NEW PROCESSING ALTERNATIVES FOR PRODUCTION OF LOW FAT AND ASH SORGHUM FLOUR

By

FLORIN I. IVA

B.S., AUREL VLAICU UNIVERSITY, 1995

A THESIS

submitted in partial fulfillment of the requirements for the degree

MASTER OF SCIENCE

DEPARTMENT OF GRAIN SCIENCE AND INDUSTRY

COLLEGE OF AGRICULTURE

KANSAS STATE UNIVERSITY

Manhattan, Kansas

2011

Approved by:

Major Professor

Dr. Jeffrey A. Gwirtz

ABSTRACT

Sorghum grain is underutilized in the United States. Most sorghum flour available in the market place is whole grain flour with inferior stability and baking characteristics. The demand exists for high quality stable sorghum flour with low fiber and fat content. However, the current decortication step used for separating the bran from endosperm in sorghum milling is not economically viable and the alternatives techniques, which are based on abrasion and frictions, do poor jobs and tend to increase endosperm loss. The lack of information regarding sorghum dry milling to obtain low fat and low ash white sorghum flour is the rationale for developing a suitable flow. Previous research works in this field made some progress towards the achievement of that goal, but not enough to meet the need for high quality white sorghum flour.

The main method (named F20105) developed in this study for processing sorghum (without decortication) consists of the following systems: prebreak, a gradual reduction system with purification, and an impact technology. Also, two short laboratory methods were designed for obtaining white sorghum flour for comparison purposes. These were named F20106 and F20107. The method F20106 was based on the use of Buhler Experimental Mill, a Great Western Gyratory Sieve, and Quadrumat Brabender Sr. Experimental Mill. The method F20107 was based on processing decorticated sorghum in a process which uses a hammer mill, a Great Western Gyratory Sieve and an Alpine Pin Mill. A commercial flour was evaluated along with the flours from the different methods in order to make comparisons among them.

The long reduction system (FS20105) which included impact detaching techniques produced white sorghum flour with high extraction rate and good baking properties. An impact dehulling machine and a prebreak roller mill were effective in collecting glumes and cracking the sorghum kernels before first break. The shattering effect of the fragile sorghum bran was avoided by implementing air separation of bran from endosperm before each break. A purification system effectively cleaned and sorted the sorghum grits by size.

Sorghum flours with different protein contents were evaluated for their baking quality properties. The protein content of sorghum flour was found strongly positive correlated with the amount of water added to the batter, cell wall thickness, cell diameter and cell volume ($\rho>0.85$; $P<0.0001$), and strongly negative correlated with the number of cells/cm^2 and L-value of the bread crust ($-0.95>\rho>-0.91$; $P<0.0001$). It was also correlated with the a-value and b-value of the bread crust ($\rho=0.620$, $P< 0.014$ and $\rho=0.520$, $P< 0.047$, respectively).

The diagrams F20105, F20106, and F20107 can be used successfully in their current form or with small adjustments to obtain flour from different sorghum hybrids at the laboratory scale. These diagrams also fill a gap in the currently available milling literature. Additionally they can be scaled up in the sorghum processing industry. The growing gluten-free food product market would potentially provide a rapid return on the necessary investment.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

I have been very fortunate, that throughout my study, there were many kind people who have helped me in one way or another. I am very grateful to them.

I thank Dr. Jeff Gwirtz for his guidance and confidence in me; his continued optimism and encouragement.

Sincere appreciation is also due to Dr. Hulya Dogan and Dr. Jon Faubion for serving in my committee. Thank you for your patience in teaching and guiding me throughout this process.

My sincere appreciation to Dr. Scott Bean , Dr. Jeff Wilson and Dr. Tom Herald of USDA-ARS Manhattan, KS, for their help and for the opportunity to use their facilities for a portion of my research.

Dr. Subramanyam Bhadriraju	Dr. Dirk Maier
Dr. Chris Miller	Dr. Becky Miller

Dr. Charles Walker	Dave Krishock	Dr. Dave Wetzel
Mr. Ron Stevenson	Mr. Royal Denning	Mr. Dave Trumble
Mr. Earl Roemer	Mr. Chalk Kirk	Mrs. Dilek Abzular
USDA - Mr. Brennan Smith	Mr. Rhett Kaufman	Mr. Brian Yoerger
	Mr. Tilman Shober	Mr. Kevin Fay

Students KSU- Mr. Oscar Ramos Mr. Moses Khamis Mrs. Hyma Gajula

Mrs. Sue Ruan Mr. Sam Rice Mr. Drew Thompson

Statistical Dept.- Dr. Leigh Murray Mrs. Zhining Ou

Chapter 1: Literature Review

1.1 Sorghum

Introduction

Sorghum is a versatile grain. It is commonly grown in many countries in the world where it is used as a main ingredient in a variety of foods. Sorghum crops are cultivated in hot and dry areas where wheat crop does not naturally occur. Therefore, this crop is an important food source in Africa, Central America, Mexico, and South India. In the United States, sorghum is mainly processed into animal feed. It has almost the same nutritional value of corn in the diet of ruminants and, except for particular micro-nutrients, its value is similar to corn when fed to poultry.

Historically, the US production of sorghum has been driven by different factors. From 1930 to the 1960's, the sorghum production increased at a more accelerated rate than the acreage cultivated due to the development of agricultural machinery appropriate for this type of grain, the expanding need for starch and tapioca substitutes during the World War II, the development of hybrid seed, and subsequent increase in yields. Since mid 1960's when the number of US acres cultivated with this crop reached a peak of 13 million, it has fluctuated due to the acreage allotment on other crops which, for different reasons, at the time became more relevant into the agricultural economics of the US Great Plains.

More recently, the acreage planted to sorghum has been declining. The US area planted with sorghum steadily decreased from 13 million acres in 1996 to 6.5 millions acres in 2006. The net increase has been only about 1 million in 2007 and 2008. The potential for using sorghum grain as either a novel food for selected markets or a source of bio-fuels, and the ability of the plant to tolerate drought and heat might become important characteristics of this crop, especially as the influence exerted by global weather changes and US energy policies on agriculture at large increases.

Sorghum throughout history

Sorghum originated from Africa, which was then brought to Asia and parts of Europe and finally introduced to the United States in the 1850's (Rooney and Clark, 1968; Maunder, 2002). Sorghum seeds spread quickly in the United States. By 1930, 49 million bushels were produced, in 1965, 666 million bushels and in 1967, the United States was producing more than 700 million bushels in Texas, Kansas, Nebraska, Oklahoma, Missouri, New Mexico, Arizona, South Dakota, Colorado, and California . From 1930's to 1960's, the US production of sorghum increased 1360%, while the cultivated area only increased 390% (Rooney and Clark, 1968). In 2008, there were about 7.4 million acres planted with sorghum, and only 6.4 million harvested. Unfortunately only about 20.21% percent of sorghum grown in the United States is used for human food, seed or industrial purposes (US Grain Council, 2010).

Sorghum in the world today

The largest producers of grain sorghum are the United States, India and Nigeria. In Africa it is the leading cereal grain produced. Currently, the United States is the largest producer and number one exporter of sorghum in the world. Australia and Argentina follow the United States as leading exporters. The United States exports to Mexico and Japan. Japanese millers use sorghum to make flour and snack foods. After sorghum flour research and recipe development, the Japanese use it to make commercialized food products. Japan and North America are each working on creating whiter sorghum flour for food use (US Grains Council, 2010).

Sorghum is being developed for human food but it is also used as animal feed in the United States, Mexico, South America and Australia. In the United States, about 12% of sorghum is used to produce ethanol and other fuel sources. There are five states in America that harvests sorghum: Kansas, Texas, Nebraska, Oklahoma and Missouri. These five states harvested about 8.3 million acres of sorghum in 2008/2009. Africa, the largest producer of sorghum, annually harvests about 21.6 million metric tons. (US Grains Council, 2010).

This crop is the fifth most important cereal in total world production (Serna-Saldivar et al, 1988). Open pollinated varieties are grown in developing countries in Africa (Atokple, 2004), India (Blum et al, 1991), Mexico (Osuna-Ortega et al 2003), and Central America (Clara-Valencia, 2000). Hybrid sorghum is grown primarily in the United States.

Types of commercial sorghum hybrids

White food sorghum caryopses are harder, more dense, and lighter in color than are grains from white purple-plant color or red purple-plant color hybrids. White food sorghums do not contain genetically modified organisms, are gluten-free (as are all sorghums), bland in flavor, and light colored, and have excellent processing properties (Rooney and Awika, 2005). Varieties that produce this type of food sorghum are being grown in India, Africa, and Central America for use in roti (flatbread), injera (pancake-like Ethiopian bread), and various tortillas, biscuits, and muffins, respectively.

High condensed tannin sorghum: "Condensed tannins" is the term used to describe a family of chemical compounds called proanthocyanidins, which are non-hydrolysable polymeric polyphenols that can act as antioxidants in biological systems (Schofield et al, 2001). Their presence in the kernel is under genetic control. According to Waniska (2000), the grains from this type of sorghum appear brown or purple. They have condensed tannins in the inner integument testa (layer between the pericarp and aleurone layer). Black sorghum is another specialty type that has a high content of anthocyanins (Rooney and Waniska, 2005).

Composition and structure

From a physical point of view, the shape and size of a kernel of sorghum is different from that of yellow dent corn. However the relative sizes of endosperm, germ, and pericarp, proximate composition, and endosperm structure are similar to those of dent maize.

Proximate composition: Three sorghum hybrids grown in the US Southern Plains had 11.6±0.1% Protein, 76.03±0.23% Starch, 3.27±0.15% Fat, 1.85±0.07% Fiber, and 1.3±0.07% Ash (Jones and Beckwith, 1970). These values were within the range for proximate composition of sorghum compiled by Serna-Saldivar and Rooney (1995). These authors reported that the ranges in protein, starch, fat, fiber, and ash content for several sorghum varieties were 7.3-15.6%, 55.6-75.2%, 0.5-5.2%, 1.2-6.6%, and 1.1-4.5%, respectively.

Endosperm structure: In general, there are two types of endosperm tissue, the corneous and the floury. The starch granules are embedded in a protein matrix in the corneous endosperm, and the structure locks voids, thus it looks translucent or vitreous. The floury endosperm is usually found in the center of the endosperm tissue, and it is mostly composed of largely loose starch granules, relative to the corneous endosperm (Waniska, 2000). The resulting void spaces in the endosperm make it appear opaque or floury.

Endosperm texture: This term is also called hardness, and it refers to the proportion of corneous (hard) fraction of endosperm with respect to the floury (soft) fraction. According to

Anglani (1998), the endosperm texture affects some important factors related to food quality of sorghum; it is related to the milling performance and to physical and chemical characteristics of different food preparations.

