EVALUATION OF FOUR SORGHUM HYBRIDS IN A GLUTEN-FREE NOODLE SYSTEM

by

LIMAN LIU

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Approved by:

Co-Major Professor
Thomas J. Herald

Approved by:

Co-Major Professor
Donghai Wang

Abstract

The number of people diagnosed with celiac disease has increased and subsequently the market for gluten-free products is rising. Sorghum has been identified to be a safe grain to use as a wheat alternative for the celiac community. There are many sorghum hybrids that are commercial available for use in food and feed. Noodles are selected for the growing market in the US and the lack of research and availability for sorghum noodles. Viscoelastic properties are crucial for making acceptable noodles which makes this research more challengeable. The research hypothesis is that sorghum can be used in making gluten-free noodles and there are end product quality differences that exist among the hybrids in production of gluten-free noodles. A series of chemical and physical analyses were conducted to compare four sorghum hybrids (Orbit, NE #8, F-525, NE #4) in a gluten-free noodle system. The noodles were formulated with 100% sorghum flour and the other functional ingredients including dried whole eggs, egg whites, xanthan gum and corn starch. Sorghum noodles were significantly different in color, texture and cooking quality among hybrids. The starch properties were found to have more effect than protein content on sorghum noodle qualities. Sorghum flour with fine particle size and low ash content was crucial for making acceptable sorghum noodles. Noodles made from sorghum F-525 exhibited some properties significantly closer to the commercial wheat flour noodles.

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CHAPTER 1 - Literature Review

Food Allergies

Introduction:

Eating is a necessary activity to sustain life that should be an enjoyable experience for people. However, some individuals may die from consuming certain foods because of food allergies. According to the U.S. Food and Drug Administration (2004), approximately 30,000 people in the United States require emergent care and 150 people die each year due to an allergic reaction to food. Around 2% of adults and 5% of children suffer from food allergies (U.S. Food and Drug Administration 2004). The annual cost of allergies is estimated to be nearly $7 billion (Asthma and Allergy Foundation of America 2004). The treatment for food allergies is to avoid the allergic food and seek alternative foods.

Definition:

Food allergies and other food sensitivities are defined as individualistic adverse reactions to foods (Taylor 1987). Those adverse reactions include 1) immunological sensitivities, 2) non-immunological food intolerances and 3) secondary sensitivities (Figure 1.1). A true food allergy is a reaction of the immune system to a food or food ingredient that most people find harmless (American Medical Association). The true food allergies are divided into two categories: 1) immediate hypersensitivity reactions; 2) delayed hypersensitivity reactions (Lemke and Taylor 1994). The immediate hypersensitivity reactions are caused by the abnormal responses of immune system with the allergen-specific immunoglobulin E (IgE) antibodies (Mekori 1996). The delayed hypersensitivity reactions are caused by the abnormal responses of the cellular immune system with the sensitized T cells (Lemke and Taylor 1994). Celiac disease is an example of delayed hypersensitivity reaction which involves abnormal immunological response to wheat and related grains (Ferguson 1997).

Food intolerances are abnormal reactions that do not involve immune system. Food intolerances include metabolic food disorders, anaphylactoid reactions (which are a rapidly progressing, life-threatening allergic reaction) and idiosyncratic reactions (which are drug reactions which occur rarely and unpredictably) (Taylor 1987). Lactose intolerance is an example of a metabolic food disorder (Kocian 1988).

The secondary sensitivities to foods involve the adverse reaction that may occur with or after the effects of other conditions. The lactose intolerance secondary to gastrointestinal disorders such as Crohn's disease is an example of such reactions (Metcalfe 1984a)

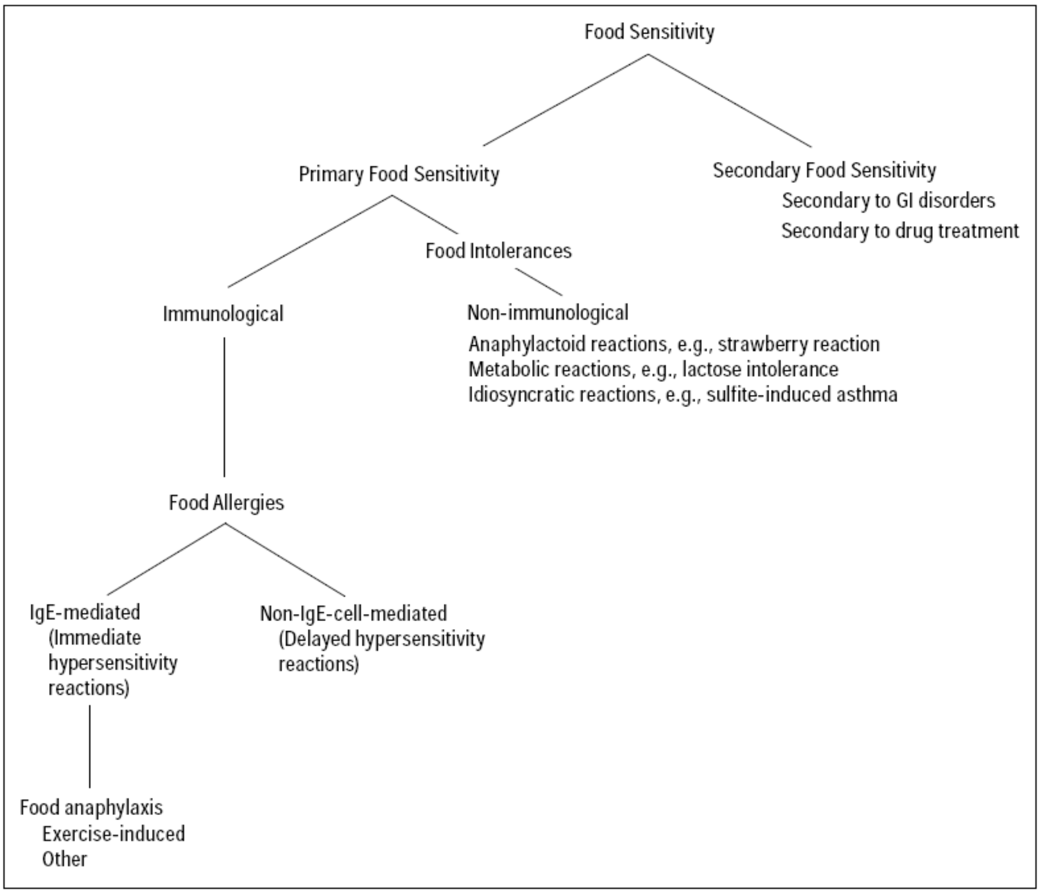

Figure 1.1 Relationships among the various types of food sensitivities. Taken From Taylor 2001.

IgE-mediated food allergy:

The IgE molecules bind with the causal food proteins and trigger the release of mediators that cause symptoms. One or more organs may be affected by IgE-mediated food allergies: the skin, respiratory tract, gastrointestinal tract and cardiovascular system (Sicherer 2002). IgE-mediated food allergies are accompanying with acute onset of symptoms after ingestion. The IgE-mediated food allergies are estimated to affect 3.5% to 4% of Americans (Munoz 2004). Infants (1–3 years of age) and children are more commonly affected by food allergies (Taylor 1999). Fortunately, within the first 3-5 years of life, most children lose their sensitivity to most allergenic foods. Compare to children adult food allergies are long-lived (Sicherer 2002). The eight major food allergens are: milk, eggs, fish, crustacean shellfish, tree nuts, peanuts, wheat, and soybeans (U.S. Food and Drug Administration 2004; McEvoy 2007). If a patient has a food allergen-specific IgE level exceeding any of the values in Table 1.1, then there is a greater than 95% chance that the patient will experience an allergic reaction if they ingest that specific food. Zeiger and Helloer (1995) reported that IgE-mediated food allergies may be only delayed but not prevented.

Table 1.1 Predictive value of food allergen-specific IgE levels. Adapted From Sampson 2003.

95% Predictive Chance to Experience an Allergic Reaction	
Allergen	IgE levels [KiloUnits / Liter]
Egg	> 7
Milk	> 15
Peanut	> 14
Fish	> 20
Tree nuts	> 15
Soybean	> 30
Wheat	> 26

Diagnostic tests for IgE-mediated food allergy:

The skin prick test is generally used to detect patients that are sensitive to specific food for IgE-mediated disorders (Sampson 2000). The procedure is almost painless and allows the test protein to interact with food-specific IgE on the surface of skin mast cells. The mast cells will degranulate and release mediators (Figure 1.2) that cause localized angio-oedema, vasodilation, and a wheal and flare within 15 min if the antibody is present (Sampson 2003).

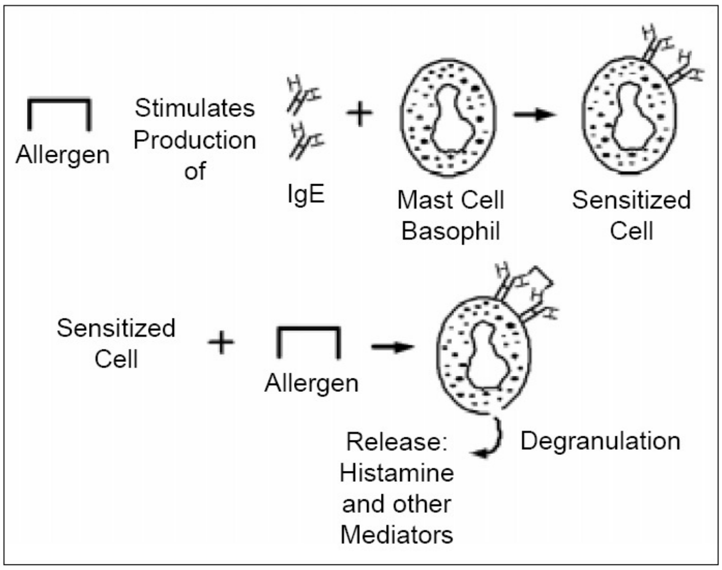

Figure 1.2 Mechanism of IgE-mediated allergic reaction. Taken From Taylor et al 1999.

Non-IgE-Cell-mediated food allergy:

Non-IgE-mediated food allergies involve the disorders that are mediated by T cells (Sampson 2000). The symptoms start to appear 24 hr or longer after the ingestion of specific foods (Lemke and Taylor 1994). Strober (1986) reported that celiac disease occurs through a T cell-mediated mechanism.

Celiac disease:

Introduction:

The "Coeliac Affection" was first reported by Gee in 1888, unfortunately identifying wheat as the causal food was not determined until 1950 (Semrad 2000). Other grains such as rye, barley, triticale, spelt and kamut were reported to have similar proteins so these foods were also identified as possible causal agents responsible of celiac disease (Ferguson 1997; Lemke and Taylor 1994). Additionally, Taylor (2001) reported that oats may also may be included in grains that affected celiac. Approximately 1% of U.S. population is inflected with celiac disease (Case 2006). The highest prevalence known so far is 5.6 % in the Saharawi (Smith 2008). Celiac disease rarely occurs in China or African descent but the reasons are not clear (Ferguson 1997).

Celiac disease is an autoimmune disorder characterized by inflammation, villous atrophy, and crypt hyperplasia of the small bowel mucosa (Collin 2002). When celiac patients ingest gluten, an immunological reaction will be induced to cause the damages on the intestine’s villi (Collin 2002). The finger-like villi (Figure 1.3) are used to absorb nutrients from food to the blood stream (National Digestive Diseases Information Clearinghouse 2007). Once the villi are damaged, the nutrients will be inefficiently absorbed. Some chronic and life threatening damage to the small bowl may occur if the patient is not treated. Other autoimmune disorders such as dermatitis Herpetiformis (DH), insulin-dependent Type I Diabetes Mellitus, thyroid disease, liver diseases may be associated with celiac disease (Collin 2002).

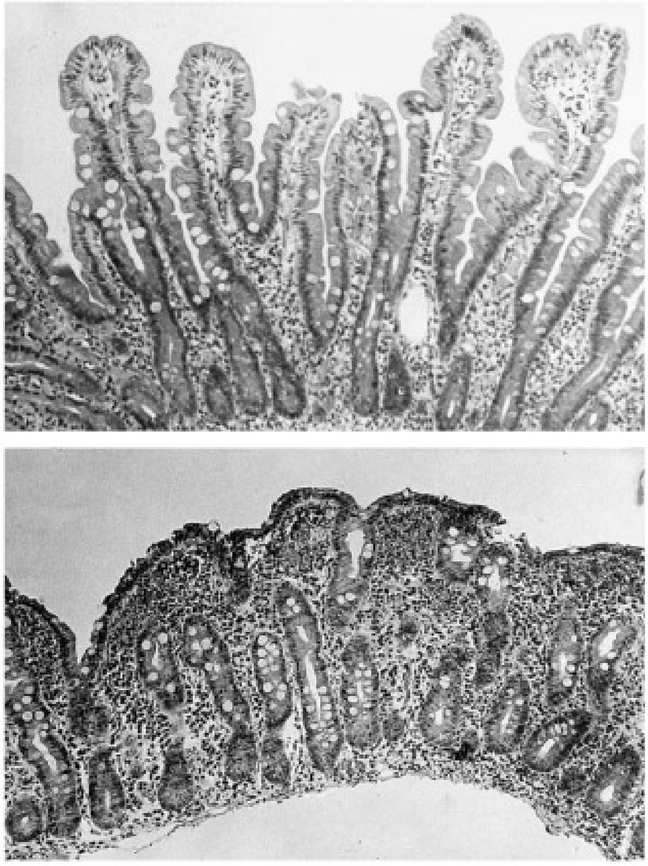

Figure 1.3 Top, Normal small-bowel biopsy with finger-like villi. Bottom, Small-bowel biopsy from a patient with celiac disease showing villous atrophy and hypertrophy of crypts. Taken From Collin 2002.

Symptoms:

Individuals that have Celiac disease may have different symptoms. Symptoms may not only occur in the digestive system, but in other parts of the body including the skin, liver, nervous system, bones, reproductive system and endocrine system (Rewers 2004). Presutti (2007) gives a list of the common and uncommon symptoms of celiac disease (Table 1.2).

Table 1.2 Signs and Symptoms of Celia Disease. Adapted From Presutti 2007.

Sign or symptom	Prevalence in patients with celiac disease (%)
Common	
Diarrhea	45 to 85
Fatigue	78 to 80
Borborygmus	35 to 72
Abdominal pain	34 to 64
Weight loss	45
Abdominal distention	33
Flatulence	28
Uncommon or rare	
Osteopenia or osteoporosis	1 to 34
Abnormal liver function	2 to 19
Vomiting	5 to 16
Iron-deficiency anemia	10 to 15
Neurologic dysfunction	8 to 14
Constipation	3 to 12
Nausea	4

Diagnostic Tests:

Celiac disease is difficult to diagnose because the disease may be confused with other diseases with the similar symptoms such as irritable bowel syndrome, iron-deficiency anemia and Chrohn's disease (National Digestive Diseases Information Clearinghouse 2007). An average cost of misdiagnosis on celiac disease is $5,000-$12,000 per person/per year (National Foundation for Celiac Awareness). There is no single standard test accepted within the medical community for diagnosing celiac disease. Dual methology using serologic testing and small bowel biopsy are regarded to be effective in diagnosing the celiac disease (Presutti 2007).

Diagnostic testing must be performed while the patient is on a gluten-containing diet to avoid false negative results (Presutti 2007). The first step is using specific antibody blood tests to identify the presence of celiac disease. The specific antibodies need to be tested are IgA anti-endomysium antibodies (AEA or EMA), anti-tissue transglutaminase (tTG), IgG tissue transglutaminase and total IgA antibodies (Celiac Disease Foundation 2008). Positive test results indicate the presence of celiac disease. However, since the antibody test is not 100% accurate, to confirm the celiac disease, a small intestinal biopsy is suggested to perform even if the antibodies test is negative (Case 2006). The small bowel biopsy test is performed endoscopically and used to evaluate the degree of mucosal damage (Celia Disease Foundation 2008). If both serology and biopsy test results are positive, the performance of a test for specific HLA (human leukocyte antigen) genes is helpful to diagnose the celiac disease. If these genes are not present, then the chance for the individual to develop this disease is minimal (Presutti 2007).

Treatment:

There is no treatment for celiac disease and the only cure for celiac disease patients is to avoid food products that contain gluten proteins. Once the gluten is removed from the diet the small intestine will start to heal and overall health improves. It is essential for the celiac disease patients that they should read labels carefully and learn how to identify ingredients that may contain hidden gluten such as: soups, hard candies, soy sauce and jelly beans (Celiac Disease Foundation 2008). The symptoms subside within 2 wk if the patients stop eating gluten-containing foods.

