, VA) was used to measure the color of the tortilla samples. “L”, “a”, and “b” values were given as output. “L” was the measurement for lightness (0 = black and 100 = white). Red and green colors were indicated by the “a” value (+a = red and –a = green). The “b” value indicated yellow (+b) and blue (-b) colors.

The device was calibrated with a light trap and white tile provided by Hunter Associates Laboratory Inc. The type of illuminant used was C, average daylight, with a 10° Standard Observer.

pH

A Fisher Scientific Accumet portable pH/mV/Ion meter (Model AP63, Thermo Fisher Scientific, Inc. Waltham, MA) with a glass pH electrode was used to attain pH values. Calibration was performed before each use using buffer solutions of pH 4.0 and 7.0. The AACC method 02-52 was followed according to the flour procedure.

Water Activity

Water activity measurements were determined using an AquaLab water activity meter (Model Series 3, Decagon Devices Inc., Pullman, WA 99163). The instrument was standardized prior to experimental readings. The tortilla samples were broken up into small pieces and placed into disposable sample cups for AquaLab (WP4, Decagon Devices, Inc. Pullman WA 99163). These cups were filled about halfway and placed into the measuring chamber. The dial was turned to read and the results recorded from the digital display on the instrument.

Moisture Content

The moisture content of each tortilla sample was obtained using the AACC method 44-40. The method calls for 2 grams of sample. Instead, 5 grams of each sample was used as this provided better readings. The percentage of moisture and volatile matter were calculated using the following equation.

$$\%\text{ Moisture} = \frac{[\text{Wet Weight (g)} - \text{Dry Weight (g)}] \times 100}{\text{Wet weight (g)}}$$

Sensory Analysis

Descriptive Analysis

Seven panelists took part in a descriptive analysis of the sorghum flour tortillas. The panelists met once a week for 2 to 3 hours. A total of 4 sessions were held for training and development of attributes.

The first session consisted of tasting a sorghum flour tortilla made with commercial flour and determining attributes in terms of appearance, texture in the hand, odor, flavor, and texture by the mouth. First, each panelist created a list of attributes individually. Then, these attributes were shared and a consensus made of all the attributes found in the sorghum flour tortilla. These attributes were compared to those found in grain sorghum (Brannan and others 2001) and wheat flour tortillas (Bejosano and others 2005) in order to confirm all characteristics were accounted for. Finally, each attribute was defined and references suggested for the next session.

In the second and third session, all suggested references were available and the panelists decided on which references to keep, assigned references to appropriate attributes, and scored the references on a scale from 1 to 15. This was done individually first, then as a group to develop a consensus.

The fourth session was used to practice evaluating a sorghum flour tortilla with the descriptive terms, definitions, and references the panelists had developed. The panelists were asked to work quietly as they went through each attribute using the references to determine a score for the tortilla. Distilled water and unsalted saltine crackers were given to cleanse the palate during tasting.

Once training was complete, two more sessions were held to test the five flour samples in prepared sorghum flour tortillas. Two samples were scored at the first session and three samples at the second in order to eliminate panelist fatigue. The samples were given to the panelists with random three-digit number codes. Samples were tested in the same way as the fourth session of training.

Consumer Study

A consumer study was held at Kansas State University in Call Hall. Only one of the five sorghum flours used in the previous experiments was used in this study. Which flour to use was determined by members of the descriptive panel based on a consensus of the most acceptable tortilla sample. TVM was the flour recommended and tortillas were made using the procedure previously mentioned. These tortillas were tested in the consumer study along with a gluten-free wrap made that is currently in the market.

A total of 100 untrained panelists volunteered to participate in the study. Each panelist was given a pre-screening form to obtain information about age, gender, education completed, frequency of flour tortilla consumption, and any known food allergies. If the panelist had a food allergy, then they were asked not to participate in the study. Although the tortillas being tested are considered allergen-free, there was not enough control over the equipment used to ensure no traces of allergens. The panelists were also asked to sign an informed consent statement before participating.

Each of the two samples were placed on white paper plates with an assigned random three-digit number code. Both samples were given to the panelists at one time along with ballots having corresponding three-digit codes. The panelists were asked to test each sample in the order it was given in order to eliminate bias. Unsalted saltine crackers and distilled water were provided for cleansing of the palate.

The ballots contained a 9-point hedonic scale for each attribute. The 9-point hedonic scale displayed the degree of liking with 9 being like extremely, 5 being neither like nor dislike, and 1 being dislike extremely. The attributes tested were overall acceptability, appearance, flavor, texture in the hand, and texture in the mouth. Consumers were also given the change to write additional comments on the ballot.

Statistical Design

Five treatments of sorghum flour tortillas were evaluated for all tests except the consumer study where two treatments were studied. Three replications were treated as blocks in a randomized block design. Triplicate readings of each physical, chemical, and textural test were performed with exception of water activity and pH in which case duplicate readings were taken. Sensory analysis was performed only once for both descriptive analysis and consumer study.

All physical, chemical, textural, and sensory data were analyzed using SAS, Software Release 9.1 (SAS, Institute Inc., 2003). When treatment effects were found significantly different, the least square means with Tukey-Kramer groupings were used to differentiate treatment means. A level of significance was observed at $\alpha = 0.05$.

Results and Discussion:

Physical and Chemical Measurements

Weight, Diameter, and Thickness:

Table 2 shows the averages for weight, diameter, and thickness of the five sorghum flour samples. Tortilla weight range was from 20.9g (5040C) to 21.5g (F-625). Diameter range was from 13.8cm (TVM) to 14.3cm (NE#20). Thickness range was from 1.3mm (TVM) to 1.4mm (F-625).

Table 2. Comparison of weight, diameter, and thickness of sorghum flour tortillas from five different sorghum flours*

Sample	Weight (g)	Diameter (cm)	Thickness (mm)
F-625	21.5 ± 0.2^{a}	14.0 ± 0.1^{b}	1.38 ± 0.08^{a}
F-1000	21.1 ± 0.2^{bc}	14.3 ± 0.2^{a}	1.33 ± 0.05^{ab}
NE#20	21.2 ± 0.1^{b}	14.3 ± 0.2^{a}	1.27 ± 0.09^{bc}
5040C	20.9 ± 0.3^{c}	14.3 ± 0.2^{a}	1.32 ± 0.10^{ac}
TVM	21.3 ± 0.1^{ab}	13.8 ± 0.2^{b}	1.26 ± 0.07^{bc}

*Means with different superscripts in columns indicate significa differences among treatments ($p<0.05$)

Rollability

All of the five samples received an average score of 1.00 for rollability as they could not roll around a 1cm dowel without breaking. Using simply both hands to roll the tortillas, it was found that TVM could roll to a diameter of about 3cm without cracking. The other hybrids could roll to a diameter of about 5cm with 5040C having the most cracking.

Extensibility

TVM was the only sample significantly different for force ($p<0.05$) with the lowest value of 534.9g (Table 3). F-625 had the highest force value of 664.7g. F-625 and TVM both had significantly higher distance values (0.52mm and 0.47mm, respectively). F-1000, NE#20, and 5040C were not significantly different from each other for both force and distance.

A low force value and longer distance of extension indicates soft and extensible tortillas. On the other hand, hard and brittle tortillas show higher force values and shorter rupture distances (Suhendro and others 1999). TVM had a significantly lower force value and higher distance. F-625 had a significantly lower distance value, but the force was high. These longer distance values were probably due to the smaller particle size of the flours. F-625 had the smallest flour particle size (<154.4µm at 50%) and after testing TVM even smaller values were found (<114.6µm at 50%). In gluten-free products, the cohesiveness of dough is relying on inert particles held together by water through surface tension. Finer particle size in the correct amount of water produces more cohesion (Hoseney 1994).