Sorghum products

Snack foods: Special varieties of sorghum have been used to produce snack foods. Black sorghum was cooked in alkali to produce tortilla chips with an intense blue color (Zelaya et al, 1999). On the other hand, the same researchers produced dark tortilla chips from Brown sorghum (Zelaya et al, 1999). Both types of sorghum contain polyphenols which act as antioxidants, and thus their products can be appealing to healthy foods-oriented consumers (Rooney and Awika, 2005).

Tortillas: The tortilla is a type of unfermented bread usually prepared from alkali-cooked, steeped corn. However, in certain parts of Central America, sorghum is used alone or in combination with corn for preparation of this food product (DeWalt, 1982). When used in combination with corn, a mixture of 25% sorghum and 75% maize flour produces acceptable tortillas (Choto et al 1985). Sorghum varieties with light-colored pericarp, intermediate endosperm texture and low amounts of color precursors are preferred for making tortillas (Iruegas et al, 1982).

Couscous: Couscous is one of the main staple foods is West Africa (Sidibe et al, 1982, Galiba et al, 1987). Most types of sorghum, except waxy sorghums, yield acceptable couscous; one especial exception is hard endosperm sorghum, which yields more and better flour for couscous than does soft endosperm sorghum (Galiba et al 1988).

Porridges: This food product is made by cooking sorghum flour in acid, alkali, or water (Waniska and Rooney, 2000), and it is common in West Africa. A combination of different types of flour (can be fermented in some cases) has been previously studied to improve sensorial properties of porridges. Bangu et al (1994) found that the combination of sorghum, maize, and casava in a proportion of 30:40:30 was very acceptable to sensory panelists. The sorghum properties needed to make good quality porridge are not clearly defined. However, Bello et al (1990) stated that amylose content and the interaction between protein and starch are two important factors for making high quality porridges.

Leavened Bread: Two approaches have been taken when attempting to make functional formulations for sorghum bread: partial substitution of wheat flour with sorghum flour in the bread formulation, and/or addition of other ingredients that help improve breadmaking process and loaf quality characteristics of sorghum only formulas. Several studies have focused on the first approach. Perten et al (1983) reported that 30% substitution of wheat flour with sorghum flour still produced good quality bread.

Some researchers have taken the second approach to sorghum breadmaking. Satin (1988) concluded that acceptable sorghum bread was produced by addition of xanthan gum to

sorghum flour in the formula. Specifically, that author recommended to solvate the gum in water before adding it to the dough as a measure to improve bread quality. Several researchers have also included a sorghum flour/starch mixture and various functional food ingredients in the formulation for sorghum bread. Pre-gelatinized starch and egg were used by Keregero and Mtebe (1994); a sorghum flour/starch mixture and addition of emulsifiers were investigated by Olatunji (1992), while others have included skim milk powder, sodium carboxy methyl cellulose (CMC), baking powder, soy flour, corn starch, dried egg albumen in the formulation for the purpose of improving breadmaking and final product characteristics (Cauvain, 1998).

Formula: Water content is a critical step in the breadmaking process. The control of this step becomes even more relevant when making sorghum bread because, in addition to being gluten free, the physical and proximate composition of the sorghum flour is different than that of wheat flour. Taylor et al (2006) recommended that more water should be added to the sorghum flour relative to hard wheat flour because the proportion of bran and coarse endosperm particles to fine endosperm particles is high in sorghum flour. These researchers also noted that the good quality of sorghum breads made with dry sorghum flour/starch mixtures was due to a reduction in the negative effect of bran and coarse endosperm particles on the batter by adding pure starch to the sorghum flour.

1.2 Related sorghum milling research in the past

Tempering: This is the process of increasing the moisture content of grains through the addition of water before it enters the dry milling operations. The purpose of this step is to make the bran tough, and the endosperm softer and more friable; therefore, facilitating their separation. According to Abdelrahman et al (1981), the optimum treatment for dry milling sorghum is 17% moisture content in the grain, and 8 hours of tempering time.

Dry milling: The main purpose of this process is to achieve a clean separation of bran, endosperm, and germ (Hahn, 1969). It is usually preceded by the tempering process. Grits, from the endosperm of the kernel, are among the most valuable products obtained from dry milling. Appropriate tempering and milling will yield a large amount of low-fat grits. In a study by Abdelrahman et al (1981), dry milling of sorghum with a prebreak system produced grits with lower fat and ash content than did a break system. Prebreaking cracked the kernel open and increased its surface area. The final result was that the grits and germ were more easily separated with sieves, and the bran was segregated by gravimetric tables.

Decortication or dehulling: This process consists of removing the outer layers of the grain, i.e. pericarp, before dry milling (Anderson et al, 1969). The equipment used for decortication is usually an abrasive mechanism, such as rice decortication or debranning machines, or pearlers containing stones or resinoid disks (Rooney and Waniska, 2000). The purpose of this process is to produce a low fiber intermediate product which will undergo further particle size reduction and separation. A variant of this process is decortication of the

kernel, followed by degermination of tempered kernels with pin mills. This latter variant of the process will produce low fat and low fiber grits which are more stable during storage, and meet the requirements for many uses (Hahn, 1969).

Roller milling: This is the most common type of dry milling operation used to produce grits and flour. It consists of two or more consecutive breaking steps designed to reduce the particle size of the kernel into grits and flour (Hoseney et al, 1981). This process is especially used on white food sorghum due to the lack of red or purple-colored pericarp and because the floury endosperm texture yields more fine particles in the flour fraction (Gomez, 1993).

Wet milling: The sequence of steps of this operation is similar to wet milling of corn; however, , it is more difficult to separate protein from starch in wet-milling sorghum kernels compared to corn, its starch granules must be bleached, and sorghum oil must undergo further refining (Rooney and Waniska, 2000).

1.3 The health benefits of sorghum and sorghum products

Celiac disease

Introduction:

Celiac disease is also known as gluten- sensitive enteropathy, nontropical sprue, and celiac sprue. (Mayo Clinic, 2010). It is a serious chronic disease that affects approximately 1% of the population according to studies conducted in the United States and Europe (Wieser and

Koehler 2008). Contrary to common belief, celiac disease is not an allergy to wheat or wheat products, but a disease that, although the exact cause is still undetermined, it is often inherited. Nevertheless, it definitely occurs to people who have a susceptibility to gluten (Mayo Clinic, 2010).

Celiac disease is a syndrome characterized by an immune response of the body to gluten, and damage to the small intestine mucosa caused by ingestion of the prolamins, which are commonly found in wheat, rye, and barley, and its food derivatives (Fasano and Catassi, 2001).

Ingesting grains such as wheat, rye, barley, spelt, and oats, and its food derivatives, all of which contain related prolamins, will cause damage to the villi, which are tiny hair-like projectiles lining the surface of the small intestine. Damage to the villi results in the body's inability to absorb certain nutrients (Leeds, et al 2008). With time, this mal-absorption (decreased absorption of nutrients) can cause vitamin deficiencies that deprive the brain, peripheral nervous system, bones, liver and other organs of nourishment (Mayo Clinic, 2010). Instead of being absorbed, these nutrients are eliminated in the body's stool (Mayo Clinic, 2010)

The exact cause of celiac disease is undetermined. However, there is research that links some of the human leukocyte antigens (HLA) genes as well as other non-HLA genes to celiac disease (Wieser and Koehler 2008). These genes seem to regulate the body's immune reaction to gluten-protein (Celiac Disease Foundation 2008). According to the Celiac Sprue

Association (2010), three requirements must exist to confirm that a person has celiac disease: a genetic disposition, an activator such an emotional, environmental, or physical event in a person's life that sets off the disease, and food consumption of products that contain wheat, barley, rye, oats, or any of their derivatives.

Symptoms

This disease affects both children and adults. In children, celiac disease leads to stunted growth, as well as other illnesses. (Mayo Clinic, 2010). There are many signs and symptoms of celiac disease, some of which include intermittent diarrhea, abdominal pain, and bloating. However, sometimes the symptoms are not of gastrointestinal nature at all. (Mayo Clinic, 2010). Other symptoms may include: anemia, stomach upset, joint pain, muscle cramps, skin rash, mouth sores, dental or bone disorders (osteoporosis), and tingling in the legs and feet (neuropathy; Mayo Clinic, 2010). Symptoms of celiac disease are not only physical they are emotional also. Among them, depression, disinterest in normal activities, irritability, mood changes, and inability to concentrate, are important (Celiac Sprue Association, 2010).

In addition to the aforementioned ailments, the symptoms of celiac disease can be similar to irritable bowel syndrome, Crohn's disease, anemia, gastric ulcers, parasite infections, and skin disorders or nervous conditions. Consequently it is difficult to diagnose it quickly (Mayo Clinic, 2010). The immune system attacks the body's healthy cells and tissues causing people with celiac disease to have other diseases as well. Theses diseases include, but are not limited to, type 1 diabetes, autoimmune thyroid disease, autoimmune liver disease, rheumatoid arthritis, Addison's disease, and Sjögren's syndrome (NDDIC, 2010).

All too often a person discovers they have celiac disease once they suffer from malabsorption. Symptoms of malabsorption can also help indicate celiac disease. These symptoms are weight loss, diarrhea, abdominal cramps, gas, and bloating, weakness and fatigue, foul smelling or grayish stools that may be fatty or oily, osteoporosis, and anemia (Mayo Clinic, 2010).

Diagnosis

About 10 to 20 % of patients with celiac disease experience dermatitis herpetiformis (Leeds, et al 2008). This is a skin disorder that causes blisters and intense itchiness usually around the face, elbows, knees, and buttocks (Alaedini and Green 2005). It is possible that patients with dermatitis herpetiformis will have intestinal damage, but without discernible symptoms. (Leeds, et al 2008). There also seems to be close connection between celiac disease and other disorders, such as type-1 diabetes, thyroid disease, occurrence of some cancers, and neurologic disorders (Alaedini and Green 2005, Wieser and Koehler 2008).

Because the symptoms of celiac disease can be similar to irritable bowel syndrome, Crohn's disease, anemia, gastric ulcers, parasite infections, and skin disorders or nervous conditions, it is also difficult to diagnose it and to diagnose it quickly (Mayo Clinic, 2010). The first step to would be to obtain information such as medical history and symptoms, and for a physical exam and a blood test to be conducted. A person with celiac disease can produce higher levels of the antibodies called auto antibodies (anti-gliadin, anti-endomysium and anti-tissue transglutaminase) (Mayo Clinic, 2010). According to the same authors, these auto antibodies

are produced because the body is trying to defend itself against gluten. The blood tests that are conducted are considered to be 98% accurate. However, sometimes false negatives are not uncommon (Bower, 2007; WD, 2010). The second step would be to conduct a duodenal biopsy. A small portion of the intestinal tissue is examined to check if the villi are damaged (Wieser and Koehler, 2008; Mayo Clinic 2010). It is possible for the biopsy to result in a false negative if the person started on a gluten-free diet which had already caused the villi to heal (Leeds et al, 2008).