Gluten-free Diet:

Glutenin and gliadin are the specific names for wheat glutelins and prolamins, respectively. Gliadin is known as the toxic protein to those with celiac disease. However, glutenin has been found to be intolerable as well (Vader et al 2002). The prolamins in rye (secalin) and barley (hordein) are also harmful to celiac disease patients and therefore must be avoided. Rice and corn prolamin, orzenin and zein respectively, are not damaging (Case 2006). The avenin prolamin in oats is still under contravention for safety of consumption (Presutti 2007). Therefore, a gluten-free diet means not eating foods that contain wheat, rye and barley. Celiacs may eat potato, rice, sorghum, soy, amaranth, quinoa, buckwheat or bean flour instead (Celiac Disease Foundation 2008, Kasarda 2003). Checking labels for "gluten-free" is very important for people concerned if they have celiac disease. In 2000, the FDA reported that the amount of recalls from unlabeled allergens rose from 35 to 121 cases (U.S. Food and Drug Administration 2004). Therefore, strict government enforcement is necessary to control ingredient labeling.

On January 23, 2007, the FDA publicized a proposed rule in the Federal Register (Volume 72, Number 14) for Gluten-Free Labeling of Foods:

> "The term ``gluten-free" for voluntary use in the labeling of foods 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."

Market for Gluten-Free Products:

As the number of people diagnosed with celiac disease increases, the demand for gluten-free products will rise. The market for gluten-free food and beverage products grew at a compound annual growth rate (CAGR) of 28% from 2004 to 2008 (Supermarket Industry News 2009). More than 225 marketers introduced new gluten-free products into the United States in 2008 (Supermarket Industry News 2009). The market for gluten-free foods and beverages in the US currently stands approximately $700 million, and is estimated to $1.7 billion by 2010 (Heller 2006). Most gluten-free products are made with alternative grains and flours, such as rice, corn, amaranth and quinoa and those products (Supermarket Industry News 2009). Heller (2006) reported that approximately 40% of the gluten free food products are sold in health and natural food stores, such as GNC, Whole Foods and Wild Oats and additional 20% of sales occurred through specialty food website or catalog purchases.

Sorghum Production:

Sorghum does not contain gluten and possesses a number of beneficial phytochemicals. These attributes may have significant positive impact on human health for celiac patients. Sorghum is the fifth most important cereal crop grown in the world and the third most important in the US. Sorghum is typically used for feed, and because of the lack of the unique viscoelastic properties found in gluten, sorghum has not been considered a viable food ingredient in food products such as bread and flour-based noodles. In recent years, sorghum started being considered a viable ingredient in food. Approximately 50% of sorghum is consumed by humans (Agricultural Marketing Resource Center 2008). This number is anticipated to increase if sorghum is used in gluten-free products.

Sorghum Grain:

History:

Sorghum grain is drought tolerant and heat tolerant and can withstand a considerable degree of water logging (Doggett 1988). Sorghum originated from East Central Africa (Doggett et al 1970) and belongs to the grass family (Figure 1.4). During the first millennium BCE sorghum spread to India. Sorghum entered America from West Africa in the middle of 19th century. Sorghum is known under different names in different countries: 1) great millet and guinea corn in West Africa, 2) kafir corn in South Africa, 3) dura in Sudan, 4) mtama in eastern Africa, 5) jowar in India and 6) kaoliang in China (Purseglove 1972). In the United States sorghum is usually referred to as milo or milo-maize. Sorghum is the world's fifth most important cereal, following rice, wheat, corn and barley (Dendy 1995b).

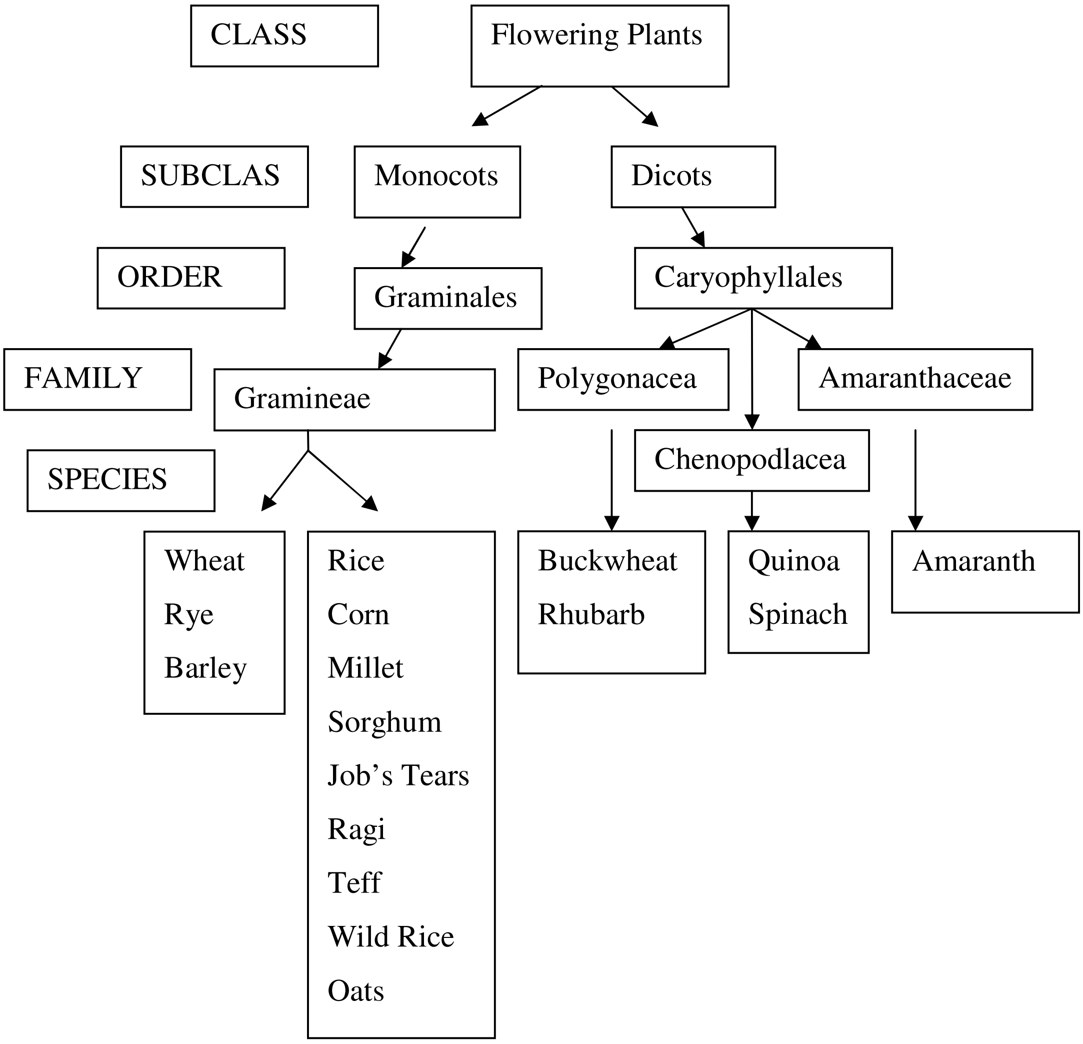

Figure 1.4 Plant Taxonomy. Adapted From Kasarda 2003.

Sorghum Production:

The five largest producers of sorghum in the world were the United States, Nigeria, India, Mexico and Sudan with 20, 16, 12, 10 and 7%, respectively (U.S. Grains Council 2008) (Figure 1.5). Of the US production, 41% sorghum came from Kansas (USDA World Agricultural Outlook Board 2004) (Figure 1.5). In 2007, the largest production of sorghum came from Kansas which was 212,000 million Bushels, followed by Texas (161,700 million Bushels), Louisiana (23,765 million Bushels), Nebraska (23,520 million Bushels) and Arkansas (20,210 million Bushels) (USDA, 2008 Agricultural Statistics).

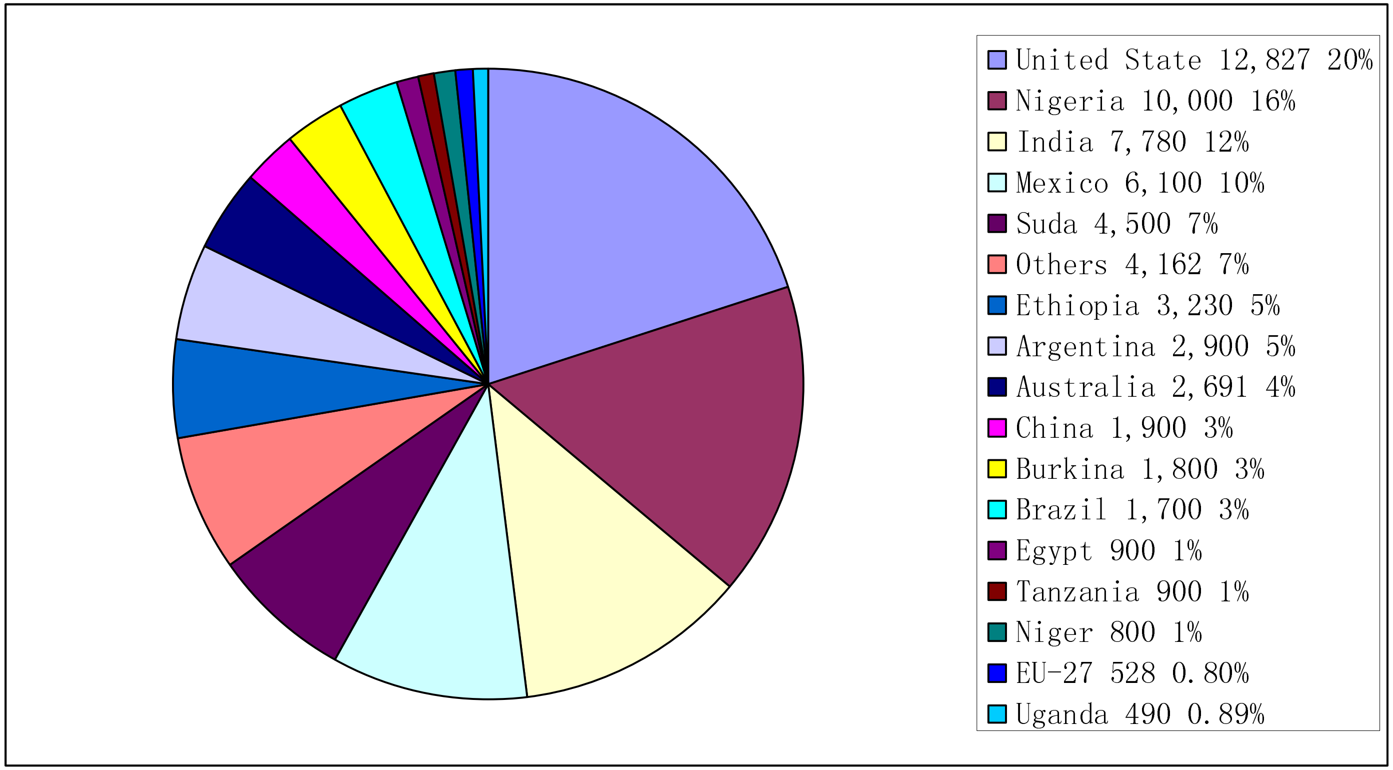

Figure 1.5 Sorghum World Production. Adapted From U.S. Grains Council 2008.

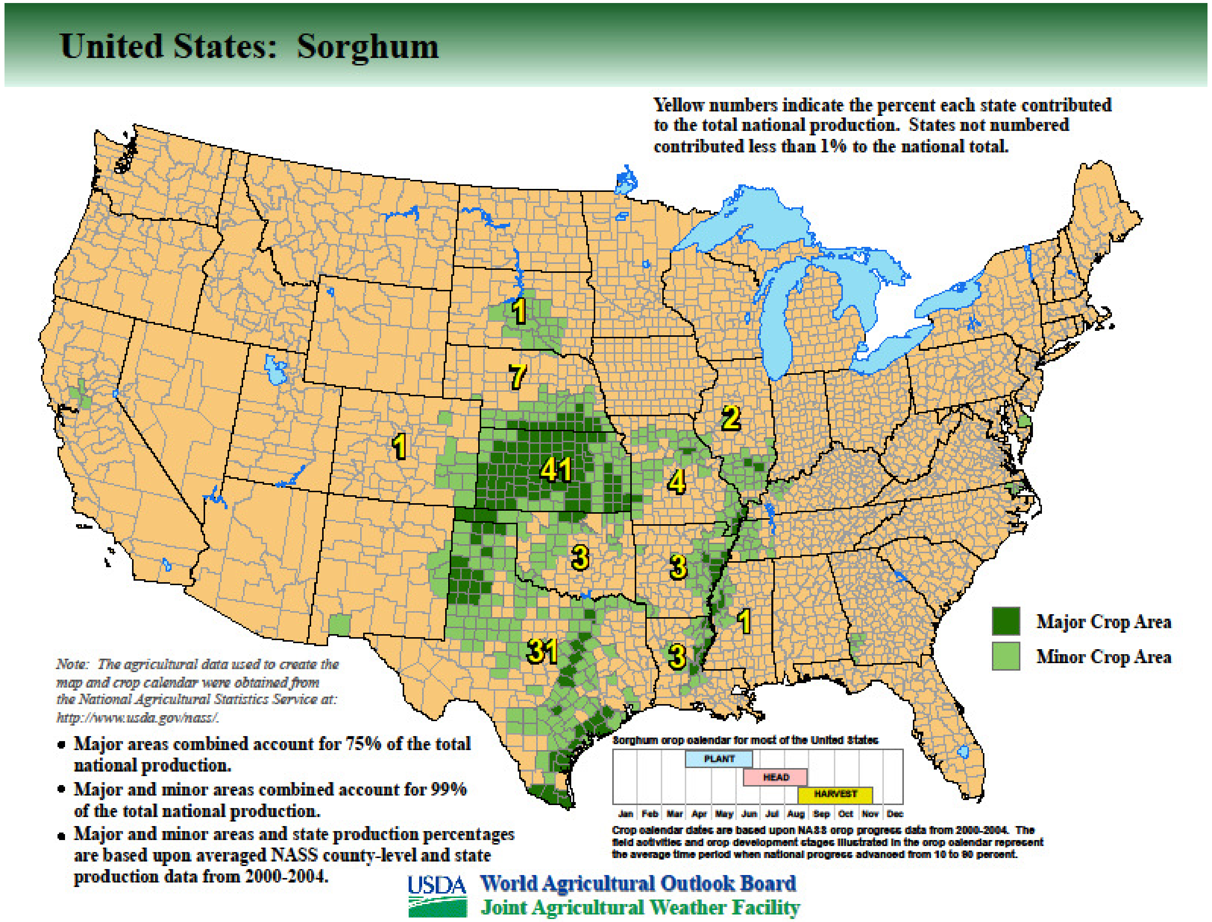

Figure 1.6 United States Sorghum Production. Taken From USDA World Agricultural Outlook Board 2004.

Sorghum Structure:

The color of sorghum kernel varies from white through shades of red and brown to pale yellow to deep purple-brown. The most common colors are white, bronze and brown. Sorghum is smaller and oval shape compared to the other cereals. Kernels of U.S. sorghums are 4-mm long, 2-mm wide, 2.5-mm thick, weighing 25-35 mg, and have densities from 1.28-1.36 g/cm3 (Serna-Saldivar and Rooney 1995). The major components of the grain are the 1) pericarp (outer covering), 2) the testa between pericarp and endosperm (which may or may not be present), 3) the endosperm, and 4) the embryo (Figure 1.6).

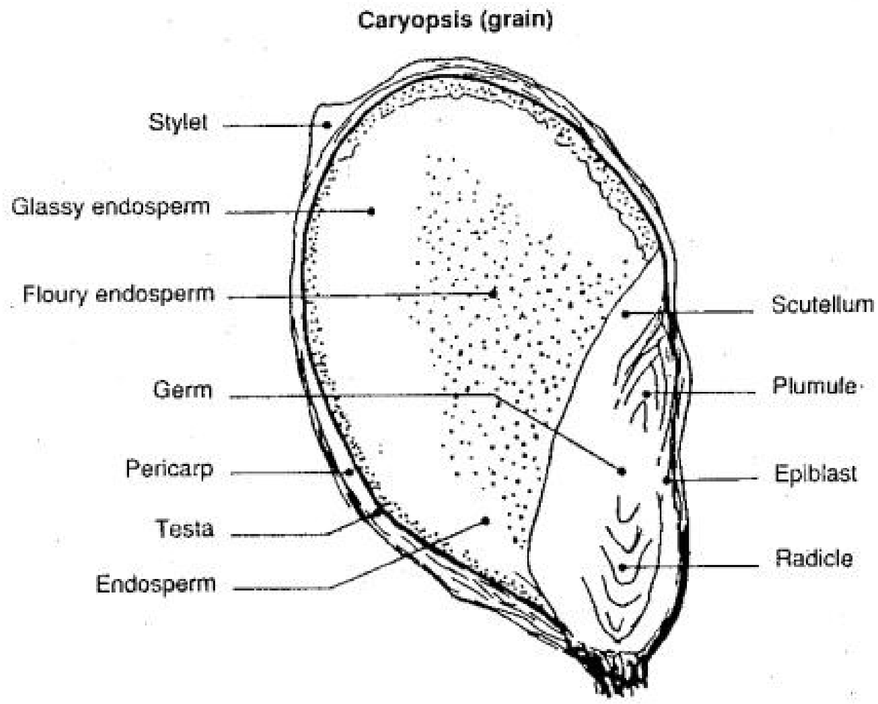

Figure 1.7 Structure of sorghum grain. Taken From FAO.