Also, starch damage was found to be much higher for TVM (12.2) than the other four samples (2.7-3.0). Damaged starch increases water absorption (Evers and Stevens 1985). Allowing more water to flow in the system would create a more pliable product as water is considered a plasticizer.

Stretchability/Flexibility

TVM had a significantly lower force (67.5g) and F-625 had a significantly higher force (130.4g) compared to all samples ($p<0.05$) (Table 3). F-1000, NE#20, and 5040C force values were not significantly different from each other. Significant differences were found among samples for distance with values ranging from 4.06mm (TVM) and 5.43mm (F-625).

As the distance of rupture increased, the force increased. A higher force indicates greater stretchability. Mao and Flores (2001) found higher stretchability in wheat flour tortillas with lower starch damage and coarser particle size. After testing TVM for starch damage, our results agree with Mao and Flores (2001). TVM (with the lowest force) had an average value of 12.2 compared to the low 2.7 for F-625 found in Ch. 2. However, particle size was smallest for F-625 which contradicts Mao and Flores (2001).

Through observation, TVM created a softer tortilla. The stretchability test may not be a good indicator of sorghum flour quality for tortillas. A gluten-network is not being formed. The gluten-network in wheat tortillas is what creates a flexible product. Therefore, the goal in gluten-free tortillas is more a means of softness in order to roll. A higher force in this test could mean the tortilla is harder and not as conducive to rolling.

Table 3. Comparison of extensibility and stretchability texture results of sorghum flour tortillas from five different sorghum flours*

	Extensibility		Stretchability	
Sample	Force (g)	Distance (mm)	Force (g)	Distance (mm)
F-625	664.7 ± 56.4^{a}	0.52 ± 0.07^{a}	130.4 ± 12.6^{a}	5.43 ± 0.38^{a}
F-1000	629.7 ± 72.0^{a}	0.39 ± 0.05^{b}	96.3 ± 5.5^{b}	4.58 ± 0.42^{bc}
NE#20	611.2 ± 48.6^{a}	0.40 ± 0.04^{b}	110.5 ± 8.6^{b}	4.98 ± 0.39^{ab}
5040C	617.9 ± 92.2^{a}	0.39 ± 0.07^{b}	104.1 ± 15.4^{b}	4.92 ± 0.42^{ab}
TVM	523.9 ± 42.3^{b}	0.47 ± 0.04^{a}	67.5 ± 9.6^{c}	4.06 ± 0.50^{c}

*Means with different superscripts in columns indicate significant differences among treatments ($p<0.05$)

Color:

Significant differences were found among all samples for “L”, “a”, and “b” values of color ($p<0.05$) (Table 4). F-625 and F-1000 were significantly lighter than the other samples with “L” values of 70.38 and 69.29, respectively. 5040C (61.68) and TVM (62.81) were the darkest samples.

For the “a” values, 5040C (11.11) was significantly higher than the other samples. This result was expected as 5040C is a red sorghum. NE#20, a white sorghum, is the second highest in redness with a value of 5.57. NE#20 had the highest particle size distribution (191.766µm at 50%) which could be an indication of large pieces of bran. Bran pieces would increase the red color.

The “b” values ranged from 17.94 (5040C) to 22.28 (NE#20). 5040C had a lower yellow color since it is a red sorghum.

pH:

pH values ranged from 5.12 (NE#20) to 5.24 (TVM) (Table4). Significant differences were found among the samples ($p<0.05$). No studies have been found that correlate pH of sorghum flour to performance.

Water Activity and Moisture Content:

Table 4 shows the water activity (A_w) and moisture content averages of the five samples. TVM was significantly higher in both A_w and moisture content with values of 0.89 and 25.29, respectively. No significant differences were found among the other four samples.

These higher water values are due to the greater amount of water needed to make the dough with TVM. In making the tortillas, TVM had 130g of water added while the other four samples had between 70 and 85g. TVM required more water because of the small particle size and high starch damage. The flour particle size distribution of TVM was 114.6µm at 50% volume. The other four samples had a range of 154.4µm to 177.9µm at 50% volume. Smaller particles in the flour allow for a greater surface area for water to fill around.

Also, the starch damage for TVM was 12.2. The other four samples had a starch damage range of 2.7 to 3.0. Damaged starch increases water absorption (Evers and Stevens 1985). Disruption of the crystalline region in starch granules allows water access to the whole granule (Multon and others 1980).

Table 4. Comparison of color, pH, water activity, and moisture of sorghum flour tortillas from five different sorghum flours*

	Color					Moisture
Sample	L	a	b	pH	A_w[1]	Content (%)
F-625	70.38 ± 1.32^{a}	1.73 ± 0.29^{d}	22.14 ± 1.22^{ab}	5.15 ± 0.03^{bc}	0.78 ± 0.01^{b}	17.31 ± 0.60^{b}
F-1000	69.29 ± 1.66^{a}	3.91 ± 0.40^{c}	20.85 ± 1.07^{bc}	5.19 ± 0.05^{abc}	0.78 ± 0.04^{b}	16.93 ± 0.89^{b}
NE#20	64.71 ± 1.34^{b}	5.57 ± 0.31^{b}	22.28 ± 0.82^{a}	5.12 ± 0.03^{c}	0.79 ± 0.02^{b}	16.90 ± 1.73^{b}
5040C	61.68 ± 1.83^{c}	11.11 ± 1.08^{a}	17.94 ± 0.54^{d}	5.21 ± 0.04^{ab}	0.77 ± 0.02^{b}	16.06 ± 2.47^{b}
TVM	62.81 ± 2.07^{bc}	2.27 ± 0.27^{d}	21.12 ± 1.17^{ac}	5.24 ± 0.05^{a}	0.89 ± 0.00^{a}	25.29 ± 0.99^{a}

*Means with different superscripts in columns indicate significant differences among treatments ($p<0.05$)

1 Water Activty

Sensory Analysis

Descriptive Analysis

Significant differences were found ($p<0.05$) for some attributes in descriptive analysis (Tables 5 –8). For appearance, the only significant difference was in grain specks. TVM had a significantly lower score (5.67). The smaller flour particle size distribution (114.55µm at 50% volume) of TVM means there are less large particles or "specks" visible to the human eye.

The angle bend was the attribute with significant differences found for texture in the hand. TVM had the highest score (12.92) while F-625 had the lowest score (8.43). The TVM sample's high score can be related to the extensibility values. With a low force and high distance values, the TVM is more extensible making it easier to bend without breaking.

In odor attributes, significant differences were found for rancid. TVM had the highest score (4.00) and NE#20 the lowest (1.67). These differences are most likely due to the release of free fatty acids during storage. The storage of the commercial flour (TVM) prior to purchase is unknown. The other four samples were stored in a freezer to delay the unset of fat oxidation.

The sweet attribute was the only flavor descriptor with significant differences. The values ranged from 4.67 (NE#20) to 6.86 (F-625). The differences are probably due to the variations in maturity level of the sorghum caryopses. Sugars accumulate in the endosperm during germination (Newton and others 1980).

Springiness, hardness, and grittiness showed significant differences in texture by the mouth. Springiness ranged from 1.29 (F-625) to 3.50 (TVM). Hardness ranged from

3.83 (TVM) to 8.00 (F-625). Grittiness ranged from 4.00 (F-625) and 8.92 (5040C). The texture results from the texture analyzer show force being lowest for TVM in both extensibility and stretchability. This would explain the lower hardness score. A harder material requires more force to rupture.