In summary, three requirements to diagnose celiac disease are to have blood test results positive for higher than normal auto antibodies (anti-gliadin, anti-endomysium and anti-tissue transglutaminase), a positive result in a biopsy, and the symptoms to be reduced on a gluten-free diet (Celiac Sprue Association 2009).

Treatment

Unfortunately there is no cure for celiac disease. The only treatment discovered to be successful thus far is a lifetime commitment to a gluten free diet. Once gluten is removed from the diet, the small intestine begins to heal (Celiac Disease Foundation, 2010; Kupper 2005; Green, 2006). A gluten free diet excludes the consumption of storage protein which is found in wheat, barley, and rye, and their food derivatives (Mayo Clinic, 2010).

Foods that are healthy and can be consumed by people with celiac disease are corn, soy, rice, potato, bean, tapioca, quinoa, pure corn tortillas, buckwheat, and arrowroot (Mayo Clinic, 2010). In addition to these foods, millet, teff, amaranth, flax seed and sorghum are also

acceptable (Bower 2007; Kupper 2005). Sorghum flour can be used as a substitute of up to 100% of wheat flour in an array of gluten-free food products for people with celiac disease (Rooney and Awika, 2005).

The Food and Drug Administration has a voluntary "gluten-free" label for certain foods that contain "20 parts per million or less gluten". This level was based on the lower bound for gluten detection by current analytical techniques. Among the foods that cannot contain the "gluten-free" label are foods that contain barley, common wheat, and rye. The FDA has proposed the gluten free label, that has been in enacted since 2008, in response to the *Food Allergen Labeling and Consumer Protection Act of 2004*, Title II of Public Law 108-282, enacted on August 2, 2004 (FDA, 2010). Adding this claim to a product's label is voluntary.

Diabetes

Introduction:

For people who suffer from diabetes and obesity, sorghum can be an alternative food because of its resistant starch (Dicko et al, 2005). Approximately 23.6 million people in the United States suffer from Type 1 diabetes (American Diabetes Association, 2010). Of 23.6 million, about 11.8 million also have celiac disease, which is equivalent to 1 in 20 people (American Diabetes Association, 2010). The connection between type 1 diabetes and celiac disease is that they are both autoimmune diseases, which means the body attacks itself (American Diabetes Association, 2010; Diabetes and Celiac Disease, 2010). Type 1 diabetes is a disease in which the body does not produce insulin, the hormone that converts sugar, starches, and other foods into energy (American Diabetes Association, 2010). Patients who suffer from

Type 1 diabetes and celiac disease, sometimes, also have thyroid problems as well (Ventura, 2000).

Symptoms

Some symptoms that would indicate a person could have type 1 diabetes are: fatigue, irritability, unusual weight loss, extreme hunger, unusual thirst, and frequent urination (American Diabetes Association, 2010). If blood sugar is very high, it might also lead to experience stomach pain, nausea or vomiting, dry skin and mouth, deep, rapid breathing, and a flushed face (Google Health, 2010). When the blood sugar is low, it can lead to experience weakness, sweating, nervousness, headaches, and hunger (Google Health 2010).

Diagnosis

There are a few blood tests that can diagnose diabetes. The first tests is the level of glucose in the blood during fasting period; if the glucose level is higher than 126mg/dL on two test runs, then diabetes is diagnosed. The second is randomly testing the blood for glucose levels while the person is not fasting; diabetes is suspected if the level is higher than 200 mg/dL. Finally, the oral glucose tolerance test, which tests the level of glucose in the blood about two hours after glucose is ingested by mouth (Google Health 2010). In case of pregnancy, illness such as stroke or heart attack, or a blood sugar level higher than 240 mg/dL, the ketone test is conducted. A urine sample is required for the ketone test (Google Health 2010).

Treatment

The treatment of type 1 diabetes is insulin and those with celiac disease must also adhere to a gluten free diet (Diabetes and Celiac Disease, 2010). A gluten free diet can help resolve many symptoms of those with celiac disease and who also have diabetes due to celiac disease (Ventura, 2000).

Slow digestibility of sorghum is a desirable characteristic in foods for diabetics. This characteristic is probably due to the binding that occurs between condensed tannins (anthocyanidins), proteins, and other grain components in Tannin sorghum, whereas the higher amount of crosslinked prolamins found in the endosperm compared to other cereal grains might account for slow digestibility in all other types of sorghum (Rooney and Awika, 2005).

Dermatitis Herpetiformis

Introduction

Dermatitis herpetiformis is formed on the skin as a rash with red blisters and bumps that itch and heal very slowly (Bower, 2007). It is a chronic rash, which means, it lasts for a long period of time and, unlike what its name might suggest, it is not caused by the herpes virus (Bower, 2007). Dermatitis herpetiformis is caused by a genetic predisposition, the consumption of gluten, and the body's response to gluten protein found in wheat, barley, and rye (Green, 2006; Bower, 2007). Usually dermatitis herpetiformis appears on individuals around 25 to 45 years of age and people who suffer from it also suffer from celiac disease (Green, 2006).

Symptoms

The symptoms of dermatitis herpetiformis are blistering, intense itchiness, lesions that are symmetrical and are usually found on the face, elbows, knees, and buttock (Alaedini and Green 2005). However, the lesions are not limited to the above areas of the body; they can also be found on other parts of the body such as lower limbs, trunk, groin, hands, fingers, scalp, and along the hairline (Green, 2006). Approximately 20 to 30 percent of people who suffer from dermatitis herpetiformis also have thyroid abnormalities and may not have symptoms of gastrointestinal problems (Green, 2006). Those who use drugs to repress their symptoms and continue to eat gluten are at a higher risk of developing a lymphoma (Green, 2006).

Diagnosis

According to Green (2006), a skin biopsy, a blood test, and historical occurrence of the rash or lesions are used to diagnose dermatitis herpetiformis. The skin biopsy test for granular immunoglobin A (IgA) can be used to diagnose the disease, but even if the result turn out to be negative, it does not necessarily mean the person does not have dermatitis herpetiformis, especially if the individual expresses symptoms after gluten-containing food consumption (Green, 2006). The same goes for the blood test, the result may be positive or negative for endomysial antibodies (EMA) and antitissue transglutaminase (tTG), which sometimes shows when a person has celiac disease (Green, 2006).

Treatment

People who suffer from dermatitis herpetiformis can be treated with certain medications such as dapsone, sulfapyridine, and topical creams containing cortisone, and a strict gluten free diet (Green, 2006). The medications are used to relieve a person from some discomfort caused by dermatitis herpetiformis but a gluten free diet is necessary to live a healthy life.

As mentioned earlier, a gluten free diet excludes the consumption of gluten protein, which is found in wheat, barley, and rye, among others, but includes foods such as corn, soy, rice, potato, bean, tapioca, quinoa, pure corn tortillas, buckwheat, arrowroot, millet, teff, amaranth, flax seed, and sorghum (Mayo Clinic, 2010; Bower, 2007; Kupper, 2005).

Other nutritional components of sorghum grain

Antioxidants: The grain and bran fractions of Tannin and Black sorghums with added ingredients make excellent quality bread that contains high levels of antioxidants, dietary fiber, and a natural dark brown color (Gordon, 2001). The antioxidant compounds found in sorghum are mostly polyphenols, i.e. condensed tannins.

Phenols: Sorghum varieties have both free and bound phenolic acids (Hahn, 1983). Free phenolic acids are extracted with methanol from the pericarp, testa, and aleurone layer. Bound phenolic acids are hydrolyzed and released them from cell wall polymers with HCL (Hahn, 1984). Ferulic and p-coumaric acid are the two most abundant phenolic acids in sorghum. The relative amounts of free to bound form of Ferulic and p-coumaric acid in

different sorghum types decrease in the following order: White, Red, and Brown sorghum (Dykes and Rooney, 2006).

Other: Sorghum contains phytochemicals that can potentially reduce serum cholesterol levels and, thus promote human health (Varady et al, 2003). Phytosterols and policosanols, long chain fatty alcohols which represent 41% of sorghum wax (Hwang et al, 2002), are two groups of these phytochemicals. However, these components are found in small amounts, and often times in cell layers between the pericarp and endosperm, which make their extraction and purification costly.

1.4 Gluten-free market for sorghum products

The gluten free market is growing and is expected to grow even more as the popularity of gluten free foods increases. There was a 27% per year growth rate in that market from 2001 through 2006. The market for gluten free products was valued at $210 million in 2001 and $696.4 million in 2006 (Heller, 2010). According to a survey conducted by the market research company, Mintel, 8% of the US population was in search of gluten free products when they shop for groceries (Cromley, 2008). By 2014, the US market is expected to grow by more than $500 million, making the United States population alone 53% of the world market (U.S. Driving Gluten-Free Market Growth, 2010). According to a 2010 Datamonitor analysis, globally, the gluten free market is expected to reach $4.3 billion in the next five years (U.S. Driving Gluten-Free Market Growth, 2010).

The market for gluten free products includes but isn't limited to people who would benefit medically from such products. This segment includes those who suffer from celiac disease, dermatitis herpetiformis, wheat allergy, and diabetes. More recently, the market for gluten-free diet has been widening, especially for food consumption-related diseases. It is often suggested that people with irritable bowel syndrome, Crohn's disease, and ulcerative colitis adhere to a gluten free diet (Engleson and Atwell, 2008). According to Dr. George Christison, a professor of psychiatry at Loma Linda University School of Medicine, when children with autistic spectrum disorder are prescribed a gluten/casein free diet their behavior improves somewhat (Cromley, 2008).

Often when one member of the family is prescribed a gluten free diet, the entire family will adhere to that same diet as a sign of support, thus expanding the market (Cromley 2008). There also people who are health conscious and are always looking for the newest healthy foods. These people might choose to consume a gluten free food product because they feel it is healthy to do so and, in general, it creates in them a sense of satisfaction (Engleson and Atwell 2008). However, there are some concerns for people who have not been diagnosed with celiac disease to go on a strict gluten free diet. First, it will make it difficult to diagnose celiac disease and secondly avoiding gluten altogether may cause nutritional deficiencies (Cromley, 2008).

1.5 Methods

Proximate Analysis

Moisture Content (AOAC 930.15): This procedure utilizes oven drying to evaporate moisture from the sample and determines its content by difference in weight before and after drying. A flour sample size of 2 g is usually needed, which is dried in a convection oven at 135 C for 2 hours.