Pericarp:

The pericarp of sorghum is more friable than that of other cereals because of a starchy pericarp (Rooney 1973). Pericarp is the outer component and contains more than half of the kernel fiber content (Glennie 1984) and consists of three sublayers: epicarp, mesocarp, and endocarp (Earp and Rooney 1982). The epicarp is the outermost layer and divided into epidermis and hypodermis, generally covered with a thin waxy film. The mesocarp is the thickest layer of the pericarp and contains starch granules (Serna-Saldivar and Rooney 1995). The thickness of the mesocarp varies from very thin to thick with 3 or 4 cellular layers. The endocarp is the innermost layer of the pericarp and includes cross and tube cells that transport the moisture into the kernel (Waniska and Rooney 2000).

Testa:

In some sorghum genotypes the testa is present, whereas in others the testa may not be apparent or maybe completely absent (Figure 1.6). The thickness of the testa depends on the regions of the kernel (Blakely 1979). Pigmented testa sorghum genotypes have genes of β1 and β2 (Serna-Saldivar and Rooney 1995). The testa may contain tannins that are considered a desirable agronomic trait. Tannins conferring bitter taste may protect sorghum from being damaged by birds, insect pests and diseases (Waniska 2001). However, tannins are considered undesirable in the view of nutritive value since it can bind proteins and make them less digestive (Ambula 2003). The methods of mechanical dehulling can overcome the negative effects of tannins on nutritional value (Chantereau and Nicou 1994).

Figure 1.8 Testa of sorghum kernels: Top: purple testa; bottom left: brown testa; bottom right: no testa. Taken From Cheng 2009.

Endosperm:

The endosperm is the largest part of the kernel. Kernel protein and kernel starch are stored in the endosperm. The endosperm consists of an aleurone layer, peripheral, corneous and floury zones (Earp and Rooney 1982). The aleurone layer lies below the seed coat or testa and contains proteins, ash, B-complex vitamins and oil. The peripheral endosperm is distinguished by densely packed long rectangular cells that contain starch granules and protein bodies enmeshed in a dense protein matrix (Rooney and Sullins 1977). The corneous endosperm is translucent or vitrious and consists of protein matrix (Seckinger and Wolf 1973). The floury endosperm is located in the center of the endosperm and consists of protein phase, air voids and loosely packaged, round-lenticular starch granules (Hoseney 1974). The endosperm of sorghum comprises both a hard (also known as corneous) outer part and a soft (also known as floury) inner part. The kernels are soft-textured when the floury endosperm in higher proportions and hard-textured when the corneous endosperm is in higher proportions. Sorghums with a high proportion of corneous endosperm are preferred for milling as they give higher yields of endosperm flour (Maxson 1971). Floury endosperm sorghums are preferred for making both fermented and unfermented bread (Rooney et al 1986).

Chemical Composition:

Sorghum is similar in chemical composition to corn (Maize). A comparison of nutrients in various cereals is presented in Table 1.3.

Table 1.3 Comparison of nutrients in 100-g edible portions of various cereals at 12% moisture.[1]

Cereal	Protein (g)	Fat (g)	CHO (g)	Crude Fiber (g)	Ash (g)	Energy (kcal)	Calcium (mg)	Iron (mg)	Thiamin (mg)	Niacin (mg)	Riboflavin (mg)
Wheat	11.6	2.0	71	2.0	1.6	348	30	3.5	0.405	5.05	0.101
Brown rice	7.9	2.7	76	1.0	1.3	362	33	1.8	0.413	4.31	0.043
Maize	9.2	4.6	73	2.8	1.2	358	26	2.7	0.378	3.57	0.197
Sorghum	10.9	3.2	73	2.3	1.6	329	27	4.3	0.300	2.83	0.138
Pearl millet	11.0	5.0	69	2.2	1.9	363	25	3.0	0.300	2.0	0.15
Foxtail millet	9.9	2.5	72	10.0	3.5	351	20	4.9	0.593	0.99	0.099
Finger millet	6.0	1.5	75	3.6	2.6	336	350	5.0	0.300	1.4	0.10
Kodo millet	11.5	1.3	74	10.4	2.6	353	35	1.7	0.150	…	…
Japanese bamyard millet	10.8	4.5	49	14.7	4.0	…	22	18.6	…	…	…
Proso millet	10.6	4.0	70	12.0	3.2	364	8	2.9	0.405	4.54	0.279

[1]Adapted From Sorghum and Millets 2004.

Protein:

Protein content is the second largest component of sorghum grains. The protein is characterized based on their solubility as: albumins (water-soluble), globulins (soluble in dilute salt solutions), prolamins (kafirins) (soluble in alcohol) and glutelins (extractable in dilute alkali or acid solutions) (Hoseney 1994). Around 80% of proteins are stored in the endosperm, 15-16% in the germ and 3-4% in the pericarp (Rooney 1982). Sorghum protein content is comprised mainly of prolamins which make up 50% or more of the protein (Rooney and Serna-Saldivar 2000). The prolamins are storage protein found in the endosperm, whereas the albumins and globulins are functional proteins and found in germ (Taylor and Schussler 1986). Glutelins are the second major protein fraction and found in the peripheral and inner endosperm of the sorghum kernel (Rooney and Serna-Saldivar 2000).

Starch:

Starch may represent between 50% to 75% of the grain weight (Serna-Saldivar and Rooney 1995). Starches consist of two major components: a linear and a branched component. Amylose is the linear component made of unbrancehed chains of glucose units joined by alpha-1, 4 glycosidec bonds. Amylopectin is the branched component formed by branched chains of glucose units joined by alpha-1, 4 and alpha-1, 6 glycosidic bonds. Amylopectin is larger in molecule weight than amylose. Sorghum endosperms are composed of 23-30% of amylose (Horan and Heider 1946; Ring et al 1982). The gelatinization temperature of sorghum starch is ranged from 68-78℃ that is slightly higher than that of maize (62-72℃), and much higher than that of wheat (58-64℃) and barley (51-60℃) (Hoseney 1994). Sorghum starches have lower swelling power and solubilities than wheat starch at lower temperatures (50-70℃) (Carcea 1992). Sorghum starch has lower water-binding capacity and higher swelling-power compared to wheat and corn starches (Abdallah 1987)

Soluble sugar:

The average of soluble sugar content in sorghum grain is about 1.3% (Jambunathan 1984). The primary sugars present in sorghum grain are fructose, glucose, raffinose, sucrose and maltose (Anglani 1998). Of the sugras, sucrose comprises the largest amount of soluble sugar found in mature sorghum grain, followed by glucose and fructose (Subramanian 1980).

Lipids and fiber:

The lipids are mainly located in the germ and the content ranges from about 1.4 to 6.2% and an average is about 3.4% (Rooney 1982). The amount of lipids is related to the degree of decortication. Decortication is a process by which the germ is removed leading to a significant reduction in lipid content (Waniska and Rooney 2000). The fiber content of sorghum is mostly located in the pericarp. Around 86.2% of the fiber in sorghum is insoluble in water (Bach Knudsen and Munck 1985). Sorghum contains 6.5 to 7.9% insoluble fiber and about 1.1 to 1.23% soluble fiber (Bach-Knudsen and Munck 1985). The total fiber content depends on the amount of the tannin content of the grain.

Phenolic compounds:

The phenolic compounds are a unique compositional constituent of sorghum. Phenolic compounds are divided into three categories: 1) phenolic acid, 2) flavonoids, and 3) condensed tannins (Hahn et al 1984), the latter two are grouped as polyphenols.

Phenolic acids play a role in imparting resistance to fungal attack (Hahn et al 1983). The flavonoid compounds are responsible for the color of the pericarp of sorghum grains (Kambal and Bate-Smith 1976). The condensed tannins in sorghum can bind proteins reducing nutritional value (Hahn et al 1984). Tannins content could be reduced by abrasive decortication (Chibber 1980), fermentation (Hassan and El 1995) and germination of the grain (Osuntogun 1989).

Current Sorghum Products:

Sorghum food products are mostly homemade and found ubiquitously in traditional types of foods in China and India (Anonymous 1998b). For example, porridges can be produced by sorghum. The porridge is either thin or thick. The thick sorghum porridge, also known as “tô”, is produced by cooking fermented or unfermented flour (Bello et al. 1990) and steeped in alkali, acid or water (Anglani 1998). The quality of this porridge depends on the endosperm hardness, amount of pericarp remaining after decortication, flour particle size, pH of the cooking water and presence of nonstarch flour components (Bello 1990). Steeped and fermented sorghums may produce good quality thin porridge, called ogi (Banigo 1972). Nonwaxy sorghums produce a more consume preferred ogi than waxy sorghums (Akingbala et al 1981).

Another traditional but gaining popularity in the U.S. is couscous a steamed, agglomerated food made from decorticated sorghum flour. Couscous may be consumed with milk for breakfast or with a sauce containing fish or meat for lunch or dinner (Anglani 1998). Sorghum with a pigmented testa and high condensed tannin contents may be used to make a reddish brown with astringent stage couscous (Galiba et al 1987).

Sorghum may be used to make bread. However, the volume of bread made with sorghum was smaller than that of bread made with wheat flour (Anglani 1998). The crumb of sorghum bread was less elastic, drier and darker than that of wheat bread. Composite breads were formulated with sorghum flour and wheat flour to produce consumer acceptable bread (Hulse 1980; Dendy 1995; Carson et al 2000). This kind of bread is not totally gluten-free, therefore is not suitable for people with celiac disease. Gluten-free dough tends to be more fluid and close to cake batters (Cauvain 1998). Gums, stabilizers, pregelatinized starch and milk powder were suggested to use in gluten-free breads to give the desired textural attributes (Cauvain 1998; Satin 1988 and Gallagher 2003). Schober et al (2005) reported that the gluten-free bread may be made only by sorghum and corn starch.

Cookies may be made from sorghum but the texture was tough, hard, gritty, mealy and more fragile, and the color was darker than the wheat cookies (Badi and Hoseney, 1976). The lipids of phosphatidyl ehanolamine, digalactosyl diglycerides and phosphatidyl choline can be added to sorghum flour to improve the cookie baking quality (Badi and Hoseney 1976). Morad et al (1984) found that particle size and extraction rate of the flours are critical factors in the spread of sorghum cookies.

Tortilla chips, tortillas have been made with sorghum in many Central American countries (Rooney and Waniska 2000).

Alcoholic beverages such as clear and sweet and opaque and sour beers and non-alcoholic sorghum beverages are prepared commonly from sorghum (Rooney 1985)

Sorghum noodles may be made with decorticated sorghum flour (Desikachar 1977). The major problems using sorghum flour to produce noodles is that the grain lack of cohesiveness due to the absence of gluten. Suhendro et al (2000) reported that using sorghum flour, water, and salt may create sticky, soft noodles. The research found that a two stage high heat, high humidity (60℃ – 100% RH for 2 hr, then 60℃ – 30% RH for 2 hr) drying step following cold-extrusion of pre-cooked sorghum four produced better noodles with low cooking losses and strong textural properties. Miche (1977) reported that the firmness and cooking quality of noodles could be improved by adding pre-gelatinized maize starch to sorghum flour. Kunetz et al (1997) reported that pre-cooking of the flour, water and salt mixture using microwave prior to dough extrusion may produce good quality noodles.

Noodle

Market for Noodles

Noodles are traditionally consumed in many countries, such as China, Japan, Thailand, Korea and Malaysia. Noodles have become one of the fastest growing sectors in the world with the compound annual growth rate (CAGR) reaching 4% globally (Noodles face the European Snack Challenge 2003). The noodle sales in US increased by 16% between 1998 and 2002 which makes US the third largest noodle market in the world behind Japan and China (Noodles face the European Snack Challenge 2003). The market for Pasta & Noodles in the US is growing at an average annual rate of 1% since 2002 (Pasta and Noodles in the USA to 2010). Global sales of noodles increased by 15% between 2002 and 2007 to reach $312 million and may reach $422 million by 2012 (Global Information 2007).

Noodle Classification:

Noodle classification is based on several criteria such as the type of flour, noodle shape and size, salt used, processing method (Hou 2001). However, noodles may be simply classified into three main groups: 1) white-salted noodles popular in China, Japan and Korea, 2) yellow-alkaline noodles popular in Malaysia, Singapore, Indonesia, Thailand and Southern China, and 3) instant noodles preferred in East and Southeast Asia (Corke and Bhattacharya 1996).

Production of Noodles:

The production of noodles can be divided into two categories: Hand-Made and Machine-Made. The general procedure of making noodles is shown as follows (Figure 1.9).

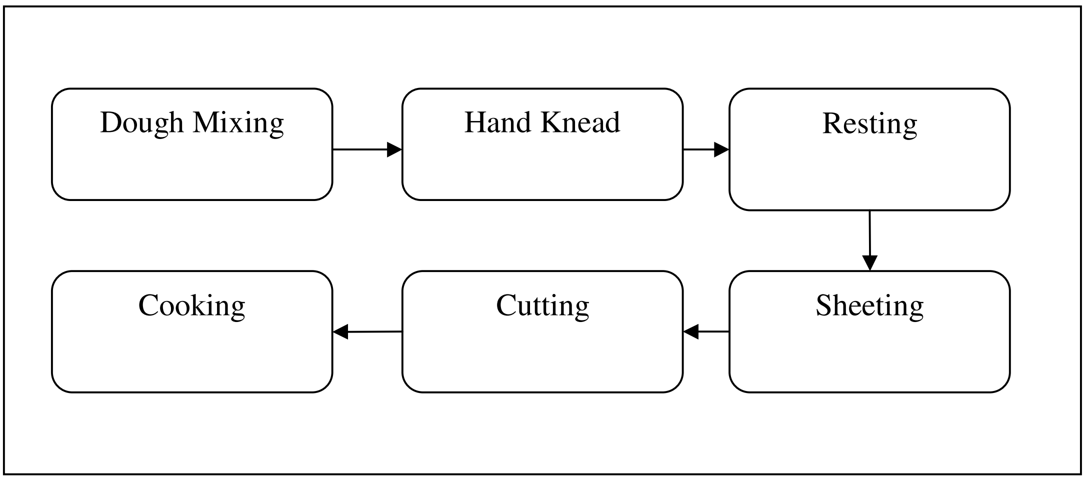

Figure 1.9 Noodle Process.

Hand-Made:

Lidz (1985) reported that hand-made noodle dough requires more water than machine-made noodle dough during the mixing process to assist with gluten development. The hand-made method may produce more uniform dough by increasing the retention of starch granules in the gluten network (Ogawa 1985). Hand-made noodles are sheeted and cut using a roller pin and knife. Appropriate thickness of dough sheet can be made by repeating rolling the sheet with the roller pin. Different noodle shapes may be produced by using different cutting techniques. Compared to the machine-made noodle process, hand-made noodle making is time consuming.

Machine-Made:

Machine-made noodles are produced in three simple steps: 1) mixing the ingredients to form a uniform dough, 2) sheeting the dough through rollers and 3) cutting dough into strands. If not enough water is added, noodles tend to crack (Moss et al 1987). After the dough is formed, the mass is gradually rolled thinner by 5-10 successive passes through the reduction rolls. Moss (1987) reported that the upper and lower surfaces of the noodle sheet have a slightly less continuous protein matrix than the center of the sheet. The dough is sheeted to 1-4 mm thickness. The dough is cut into strands by passing through a pair of cutting rolls. The factors of the speed of the rolls, the magnitude of shear and the dough thickness reduction ratio may affect the dough function during sheeting stage (Levine 1991). Excessive roll speed and reduction ratio may cause breakdown of the gluten network and over development of the dough.

Quality Assessment

Noodle Color:

Brightness is required color for all noodles and bright creamy white is the best white noodle color. Flour color is one of the most important factors in the value of noodle color (Miskelly 1984). Miskelly and Moss (1985) reported that flour protein content is negatively correlated with white noodle brightness. High Protein content is associated with increased grayness (Barnes 1989). Jun et al (1998) found that noodle color is influenced more by protein than by ash content.