Table 5. Comparison of appearance attributes in descriptive analysis of sorghum flour tortillas from five different sorghum flours*

				APPEARANCE				
Sample	Yellow Color	Brown Color	Evenness of Color	Opacity	Shape (round)	Surface	Grain Specks	Glossiness
F-625	3.57 ± 0.79^{a}	2.71 ± 1.11^{a}	8.86 ± 3.63^{a}	8.43 ± 1.72^{a}	12.43 ± 0.98^{a}	3.29 ± 2.69^{a}	9.00 ± 4.69^{a}	2.86 ± 1.21^{a}
F-1000	3.14 ± 1.07^{a}	3.00 ±1.63^{a}	8.00 ± 5.45^{a}	8.86 ± 1.68^{a}	12.86 ± 1.46^{a}	6.86 ± 4.88^{a}	10.29 ± 4.50^{a}	3.00 ± 1.63^{a}
NE#20	3.17 ± 2.56^{a}	3.67 ±1.63^{a}	10.17 ± 1.83^{a}	9.33 ± 2.94^{a}	12.00 ± 2.53^{a}	4.33 ± 3.14^{a}	11.17 ± 2.71^{a}	2.67 ± 1.03^{a}
5040C	1.67 ± 1.21^{a}	4.33 ± 5.32^{a}	11.17 ± 1.33^{a}	9.50 ± 2.74^{a}	11.17 ± 3.31^{a}	2.67 ± 1.37^{a}	12.83 ± 2.48^{a}	2.67 ± 1.03^{a}
TVM	3.8 ± 1.33^{a}	3.83 ± 0.98^{a}	10.00 ± 0.00^{a}	6.00 ± 2.19^{a}	13.83 ± 0.75^{a}	3.33 ± 1.37^{a}	5.67 ± 1.51^{b}	4.33 ± 2.16^{a}

*Means with different superscripts in columns indicate significant differences among treatments ($p<0.05$)

Table 6. Comparison of texture (in the hand) and odor attributes in descriptive analysis of sorghum flour tortillas from five different sorghum flours*

	TEXTURE (in the hand)			**ODOR**		
Sample	Roughness	Angle of Bend	Tearability	Sweet	Rancid	Musty
F-625	3.43 ± 0.98^{a}	8.43 ± 1.90^{bc}	7.50 ± 2.93^{a}	3.57 ± 1.13^{a}	1.83 ± 0.75^{bc}	6.79 ± 2.16^{a}
F-1000	2.93 ± 0.84^{a}	9.71 ± 1.47^{bc}	6.71 ± 2.56^{a}	4.00 ± 2.31^{a}	2.14 ± 0.90^{ac}	7.14 ± 1.21^{a}
NE#20	2.83 ± 0.41^{a}	10.25 ± 2.36^{ac}	7.50 ± 1.38^{a}	3.67 ± 0.52^{a}	1.67 ± 0.52^{bc}	6.67 ± 1.75^{a}
5040C	2.67 ± 0.52^{a}	10.42 ± 0.92^{ab}	6.50 ± 2.17^{a}	4.17 ± 0.98^{a}	3.17 ± 0.75^{ab}	7.17 ± 2.32^{a}
TVM	2.33 ± 0.52^{a}	12.92 ± 1.69^{a}	5.67 ± 2.58^{a}	4.67 ± 1.21^{a}	4.00 ± 2.45^{a}	7.17 ± 2.79^{a}

*Means with different superscripts in columns indicate significant differences among treatments ($p<0.05$)

Table 7. Comparison of flavor attributes in descriptive analysis of sorghum flour tortillas from five different sorghum flours*

	FLAVOR							
Sample	Sour	Salty	Sweet	Bitter	Doughy	Nutty	Mouthcoating	Aftertaste
F-625	3.14 ± 2.04^{a}	2.71 ± 1.38^{a}	6.86 ± 1.07^{a}	3.71 ± 0.95^{a}	4.14 ± 2.04^{a}	6.43 ± 2.23^{a}	4.43 ± 2.23^{a}	8.00 ± 1.10^{a}
F-1000	2.29 ± 1.11^{a}	2.86 ± 1.35^{a}	6.14 ± 0.90^{ab}	4.29 ± 0.76^{a}	4.57 ± 1.72^{a}	7.14 ± 2.04^{a}	4.43 ± 2.51^{a}	8.17 ± 2.14^{a}
NE#20	2.33 ± 1.21^{a}	2.83 ± 0.98^{a}	4.67 ± 0.52^{cd}	4.00 ± 1.26^{a}	3.67 ± 0.82^{a}	5.67 ± 2.16^{a}	3.33 ± 0.82^{a}	6.83 ± 1.72^{a}
5040C	2.5 ± 1.76^{a}	2.67 ± 1.21^{a}	5.33 ± 0.82^{bc}	4.00 ± 1.26^{a}	3.83 ± 0.75^{a}	7.00 ± 2.90^{a}	4.67 ± 1.63^{a}	8.20 ± 1.64^{a}
TVM	3.50 ± 1.76^{a}	2.50 ± 1.22^{a}	4.83 ± 0.75^{bd}	3.17 ± 0.98^{a}	4.33 ± 1.37^{a}	6.50 ± 1.05^{a}	4.83 ± 2.79^{a}	10.42 ± 3.67^{a}

*Means with different superscripts in columns indicate significant differences among treatments ($p<0.05$)

Table 8. Comparison of texture (by the mouth) attributes in descriptive analysis of sorghum flour tortillas from five different sorghum flours*

	TEXTURE (by the mouth)						
Sample	Springiness	Hardness	Cohesiveness of Mass	Fracturability	Moisture Absorption	Grittiness	Tooth Packing
F-625	1.29 ± 0.49^{c}	8.00 ± 1.41^{a}	5.57 ± 0.79^{a}	4.5 ± 0.76^{a}	7.29 ± 2.14^{a}	4.00 ± 2.31^{bc}	6.21 ± 1.95^{a}
F-1000	2.00 ± 0.89^{bc}	6.71 ± 1.80^{ac}	6.86 ± 2.04^{a}	4.57 ± 2.07^{a}	6.71 ± 1.70^{a}	4.57 ± 2.94^{bc}	5.36 ± 1.60^{a}
NE#20	2.83 ± 0.41^{ab}	5.33 ± 1.51^{bcd}	8.00 ± 3.16^{a}	4.50 ± 0.84^{a}	7.17 ± 1.60^{a}	6.17 ± 2.93^{ab}	5.50 ± 1.64^{a}
5040C	2.33 ± 0.52^{ac}	7.17 ± 1.83^{ab}	4.83 ± 1.72^{a}	4.50 ± 1.64^{a}	7.17 ± 2.14^{a}	8.92 ± 1.69^{a}	5.33 ± 1.63^{a}
TVM	3.50 ± 1.05^{a}	3.83 ± 0.98^{d}	8.00 ± 1.26^{a}	4.17 ± 0.75^{a}	6.00 ± 0.00^{a}	6.00 ± 2.10^{ac}	4.75 ± 1.47^{a}

*Means with different superscripts in columns indicate significant differences among treatments ($p<0.05$)

Consumer Study:

Of the 100 panelists, 52 were female and 48 were male. The age ranged from 18 to 90 years with 66% of the panelists being in the 18 to 25 age group. For consumption, 37% of panelists claimed to eat flour tortillas at least once a week, 32% once every two weeks, and 26% once a month.