Ash Content (AOAC 942.05): In this procedure, relatively high temperature is used to incinerate all organic matter from the sample; the minerals remain. Two grams of sample are weighed in a porcelain crucible of known weight and then, it is kept in a furnace at 600 C for 2 hours. The crucible is transferred directly into a dessicator in order to allow it to cool off. The weight is measured and recorded. The percentage of ash content in the sample is the difference in crucible weights from before and after incineration, divided by weight of the sample.

Protein Content (AOAC 990.03): Crude protein was determined by the measuring the nitrogen released during combustion of flour at high temperature (950 C) in pure oxygen (99.9%) environment. This method detects the freed nitrogen by using a thermal conductivity detector. The value of nitrogen (%) obtained is multiplied by 6.25 to convert it to crude protein (%). The size of sample used ranged from 150-500 mg (RK Owusu-Apenten, 2002).

Fat Content (AOAC 920.39): A flour sample of 2 grams is weighed and placed on top of a Beckman filter paper. This is wrapped carefully and sealed at the ends to avoid spilling. The flour weight is recorded. The sample is then placed on a thimble in a Soxhlet countercurrent extraction unit. Ether is used as solvent. At the end of solvent extraction, the sample is removed and weighed. Fat content is determined by weight difference in sample before and after extraction.

Fiber Content (AOAC 962.09): Crude fiber was determined by, first, digesting approximately 1 g of sample with 1.25% (w/v) sulfuric acid and 1.25% (w/v) sodium hydroxide and, second, incineration of dried residue. The weight of the sample are measured and recorded before and after digestion, and at the end of incineration for calculation of crude fiber content.

Physical Analyses

Total Starch Content (AACC Method 76.13): The Megazyme Total Starch Assay kit for total starch content was used. Flour was solvated in water, and incubated with thermo-stable alpha-amylase at 100°C. During this step, starch is broken down to dextrins, which are then hydrolyzed to D-glucose by another enzyme, amyloglucosidase. The amount of D-glucose was determined spectrophotometrically, and the starch content was calculated based on it.

Starch damage (AACC Method 76.31): In order to determine the amount of damaged starch, the Megazyme Starch Damage Assay was utilized. Approximately 100 mg of flour

contained in a test tube were pre-warmed at 40°C for 5 minutes before addition of 1 mL of fungal α-amylase solution (50 U/mL). After 10 minutes of incubation, 8 mL of dilute sulphuric acid solution was added to inactivate the enzyme and terminate the enzymatic hydrolysis. The sample was centrifuged, and 0.1 mL aliquots of the supernatant were transferred into another test tube. Amyloglucosidase (0.1 mL) was added to the sample, and this was incubated at 40°C for another 10 minutes in order to obtain D-glucose. The absorbance of the sample containing D-glucose was measured at 510 nm, and the amount of starch was determined.

Particle size: The distribution of particle sizes in the flour was measured with the Beckman Coulter LS 13 320 Laser Diffraction Particle Size Analyzer Beckman-Coulter, Inc., Miami, FL. The flour was placed into the load cell until it was approximately 2/3 full. The Tornado Dry Powder Dispersing attachment was used to load up the sample and measure its particle size. This instrument uses light scattering properties to measure the particle size of flours.

Color: This property was measured with the Colorimeter Minolta CR-300 (Konica Minolta, Spectrophotometer, Osaka, Japan), which uses diffuse illumination/0° angle viewing geometry to provide the following parameters: L* (L*=0, black; L*=100, white), a* (-a*=greenness; +a*= redness), b* (-b*=blueness; +b*=yellowness). The L* value provides a measure of the lightness or darkness of the grain, lighter grains have higher L* values, while dark colored grains (red pericarp) have lower L* values.

1.6 Sorghum batter preparation

Water Standardization

This step is necessary prior to breadmaking since there are not standard methods to determine the amount of water to be added to gluten free-flour. In this particular study, water optimization was conducted by measuring the force necessary to extrude each batter using a texture analyzer (Sanchez et al, 2002; Schober et al, 2005). During testing, 5% more and 5% less water than the pre-determined value were used as max and min values, respectively, to interpolate the optimum amount of water for each sample of flour. After the amount of water to be added to each type of flour was determined, the batter was prepared. The ingredients and amounts contained in the batter are shown in Table 1.1

Table 1.1 Formulation of sorghum bread

Ingredients	% Flour Basis
Sorghum flour	70
Potato starch	30
Flour	**100**
Salt	1.75
Sugar	1
HPMC	2
Active dry yeast	2
Water	Variable

Yeast was omitted. Mixing of the batter was done with a 300W KitchenAid mixer (Ultra Power, St Joseph, MI), which was equipped with a flat beater attachment (fig 1.1). Each batter was mixed for 30 seconds at the lowest speed, mixer stopped, the batter on the sides of

the bowl was scraped, and then continued for 90 seconds at speed level 2 out of 10. After resting for 5 minutes, the extrusion force of the batter was measured with a Texture analyzer TA-XT2 (Stable Micro Systems, Godalming, United Kingdom). This equipment (fig.1.2) was loaded with a 30 kg cell, the forward extrusion cell, and a 10 mm nozzle. The extrusion force was measured at a test speed of 1.0 mm/sec over a distance of 20 mm. Speed of 1.0 mm/sec was used for pre-test, and 10 mm/sec was set for post-test. The trigger force was 50 g. The batter firmness was determined by the average force after reaching plateau.

Fig. 1.1 Preparation of ingredients and mixing equipment (KitchenAid) for sorghum bread experiment

Fig.1.2 Texture analyzer TA-XT2 (Stable Micro Systems, Godalming, United Kingdom)

Breadmaking

The formulation for the bread was described by Schober et al (2007) and is shown in Table 1.1. The flour weight was made up of sorghum flour and potato starch. The dried yeast (Fleischmann's Active Dry) was hydrated by dissolving it in the amount of water to be used in each flour mix. The water and yeast were kept at 30 C. The dry ingredients were mixed separately so that clumps were avoided. Then, the dry ingredients were added to the water and yeast mixture. This batter was mixed with the KitchenAid mixer equipment and it was mixed in the manner described above. A sample of 250 g from each batter was placed into

greased bread baking tins (9x15x5.5 cm) and proofed at 34 C and 83-85% relative humidity in a Metro C5 proofing cabinet (Intermetro Industries Co., Wilkes-Bare, Pa). Each batter was allowed to rise up to one centimeter below the brim of the tin (approximately 40 minutes). After proofing, the baking tins were placed on a double-deck electrically-heated Doyon 1T2 oven (Doyon, Linier, Canada) (fig.1.3), which was pre-heated to 232 C (450 F). After baking for 30 minutes, the loaves were taken out of the baking tins and allowed to cool for 1.5 hours at ambient temperature.

Specific Volume

This was measured after loaves were cooled and weighed by the rapeseed displacement method (AOAC 10-05). Loaf specific volume (loaf volume, cc/ loaf weight, g) was calculated.

Crumb Structure Evaluation

The bread was sliced transversely using a in-house manufactured slice regulator and bread knife. Four slices, 25 mm thick each, were used for crumb structure evaluation. The C-Cell instrument (Calibre Control International Ltd., Appleton, Warrington, United Kingdom) was used for this analysis. This equipment used a high definition image feature and controlled illumination to record images. It has the capability to determine important bread crumb attributes such as average cell diameter and volume, average cell wall thickness, average crumb fineness, and slice brightness (Chen et al, 2007).

Fig.1.3 Doyon 1T2 Oven (Doyon, Linier, Canada)

1.7 Flour Evaluation by Mixolab

The Mixolab equipment (Chopin, France), was used to study the rheological behavior of dough obtained from sorghum flour. The Mixolab is equipment which can control the kneading action and the temperature during the dough formation. By measuring the torque (expressed in Nm) produced by interaction between the kneading arms and the dough, the Mixolab has the capabilities to measure the physical properties of dough, such as dough strength and stability, and also to measure the pasting properties of starch on actual dough (Kahraman, 2008). Additionally it can determine the hydration capacity, development time,

and gelatinization temperature of starch. Based on the initial flour moisture content, this equipment calculates and adds the necessary amount of water to each flour sample to obtain dough at uniform moisture content. This allows comparing the rheological properties of all flour samples. Another advantage of using the Mixolab is that it can work with a constant dough weight, and this eliminates the influence of mixer filling ratio. Some terms which were used are: water content (the amount of water incorporated in flour), hydration (the amount of water present in the dough), hydration index (the reference system that is used to characterize hydration; they are always linked), and water absorption capacity of flour (the amount of water needed to obtain a maximum dough consistency of 1.1 Nm).

After running the standardized protocol "Chopin+", five critical points on the resulted curve, describe the dough characteristics. For calculation of water absorption point C1 is used, and for measuring the protein weakening is used point C2. The point C3 is indicative of starch gelatinization. For measuring the stability of the starch paste point C4 is used, and for measuring the starch retrogradation point C5. The heat produces the weakening of the protein, which is reflected by the slope α. The starch gelatinization and the enzymatic degradation rates are described by the slopes β and γ respectively (Chopin Mixolab User's Manual) (***, 2009).

1.8 Statistical Analysis

A factorial experimental design was used in this study. The factors were tempering moisture and tempering time, material of the inner ring and motor speed. Tempering moisture had three levels, and tempering time had eight levels. Material of the inner ring had two levels, and motor speed had three levels.

Tests were made in triplicates, and for some four replicates were used. There were a few exceptions where duplicates were tested.

The results were analyzed with SAS software 9.2, SAS institute, North Carolina (2008). The factorial experiments were analyzed using ANOVA to detect which treatment (s) was statistically significant. Then, the REGWQ multiple range test was used in order to determine whether the differences detected in treatment means were significant at the overall $\alpha \leq 0.05$ level. The Pearson coefficient analysis was used to correlate the properties of sorghum flour with those of the resulting bread.

1.9 Literature cited

Abbas, F.M.A.; Saifullah, R.; Azhar, M.E. 2009. Assessment of physical properties of ripe banana flour prepared from two varieties: Cavendish and Dream banana. International Food Research Journal 16: 183-189.

Abdelrahman, A.A., Farrell, E.P. 1981. Grits from grain sorghum dry milled on roller mills. Cereal Chem. 58(6):521-524.

Alaedini A, Green HR. 2005. Narrative Review: Celiac Disease: Understanding a Complex Autoimmune Disorder. Annals of Internal Medicine 142(4): 289.