Noodle Texture:

Cooked noodle texture is a very important assessment of noodle quality. The Chinese prefer noodle with medium firmness and strong chewiness texture, but the Japanese prefer soft texture (Huang and Morrison 1988). Oda et al (1988) found that starch composition and pasting properties are correlated with Japanese white noodle texture, whereas protein content and quality influence Chinese white noodle texture.

Effect of Starch pasting Properties on Noodle Texture:

Noodle texture is related with starch pasting properties (measured on the amylograph or Rapid Visco Analyzer) (Oda et al 1980). The properties of starch gelatinization and retrogradation properties are crucial to the quality of noodles. Soft and pliable noodles may be produced by the starch with low gelatinization temperatures and high pasting viscosity (Konik et al 1992 and Jun et al 1998). High starch swelling properties was found to be correlated with good noodle quality (Toyokawa et al 1989a; Crosbie 1991; Wang and Seib 1996). The quality of noodles made from rice flour, mung bean flour, tapioca, sweet potato, sorghum and corn flour especially depends on the role of starch, because noodles made from those flours other than wheat do not possess the ability to develop a functional gluten protein network (Faure 1992, Bhattacharya et al 1999; Suhendro et al 2000).

Effect of Amylose/Amylopectin on Noodle Texture:

The ratio of amylose to amylopectin plays an important role in the end-use product. Starch with lower amylose content reached to the peak viscosity at a lower temperature and had greater breakdown (Oda et al 1980). Hou (2001) found that good quality of Japanese noodles may be produced by flour with amylose content between 22-24%. Flour with lower amylose content gave noodles smooth surface and soft texture. The amylose crystallization formed by either complex formation (V-form) or retrogradation (B-form) is crucial for making acceptable quality non-wheat noodles (Mestres et al 1993).

Effect of Protein Content and Quality on Noodle Texture:

Flour protein content is correlated with cooked noodle texture (Nagao et al 1977). Oh et al (1985b) reported that low protein content causes noodles have soft texture and are easily broken during the drying process. Traditional wheat noodles contain a well-developed continuous gluten matrix when the wheat flour was mixed with water and in the sheeting process (Moss et al 1987). The gluten network is responsible to give noodles cohesive integrity and structural strength during processing. The gluten protein network restrains the swollen starch during cooking. Therefore, higher protein content led to lower cooking losses in traditional and extruded wheat noodles (Edwards et al 1993). The cooking time of noodles is influenced by protein contents. Higher protein contents led to longer cooking times by slowing down water penetration into the noodle (Moss et al 1987).

Other than protein quantity, protein quality plays an important role in noodles quality. However, not like bread-making, seldom research was done on the relationship between protein quality and noodle quality (Kruger 1996). Baik (1994a) reported that protein quality plays a more important role than protein content on noodle texture.

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CHAPTER 2 - Physical and Chemical Analysis of Four Sorghum Hybrids

Abstract

Celiac disease is ubiquitous and insidious; impacting the daily lives of over 3 million individuals just in the U.S. alone. Sorghum grain has been shown to be tolerated by Celiac patients and has demonstrated to exhibit potential as a food ingredient. The hypothesis of the study is that not all sorghum hybrids and respective flours perform or provide the same physical and chemical attributes. These attributes will directly impact final end product quality. The objective of this research was to evaluate and compare the chemical and physical attributes of four selected sorghum hybrids (Orbit, NE #8, F-525, NE #4). The sorghum hybrids were characterized for grain quality, starch properties and overall flour analysis. Orbit and NE#4 were significantly higher in single kernel hardness in which the values ranged from 98.35 (Orbit) to 10.26 (NE #8). F-525 exhibited a significantly smaller flour average particle diameter (118.9 µm), whereas Orbit exhibited a significantly larger starch average diameter (21.3 µm). Orbit exhibited a significantly higher starch damage (3.29%) compared with the other three sorghum flour (2.58 – 2.81%). F-525 had significantly smaller amylose content (22.06%) compared to the other three (27.51 – 28.46%). Crude protein values (%db) ranged from 8.96 (NE #4) to 10.68 (Orbit). The white sorghum hybrids used in this study exhibited significantly ($P<0.05$) higher moisture content and lower ash content compared to the red sorghum hybrids. The quality attributes measured suggested that physical and chemical differences did exist among sorghum hybrids.

Introduction：

Celiac disease is a life-long autoimmune response to the gliadin fraction of wheat and the prolamins of rye (secalins) and barley (hordeins) (Murray 1999). Approximately one percent of the US population suffers from celiac disease (Case 2006). Dual methology using serologic testing and small bowel biopsy are regarded to be effective in diagnosing the celiac disease (Presutti 2007). Celiac patients are faced daily with the arduous task following a strict gluten free diet in a wheat or gluten based society. The market for gluten-free foods and beverages in the US currently stands approximately $700 million, and is estimated to $1.7 billion by 2010 (Heller 2006).

Ciacci et al (2007) conducted the first direct test of the safety of sorghum for people with celiac disease and found that sorghum is safe for consumption by those who have celiac disease. Sorghum grain did not exhibit any deleterious effects to celiac and also has a number of beneficial phytochemicals (Awika and Rooney 2004). These attributes may have significant positive impact on human health for both celiac patients and non-celiacs. Sorghum is the fifth most important cereal crop grown in the world and the third most important in the US (Doggett 1988). Additionally, sorghum is resistant to thermal stress and is drought resistant. Therefore, sorghum may serve as a pivotal grain in development of gluten-free food products.

Many studies have been conducted on sorghum foods but the literature remains scarce in characterizing the physical and chemical properties of many sorghum hybrids. Therefore, the objective of this study was to compare chemical and physical characteristics of the grain and flour from four selected sorghum hybrids. The traits may provide guidance in developing the gluten-free products from sorghum.

Materials and Methods

Sorghum Hybrids

USDA-ARS in Manhattan, KS provided four sorghum hybrids from their collection for this study. The four sorghum hybrids were Orbit, Fontanelle – 525 (F - 525), AT×2752×RT×2783 (NE #4) and AT× 3197× RT× 7078 (NE #8). Orbit and F – 525 are white sorghums; NE #4 and NE #8 are red sorghums. The hybrids were cleaned before analysis by sieving over a screen with 2.0-mm triangular openings (B-P triangle screen, Seedburo Equipment Company, Chicago, IL). Samples were first decorticated until 20% of the initial weight was removed, then were milled by a Bliss Hammermill.

Grain Characterization

Single Kernel Characterization System (SKCS):

Single kernel properties are important in the processing of cereal grains and in the end-use food products. Single kernel hardness of sorghum was analyzed using SKCS 4100 Single Kernel Characterization System (Perten Instruments, Huddinge, Sweden) (Figure 2.1). The SKCS analyzes 300 randomly selected kernels per sample and provides the average of kernel hardness, kernel weight, kernel size and kernel moisture. Individual kernels were weighed and then crushed between a toothed rotor and a progressively narrowing crescent gap (Martin et al 1992). As the kernel was crushed, the force (between the rotor and crescent) and the conductivity (between the rotor and the electrically isolated crescent) were measured. This data was processed to provide weight, diameter, moisture and hardness on an individual kernel basis.

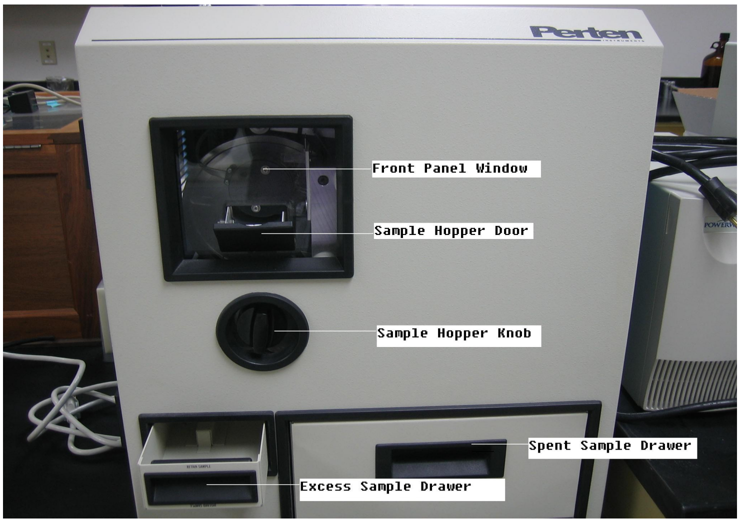

Figure 2.1 Image of SKCS 4100 Single Kernel Characterization System

Kernel Abrasive Hardness:

The abrasive hardness provides a gauge of measurement related to the amount of energy needed to remove the pericarp without destroying the kernel. Samples were decorticated for 4 min using the Tangential Abrasive Dehulling Device -TADD (Venebles Machine Works, Saskatoon, Canada) (Reichert et al 1982) (Figure 2.2). TADD is a method for determining the dehulling characteristics of sorghum grains (Oomah et al. 1981). Each sorghum sample (10g) was placed in the decorticator sample cup to remove the pericarp from the sorghum seeds. A vacuum sample collector was used to remove the abraded samples from the sample cups. The percent of kernel removed after a specified time of abrasion (1, 2 and 4 min) were calculated and plotted against the retention times to develop a regression line. The inverse of the slope for each sample regression line was multiplied by 60 (sec) to give the abrasive hardness index (AHI), which is defined as the time in seconds necessary to abrade 1% of the kernel (Oomah et al 1981).

Figure 2.2 Image of a Tangential Abrasive Dehulling Device

Flour Characterization

Starch Isolation:

High-intensity ultrasound (sonication) was used to purify starch from sorghum flour following the procedure of Park (2006). To isolate starch, 500 mL of pH 10 buffer was prepared. Approximately, 7.5 g decorticated sorghum flour was added in a beaker and mixed with 150 mL buffer to make a 1:20 ratio. The mixture was stirred until no clumps were visible. The beaker was submersed in ice water and sonicated 100 sec in a VCF-1500 ultrasonic processor (Sonics & Materials, Inc., Newton, CT). After sonication, the mixture was poured into a centrifuge tube and placed in a Centrifuge 5810 (Eppendorf, Westbury, NY) for 10 min at 4000 rpm (2683 x g). After centrifugation, the remaining liquid was decanted. The solid was washed with approximately 40 mL distilled water through a 62 µm screen. The suspension was centrifuged for 5 min at 4000 rpm (2683 x g). The liquid was decanted. The solid precipitate was washed again with approximately 40 mL distilled water through a 62 μm screen. The suspension centrifuge for 5 min at 4000 rpm (2683 x g) decanted and washed. The suspension centrifuge for 5 min at 4000 rpm (2683 x g) and decanted. The isolated starch was dried in Labconco Freezone 6 Freeze Dryer (Labconco Corporation, Kansas City, MO)

Starch Particle Size Distribution:

Starch particle size distribution was determined using a LS™ 13 320 Laser Diffraction Particle Size Analyzer (Beckman-Coulter, Inc., Miami, FL) (Figure 2.3). The freeze dried starch from the aforementioned isolatione procedure was ground with a coffee grinder (Mr. Coffee, Shelton, CT). Approximately 0.01 g of ground starch was dissolved in a microfuge tube by adding 1% sodium azide (toxic) to prevent starch granule clumping. Additionally, the starch solution was sonicated to help break up any remaining clump. Four drops of the sample were dropped into the instrument of Universal Liquid Module (Beckman-Coulter, Inc., Miami, FL) that was used for small particle size samples (citation) and the measurements were taken.

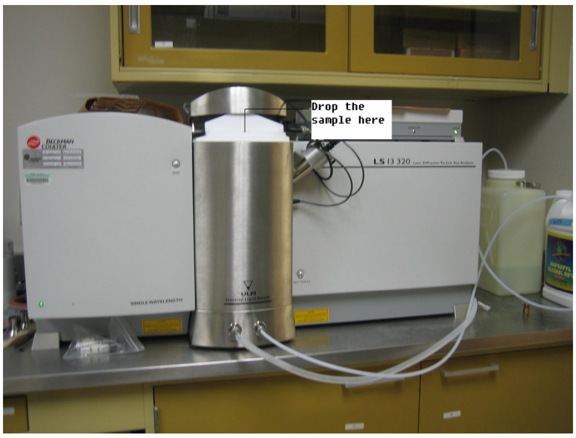

Figure 2.3 Image of a LS™ 13 320 Laser Diffraction Particle Size Analyzer with Universal Liquid Module

Flour Particle Size Distribution:

Flour particle size distribution was determined using by instrument of LS™ 13 320 Laser Diffraction Particle Size Analyzer (Beckman-Coulter, Inc., Miami, FL) (Figure 2.4). The sorghum flour was transferred to the measuring canister and filled approximately 2/3 full The canister was placed in the instrument and the measurements were taken.

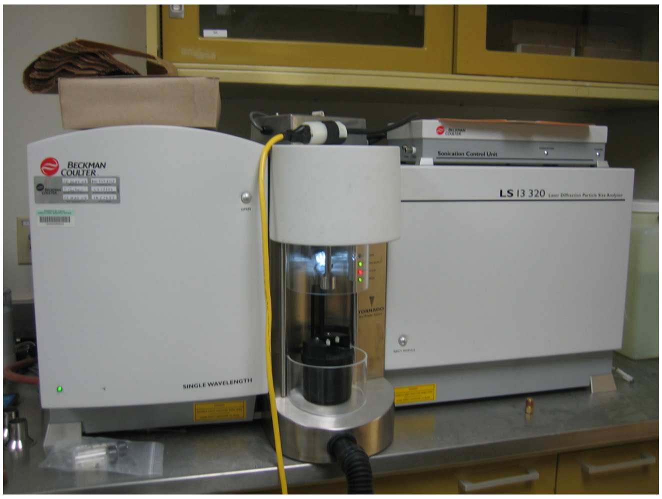

Figure 2.4 Image of a LS™ 13 320 Laser Diffraction Particle Size Analyzer

Starch Pasting Properties:

The pasting properties of sorghum starch from the four sorghum hybrids were assessed using the Rapid Visco Analyser (RVA Model 4, Newport Scientific, Australia). During the RVA test, samples could be assessed for pasting temperature, peak paste viscosity, time to peak, temperature at peak, breakdown, setback and final viscosity. The pasting curve is a result of the starch slurry being subjected to a specified thermal profile. In the RVA, the short temperature profile (13 min) was used and the mixture was stirred at 960 rpm for 10 s, and then at 160 rpm for the remainder of the test. The temperature of the test initiated at 50℃ held for 1 min and ramp to 95℃ over 3 min and 45 s where the sample was held for 2 min and 30 s, the temperature was then decreased back down to 50℃ over 3 min and 45 s and was held again for 2 min.

The RVA requires 30 min to equilibrate prior to conduction analysis. A control (wheat flour) was evaluated on the RVA to ensure that the instrument was operating properly. Prior to analysis, the starch was analyzed for moisture content. The quantity of starch and water were adjusted each time to ensure a 14% moisture content. The correction formula for 14% moisture basis is:

$M_2 = M_1 \times (100 - 14) / (100 - \text{Moisture Content of Sample})$
$W_2 = 25.0 \text{ mL} + (M_1 - M_2)$

Where M_1 = sample mass for the material (3 g)
M_2 = corrected sample mass
W_2 = corrected water volume (1)

The calculated volume of distilled water for the respective sorghum starch sample was poured into the RVA canister. The sorghum starch sample was gently dispersed onto of the surface of the distilled water. The RVA mixing paddle was slowly forced in and out of the distilled water-sorghum starch mixture in an up and down motion to blend and hydrate the starch. This action was repeated 10 times. Finally, the mixture was stirred/sheared 20 times in a circular motion to ensure no clumping of the starch existed.

Total Starch:

The total starch content of the four sorghum flours was determined by Megazyme Total Starch Assay kit, K-TSTA 05/06 (Megazyme International Ireland Ltd., Co. Wicklow, Ireland). The assay is based on the amyloglucosidase/α-amylase method (AOAC Method No. 996.11). The thermostable α - amylase was added to solubilize the starch. The amyloglucosidase was added to give complete degradation of dextrins to glucose. Since sorghum starch may have high levels of resistant starch, a pretreatment with dimethyl sulphoxide (DMSO) was performed.

Starch Damage:

Starch damage of the four sorghum flours was determined using Megazyme Starch Damage Assay kit, SDA 11/01, AACC Method 76-31 (Megazyme International Ireland Ltd., Co. Wicklow, Ireland). Damaged starch granules were hydrated and hydrolyzed to maltosaccharides with purified fungal α-amylase. Approximate 8.0 mL sulphuric acid (0.2%, v/v) was added to stop the reaction and amyloglucosidase was added for complete degradation of dextrins to glucose.