Table 8 shows the average scores from the consumer study. Significant differences were found for each attribute ($p<0.05$). A more acceptable gluten-free tortilla was made using TVM in the sorghum flour tortilla formula from this study. The overall acceptability score was 5.94 for TVM and 4.42 for LTF. The TVM scored better than predicted as the tortilla was tested on consumers of wheat. With a higher score than LTF, the sorghum flour tortilla developed in this study has great potential in the gluten-free market.

Table 9. Comparison of scores from consumer study of a sorghum flour tortilla and a commercial gluten-free wrap

Sample	Overall acceptability	Appearance	Flavor	Texture (hand)	Texture (mouth)
LTF[1]	4.42 ± 1.68^{b}	5.45 ± 1.64^{b}	4.18 ± 1.80^{b}	$5.70 + 1.63^{b}$	4.09 ± 1.94^{b}
TVM[2]	5.94 ± 1.70^{a}	5.94 ± 1.60^{a}	6.06 ± 2.00^{a}	$5.99 + 1.67^{a}$	5.86 ± 1.85^{a}

*Means with different superscripts in columns indicate significant differences among treatments ($p<0.05$)

1 La Tortilla Factory Gluten Free Wrap

2 Sorghum flour tortilla made with Twin Valley Mills

Conclusions/Recommendations:

This research was successful at developing a formula for a gluten-free and allergen-free tortilla with sorghum flour being the only starch. Physical, chemical, textural, and sensory tests showed differences among five sorghum flours. An acceptable sorghum flour tortilla could not be produced from the four hybrids. The commercial flour could produce a quality sorghum flour tortilla. The reason for such a better performance by the commercial flour is most likely due to the smaller particle size and higher damaged starch. Further research should include the four sorghum hybrids milled to meet the commercial flour standards. This would allow for appropriate testing among sorghum hybrids to find the best quality sorghum for gluten-free flour tortillas.

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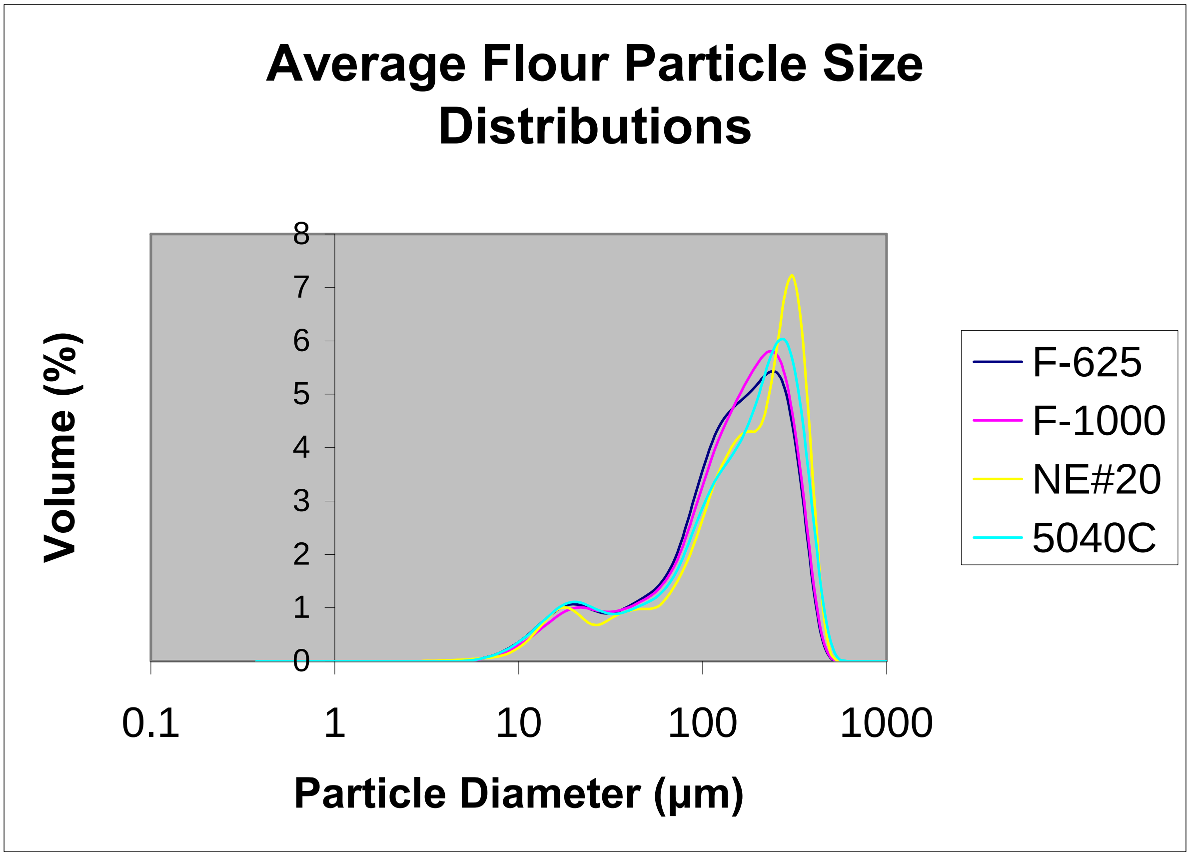
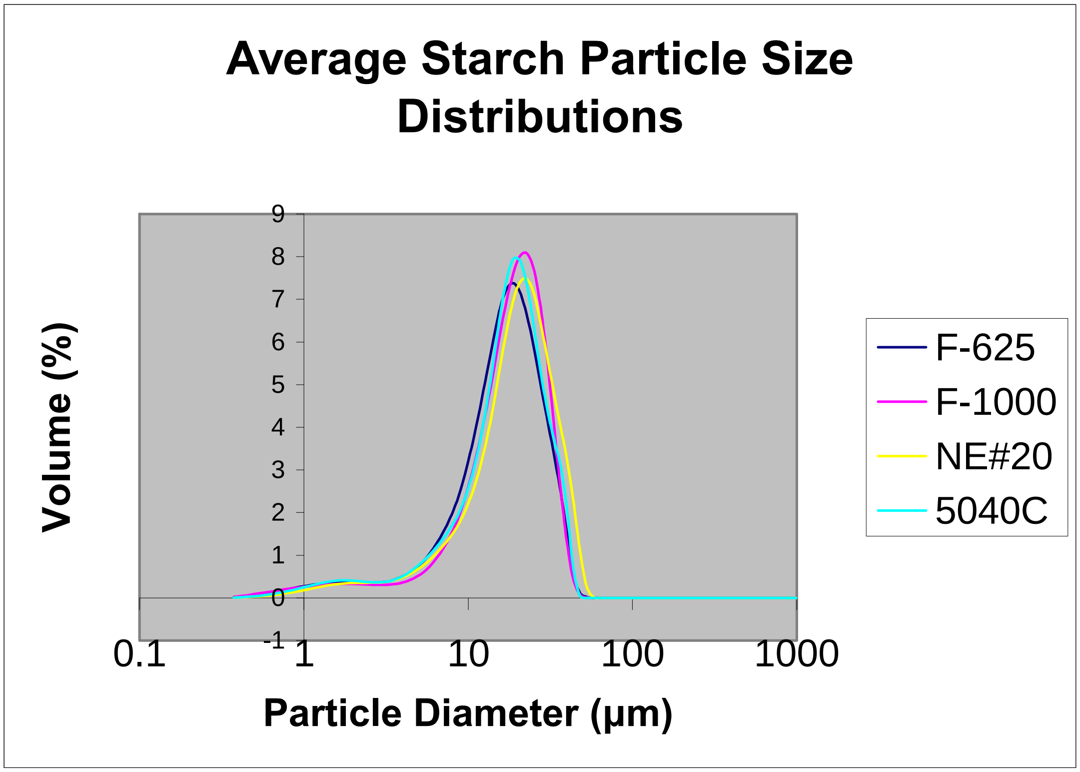
Appendices