American Diabetes Association. 2010. Accessed on July 14th 2010. http://www.diabetes.org/diabetes-basics/diabetes-statistics/
<http://www.diabetes.org/living-with-diabetes/complications/mens-health/serious-health-implications/celiac-disease.html><http://www.diabetes.org/living-with-diabetes/complications/mens-health/serious-health-implications/celiac-disease.html>
< http://www.diabetes.org/diabetes-basics/type-1/>
< http://www.diabetes.org/diabetes-basics/symptoms/>

Anderson, R.A., Montgomery, R.R., Burbridge, L.H. 1969. Low-Fat endosperm fractions from grain sorghum. Cereal Science Today 14(11):366-368.

Anglani C (1998). Sorghum for human food: a review. Plant Foods Hum. Nutr. 52: 85-89.

ANKOM Technology A2000, A20 00I. 2006. Ankom Technology Method 10; AOCS Approved Procedure Ba 6a-05. Crude Fiber Analysis in Feeds by filter bag technique.

Atokpke, I.D.K. (2003). Sorghum and millet breeding in West Africa in practice. In:Belton, P.S and Taylor, J.R.N. (eds.) The proteins of sorghum and millet:
Enhancing nutritional and functional properties for Africa. Pretoria: AFRIPRO, pp.137-148.

Bangu, N.T.A., Mtebe, K., Nzallawahe, T.S. 1994. Consumer acceptability of stiff porridge based on various composite flour proportions of sorghum, maize and cassava. Plant Foods Hum Nutr 46:299-303.

Bello, A.B., Rooney, L.W., Waniska, R.D. 1990. Factors affecting quality of sorghum To, a thick porridge. Cereal Chemistry 67(1):20-25.

Blum, A., Golan, G., Mayer, J. 1991. Progress achieved by breeding open-pollinated cultivars as compared with landrances of sorghum. The Journal of Agricultural Science 117: 307-312.

Bower, Sylvia Llewelyn with Sharrrett, Mary Kay, and Plogsted, Steve. 2007. Celiac Disease: A guide to Living With Gluten Intolerance. Demos Medical Publishing, LLC.

Cauvain, S.P. 1998. Other cereals in breadmaking. In: Technology of breadmaking. Edited by S.P. Cauvain and L.S. Young. Blackie Academic and Professional, London, pp. 330-346

Celiac Sprue Association. 2010. Celiac Disease. Last Updated July 1, 2009. <http://www.csaceliacs.org/CeliacDisease.php>
<http://www.csaceliacs.org/celiac_defined.php>
<http://www.csaceliacs.org/celiac_symptoms.php>

Clara-Valencia, R. 2000. Sorghum Research Reports. Genetics and Plant Breeding. Centro Nacional de Tecnologia Agropecuaria y Forestal (CENTA), El Salvador, Central America.

Chen, Y.R., Feng, X., Seabourn, B.W., Caley, M.S. 2007. Objective Image Analysis for Bread Quality Characteristics Using C-Cell Instrument. Cereal Foods World. 52:A38

Choto, C.E.; Morad, M.; Rooner, L.W. 1985. The quality of tortillas containing whole sorghum and pearled sorghum alone and blended with yellow maize. Cereal Chem. 62(1): 51-54.

Cromley J. 2008. Going gluten-free—for many reasons. Los Angeles Times, 07 July, 2008.

DeWalt, K. 1982. Sorghum use in Honduras. A case study. In: Proc. Sorghum Quality Workshop for Latin America. International Maize and Wheat Improvement Center, El Batan, Mexico.

Diabetes and Celiac Disease. 2010. Copyright 1997 by Gluten Free Living
< http://www.enabling.org/ia/celiac/dia-cd1.html>

Dykes, L. and Rooney, L. W. 2006. Sorghum and millet phenols and antioxidants. J. Cereal Sci. 44:236-251.

Dicko, H., Gruppen, H.,Traore, A,Voragen,J.& Berker, J., 2005. Sorghum grain as human food in Africa. Relevance of content of starch and amylase activities. *African Journal of Biotechnology*, 5 (5): 384-395

Engleson J, Atwell B. 2008. Gluten-free product development. Cereal Foods World 53(4): 180-184.

Fasano, A., Catassi, C. 2001. Current approaches to diagnosis and treatment of celiac disease: an evolving spectrum. Gasterenterolgy. American Gastroenterological Association. 120:636–651.

Galiba, M., Rooney, L.W., Waniska, R.D., Miller, F.R. 1987. The preparation of sorghum and millet couscous in West Africa. Cereal Foods World 32:878.

Galiba, M., Waniska, R.D., Rooney, L.W., Miller, F.R. 1988. Couscous quality of sorghum with different kernel characteristics. J. Cereal Sci. 7:183-193

Gomez, M.I. 1993. Comparative evaluation and optimization of a milling system for small grains. In: Proc. Cereal Science and Technology: Impact on a changing Africa. Council for scientific and industrial research, Pretoria, South Africa, pp. 463-471.

Google Health. 2010. Accessed on July 20th, 2010. <https://health.google.com/health/ref/Type+1+diabetes>

Gordon, L.A., 2001. Utilization of sorghum brans and barley flour in bread. M.S. Thesis, Texas A&M University, College Station, TX.

Green M.D., Peter H R, and Jones, Rory. 2006. Celiac Disease: A Hidden Epidemic. Collins: An imprint of HarperCollins Publishers. Pg 142

Hahn, R. 1969. Dry milling of grain sorghum. Cereal Science Today 14(7):234-237.

Hahn, D.H., Faubion, J.M., and Rooney, L.W. 1983. Sorghum phenolic acids, their performance liquid chromatography separation and their relation to fungal resistance. Cereal Chemistry 60:255–259.

Hahn, D.H., Rooney, L.W., and Earp, C.F. 1984. Tannins and phenols of sorghum. Cereal Foods World 29:776–779.

Heller, Lorraine. 2010.Gluten-free market set to boom. 07-Jul-200) http://www.foodnavigator-usa.com/Financial-Industry/Gluten-free-market-set-to-boom-says-report.

Hoseney, R.C., Varriano-Marston, E., Dendy, D.A.V. 1981. Sorghum and millets. In: Advances in cereal science and technology. Edited by Y. Pomeranz. Vol.4. American Association of Cereal Chemists. St. Paul, MN.

Hwang, K. T., Cuppett, S. L., Weller, C. L., and Hanna, M. A. 2002a. Properties, composition, and analysis of grain sorghum wax. J. Am. Oil Chem. Soc. 79:521-527.

Iruegas, A.; Cejudo, H.; Guiragossian, V. 1982. Screening and evaluation of tortilla from sorghum and sorghum-maize mixtures. In L.W. Rooney and D.S. Murty (eds), Proc. International Symposium on Sorghum Grain Quality. International Crops Research Institute for the Semi-Arid Tropics, Patancheru, A.P., India, pp. 92-99.

JONES, R. W., and BECKWITH, A. C. 1970. Proximate composition and sorghum protein levels in Kansas sorghum grain. Agron. J. 56:302.

Keregero, M., Mtebe, K. 1994. Acceptability of wheat-sorghum composite flour products: an assessment. Plant Foods Hum Nutr 46:305-312.

Kahraman, K.; Sakyyan, O.; Ozturk, S.; Koksel, H.; Sumnu, G.; Dubat, A. 2008. Utilization of Mixolab to predict the suitability of flours in terms of cake quality. European Food Research Technology. **227**, 565–570.

Kupper, C. 2005. Dietary guidelines and implementation for celiac disease. American Gastroenterological Association 128:S121-S127

Leeds JS, Hopper AD, Sanders DS. 2008. Coeliac disease. British Medical Bulletin 88:157-170.

Maunder, B. A. 2002. Sorghum worldwide. In: Sorghum and Millets Diseases.
J. F. Leslie, ed. Iowa State University,Ames. pp. 11-17.

Mayo Clinic. 2010. Celiac Disease. Accessed on July 14th, 2010. Website: http://www.mayoclinic.com/health/celiac-disease/DS00319/DSECTION=causes>
<http://www.mayoclinic.com/health/celiac-disease/DS00319>
<http://www.mayoclinic.com/health/celiac-disease/DS00319/DSECTION=causes>
<http://www.mayoclinic.com/health/celiac-disease/DS00319/DSECTION=symptoms>
<http://www.mayoclinic.com/health/celiac-disease/DS00319/DSECTION=tests%2Dand%2Ddiagnosis>
< http://www.mayoclinic.com/health/gluten-free-diet/MY01140>
<http://www.mayoclinic.com/health/gluten-free-diet/MY01140>

National Digestive Diseases Information Clearing House (NDDIC).2010. September 2008. <http://digestive.niddk.nih.gov/ddiseases/pubs/celiac/>

Osuna-Ortega, J., Mendoza-Castillo, M., Mendoza-Onofre, L. 2003. Sorghum cold tolerance, pollen production, and seed yield in the Central High Valleys of Mexico. Maydica 48(2): 125-132.

Owusu-Apenten., R.K. 2002. Food Protein Analysis: Quantitative effects on processing. Marcel Deker, Inc. New York, page 33.

Olatunji, O., Koleoso, O.A., Oniwinde, A.B. 1992. Recent experience on the milling of sorghum, millet, and maize for making non-wheat bread, cake, and sausage in Nigeria. In: Utilization of Sorghum and Millets. Edited by M.I. Gomez, L.R. House, L.W. Rooney, D.A.V. Dendy. International Crops Research Institute for the Semi-Arid Tropics, Patancheru, India, pp. 83-88.

Perten, H. 1983. Practical experience in processing and use of millet and sorghum in Senegal and Sudan. Cereal Foods World 28: 680-683.

Rooney, L.W.; Awika, J.M. 2005. Overview of products and health benefits of specialty sorghums. Cereal Foods World 50(3).

Rooney LW, Clark LE. 1968. The chemistry and processing of sorghum grain. Cereal Science Today 13(7):258-261.

Rooney, L.W.; Waniska, R.D. 2000. Sorghum food and industrial utilization. In: Sorghum: Origin, History, Technology, and Production. C. Wayne Smith (ed). John Wiley and Sons, Inc.

Sanchez HD, Osella CA, de la Torre MA. 2002. Optimization of gluten-free bread prepared from cornstarch, rice flour, and cassava starch. J Food Sci 67:416-419.

Satin, M. 1988. Bread without wheat. Novel ways of making bread from cassava and sorghum could replace the Third World's dependence on imported wheat for white bread. New Scientist (28 April), pp. 56-59.

Schober TJ, Messerschmidt M, Bean SR, Park SH, and Arendt EK. 2005. Gluten-free bread from sorghum: quality differences among hybrids. Cereal Chem 82 (4): 394-404.

Schober TJ, Bean SR, Boyle DL. 2007. Gluten-free sorghum bread improved by sourdough fermentation: Biochemical, rheological, and microstructural background. J Agric Food Chem 55:5137-5146.

Schofield, P., Mbugua, D.M., Pell, A.N., 2001. Analysis of condensed tannins: a review. Animal Feed Science and Technology 91, 21–40.