Amylose:

The amylose and amylopectin content of starch was determined by the method of Gibson et al (1997) using Megazyme Amylose/Amylopectin Assay Kit, K-AMYL 04/06 (Megazyme International Ireland Ltd., Co. Wicklow, Ireland).The starch was dispersed by heating in dimethyl sulphoxide (DMSO) in a boiling water bath for approximately 1 min and the lipids were removed by precipitating the starch in ethanol (95%, v/v). The amylopectin was precipitated by concanavalin A (Con A) and removed by centrifugation at 14,000 x g for 10 min. Amylose was hydrolyzed to D-glucose with glucose oxidase/peroxidase reagent.

Proximate Analysis:

The crude protein was determined using a LECO FP-528 instrument (Leco Corporation, St. Joseph, MI), the AACC approved method 46-30 (10th edition). The ash content was determined using the AACC approved method 08-01. Modifications were made as following: 3 to 4 g of flour, 21 hr at 538 ℃, cool for 1 hr in desicator and weigh. The moisture, crude fat and crude fiber were measured using AOAC Official method # 930.15, AOAC Official method # 920.39 and Ankom method.

Statistical Design

Four treatments of sorghum flour were evaluated for grain and flour characterizations. Two replications were treated as blocks in a randomized block design. 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 $p < 0.05$.

Results and Discussion

Grain Characterization

Single Kernel Characterization System (SKCS):

The average hardness indexes of sorghum kernels ranged from 74.98 (NE #8) to 98.35 (Orbit) (Table 2.1). Orbit and NE#4 had significantly higher kernel hardness than NE#8 and F-525. According to the sorghum single kernel hardness classification by Bean et al. (2006) (36.5 – 110.7), two of our samples had mediate single kernel hardness (74.98 – 78.07), two of our samples had high single kernel hardness (96.32 – 98.35). Murty and House (1980) reported that kernel hardness of sorghum influenced the quality of traditional sorghum food products. Muhamad (2004) calculated that the energy required to mill sorghum into flour was greater for kernels with greater hardness values. Cagampant et al (1982) reported that the texture and stickiness of cooked sorghum porridges was associated with sorghum grain hardness. Kernel weight ranged from 23.84 mg (F-525) to 30.82 mg (Orbit). Orbit and NE #4 had significantly higher kernel moisture (14.86% and 14.92%) followed by NE #8 (14.48%) and F-525 (14.15%). Kernel diameter averages ranged from 1.93 mm (NE #4) to 2.55 mm (Orbit). The kernel size range was comparable to that reported by Bean et al (2006). He reported that kernel size for the sorghums ranged from 1.4-2.8 mm. According to Lee et al (2002), kernel size had effect on milling yields and some of flour properties, like flour color, water absorbance, flour particle size, protein and ash. Kernel weight and moisture may affect protein content (Regnier et al 2002)

Abrasive Hardness Index:

The average abrasive hardness indexes of sorghum kernels ranged from 10.26 (NE #8) to 14.16 (Orbit) (Table 2.1). Bean et al (2006) reported that the sorghum abrasive hardness ranged from 6.4 – 22.0 based on the hybrids they evaluated. Thus, the samples evaluated in this research would be considered to have an intermediate abrasive hardness designation. Although, there are other factors that may the affect abrasive hardness index including kernel shape, kernel size, and pericarp thickness (Kirleis and Crosby 1982; Lawton and Faubion 1989). Kon et al (1973) noted that abrasive dehulling improved end product quality related to appearance, texture, and cooking quality.

Flour Characterization

Starch Particle Size Distribution:

The distribution of starch particle diameters (μm) for each sorghum hybrid is shown at five different volume percents 10, 25, 50, 75 and 90 (Table 2.2). The average starch particle diameters ranged from 6.13 µm to 7.38 µm, 11.51 µm to 13.96 µm, 17.58 µm to 20.85 µm, 23.96 µm to 28.16 µm, 39.67 µm to 35.70 µm at 10, 25, 50, 75, and 90 volume percents, respectively. Orbit had significantly ($P < 0.05$) larger mean particle diameter (21.3 µm) compared to the other three hybrids (17.82 – 19.13 µm). Raeker et al (1998) evaluated starch particle size of wheat at small granules with diameters <2.8 µm, midsize granules with diameters of 2.8–9.9 µm, and large granules with diameters >9.9 mm, and found that smaller starch granules tended to have higher lipid contents. Morrison (1995) reported that starch particle size distribution of wheat starch can influence its chemical composition and may affect its functionality. Raeker (1998) reported that cultivars that had different starch particle size distribution exhibited different starch pasting, swelling and gelatinization properties.

Flour Particle Size Distribution:

The flour particle diameters (µm) for each sorghum hybrid is shown at five different volume percents 10, 25, 50, 75 and 90 (Table 2.3). Significant differences were found at each of volume percent. The average flour particle diameters ranged from 25.65 µm to 34.10 µm, 78.20 µm to 92.95 µm, 148 µm to 177 µm, 238 µm to 271 µm, 314 µm to 351 µm at 10, 25, 50, 75, and 90 volume percents, respectively. F-525 had significantly smaller mean flour particle diameter (118.9 µm) compared to the other three hybrids (131.60 – 136.55 µm). Hatcher (2002) reported that flour particle size had critical effect on final product. The researcher concluded that white salted noodles made by flours with fine particle size (85-110 µm) resulted in a product that exhibited better textural attributes than a coarser particle size (132-193 µm) flour.

Starch Pasting Properties:

The starch pasting properties is correlated with the quality of end-product. Significant differences were found among all the parameters in the starch pasting properties (Table 2.4). Peak viscosity ranged from 371.83 RVU (NE #8) to 425.92 RVU (F-525). More starch granules with a high swelling capacity result in a higher peak viscosity. Higher peak viscosity indicated that more starch has been gelatinized during processing (Suhendro et al 2000). Zobel (1994) explained that the term gelatinization is used to describe the swelling and hydration of granular starches which disrupt the order of starch molecular. Trough viscosity ranged from 75.58 RVU (NE #4) to 86.29 RVU (NE #8). Breakdown viscosity ranged from 285.54 RVU (NE #8) to 348.05 RVU (Orbit). Higher breakdown indicates lower paste stability. Setback viscosity ranged from 147.7 RVU (NE #4) to 209.00 RVU (Orbit). Final viscosity ranged from 223.29 RVU (NE #4) to 284.96 RVU (Orbit). During cooling, starch molecules started to reorder and form a gel structure and viscosity increased to a final viscosity. This phase is called setback. The low setback values indicate low rate of starch retrogradation and syneresis. Peak time ranged from 3.78 min (F-525) to 4.02 min (NE #8). Pasting temperature ranged from F-525 (70.15 ℃) to NE #4 (75.18 ℃). Suhendro et al (2000) reported that the peak viscosity and peak development time were indicators of degree of starch retrogradation in sorghum noodles and the degree of starch retrogradation has great effect on cooking loss of sorghum noodles. Crosbie (1989) reported that desirable boiled Japanese-style noodles were made from flour with high starch paste peak viscosity.

Total Starch:

Total Starch ranged from 68.85 % (Orbit) to 78.63 % (NE #4) on a dry basis. Orbit had a significantly lower total starch compared to the other three hybrids (Table 2.5). Buffo et al (1998) reported an average starch content of 73.12±2.73 (% db) for sorghum grain and found that the amount of starch was negatively correlated with initial water absorption rate. Dicko (2006) showed that there was no significant difference of starch content between red and white sorghum grains (57.2 – 68.5% wet basis).

Starch Damage:

The level of starch damage impacts water absorption, and dough extensibility and resistance (Oh et al 1986). Orbit had significantly higher starch damage (3.29 % db) compared to the other three sorghum hybrids (2.58-2.81 % db) (Table 2.5). According to the range of starch damage (11.1 – 16.5 % db) of sorghum flour reported by Schober et al (2005), the four sorghum flour had low starch damage. The milling method may affect the level of starch damage (Oh et al 1985). Oh et al (1985) reported that the starch damage of wheat flour was negatively correlated with the internal and surface firmness of cooked noodles. The starch damage may affect the cooking quality of noodles, higher starch damage causing higher cooking loss (Hatcher 2002).

Amylose content:

The ratio of amylose and amylopectin may have effect on both the gelatinization and retrogradation of starch (Czuchajowska et al 1998, Fredriksson et al 1998, Yuryev et al 1998). The amylose content of F-525 (22.06 % db) was significantly lower than the other three sorghum hybrids (27.51-28.46 % db) (Table 2.5). Dicko et al (2006) reported that the amylose content in sorghums ranged from 10 to 17% (wet basis) and sorghum with low amylose content is good for industrial brewing and sorghum with high amylose content is desirable for "tÔ" (porridge) preparation. Whistler (1984) reported that amylose has a higher gelatinization temperature than amylopectin. The gelatinization of starch caused the leaching of amylose, which contributed to the thickening characteristics of starch and gel formation. Starch with very low amylose such as waxy maize – less than 1% of amylose, could not form gel effectively. The retrogradation of starch was formed by the re-association of leached amylose after cooling. Amylose was more susceptible to the retrogradation of starch than amylopectin. Oda (1980) and Toyokawa (1989) reported that white salted wheat noodles may have improved texture with lower amylose content. The amylose content was found to have effect on water absorption, color (lightness), fat absorption and cooking time of cooked instant noodles (Park and Baik 2004). Gomez and Waniska (1988) observed that thin porridges from extruded sorghum containing lower amylose exhibited a more viscous consistency, smoother texture, slight roasted flavor and lighter color.

Protein Content:

Protein content effects rheological and end-use quality of wheat flours. The literature is scarce that has studied the effect of sorghum protein content on noodles quality. Significant differences of protein content were found among each sorghum hybrid (Table 2.5). Protein content ranged from 8.96 % (NE #4) to 10.65 % (Orbit) on a dry basis. The range was comparable to that reported by Schober et al (2005) (9.5 -

12.9 % db). Moss et al (1987) reported that white noodles that have higher protein content have less cooking loss. Higher protein content (8.6-14.3 %) of soft wheat flour results in stronger noodles (cutting stress ranged from 22.7-33.9 g/mm^2) (Oh et al 1985). However, Baik et al (1994) found that both protein content and quality have effect on the cooking quality and texture of wheat noodles.

Ash Content:

Ash content ranged from 1.25% (F-525) to 1.41% (NE #4) on a dry basis (Table 2.5). Red sorghum hybrids (NE #4 and NE #8) had significantly ($P<0.05$) higher ash content than the white sorghum hybrids (Orbit and F-525). Kim and Flores (1999) evaluated twenty-one hard red winter wheat flour samples with ash contents of 0.30–0.58% and found that the color (Lightness) of flour (99.9–97.3) is affected by the ash content (R^2 = 0.74). Ash content reflects the degree of bran contamination in the flour. Flour with low ash content is good for utilization in human food. High quality yellow alkaline noodles were made with flour with 0.32-0.40% ash content in Japan. In China, first and second grade flours used in white salted noodle are preferred not to exceed 0.70% ash content (Sun, 2008). Gujral et al (2008) reported that increased ash content from 1% to 2 % increased wheat noodle thickness.

Moisture, Crude Fat and Fiber:

Moisture content ranged from 12.60% (NE #8) to 15.42% (F-525). The crude fat ranged from 3.33% (F-525) to 3.85% (Orbit) on a dry basis (Table 2.5). Crude fiber did not differ among the four hybrids and ranged from 1.50% (F-525) to 1.69% (NE #4) on a dry basis.

Correlation analysis:

Correlations were conducted between sorghum grain and flour properties to assist in selecting an appropriate sorghum hybrid to be used in gluten-free noodle system. The correlations among sorghum kernel properties and flour properties are shown in Table 2.6. The single kernel hardness was significantly correlated with kernel moisture (r = 0.86). A significant correlation was observed between single kernel hardness and abrasive hardness (r = 0.90) which agrees with the findings from Bean et al (2006) that single kernel hardness was significantly correlated with abrasive hardness. Kernel weight was significantly influenced by kernel size (r = 0.89). Starch particle size was found significantly influenced by kernel size (r = 0.76) and kernel weight (r = 0.92). Flour particle size was positively correlated with kernel weight (r = 0.72). However, no significant correlation of flour particle size with kernel size and kernel hardness was found in this study which conflicts with reports from Lee (2002) and Aboubacar (1999) that harder and larger kernels may have larger flour particle size. The amount of total starch was found negatively correlated with kernel weight (r = -0.92) and kernel size (r = -0.92). The starch damage was significantly influenced by kernel weight (r = 0.81) and kernel size (r = 0.61) which agrees with the findings from Aboubacar and Hamaker (1999) that larger kernels may cause more damaged starch. Larger kernels were found to have higher protein content (r = 0.95) which agrees with the findings from Lee (2002). Crude fat content was higher in larger flour granules (r = 0.90) and larger starch granules (r = 0.84).

For the starch pasting properties, the final viscosity was found significantly influenced by total starch (r = -0.84) and starch damage (r = 0.93) (Table 2.7). The time to achieve peak viscosity was positively correlated with amylose content (r = 0.72). Because when starch absorbs water, they swell, lose crystallinity and leach amylose. High amylose content may form an extensive network to reduce the extent of swelling (Bhattacharya 1999). Higher ash content was correlated with lower peak viscosity (r = -0.82), later viscosity development (r = 0.90) and higher peak temperature (r = 0.76).

Conclusion:

The results showed that the selected four sorghum hybrids did differ in both kernel and flour properties. Correlations among sorghum physical and chemical properties were found and these findings could help to predict sorghum flour quality for the purpose of gluten-free products.

Table 2.1 Comparison of grain physical properties from four selected sorghum hybrids.

		SKCS[1]				TADD[2]
Hybrid Name	Pericarp Color	Single Kernel Hardness	Kernel weight (mg)	Kernel moisture (%)	Kernel Dia. (mm)	Abrasive Hardness Index
Orbit	White	98.35 ± 1.95^{a}	30.82 ± 0.23^{a}	14.86 ± 0.01^{a}	2.55 ± 0.03^{a}	14.16 ± 0.06^{a}
F-525	White	78.07 ± 0.96^{b}	23.84 ± 0.48^{c}	14.15 ± 0.01^{c}	2.13 ± 0.04^{bc}	11.96 ± 1.17^{ab}
NE#8	Red	74.98 ± 2.18^{b}	27.31 ± 0.90^{b}	14.48 ± 0.02^{b}	2.17 ± 0.08^{b}	10.26 ± 0.54^{b}
NE#4	Red	96.32 ± 0.67^{a}	24.76 ± 0.04^{c}	14.92 ± 0.02^{a}	1.93 ± 0.01^{c}	13.58 ± 1.10^{ab}

abc means in the same column with different superscript letters differ ($p<0.05$)

1 Single Kernel Characterization System

2 Tangential Abrasive Dehulling Device

Table 2.2 Comparison of sorghum starch particle size distribution from four selected sorghum hybrids.