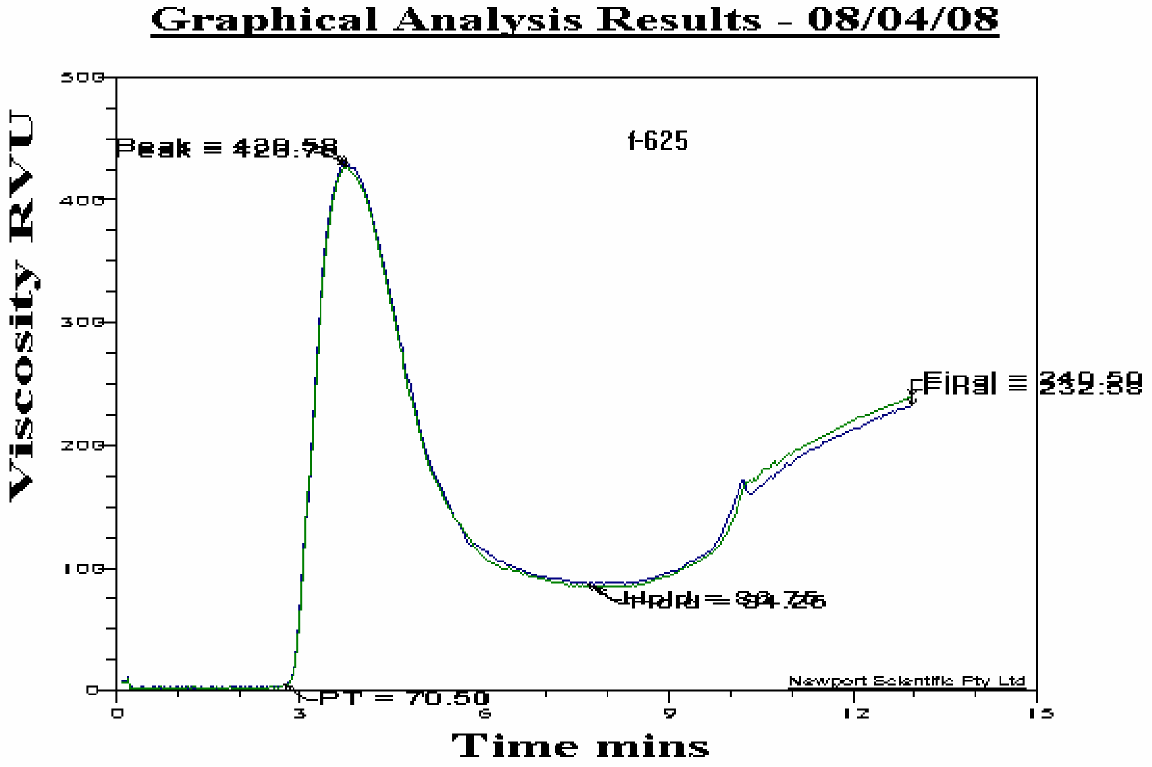
Appendix 1. Average flour particle size distributions for F-625, F-1000, NE#20, and 5040C.



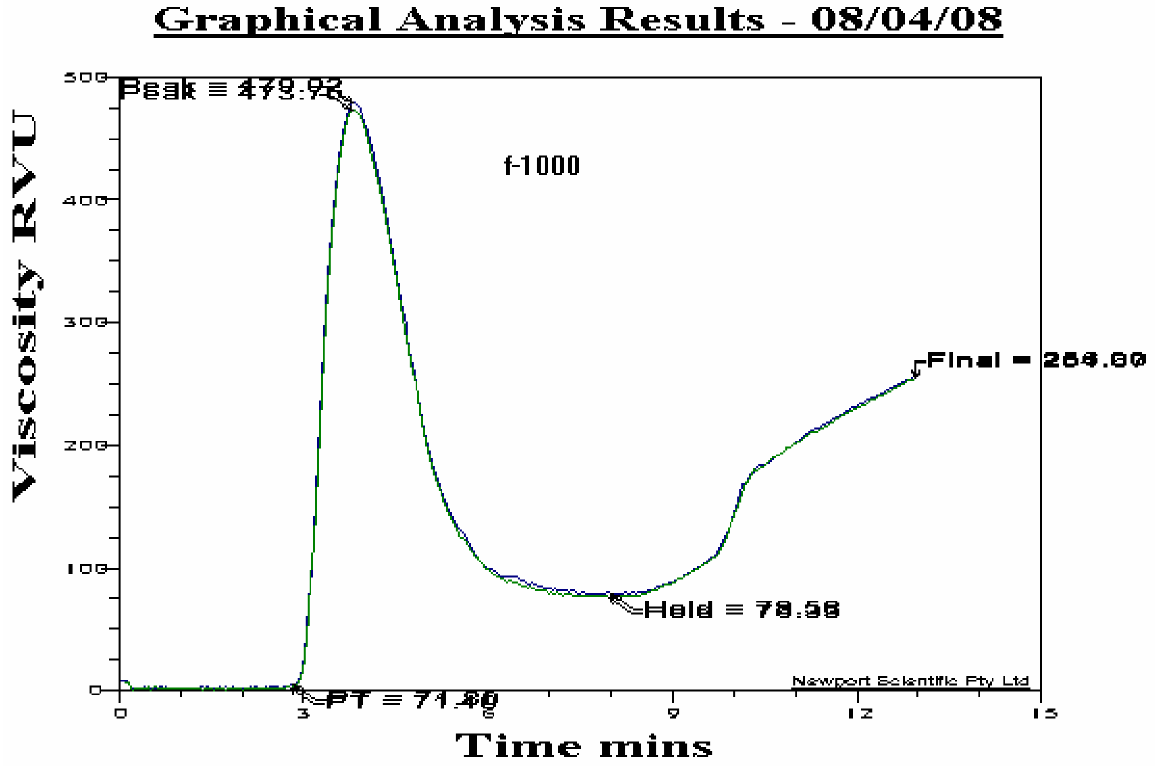
Appendix 2. Average starch particle size distributions for F-625, F-1000, NE#20, and 5040C.