Serna-Saldívar, S. O., Canett, R., Vargas, J., González, M., Bedolla, S., and Medina, C. 1988. Effect of soybean and sesame addition on the nutritional value of maize and decorticated sorghum tortillas produced by extrusion cooking. Cereal Chem. 65:44-48.

Serna-Saldivar S, Rooney LW. 1995. Structure and chemistry of sorghum and millets. In: D.A.V. Dendy, editor. Structure and Chemistry of Sorghum and Millets. St Paul: American Association of Cereal Chemists, Inc. pp. 69–124.

Sidibe, S., Diarra, M., Scheuring, J.F. 1982. Sorghum couscous: quality considerations. In: L.W. Rooney and D.S. Murty (eds), Proc. International Symposium on Sorghum Grain Quality. International Crops Research Institute for Semi-Arid Tropics, Patancheru, A.P., India, pp. 110-113.

Taylor, J.R.N., Schober, T.J., Bean, S. 2006. Novel food and non-food uses for sorghum and millets. J. Cereal Sci. 44:252-271.

United States Food and Drug Administration (FDA). 2010. Last updated 6/18/2009. Accessed on 7/29/2010

<http://www.fda.gov/Food/LabelingNutrition/FoodAllergensLabeling/GuidanceComplianceRegulatoryInformation/ucm111487.htm >

U.S. Driving Gluten-Free Market Growth, 2010. <http://www.foodproductdesign.com/news/2010/07/us-driving-gluten-free-product-growth.aspx>

U.S. Grains Council. 2010. Sorghum. Last accessed on 20 Aug. 2010. http://www.grains.org/sorghum.

Varady, K.A., Wang, Y., Jones, P.J.H., 2003. Role of policosanols in the prevention and treatment of cardiovascular disease. Nutrition Reviews 61, 376–383

Ventura. 2000. "Organ-Specific Autoantibodies Linked to Dietary Gluten in Celiac Disease Patients", Dr. Ventura, Universita of Trieste, Italy, Journal of Pediatrics, August 2000; 137,263-265

Wieser H, Koehler P. 2008. The biochemical basis of celiac disease. Cereal Chem 85(1): 1-13

Wrong Diagnosis (WD). 2010. Celiac Disease. Last Updated July 14, 2010 < http://www.wrongdiagnosis.com/c/celiac_disease/intro.htm>

Zelaya, N., H. Yeggy, E.L. Suhendro, X. Quintero, L.W. Rooney. 1999. The effect of grain color and pH on sorghum tortilla chips. AACC 84th Annual Meeting, Oct. 31-Nov. 3, Seattle, WA. Cereal Foods World 44(7).

***. 2009. Chopin Mixolab User's Manual: Tripette & Renaud Chopin, France.

Chapter 2: The Study of New Alternatives for Production of Low Fat and Ash Sorghum Flour

2.1 Introduction

Kansas is the biggest producer of sorghum in the United States. The production of sorghum is concentrated in the Southern Plains which, besides Kansas, includes Texas, Nebraska, Oklahoma, and Missouri (US Grain Council, 2010). Sorghum has been viewed as an alternative grain for processing into foods, bio-fuel, and bio-polymers and coatings.

In spite of the increasing potential for using sorghum in a variety of food products such as non-wheat bread, gluten free baked goods, tortillas, snack foods, noodles and brewed products (Taylor et al, 2006), there is hardly any current literature available on advanced industrial sorghum milling technologies, and milling flow diagrams have not been developed for sorghum yet.

The recent interest in the wide variety of antioxidants naturally found in sorghum has been driving new research on characterization of processing properties of different hybrids. Some researchers have worked on adapting the Single Kernel Characterization System (SKCS) for sorghum grains (Bean et al, 2006; Farenholz et al, 2008). This system determines some important attributes of the kernel such as hardness, weight, and size. Because antioxidants are contained in a particular sorghum kernel structure between the pericarp and endosperm, it is imperative to develop new industrial milling technologies which can aid in processing

these kernel structural components, and which incorporates them into the sorghum flour for usage in food products.

2.2 Materials and Methods

Materials

White food grade sorghum (fig.2.1), var. Fontanelle W-1000, was obtained from Mr. Earl Roemer, a sorghum producer from Scott City, Kansas.

Fig.2.1 Sorghum berries (Fontanelle W-1000)

Clean sorghum grains (Test Weight TW=60.25) were stored in plastic bags, which subsequently where placed in a barrel. An SKCS 4100 (Perten Instruments, Inc, Springfield, IL) (fig.2.2) was used for analyzing kernel characteristics, based upon method AACC Method 55-31.

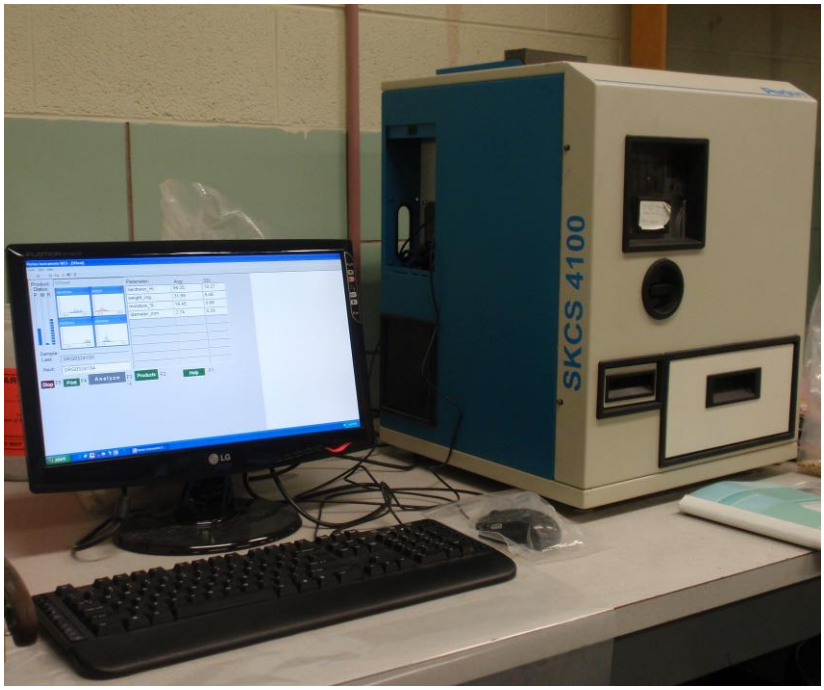

Fig.2.2 Single Kernel Characterization System SKCS (Perten Instruments, Inc, Springfield, IL)

Preparation and cleaning

Prior to milling, the glumes were removed with an Impact Forsberg machine (Forsberg's, Inc., Thief River Falls, Minnesota) (fig.2.3). This equipment was fitted with a new motor (Baldor Electric, Smith, Ar), which allowed the speed and frequency of rotation to be set at 3500 rpm and 60 Hz, respectively. The speed of the interior rotor was controlled through a remote control device, which was attached to the equipment. The inner ring on the rotor can be either plastic or rubber, according to the purpose for which it is used (fig.2.4 and 2.5).

Fig.2.3 Impact Forsberg machine (Forsberg's, Inc., Thief River Falls, Minnesota)

Fig.2.4 Rubber and Plastic Inner Rings for Impact Forsberg Machine

Fig.2.5 Centrifugal device and remote control of Impact Forsberg machine

Glumes collection study

The optimal speed and inner ring material for the Impact Forsberg machine were determined by a preliminary efficiency test. For each material (plastic or rubber), the frequency of the motor was set at three levels (15, 20, and 25 Hz), which corresponds to the following speeds: 862.5, 1150, and 1437.5 rpm respectively. The equipment was checked and cleaned after each run.

A sorghum sample of 1000 g was used for every efficiency test run. After glumes removal, the sorghum was sifted with a Great Western Laboratory Sifter (Great Western Manufacturing, Inc., Leavenworth, KS) (fig.2.6) .The sifter was equipped with a 630 micron (31GG 6-630/53) sieve and a collection pan. The throw was 4 inch and the speed was 180rpm. Each sample was sifted for 60 seconds.

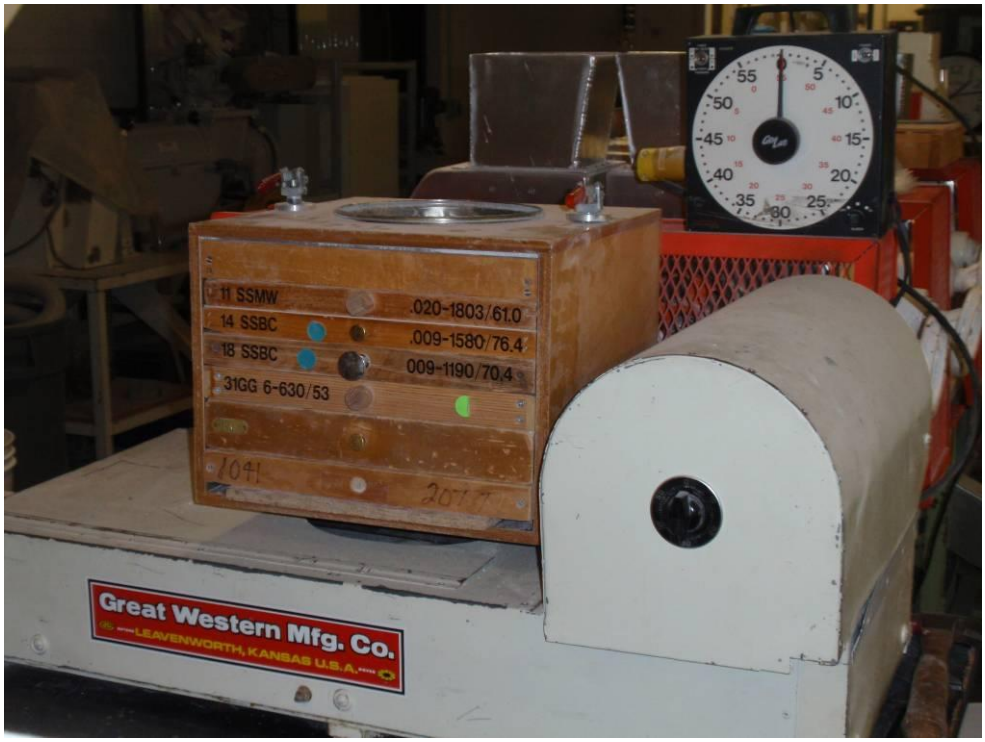

Fig.2.6 Laboratory Sifter (Great Western Manufacturing, Inc., Leavenworth, KS)

After collecting the fines, the Kice Laboratory (fig.2.7) aspirator was used for collecting the glumes and other light impurities which were not separated by sifting (fig.2.8). The suction level was adjusted in a way that no grits or other big pieces of damaged kernels were in the collected glumes fraction.