Hybrid Name	Volume %				
	10 < µm	25 < µm	50 < µm	75 < µm	90 < µm
Orbit	7.38 ± 0.48^{a}	13.96 ± 0.73^{a}	20.85 ± 0.73^{a}	28.16 ± 0.83^{a}	35.70 ± 0.79^{a}
F-525	6.13 ± 0.08^{b}	11.51 ± 0.11^{b}	17.58 ± 0.07^{b}	23.96 ± 0.02^{b}	29.67 ± 0.02^{c}
NE#8	6.35 ± 0.10^{b}	12.07 ± 0.12^{b}	18.42 ± 0.22^{b}	25.40 ± 0.36^{b}	32.47 ± 0.36^{b}
NE#4	6.39 ± 0.09^{ab}	12.31 ± 0.05^{b}	18.78 ± 0.14^{b}	25.56 ± 0.29^{b}	32.05 ± 0.41^{b}

abc means in the same column with different superscript letters differ ($p<0.05$)

Table 2.3 Comparison of sorghum flour particle size distribution from four selected sorghum hybrids

Hybrid Name	Volume %				
	10	25	50	75	90
	< µm	< µm	< µm	< µm	< µm
Orbit	34.10 ± 0.14^{a}	92.95 ± 1.91^{a}	173.50 ± 2.12^{ab}	256.50 ± 2.12^{b}	326.50 ± 3.54^{b}
F-525	25.65 ± 0.21^{c}	78.20 ± 1.13^{c}	148.00 ± 1.41^{c}	238.00 ± 1.41^{c}	314.00 ± 1.41^{b}
NE#8	28.90 ± 1.41^{b}	91.35 ± 2.76^{ab}	177.00 ± 2.83^{a}	271.00 ± 2.83^{a}	349.50 ± 6.36^{a}
NE#4	27.45 ± 0.49^{bc}	84.15 ± 0.92^{bc}	167.50 ± 2.12^{b}	271.00 ± 2.83^{a}	351.50 ± 2.12^{a}

abc means in the same column with different superscript letters differ ($p<0.05$)

Table 2.4 Comparison of sorghum starch pasting properties from four selected sorghum hybrids

Hybrid Name	Peak viscosity (RVU)	Trough (RVU)	Breakdown (RVU)	Setback (RVU)	Final Viscosity (RVU)	Peak time (min)	Pasting Temp. (℃)
Orbit	424.42 ± 7.42^{ab}	75.96 ± 1.82^{b}	348.05 ± 5.48^{a}	209.00 ± 2.72^{a}	284.96 ± 0.88^{a}	3.98 ± 0.01^{b}	72.08 ± 0.6^{b}
F-525	425.92 ± 0.12^{a}	79.88 ± 1.35^{ab}	328.46 ± 1.71^{b}	153.00 ± 0.11^{b}	232.88 ± 1.24^{bc}	3.78 ± 0.00^{d}	70.15 ± 0.56^{b}
NE#8	371.83 ± 0.71^{c}	86.29 ± 2.77^{a}	285.54 ± 2.06^{c}	156.88 ± 3.24^{b}	243.17 ± 6.01^{b}	4.02 ± 0.02^{a}	72.28 ± 0.81^{b}
NE#4	409.70 ± 2.65^{b}	75.58 ± 0.47^{b}	334.12 ± 2.18^{b}	147.70 ± 1.59^{b}	223.29 ± 2.06^{c}	3.87 ± 0.00^{c}	75.18 ± 0.11^{a}

abc means in the same column with different superscript letters differ ($p<0.05$)

Table 2.5 Comparison of flour properties from four selected sorghum hybrids

Hybrid Name	Pericarp Color	Total Starch (%db)	Starch Damage (%)	Amylose (%)	Moisture Content (%)	Protein (%db)	Ash (%db)	Crude Fat (%db)
Orbit	White	68.85 ± 0.62^{b}	3.29 ± 0.12^{a}	27.93 ± 0.29^{a}	14.77 ± 0.14^{a}	10.65 ± 0.07^{a}	1.31 ± 0.02^{b}	3.85 ± 0.06^{a}
F-525	White	78.61 ± 2.26^{a}	2.58 ± 0.07^{b}	22.06 ± 0.68^{b}	15.42 ± 0.17^{a}	9.64 ± 0.01^{c}	1.25 ± 0.00^{c}	3.33 ± 0.11^{b}
NE#8	Red	75.30 ± 0.96^{a}	2.81 ± 0.12^{b}	27.51 ± 1.72^{a}	12.60 ± 0.01^{b}	10.04 ± 0.01^{b}	1.40 ± 0.00^{a}	3.72 ± 0.02^{a}
NE#4	Red	78.63 ± 2.77^{a}	2.78 ± 0.14^{b}	28.46 ± 0.68^{a}	12.78 ± 0.10^{b}	8.96 ± 0.01^{d}	1.41 ± 0.00^{a}	3.64 ± 0.03^{a}

abc means in the same column with different superscript letters differ ($p<0.05$)

Table 2.6 Correlations among sorghum kernel properties and flour properties

	Kernel Moisture	Kernel Diameter	Abrasive Hardness	Flour Diameter	Starch Diameter	Total Starch	Starch Damage	Fat	Fiber	Protein	Ash
Kernel Hardness	ns	ns	0.90*	ns	ns	ns	ns	ns	ns	ns	ns
Kernel Weight	ns	0.89*	ns	0.72*	0.92*	-0.92*	0.81*	0.82*	ns	0.86*	ns
Kernel Moisture	1.00	ns	ns	ns	0.72*	ns	ns	0.74*	0.72*	ns	ns
Kernel Diameter	ns	1.00	ns	ns	0.76*	-0.92*	0.61*	ns	ns	0.95*	ns
Flour Particle Size	ns	ns	ns	1.00	ns	ns	ns	0.93*	ns	ns	ns
Starch Particle Size			ns	ns	1.00		0.93*	0.84*	ns	ns	ns
Flour Moisture	ns	ns	ns	ns	ns	ns	ns	ns	-0.72*	ns	-0.97*

*indicates significance at $P < 0.05$

ns indicates not significant

Table 2.7 Correlation among sorghum starch properties

	Peak Viscosity	Breakdown	Final Viscosity	Setback	Peak Time	Peak Temperature
Peak Viscosity	1.00	0.95*	ns	ns	ns	ns
Final Viscosity	ns	ns	1.00	0.98*	ns	ns
Total Starch	ns	ns	-0.84*	-0.78*	ns	ns
Starch Damage	ns	ns	0.93*	0.90*	ns	ns
Amylose	ns	ns	ns	ns	0.72*	ns
Starch Particle Size	ns	ns	0.95*	0.93*	ns	ns
Ash	-0.82*	ns	ns	ns	0.90*	0.76*

* indicates significance at $P < 0.05$

ns indicates not significan

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CHAPTER 3 - Evaluation of Four Sorghum Hybrids in a Gluten-Free Noodle System

Abstract:

Approximately 1% of the US population is inflected with Celiac disease which is an autoimmune response to gluten protein. Sorghum grain does not contain gluten but has not been a viable alternative because of the lack of the unique viscoelastic properties found in gluten. The hypothesis of this study was that sorghum flour can be used as the sole flour in the production of an acceptable gluten-free Asian noodles. The four sorghum hybrids that were used to process gluten free noodles including Orbit, F-525, NE #4 and NE#8. The objective of this research was to evaluate and compare the chemical and physical properties of sorghum hybrids for their potential use in gluten-free noodles. Sorghum noodles were formulated with 100% sorghum flour. The other ingredients including dried whole eggs, egg whites, xanthan gum and corn starch were used to help form the sorghum noodles. The noodle color, thickness, tensile strength and firmness were tested for both fresh noodles and cooked noodles. The cooking loss and water uptake were evaluated as a means to determine cooking quality. Noodles formulated with white sorghum hybrids exhibited significantly higher L and b values compared to the reds, whereas the red sorghum hybrids exhibited significantly greater firmness and tensile strength values. After cooking, L, a and b values of all treatments were decreased compared to before cooking color values. The starch properties were found to have more

effect than protein content on sorghum noodle qualities. Sorghum flour with fine particle size and low ash content was crucial for making acceptable sorghum noodles. Noodles made from sorghum F-525 exhibited some properties significantly closer to the commercial wheat flour noodles. Overall, sorghum flour can be used as an alternative to wheat in Asian noodles making.

Introduction:

Noodles are traditionally consumed in many countries, such as China, Japan, Thailand, Korea and Malaysia. Global sales of noodles increased by 15% between 2002 and 2007 to reach $312 million and may reach $422 million by 2012 (Global Information 2007). The market for Pasta & Noodles in the US is growing at an average annual rate of 1% since 2002 (Pasta and Noodles in the USA to 2010). Noodles (and pasta) are basic staples prepared from simply adding water to flour and incorporating some mechanical energy. Noodles may be formulated from several types of flours – wheat, rice, mung bean, durum, sweet potato, tapioca and corn (Hou 2001). Wheat is the most popular flour used in noodles production because of the unique viscoelastic properties exhibited by the grain. The wheat gluten proteins fractions gliadin and glutenin are responsible for the viscoelastic property. These proteins are unique to wheat and thus the reason for the grain's popularity to the food industry. However, wheat is not safe to the celiac community because they are inflected with allergies to wheat proteins.

Celiac disease is an abnormal immunological response to wheat gluten and related proteins that affects approximately one percent of the US population (Case 2006). People who have celiac disease cannot consume gluten and related protein found in wheat, rye, and barley. There are no treatments for celiac disease. The only way for celiacs to obtain their daily nutrients without ill effect is to maintain a gluten free diet. Gluten free food sales have show to be a robust market. The market for gluten-free food and beverage products grew at a compound annual growth rate (CAGR) of 28% from 2004 to 2008 (Supermarket Industry News 2009). More than 225 marketers introduced new gluten-free products into the United States in 2008 (Supermarket Industry News 2009). The market for gluten-free foods and beverages in the US currently stands approximately $700 million, and is estimated to $1.7 billion by 2010 (Heller 2006).

Typical ingredients that are commonly used to help provide the structure to gluten free foods may include, rice flour, potato flour, tapioca flour, corn flour and xanthan gum. Sorghum flour is another safe ingredient for celiacs (Ciacci et al 2007). Sorghum flour is seldom found used in gluten-free noodles making because of a bitter and astringent flavor associated to some sorghum hybrids (Brannan et al 2001). In addition to being a safe grain for celiac patients sorghum has a number of beneficial phytochemicals. These attributes may have significant positive impact on human health for both celiac patients and non celiacs.

Sorghum is the fifth most important cereal crop grown in the world and the third most important in the US (Doggett 1988). In the U.S. sorghum is well recognized for the grain's utility in animal feed but recent sorghum has gained recognition as a viable food ingredient. This should not be surprising as approximately 50% of sorghum is consumed by humans (Agricultural Marketing Resource Center 2008). This number is anticipated to increase if sorghum is used in gluten-free products.

The hypothesis of this study was that sorghum grain does possess the physical and chemical characteristics that are required to formulate and process gluten-free Asian noodles. Therefore, the objective of this research was to develop a formula for gluten-free noodles and evaluate and compare the chemical and physical properties of sorghum hybrids for their potential use in gluten-free noodles.

Materials and Methods:

USDA-ARS in Manhattan, KS provided 2 white sorghum hybrids and 2 red sorghum hybrids from their collection for this study. The four sorghum hybrids were Orbit, Fontanelle – 525 (F - 525), AT×2752×RT×2783 (NE #4) and AT× 3197× RT× 7078 (NE #8). Orbit and F – 525 were white sorghums; NE #4 and NE #8 were red sorghums. Samples were first decorticated until 20% of the initial weight was removed, then were milled by a Bliss Hammermill. Commercial dried wheat noodles (Purchased from Asian store)

Preliminary work:

Preliminary work was done in order to optimize a sorghum flour noodle formula. The first formula originally consisted of sorghum and carob flour as a flour base using different ratios. The second formula consisted of sorghum as a flour base and together with many functional ingredients.

Carob flour was used as a stabilizer and thickener together with sorghum flour as a base. The first ratio of sorghum flour and carob flour was tried at: sorghum flour 85% and carob flour 15%. However, the noodle sheet was easily fractured during the dough sheeting process, because the dough was too dry and firm. Consequently, the carob flour was decreased to 10%. The reduction in carob flour allowed sheeting of the dough, but a lot of noodle solids were lost during cooking. The cooked water looked very starchy. The carob flour was decided to remove from the formula. Thus we decided to design the experiment around the second formulation.

Dried egg whites

Dried egg whites were utilized to assist in forming a cohesive dough. Tachi et al (2004) reported that dry-heated egg whites can improve the physical and sensory properties of the noodles because of its finer structure of the egg albumen proteins. In this study, dried egg whites were used best at 8% (100% flour basis). More than 8% egg white produced a stiff dough that was hard to sheet through the rollers.

Xanthan Gum

Xanthan gum was used to give the dough a "stickiness" to achieve an attribute that is associated with the presence of gluten in the formula. Xanthan gum was determined to perform best in the noodle formulation at a level of 2.5% (based on 100% flour).

Corn Starch

In gluten-free products, corn starch was used as a neutral-flavored thickening agent to give baked products a delicate texture. Corn starch was found to work best at 7% (based on 100% flour).

Noodle Preparation:

The final formulation for the sorghum flour noodles is shown in Table 3.1. Ingredients used were: sorghum flour, iodized salt (Kroger, Cincinnati, OH), Xanthan gum (Grindsted® Xanthan 200, Danisco USA, Inc., New Century, KS), dried egg whites (NOVA 100 Egg White Extender, Scotsman's Mill Ingredients, Grinnell, Iowa), dried whole eggs (Michael Foods, Minnetonka, MN), corn starch (ARGO® CORN STARCH, Oswego, NY) and water. The dry ingredients were added in a Hobart mixer (N50-619, HOBART, North Hobart, Australia) and mixed for 1 min at low speed followed at high speed for 1 min (Figure 3.1). Optimum water (57%) was added to give a uniform, smooth, and nonsticky noodle dough. The dough was kneaded by hand for 1 min, rest for 15 min and then folded and sheeted through a noodle machine (VillaWare classic Italian Kichenware, Cleveland, OH) with the gap set at 4 (Figure 3.2). The sheet was cut into strips of about 1 cm width (Figure 3.3).

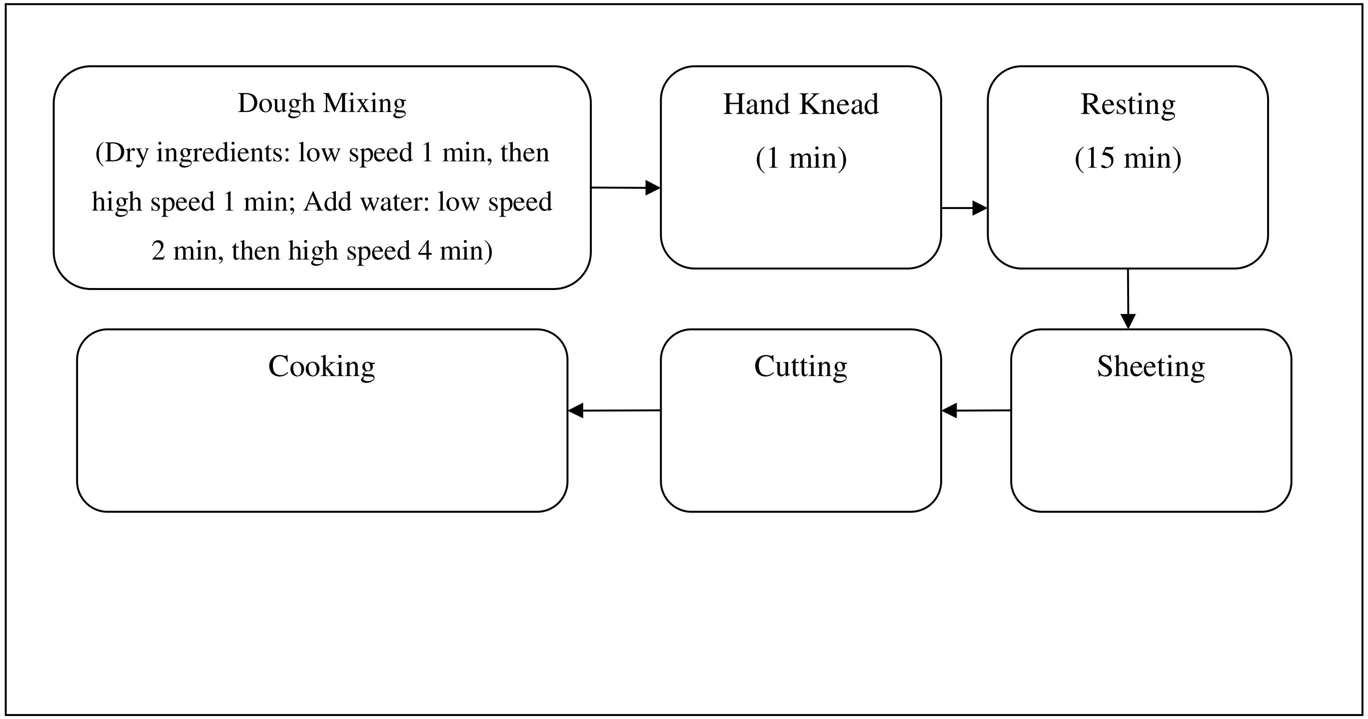

Figure 3.1 Noodle Process

Table 3.1 Formulation for sorghum flour noodles

Ingredient	Amount (g)
Sorghum	100.0
Salt	1.5
Dried egg whites	8.0
Corn Starch	7.0
Dried Whole Eggs	5.0
Xanthan Gum	2.5
Water	57.0
TOTAL	181.0

Figure 3.2 Image of sorghum noodle sheeting process

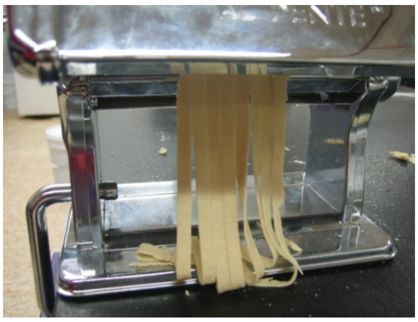

Figure 3.3 Image of sorghum noodle cutting process

Methods:

Color:

The color for both raw noodles and cooked noodles were measured by a HunterLab MiniScan (Model MS/S-4000S, Hunter Associates Laboratory Inc., Reston, VA). "L", "a", and "b" values were given as output. "L" indicated the lightness (0 = black and 100 = white). "a" was used to present red and green colors (+a = red and –a = green). "b" was used to present yellow and blue colors (+b = yellow and –b = blue). The type of illuminant used was C, average daylight, with a 10° Standard Observer.