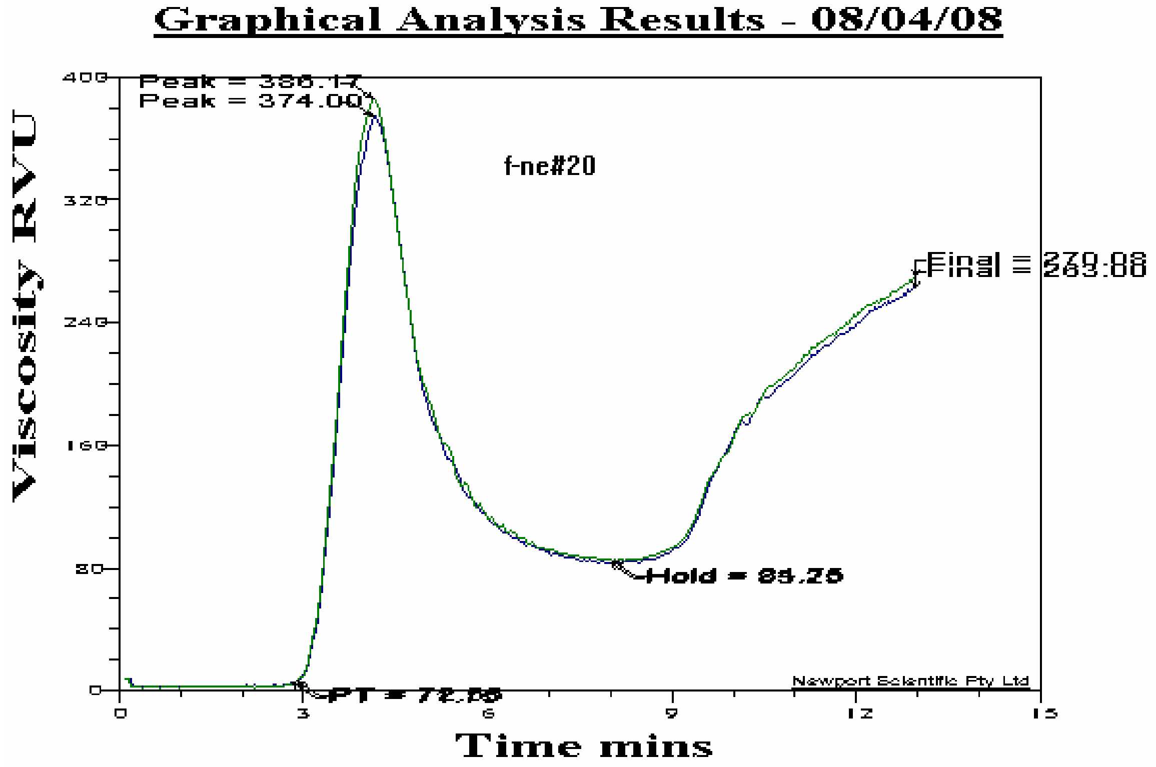
Appendix 3. RVA curve for F-625.



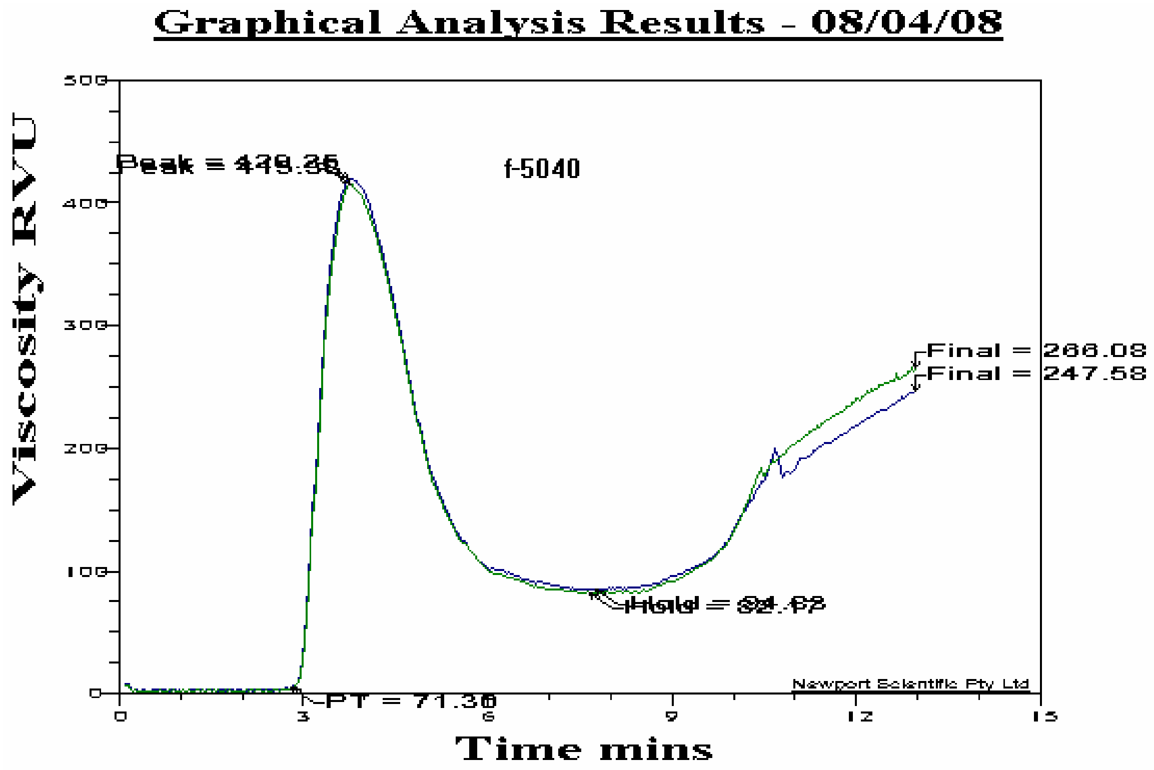
Appendix 4. RVA curve for F-1000.



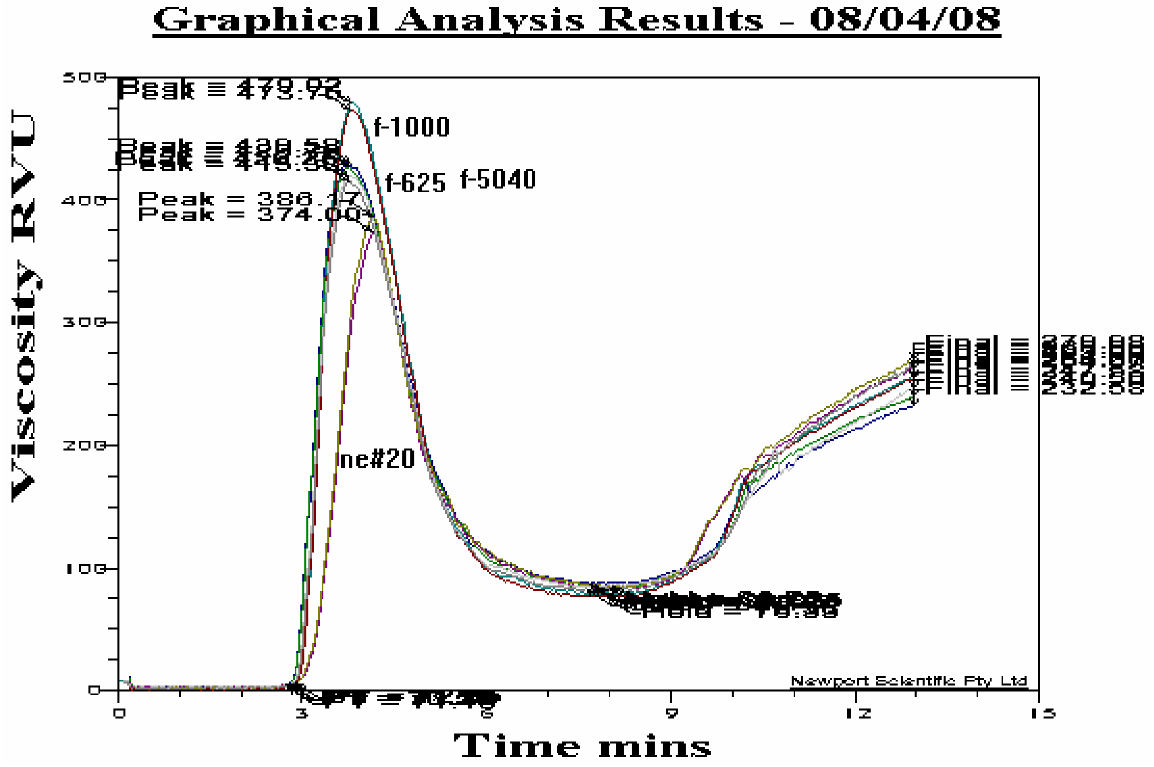
Appendix 5. RVA curve for NE#20.