Fig.2.7 Kice Aspirator (Kice Industries, Wichita, Ks)

Fig.2.8 Glumes and light impurities (fines) collected from sorghum

Tempering

In previous research, different moisture levels and tempering times were studied. Abdelrahman et al (1981) produced a good yield of low fat sorghum grits by tempering the grains to a final moisture content of 17% for 8 hours. The initial moisture content of sorghum used in this study was 11.3%, and was determined with a Steinlite moisture meter (The Steinlite Corporation, Atchison, Kansas) (fig.2.9).

Fig.2.9 Steinlite Moisture Meter (The Steinlite Corporation, Atchison, Kansas)

Effect of tempering time and final moisture content on Hardness Index

The Hardness Index (HI) of sorghum kernels was studied at different tempering treatments (variation of time and moisture content). The HI reflects the force needed to crush the kernels and other parameters which are useful processing attributes. A high HI may imply hard kernels, which consume more energy when they are milled. This is not desirable for the milling facility because it increases variable costs of operation. For the HI tests, three different samples of 2000 g each were tempered to 14.5, 16.5, and 17.5% moisture. The grain was placed on the tempering drum (fig.2.10) and as the drum rotated, the amount of water necessary to increase the moisture content was added slowly. Because the coefficient of friction increases with added moisture, and the grain begin to tumble, and mix. This sequence of actions evenly distributes the moisture among the kernels. The drum was closed and allowed to tumble for 30 minutes. After tempering, the sorghum grains were placed in plastic bags. Each bag contained 50 g; these were stored at room temperature (76°F) for periods ranging from 0 to 8 hours.

Fig.2.10 Tempering station (KSU- Ross Laboratory)

Effect of tempering time and moisture on sorghum flour yield

Flour yield was measured at the different tempering moistures; 14.5, 16.5, and 17.5%. Tempering times of 3, 5, and 7 hours were used in all remaining tests in this study based on the results from the previous (HI) experiment.

All sorghum samples were ground with a Buhler Experimental Mill (MLU-202, Uzvill, Switzerland) (fig.2.11). Whose settings were kept constant for all samples. The initial roll gap was adjusted by comparison with settings used for wheat grinding because during the first sorghum trial, flour yield was unusually low. It is possible that this was due to inappropriate reduction at the middling's roll. The roll gaps were adjusted to 0.1mm for 1BK, 0.08mm for 3BK, and 0.254mm for 1M, and 0.0025mm for 3M.

A vibration-operating feeder (Syntron Power Pulse, FMC Technologies, Tupelo, MS) was set at 120 g/min in order to assure the uniform feeding of the grain into the mill. The room temperature and relative humidity were 74ºF, and 72% respectively.

The flour particle size was determined using the Beckman Coulter LS™ 13 320 Laser Diffraction Particle Size Analyzer (Beckman-Coulter, Inc., Miami, FL) (fig.2.12) at the CGAHR (USDA-ARS, Manhattan, KS).

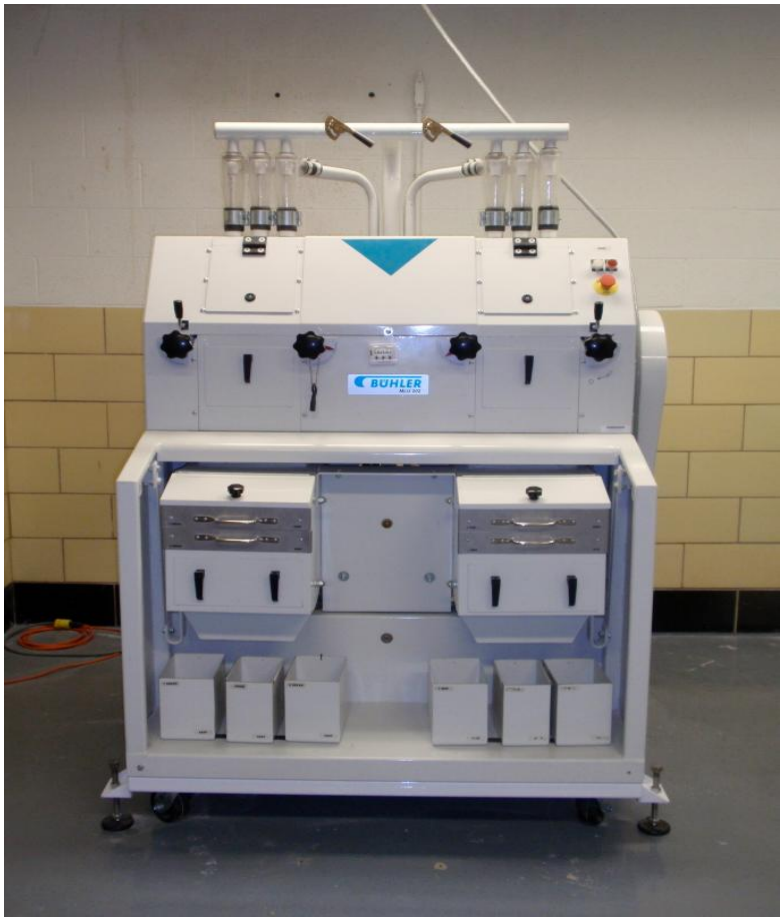

Fig.2.11 Buhler Experimental Mill (MLU-202, Uzvill, Switzerland)

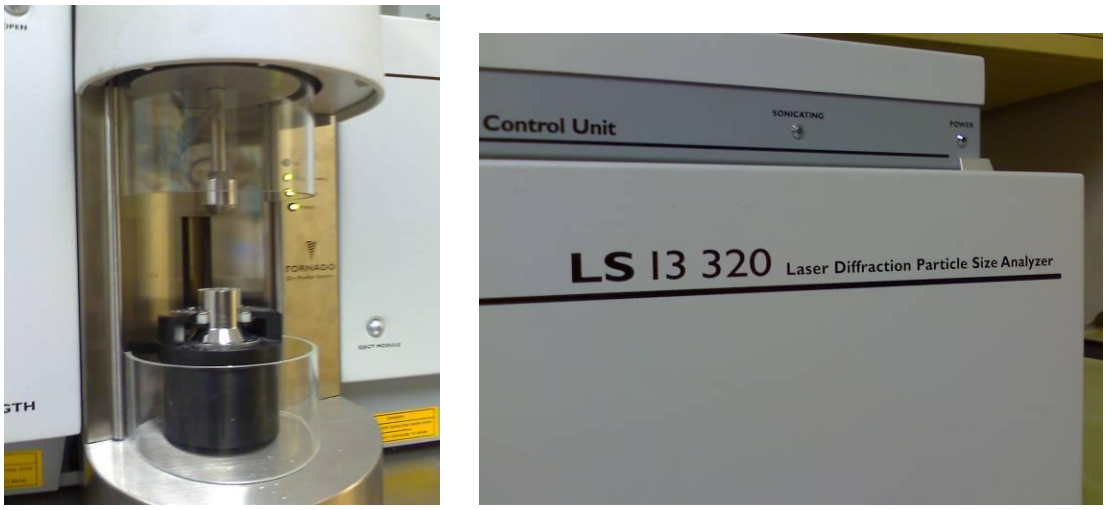

Fig.2.12 Beckman Coulter LS™ 13 320 Laser Diffraction Particle Size Analyzer (Beckman-Coulter, Inc., Miami, FL)

2.3 Flow Diagram Development

The sorghum milling procedure and diagram developed in this study was based on a regular wheat milling system which consists of the following steps: break, purification, sizing, midds reduction, residues, and low grade.

The premise behind the development of a flow diagram for sorghum flour was that, in order to obtain low fat and low ash white sorghum flour, a long reduction system can be used. In addition to this, two short flow diagrams were developed to obtain sorghum flours, for comparison with the flour produced by the long reduction system. These short diagrams could, potentially, be utilized in laboratory scale milling.

Development of Diagram F20105

Milling equipment

A series of laboratory corrugated rolls and smooth rolls (6x6 in) (Ross Machine & Mill Supply, Oklahoma City, Oklahoma) from the Experimental Mill and Ross Laboratory Mill at Kansas State University were used in the different steps of this diagram. In general, the corrugated rolls were in the break system and smooth rolls in the reduction system. The Pre-break step, which cracks the kernel open and improves the efficiency of the subsequent Break steps, was performed with an Allis Chalmers -"Le Page" roll (Utah Machine and Mill Supply Inc, Salt Lake City, UT). Four pair rolls with 12 (1BK and 2BK), 20, 24, and 28 corrugation/in were used as part of the Break system in order to fracture the endosperm bulk

and scrape off the endosperm attached to the bran. The removal of light bran was done with a Laboratory Kice Aspirator (Kice Industries, Wichita, Kansas). A laboratory sifter (Great Western Manufacturing, Inc., Leavenworth, KS) was used to separate intermediate stocks in different fractions based on particle size. The cleaning of grits from the break system was accomplished by the MIAG Purifier (fig.2.13), which uses differences in the aerodynamics, size and density of particles.

Fig.2.13 MIAG laboratory purifier (MIAG, Braunshweig, Germany)

In the reduction system, a smoothed roll was used to reduce the particle size of sorghum grits. The flattening effect (fig.2.14) on the endosperm particles, which is typical when sorghum grits pass through the reduction rolls, was avoided with the use of an impact detacher (Forsberg's Inc., Thief River Falls, Minnesota). All the resulting flour streams were mixed with a laboratory flour blender (Wenger Double Ribbon Stainless Steel Blender, Wenger Mfg., Sabetha, KS) (fig.2.15).

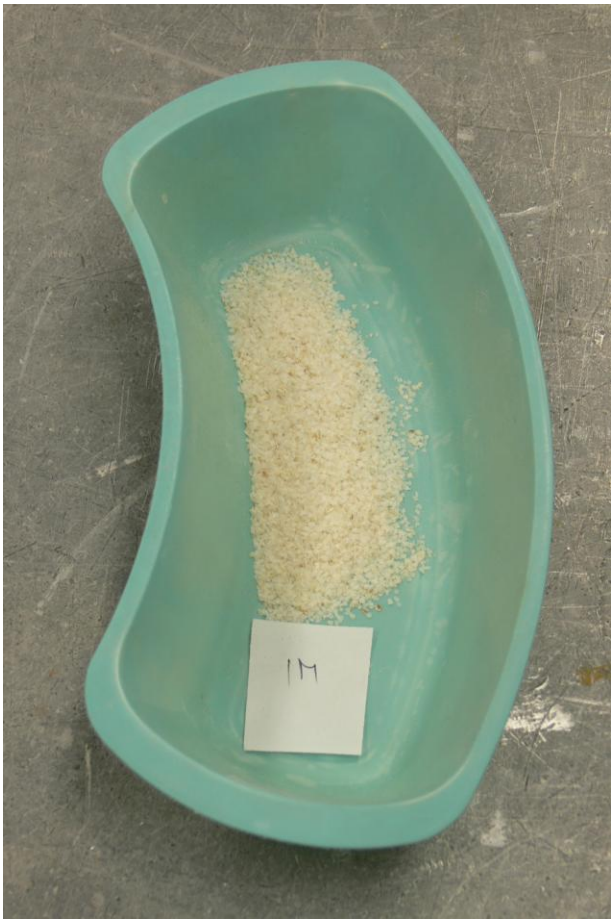

Fig.2.14 Flattened sorghum endosperm particles

Fig.2.15 Laboratory flour blender (Wenger Double Ribbon Stainless Steel Blender, Wenger Mfg., Sabetha, KS).