Thickness:

An electronic digital micrometer (Fisher Scientific, St. Louis, MO., USA) was used to determine the thickness of the noodles before and after cooking and the values were recorded in millimeters to the nearest 0.1 mm.

Tensile Strength:

The tensile strength of noodles was tested using TA-XT plus Texture Analyzer (Texture Technologies Corp., Scarsdale, NY) (Figure 3.4) and a Spaghetti tensile grips. The TA-XT Plus settings were as follows: pre-test speed of 1.0 mm/s, test speed of 3.0 mm/s, post-test speed of 10.0 mm/s, distance of 100 mm and trigger force of 5 g. Noodles were tested individually by placing one end into the lower rig arm slot and winding the loosened arm. The same procedure was performed to the other noodle end to the upper arm. The samples should not be winded too tightly to avoid a false trigger. The distance between the two arms was set as 15 mm. For the cooked noodles, test was performed after the noodles were drained, rinsed and left to stand for 15 min. The maximum peak force (g) was recorded that indicated the elastic limit/tensile strength of the noodle. Tensile strength is usually associated with a strong bite and chewiness of noodles. Noodles which have higher tensile strength are less elastic.

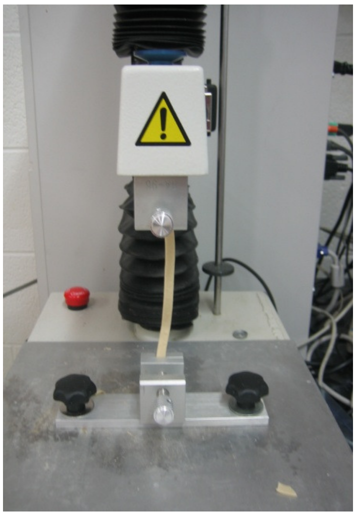

Figure 3.4 Image of a representative depiction of a tensile strength test for sorghum noodles.

Firmness:

The firmness of noodles was tested according to the approved method AACC 16-50 (1995), using TA-XT plus Texture Analyzer (Texture Technologies Corp., Scarsdale, NY) (Figure 3.5) and the AACC 1mm flat Perspex Knife Blade. The AACC method (16-50, 1995) for the measurement of firmness of pasta was first approved in 1989. This method involved destructive measurements on the samples tested (Edwards et al 1993). The TA-XT Plus settings were as follows: test speed of 0.17 mm/s, post-test speed of 10.0 mm/s, distance of 0.5 mm and trigger type of button (from starting height of 5mm). The distance of the probe to return to after sample compression for each test was 5 mm. 5 strands of cooked noodles were placed parallel on a flat plastic plate and were compressed by the noodles blade (5×5 cm) to a distance of 0.5 mm. Cooked noodles were evaluated within 5 min after cooking. The firmness was recorded as the maximum force (g) of the curve.

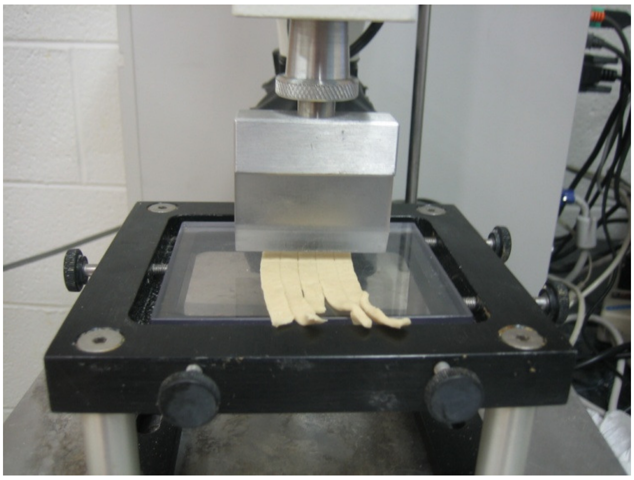

Figure 3.5 Image of a representative of a firmness test for sorghum noodles.

Noodle Cooking Quality:

Cooking Loss:

Cooking loss may be defined as the amount of noodle solids that dissolve in the cook water during the cooking process. This measurement indicates the ability of the noodles to maintain structural integrity during the cooking process. Approximately 25 g noodles were cooked in 300 mL of distilled water in a 500 mL beaker for about 2.5 min until the central opaque core in the noodle strand disappeared. Cooking loss (%) was measured by transferring the cook water to a pre-weighed beaker and evaporating the water in a conventional oven overnight at 100 ℃, then reweighing the beaker with left over solids. Cooking quality analysis was performed in duplicate.

$$\text{Cooking Loss (\%)} = (\text{dried residue in cooking water / noodle weight before cooking}) \times 100 \qquad (2)$$

Water uptake:

Water uptake (%) is the difference in weighted of cooked noodles versus uncooked noodles, expressed as the percentage of the weight of uncooked noodles. Cooked noodles were rinsed with cold water and drained for 30 s then weighed to determine the cooking gain. This analysis indicates the amount of water absorbed by the noodles during cooking process.

Statistic Design:

Three replications were treated as blocks in a randomized block design. Three subsamples were evaluated for each replicate. 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:

Color:

Significant differences were found among all sorghum noodle samples for “L”, “a”, and “b” color values ($p<0.05$) (Table 3.2). For both uncooked and cooked noodles, white sorghum hybrids exhibited significantly higher “L” values and “b” values than red sorghums, whereas red sorghums exhibited higher “a” values than white sorghums. For the uncooked noodles, the “L” values ranged from 62.55 to 79.53, with F-525 had the highest and NE #8 had the lowest. The “a” values ranged from 1.28 to 6.68, with F-525 had the lowest and NE #8 had the highest. The “b” values ranged from 17.62 to 21.99, with Orbit had the highest and NE #8 had the lowest. For the cooked noodles, the “L” values ranged from 59.19 (NE #8) to 74.56 (F-525), “a” values ranged from 0.40 (F-525) to 5.12 (NE #4) and the “b” values ranged from 11.88 (NE #8) to 19.13 (F-525). After cooking, L, a and b values of all treatments decreased. The L values for all treatments decreased after set on the table for a while before cooking that agrees with the finding from Lee and others (2008). He reported that all the L, a and b values of wheat noodles decreased from (76.68, -0.37, 11.68) to (61.06, -1.22, 10.21) after cooking.

Tensile Strength:

Tensile strength is usually associated with a strong bite and chewiness of noodles. Noodles which have higher tensile strength indicate less elastic. The tensile strength of uncooked noodles ranged from 8.43 g (Orbit) to 11.63 g (NE #4), while 31.00 g (Orbit) to 37.44 g (NE #4) for cooked noodles (Table 3.3). Before cooking, the noodles made with red sorghums exhibited significantly higher tensile strength than white. However, no significant differences were found on tensile strength of cooked noodles. Noodles exhibited significantly higher tensile strength after cooking for all treatments. Inglett et al (2003) reported that the tensile strength for the wheat and rice flour noodles at compositions of 70:30, 60:40, and 50:50 were 18.89, 17.58, and 12.80 g-force, respectively. Seib et al (2000) evaluated the texture properties of cooked salted noodles from 7 hard white wheat hybrids with a range of tensile strength from 33-58 g-force and 3 hard red wheat hybrids with a range of tensile strength from 27-42 g-force.

Firmness:

Noodles made from NE #4 (red sorghum) and NE #8 (red sorghum) were significantly firmer than Orbit (white sorghum) and F-525 (white sorghum) for both before and after cooking. Firmness of fresh noodles ranged from 191.34 g (F-525) to 343.74 g (NE #8). After cooking, the firmness of noodles ranged from 267.16 g (F-525) to 324.84 g (NE #8). After cooking, the firmness of noodles made from white sorghums became significantly higher. No significant differences were found on the firmness of the noodles made from red sorghums before and after cooking.

Thickness:

The thickness of fresh noodles ranged from 1.03 mm (F-525) to 1.31 mm (NE #4). The thickness of noodles after cooking ranged from 1.39 mm (F-525) to 1.72 mm (NE #4). After cooking, noodles became significantly thicker than before cooking because of absorbing some water during cooking. Seib et al (2000) reported that the thickness of cooked white salted noodles was ranged from 1.5 – 1.7 mm.

Factors affect noodle texture:

Effect of Starch properties:

Starch, when gelatinized, plays more important role in cooked noodle texture than wheat protein (Nagao et al 1977; Crosbie et al 1992; Yeh and Shiau, 1999). Statistical analysis of the correlations between sorghum properties and noodle qualities are shown in Table 3.5; Starch pasting peak viscosity was negatively (r = -0.65) correlated with cooked noodle firmness. Moss (1980) and Crosbie (1991) reported that high peak viscosity was responsible for superior wheat noodle quality with softer and more elastic texture. Desirable boiled Japanese-style noodles were made from flour with high swelling power of starch (Crosbie 1989). The starch swelling power was highly correlated with starch paste peak viscosity (Crosbie 1991).

Shorter peak development time (r = 0.97) and lower peak temperature (r = 0.82) were observed to give cooked sorghum noodle softer texture. Shorter peak development time and lower peak temperature suggest rapid starch swelling and gelatinization. Short time to peak viscosity (Oda et al 1980) and low gelatinization temperature (Nagao et al 1977; Oh et al 1985b; Endo et al 1988) have been reported to be responsible for superior wheat noodle quality.

The amylose content was found positively correlated with cooked noodle firmness (r = 0.62) which agrees with the findings that increased levels of amylose may increase noodle firmness and loss of elasticity (Toyokawa 1989; Baik 2003; Park 2004; Vignaux 2005). High levels of amylose means high degree of starch retrogradation that caused the water could not be absorbed into starch molecules and reduce the extent of starch swelling (Bhattacharya 1999). Li and Luh (1980) reported that high amylose content was desirable for good quality noodles, whereas Oda (1980) and Toyokawa (1989a,b) reported that wheat flour with a lower amylose content provides a good texture to white salted noodles.

Effect of Proximate properties:

The protein content of the noodles before cooking was negatively correlated with tensile strength (r = - 0.79) which means noodles before cooking with more protein content were more elastic (Table 3.5). The fresh noodle strength was assessed as a possible factor which is important to prevent the breakage of noodles during the drying process. The correlation of protein content with firmness and tensile strength of cooked noodles was not observed in this study which means the protein content was not a primary factor to affect the cooked noodle texture. Numerous researchers reported that protein content had effect on texture of cooked wheat noodles (Dexter and Matsuo 1977; Dexter et al., 1980; 1982b; 1983; Grzybowski and Donnelly 1979; Matsuo et al, 1982a; Matweef, 1966). However, the sorghum protein could not form a functional gluten network which contributes on the cooked noodle texture as wheat protein (Collado and Corke, 1997, Suhendro et al 2000). So both protein content and protein quality are correlated with noodle texture (Baik 1994). Oh et al (1985) reported that the firmness of cooked noodles was correlated with protein quality but not protein content.

Flour moisture content and ash content were found to have significant correlation with noodle firmness (Table 3.4). Noodles made from the flour with higher moisture content were softer (r = -0.98), whereas noodles made from the flour with higher ash content had firmer texture (r = 0.96). Irvine (1979) reported that wheat ash was the major factor determining firmness of cooked spaghetti.

Effect of Flour particle sizes:

Fine flour particle size was observed to give noodle softer texture (r = 0.88) (Table 3.5). Smaller particle size in the flour allow for greater water absorption on the surface area which may be the reason for the noodles softer texture. Oh et al (1985) reported that flour with fine particle size had the optimum water absorption and the breaking resistance of uncooked noodle increased. However, the effect of flour particle size on noodle texture quality was not found by Oda (1982) and Toyokawa (1989).

Noodle Cooking Quality:

Cooking Loss:

High cooking loss is not desirable for noodle quality. Significant differences were found among all the samples for cooking loss (Table 3.4). Noodles made from F-525 exhibited the lowest cooking loss (4.01%), whereas noodles made from NE #8 exhibited the highest cooking loss (5.53%). Cooking loss for all the treatments was below 12%. Inglett et al (2003) reported that the cooking loss for the wheat and rice flour noodles at compositions of 70:30, 60:40, and 50:50 were 5.78, 5.79, and 6.83 %, respectively.

Water uptake:

Water uptake indicates the degree of noodle hydration and may affect the eating quality of noodles. Water uptake for the sorghum noodles ranged from 77.14 to 98.58%. Noodles made from NE #8 had the highest water uptake (98.58%) among the four hybrids, whereas F-525 and NE #4 had the lowest (Table 3.4). Inglett et al (2003) reported that the water uptake for the wheat and rice flour noodles at compositions of 70:30, 60:40, and 50:50 were 119.62, 132.38, and 135.60 %, respectively.

Factors affect noodle cooking quality:

No significant correlation ($P > 0.05$) was found between cooking loss and starch properties (Table 3.5) which agrees with the findings from Beta (2001) that cooking loss of sorghum noodles was low and not significantly correlated to starch properties. The previous studies showed that higher starch gelatinization caused higher cooking loss in wheat noodles (Abecassis 1994, Yeh and Shiau 1999) but lower cooking loss in rice noodles (Khandker 1986, Yeh 1991).

Crzybowski and Donnelly (1979) reported that cooking loss of wheat noodles was strongly related to protein content. Increased protein content resulted in decreased cooking loss for wheat noodles (Yeh and Hwang 1992; Moss et al 1987; Edwards et al 1993). However, in this study the protein content was not found to have a relationship with sorghum noodle cooking quality, which may indicate that the protein content was not a primary factor affecting sorghum noodle cooking qualities. Flour particle size was significantly correlated with cooking loss (r = 0.73) which agrees with the findings from Moss et al (1987) and Elbers et al (1998) that smaller particle size flour gave lower cooking loss for alkali salted white noodles.

The water uptake of noodles was positively (r = 0.72) affected by starch trough viscosity and flour particle size (r = 0.70). Hatcher et al (2002, 2008) found that water uptake of white salted noodles was decreasing with decreased flour particle size and increased starch damage. However, the correlation between starch damage and water uptake for sorghum noodles was not significantly found in this study.

Compared with commercial wheat noodles:

All experimental sorghum noodles exhibited lower cooking loss and lower water uptake than traditional wheat white salted noodles (Table 3.4). All sorghum noodles were firmer than commercial wheat noodles, whereas commercial wheat noodles were more elastic than all sorghum noodles (Table 3.3). Noodles made from F-525 exhibited some properties significantly ($P < 0.05$) closer to the commercial wheat flour noodles.

Conclusion:

A sorghum-flour based gluten-free noodle may be formulated that possess the physical properties necessary to undergo the processing conditions of a wheat based noodle. Although, differences among the hybrids with respect to noodle quality was observed. Noodles formulated from sorghum hybrid, F-525, exhibited properties that similar were significantly more in line with the commercial wheat flour noodles.

Table 3.2 Comparison of sorghum noodle color values from four selected hybrids before and after cooking

	Fresh noodle Color			Cooked noodle Color		
	L*	a*	b*	L*	a*	b*
Orbit (white)	75.77 ± 0.44^{Xb}	1.82 ± 0.05^{Xc}	21.99 ± 0.52^{Xa}	72.38 ± 1.24^{Ya}	0.93 ± 0.10^{Yb}	18.93 ± 2.04^{Ya}
F-525 (white)	79.53 ± 0.49^{Xa}	1.28 ± 0.05^{Xd}	20.51 ± 0.30^{Xb}	74.56 ± 2.16^{Ya}	0.40 ± 0.11^{Yb}	17.10 ± 0.93^{Ya}
NE #8 (red)	62.55 ± 0.49^{Xd}	6.68 ± 0.18^{Xa}	17.62 ± 0.23^{Xd}	59.19 ± 2.35^{Yb}	4.32 ± 0.49^{Ya}	11.88 ± 0.62^{Yb}
NE #4 (red)	68.43 ± 0.55^{Xc}	5.54 ± 0.17^{Xb}	19.03 ± 0.64^{Xc}	61.03 ± 1.29^{Yb}	5.12 ± 0.30^{Ya}	14.36 ± 0.88^{Yb}

XYZ means with different superscrips in rows indicate significant difference among before cooking and after cooking ($P<0.05$)

abc means with different superscripts in columns indicate significant difference among treatments ($P<0.05$)

Table 3.3 Comparison of sorghum noodle texture values from four selected hybrids before and after cooking

	Fresh noodle			Cooked noodle		
	Firmness (g-force)	Tensile Strength (g-force)	Thickness (mm)	Firmness (g-force)	Tensile Strength (g-force)	Thickness (mm)
Orbit (white)	238.74 ± 25.41^{Yb}	8.43 ± 0.46^{Yb}	1.13 ± 0.00^{Yb}	306.01 ± 10.50^{Xab}	31.00 ± 5.38^{Xa}	1.61 ± 0.01^{Xa}
F-525 (white)	191.34 ± 7.53^{Yb}	9.11 ± 0.14^{Yb}	1.03 ± 0.02^{Yb}	267.16 ± 36.15^{Xb}	32.34 ± 2.77^{Xa}	1.39 ± 0.02^{Xb}
NE #8 (red)	343.74 ± 42.30^{Xa}	9.59 ± 1.77^{Yab}	1.25 ± 0.01^{Ya}	324.84 ± 5.55^{Xa}	32.53 ± 3.63^{Xa}	1.68 ± 0.02^{Xa}
NE #4 (red)	322.32 ± 34.72^{Xa}	11.63 ± 0.19^{Ya}	1.31 ± 0.01^{Ya}	320.09 ± 14.93^{Xa}	37.34 ± 4.89^{Xa}	1.72 ± 0.02^{Xa}
Commercial Wheat Noodles				213.14 ± 9.15^{b}	19.85 ± 1.57^{b}	1.28 ± 0.02^{b}

XYZ means with different superscrips in rows indicate significant difference among before cooking and after cooking ($P<0.05$)

abc means with different superscripts in columns indicate significant difference among treatments ($P<0.05$)

Table 3.4 Comparison of sorghum noodle cooking qualities from four selected sorghum hybrids.