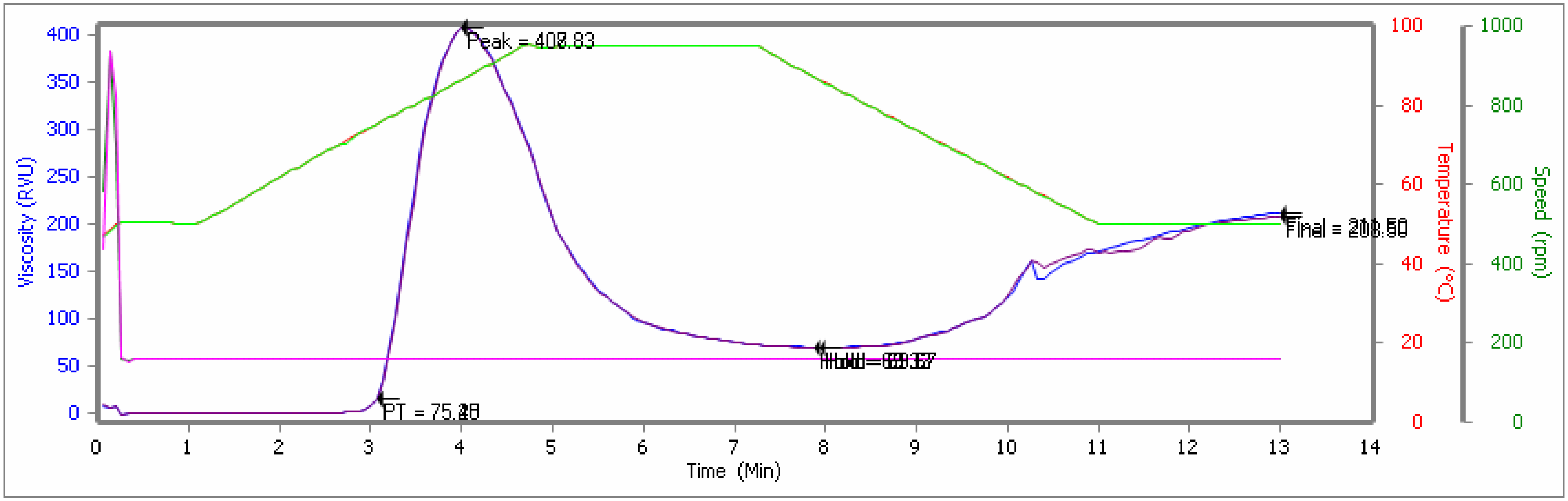
Appendix 6. RVA curve for 5040C.



Appendix 7. RVA curves for F-625, F-1000, NE#20, and 5040C.



Appendix 8. RVA curve for TVM.



Appendix 9: Sorghum Flour Tortilla Definitions and Reference Sheet for Descriptive Analysis

APPEARANCE

Yellow Color:	The hue of that portion of the visible spectrum lying between orange and green. *References: Great Value sliced Swiss cheese = 2* *KSU Call Hall butter = 7* *Lemon rind = 15*
Brown Color:	A dark tertiary color with a yellowish or reddish hue. *References: Cannellini bean = 1* *Mission 96% fat free whole wheat flour tortilla = 7* *Hershey's milk chocolate bar = 15*
Evenness of Color:	Degree to which the color is free from variations or fluctuations. *Tortilla placed on white paper.* *References: Mission flour tortilla (fajita size) = 2* *Mission 96% fat free whole wheat flour tortilla = 13*
Opacity:	Degree to which a substance is transparent or translucent. *Place hand behind tortilla and hold up to light. (Window=1)* *References: Parchment paper = 3* *Napkin = 13*
Shape (round):	Being such that every part of the surface or the circumference is equidistant from the center.
Surface:	Degree to which the outer face presents variations or fluctuations by means of blistering and puffing. *References: Mission 96% fat free whole wheat flour tortilla = 5* *Mission flour tortilla (fajita size) = 11*
Grain Specks:	A small spot of grain differing in color or substance from that of the surface upon which it lies. *References: Mission flour tortilla (fajita size) = 1* *Mission 96% fat free whole wheat flour tortilla = 15*
Glossiness:	The property of having a shiny or lustrous surface. *References: Cardboard = 1* *Magazine = 15*

TEXTURE (in the hand)

Roughness: The property of having a surface marked by irregularities, protuberances, or ridges
References: Kool-aid gels (Soarin' strawberry) = 1
Orange peel = 6
Lay's Classic potato chip = 10
Nature Valley crunchy granola bar (Vanilla nut) = 14

Angle of bend: Degree to which the tortilla will bend in half before breaking
References: $0^o = 1$
$90^o = 7.5$
$180^o = 15$

Tearability: Amount of force required to pull the tortilla apart.
With a strip of tortilla, hold the top with one hand and pull down on the bottom of the strip with the other hand.
References: Mission flour tortilla (fajita size) = 8
Kangaroo Quality pita pocket bread = 14

ODOR

Sweet: Aromatic associated with sugar, such as sucrose or honey.
References: Great Value extra fine granulated sugar = 2
Nabisco Honey Maid graham cracker = 8
Great Value clover honey = 14

Rancid: Aromatic associated with decomposition of fats or oils.
References: Crisco all-vegetable shortening = 2
Stale saltine cracker =14

Musty: Aromatic associated with a dust or earth from grain.
References: Bag of sorghum grain = 11

FLAVOR

Sour: A fundamental taste factor of which citric, malic, phosphoric and other acid solutions are typical.
References: 0.05% citric acid solution = 2
0.10% citric acid solution = 7
0.15% citric acid solution = 11
0.20% citric acid solution = 15

Salty:	A fundamental taste factor of which sodium chloride solution is typical. *References: 0.2% NaCl solution = 4* *0.4% NaCl solution = 7* *0.8% NaCl solution = 15*
Sweet:	A fundamental taste factor of which sucrose solution is typical. *References: 1.0% sucrose solution = 3* *2.0% sucrose solution = 6* *4.0% sucrose solution = 11* *8.0% sucrose solution = 15*
Bitter:	A fundamental taste factor of which caffeine solution is typical. *References: 0.02% caffeine solution =* *0.04% caffeine solution =* *0.06% caffeine solution =*
Doughy:	A flavor associated with wet flour or dough. *References: King's Hawaiian savory butter roll = 5* *Pillsbury Grands homestyle canned biscuit dough = 15*
Nutty:	A sweet, light brown, slightly musty and/or earthy flavor associated with nuts, grains, and seeds. *References: Kretschmer Original toasted wheat germ = 10*
Mouthcoating:	A layer of substance, typically fat and oil, spread over the mouth after chewing. *References: Lay's Classic potato chip = 7* *Pillsbury Grands homestyle canned biscuit dough = 12*
Aftertaste:	A taste persisting in the mouth after the substance that caused it is no longer present.