	Cooking Loss (%)	Water uptake (%)
Orbit (white)	4.88 ± 0.77^{b}	81.56 ± 4.15^{c}
F-525 (white)	4.01 ± 0.27^{d}	77.14 ± 2.85^{d}
NE #8 (red)	5.53 ± 0.89^{a}	98.58 ± 10.62^{b}
NE #4 (red)	4.42 ± 0.38^{c}	$79.12b \pm 3.72^{d}$
Commercial Wheat Noodles	6.01 ± 0.43^{a}	220.13 ± 8.53^{a}

abc means with different superscripts in columns indicate significant difference among treatments (P<0.05)

Table 3.5 Correlation of sorghum properties with noodle qualities

	Fresh Noodles		Cooked Noodles		
	Tensile strength (g)	Firmness (g)	Firmness (g)	Cooking loss (%)	Water uptake (%)
Single Kernel Hardness	ns	ns	ns	ns	ns
Starch Particle Size	ns	ns	ns	ns	ns
Flour Particle Size	ns	0.68*	0.88*	0.73*	0.70*
Peak Viscosity	ns	ns	-0.65*	ns	ns
Trough	ns	ns	ns	ns	0.72*
Breakdown	ns	ns	ns	ns	ns
Peak Time	ns	ns	0.97*	ns	ns
Peak Temperature	ns	ns	0.82*	ns	ns
Amylose Content	ns	ns	0.62*	ns	ns
Starch Damage	ns	ns	ns	ns	ns
Flour moisture	ns	-0.98*	- 0.83*	ns	ns
Protein Content	-0.79*	ns	ns	ns	ns
Ash Content	0.71*	0.96*	0.73*	ns	ns

* indicates significance at $P < 0.05$

ns indicates not significant

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Appendix A - Particle Size Distribution Figures

Figure A.1 Average flour particle size distributions for Orbit, F-525, NE#8, and NE#4.

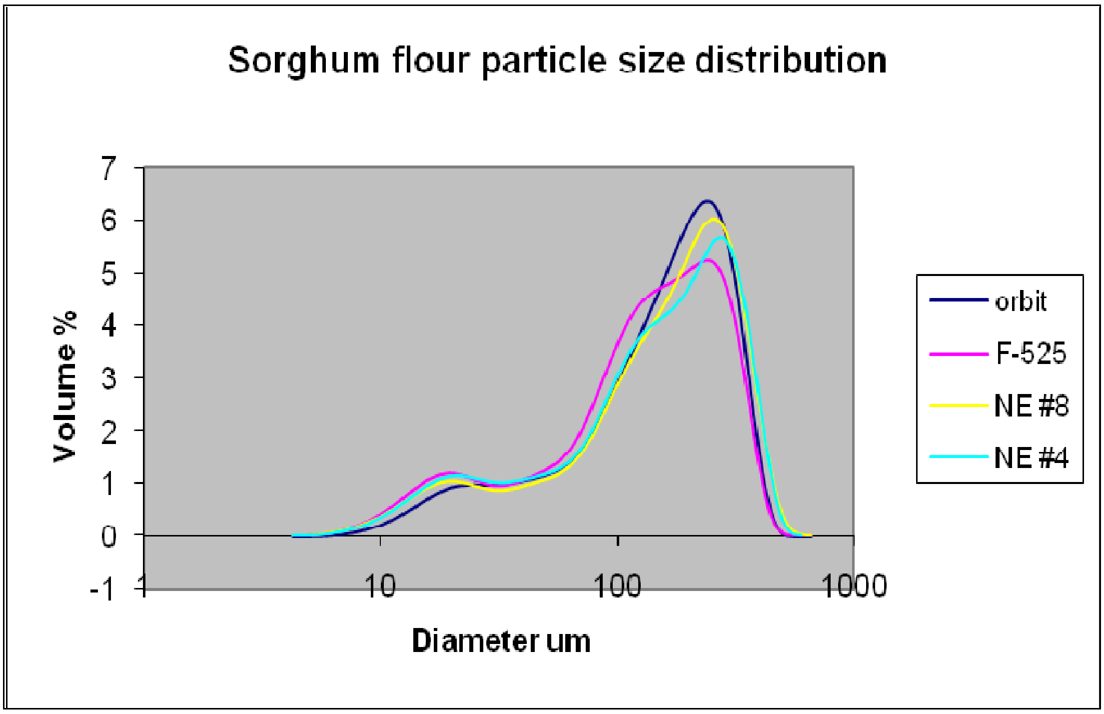
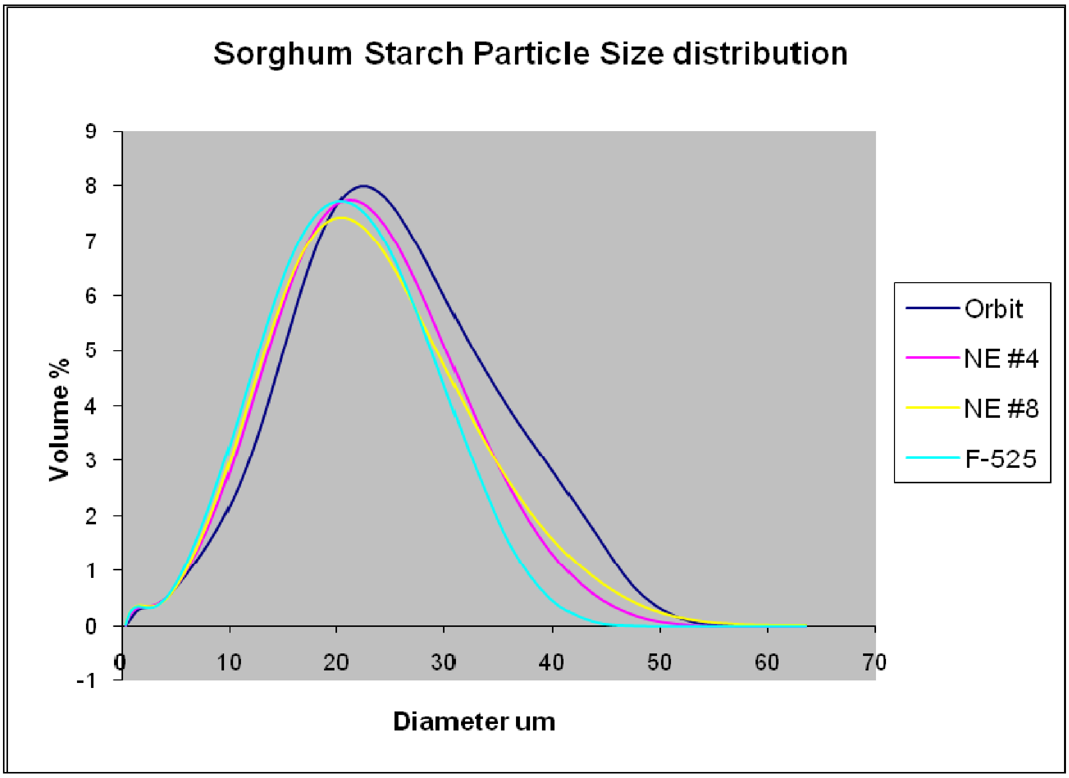


Figure A.2 Average starch particle size distributions for Orbit, F-525, NE#8, and NE#4.



Appendix B - RVA Figures

Figure B.1 RVA curve for Orbit.

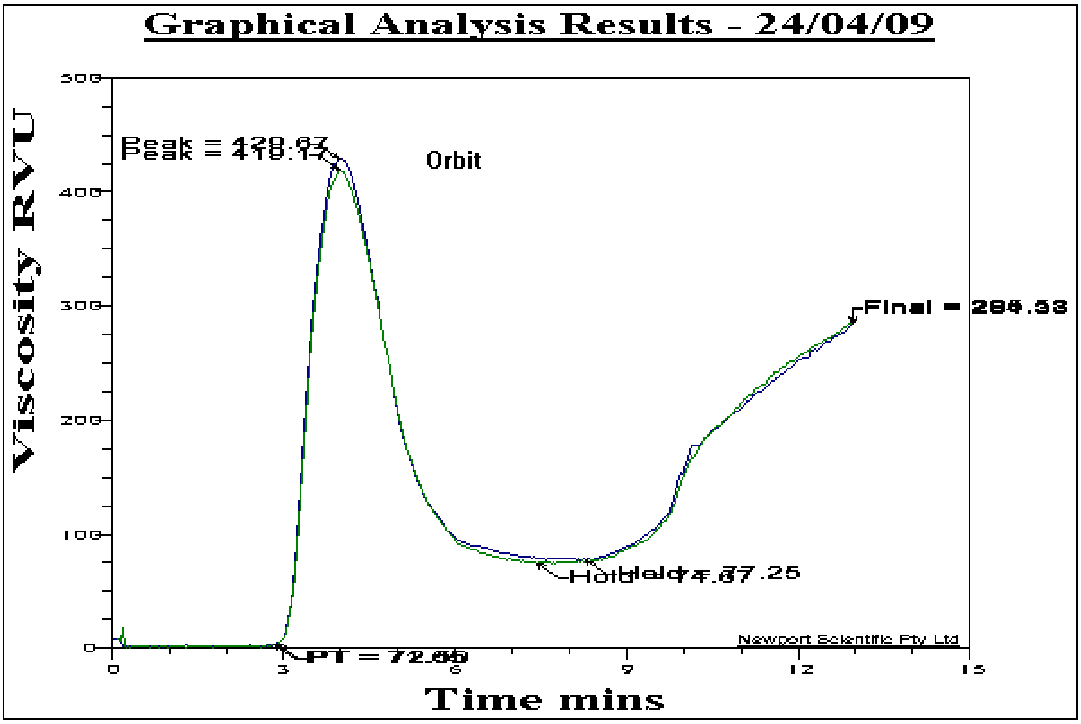


Figure B.2 RVA curve for F-525.

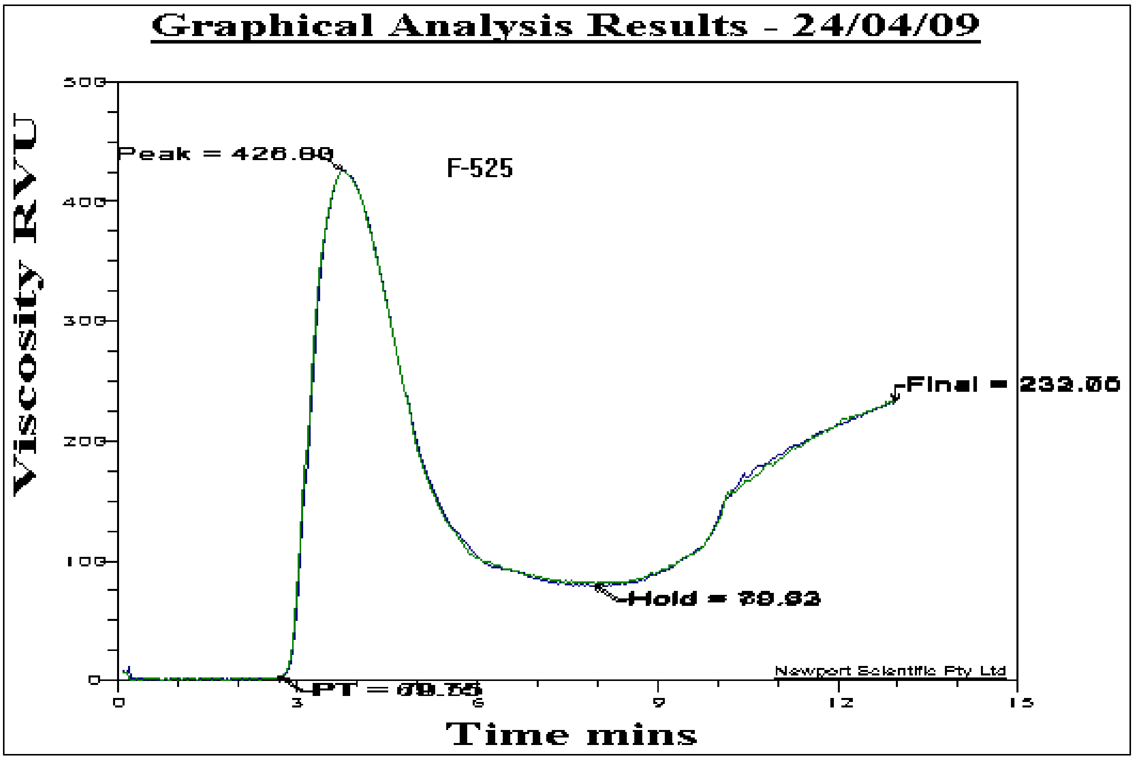


Figure B.3 RVA curve for NE#8.

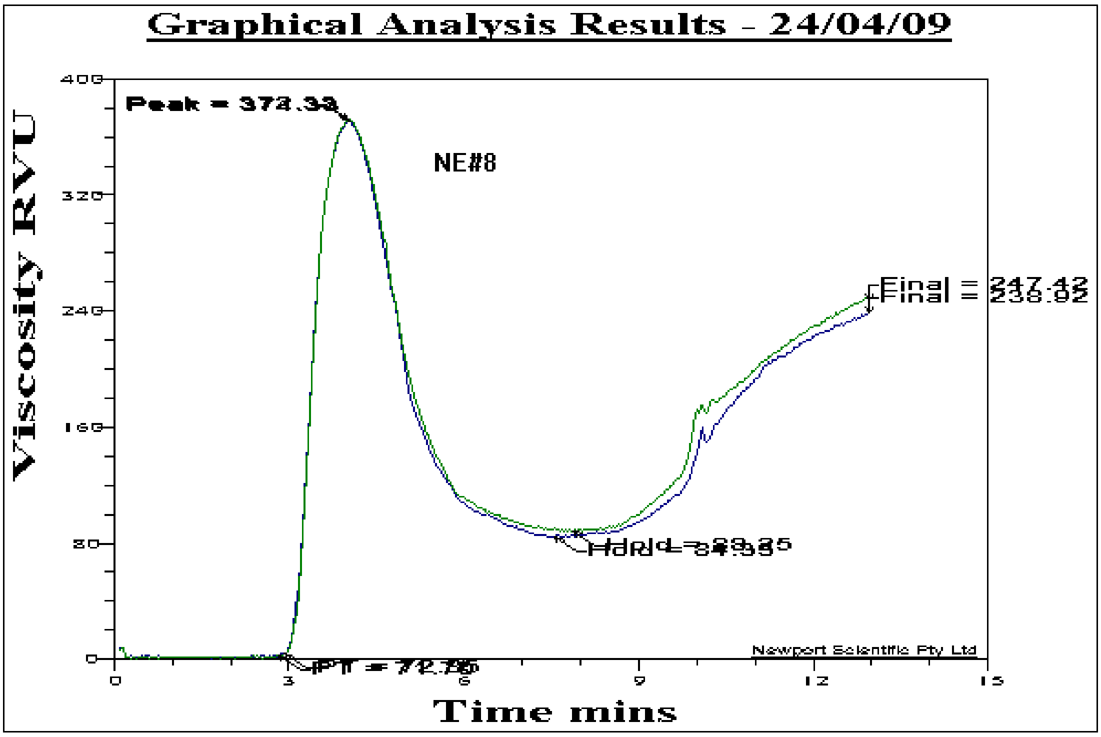


Figure B.4 RVA curve for NE#4.