TEXTURE (by the mouth)

Springiness:	Degree to which the sample can be condensed and return to its original shape. *Compress partially without breaking using front teeth.* *References: Kraft Philadelphia original cream cheese = 2* *Oscar Meyer wiener = 7* *Kraft jet-puffed marshmallow = 14*

Hardness:	The relative resistance to deformation. *Bite down evenly using front teeth.* *References: Kraft Philadelphia original cream cheese = 1* *Great Value sharp cheddar cheese = 4* *Great Value party peanuts = 13*
Cohesiveness of Mass:	Degree to which sample holds together during mastication. *Measure after 3-4 chews with molars.* *References: Nabisco Original Triscuit = 4* *General Mills Cheerio = 8*
Fracturability:	Force with which sample breaks. *Bite down evenly using front teeth until sample breaks.* *References: "Jiffy" prepared corn muffin = 2* *Graham cracker = 7*
Moisture absorption:	Amount of saliva absorbed during mastication. *Measure after 3-4 chews with molars.* *References: Twizzlers strawberry twist = 2* *Lay's Classic potato chip = 5* *Pop-secret 100 calorie pop premium popcorn (Butter) popped = 7* *Nabisco unsalted tops premium saltine cracker = 13*
Grittiness:	Amount of gritty particles perceived in the sample during mastication. *Measure after 5-7 chews with molars.* *References: Post Grape Nuts = 14*
Tooth packing:	Amount of sample packed in and between the teeth after swallowing. *References: Nabisco Honey Maid graham cracker = 7* *Great Value party peanuts = 10* *Wonka Laffy Taffy candy = 15*

Appendix 10: INFORMED CONSENT STATEMENT FOR CONSUMER SENSORY ANALYSIS OF GLUTEN FREE FLOUR TORTILLAS

The purpose of this project is to determine consumer acceptance of gluten free flour tortillas. Testing is expected to take less than 10 minutes. All ingredients in these products are food grade and approved by FDA. If you have no food allergies, there are no known risks or discomforts associated with consumption of these products. Your data will be treated as research data and will in no way be associated with you other than for identification purposes, thereby assuring confidentiality of your performance and responses.

1. I (print name)____________________, agree to participate as a panelist in a sensory consumer testing conducted by Dr. Fadi Aramouni and Mary Fernholz.

2. I understand that this study is part of a thesis project.

3. I understand that there will be a free ice cream certificate upon completion of the testing session.

4. I understand that I do not have to participate in this research and there will be no penalty if I choose not to participate.

5. I understand that I may withdraw from the research at any time.

6. If I have any questions concerning this study, I understand that I can contact Dr. Fadi Aramouni at 216 Call Hall (785-532-1668).

7. If I have any questions about my rights as a panelist or about the manner in which the study is conducted, I may contact the Committee on Research Involving Human Subjects, 103 Fairchild Hall, Kansas State University, Manhattan, KS 66506 (785-532-6195).

SIGNATURE:____________________ DATE:_______________

Appendix 11: CONSUMER PRE-SCREENING FORM FOR GLUTEN FREE FLOUR TORTILLA STUDY

Please complete the information below:

Age:
☐ 18-25 ☐ 26-30 ☐ 31-35 ☐ 36-40 ☐ 41-45 ☐ 46-50
☐ 51-55 ☐ 56-60 ☐ 61-70 ☐ 71-80 ☐ 81-90 ☐ Over 90

Gender:
☐ Male ☐ Female

Education Completed:
☐ High School ☐ Some College ☐ B.S. ☐ M.S. ☐ Ph.D.
☐ MD ☐ Other

About how often do you eat flour tortillas? (soft tacos, burritos, wraps, etc.)
☐ Every Day ☐ At least once a Week ☐ Once every Two Weeks
☐ Once a Month ☐ Once a Year ☐ Never

Do you suffer from any food allergies?
☐ Yes ☐ No

If you have any food allergies, you cannot participate in this study. Thank you for your willingness to help.

Appendix 12: CONSUMER BALLOT FOR GLUTEN FREE FLOUR TORTILLA STUDY

Panelist #_______

Instructions:
You will be testing two samples of gluten free flour tortillas. Samples are presented in the order to be tasted. Make sure to use the ballot with the sample number that matches the number by the sample. Please be sure to answer the questions completely and honestly. Check the box that best describes your answer. Take a drink of water and a bite of cracker before you start and as needed throughout testing.

SAMPLE: 294

Please check only one box that represents your response (X)

1. Please rate your overall acceptability of this sample

Dislike Extremely				Neither Like nor Dislike				Like Extremely
☐	☐	☐	☐	☐	☐	☐	☐	☐
1	2	3	4	5	6	7	8	9

2. How much do you like or dislike the appearance of this sample?

Dislike Extremely				Neither Like nor Dislike				Like Extremely
☐	☐	☐	☐	☐	☐	☐	☐	☐
1	2	3	4	5	6	7	8	9

3. How much do you like or dislike the flavor of this sample?

Dislike Extremely				Neither Like nor Dislike				Like Extremely
☐	☐	☐	☐	☐	☐	☐	☐	☐
1	2	3	4	5	6	7	8	9

4. How much do you like or dislike the texture in the HAND of this sample?

Dislike Extremely				Neither Like nor Dislike				Like Extremely
☐	☐	☐	☐	☐	☐	☐	☐	☐
1	2	3	4	5	6	7	8	9

5. How much do you like or dislike the texture in the MOUTH of this sample?

Dislike Extremely				Neither Like nor Dislike				Like Extremely
☐	☐	☐	☐	☐	☐	☐	☐	☐
1	2	3	4	5	6	7	8	9

Additional Comments:____

Panelist#_____

SAMPLE: 571

Please check only one box that represents your response (X)

1. Please rate your overall acceptability of this sample

Dislike Extremely				Neither Like nor Dislike				Like Extremely
☐	☐	☐	☐	☐	☐	☐	☐	☐
1	2	3	4	5	6	7	8	9

2. How much do you like or dislike the appearance of this sample?

Dislike Extremely				Neither Like nor Dislike				Like Extremely
☐	☐	☐	☐	☐	☐	☐	☐	☐
1	2	3	4	5	6	7	8	9

3. How much do you like or dislike the flavor of this sample?

Dislike Extremely				Neither Like nor Dislike				Like Extremely
☐	☐	☐	☐	☐	☐	☐	☐	☐
1	2	3	4	5	6	7	8	9

4. How much do you like or dislike the texture in the HAND of this sample?

Dislike Extremely				Neither Like nor Dislike				Like Extremely
☐	☐	☐	☐	☐	☐	☐	☐	☐
1	2	3	4	5	6	7	8	9

5. How much do you like or dislike the texture in the MOUTH of this sample?

Dislike Extremely				Neither Like nor Dislike				Like Extremely
☐	☐	☐	☐	☐	☐	☐	☐	☐
1	2	3	4	5	6	7	8	9

Additional Comments:____

Appendix 13: Twin Valley Mills Sorghum Flour Characterization

Moisture, protein, and ash results for Twin Valley Mills sorghum flour

Sample	Moisture (%)	Protein (%db)	Ash (%db)
TVM	9.81 ± 0.03	6.43 ± 0.03	1.61 ± 0.01

Flour particle size distirbution for Twin Valley Mills sorghum flour

	Volume % (Diameter <µm)				
Sample	10	25	50	75	90
TVM	22.4 ± 0.1	52.0 ± 0.2	114.5 ± 0.7	191.4 ± 2.2	277.5 ± 3.4

Pasting properties of starch from Twin Valley Mills sorghum flour using Rapid Visco Analyser

Sample	Peak 1	Trough 1	Breakdown	Final Visc	Setback	Peak Time	Pasting Temp
TVM	408.1 ± 0.4	69.5 ± 0.2	338.6 ± 0.1	210.0 ± 2.1	140.5 ± 1.9	4.00 ± 0.00	75.33 ± 0.11

Starch damage and amylose content of Twin Valley Mills sorghum flour

Sample	Starch Damage	Amylose %
TVM	12.2 ± 0.8	22.9 ± 2.0