Milling procedure

A preliminary test was carried out to determine the appropriate gap in the rolls of the Prebreak, designated to impact cracking action on the sorghum kernels. For this purpose, a "Le Page" roll with special corrugations was used. This has a special roll fluting design, which are distributed perpendicularly one to another. Two gaps were tested (0.055 and 0.060 in), and the results from those gap tests were compared to a roll gap of 0.040 in, which was used by Abdelrahman et al (1981). Three sorghum samples, tempered to 17.5% moisture, were used as experimental units for each roll gap setting. After each run, the sorghum stocks were inspected visually and sifted for one minute with a Great Western laboratory sifter. The sieve stocks used for this test were: 14 SSBC, 18 SSBC, 31GG, and 10xx.

Five Break passages followed the pre-break system. These were 1BK, 2BK, 3BKF, 3BKC, and 4BK. Their function was to continue the cracking action on the kernels, and to separate the endosperm pieces attached to the bran. A good Break system with roller mills is that one in which the endosperm is detached from the kernel in as large pieces as possible, and the bran powder is minimum in the ground stocks. The sorghum bran is more brittle than wheat bran. A laboratory Kice Aspirator was used before each Break to extract the fragile bran particles from the stock. The purpose of this operation was to avoid an excessive shattering of the bran in the Break reduction system, which is detrimental to the quality of the flour due to the increase of ash, fat and fiber content.

The next step in developing the diagram was stock sieve selection to follow each Break operation so as to obtain a good distribution according to the stock component

characteristics. This was accomplished by testing different sieves at all milling steps several times.

The purpose of the purification step is to clean the grits, by separating. The MIAG laboratory purifier (MIAG, Braunshweig, Germany) was equipped with three different set of sieves according with the granulation of the grits. The air flow of the suction system attached to the purifier, the guiding panels under the sieves and the purifier air control devices were adjusted for obtaining a good separation of the bran and germ particles from the endosperm stock, and for separating the stocks into appropriate size ranges.

The sizing system was comprised of two sizing roller mills and sieves in order to continue the reduction of particle size but most importantly, to segregate the endosperm particles, bran and germ particles. A set of corrugated rolls (28 corr/in) was used for the coarse size particles (CSIZ) collected from the first and second purifiers, and a set of smooth rolls for the fine size particles (FSIZ), which were supplied by the second and third purifiers. The differential in this system was chosen at 1.5:1 based on current our laboratory equipment.

A set of smooth rolls was used in the midds reduction system. The differential was 1.5:1 to accomplish an efficient reduction of the purified middlings from the Break, Purification and Sizing systems. However, the midds tended to flatten out after passing through the roller mills instead of breaking into smaller pieces. This problem was addressed using an Impact Forsberg Laboratory machine, equipped with a plastic inner ring. The centrifugation speed of this machine was set at 3162.5 rpm, which is equivalent to a frequency of 55 Hz in the

motor. Another alternative route to avoid flattened sorghum endosperm was to utilize a pin mill. A comparison of the addition of either one of these processes to the sorghum reduction system follows.

Impact of three different types of equipments on flattened sorghum shorts

The midds flattening tendency after they passing trough smooth rolls, is the rationale of the finding the most suitable equipment for solving this undesirable situation. The flattened shorts produced in the previous tests by the Buhler Experimental Mill were used in these trials. The shorts were blended for 30 min with a ribbon flour blender (Wenger Double Ribbon Stainless Steel Blender, Wenger Mfg., Sabetha, KS). Aliquots of 1000 g each were prepared from the blend. A sample of shorts was checked for initial stock distribution and proximate analysis, and was used as a control sample. The remaining samples passed through an Impact Forsberg machine, an Alpine pin mill (160Z, Augsburg, Germany) set at two different speeds, or a Robinson Impact Detacher (Henry Simon Robinson Inc., Stockport, UK). The Impact detacher (fig.2.16), which is part of the KSU Shellenberger Pilot Mill, is usually used for removing flattened endosperm after reduction rolls in the wheat flour milling. All trials were conducted in triplicates (1000 g each), and statistical tests were used to compare the differences of different shorts fractions after different treatments.

Fig.2.16 Robinson Impact Detacher (Henry Simon Robinson Inc., Stockport, UK).

The residue system, composed of a Quality roller mill (QU) and two Tailing roller mills (1T and 2T), were used to handle the stocks which were rejected from the previous four systems. The role of this system is important because it collects good endosperm particles from compound particles, and sends it to the secondary midds reduction system for further milling (fig.2.17).

The last system in the Flow Diagram is "Low grade" (5M, 6M, and LG). This system was incorporated to the milling process to recover the low quality flours from the rejected stocks of midds reduction and residue systems.

Fig.2.17 Sorghum milling fractions – flow diagram development

All eighteen flours obtained from this Flow Diagram were collected, and tested by KSU Analytical laboratory for proximate analysis. The straight grade flour was analyzed for particle size distribution, starch damage, total starch, and baking properties at CGAHR, USDA-ARS. It was also tested for proximate analysis by the KSU Analytical lab, and for bread C-Cell and SRC analysis at KSU flour and dough testing laboratory. Agtron color and flour blending were done in KSU Ross Milling laboratory. Flour yield calculations of this milling procedure were made with flour from seven trials.

Fig.2.18 AGTRON Quality Meter (Agtron Inc., Reno, Ne)

Development of the Diagram F20106

Milling equipment and procedures

The equipments used in this milling procedure were: Buhler Experimental Mill, a laboratory sifter, and a Quadrumat Senior Experimental Mill (Brabender, Duisburg, Germany). The objective of developing this milling procedure was to obtain white sorghum flour (different flow diagram) which could be used to compare with the flour from Flow Diagram F20105 (only one commercial sorghum flour was found on the market; ash content was below 1%). A second mill was added to this procedure due to the fact that large amounts of flour and flattened endosperm particles were lost in the short fractions of the Buhler Experimental Mill.

The settings for the Buhler Mill were the same as those described in the Tempering section. The Great Western Laboratory sifter was equipped with a 180 μm sieve and five cleaners on a backwire to collect the flour from the shorts mass. The recovery of flour was achieved in 60 seconds of sifting. The shorts were passed through the Quadrumat Senior Mill to obtain the maximum amount of flour. The fine cascade corrugation rolls on the Quadrumat Mill efficiently broke the flattened sorghum endosperm particles. The diagram representing this flow is displayed in Fig. 2.5.

This milling procedure produced nine different flour fractions, all of which were collected separately during two different milling trials. Yield evaluation was performed in three trials; the resulting straight grade flour was also evaluated for proximate analysis, particle size

distribution, starch damage, total starch, baking properties, bread C-Cell and SRC analysis, and color and flour blending.

Development of Diagram F20107

Milling equipment and procedures

For same comparison reason, mentioned above, a short flow diagram based on decortication, hammer milling and pin milling, was developed. A hammer mill (Better Built By Bliss, Ponca City, Oklahoma) (fig.2.19), a laboratory sifter (Great Western Manufacturing, Inc., Leavenworth, KS), and Alpine pin mill (160Z, Augsburg, Germany) (fig.2.20) were utilized for developing this milling procedure in the KSU Ross Milling Laboratory.

Fig.2.19 Hammer mill (Better Built By Bliss, Ponca City, Oklahoma)

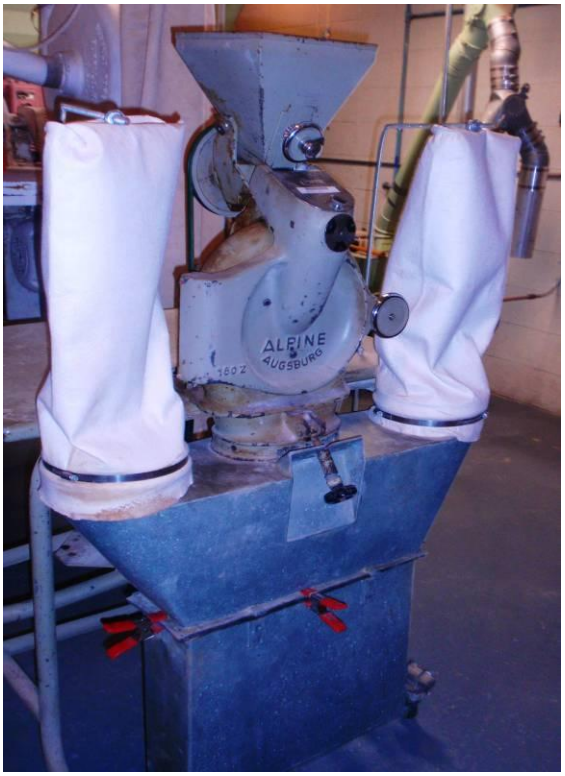

Fig.2.20 Alpine pin mill (160Z, Augsburg, Germany)

The sorghum used for this procedure was variety Fontanelle 1000, 12% decorticated (for removing the bran and the germ), supplied by CGAHR, USDA-ARS, Manhattan, KS. The hammer mill was equipped with a perforated metal sieve (0.20 mm). The stock obtained after hammer-milling (3150 rpm) was sifted in the Laboratory sifter for 30 seconds in order to collect the first flour (particles passing through 180μm). The remaining shorts were ground again with the pin mill at 3650 rpm. The flour was collected after 30 seconds of sifting. The overs on the 180μm were ground again on the pin mill at the speed mentioned before. The third flour and the remaining shorts fraction were collected after sifting. The Diagram associated with this flow is displayed in Fig. 2.21.

All three flour streams obtained from this milling procedure were collected separately in three replications. The straight grade flours were also collected three times for yield determination and evaluation of their physical, chemical, baking, dough and bread properties.

The Diagrams F20105, F20106, and F20107 are shown in Figs. 2.21, 2.22, and 2.23, respectively.

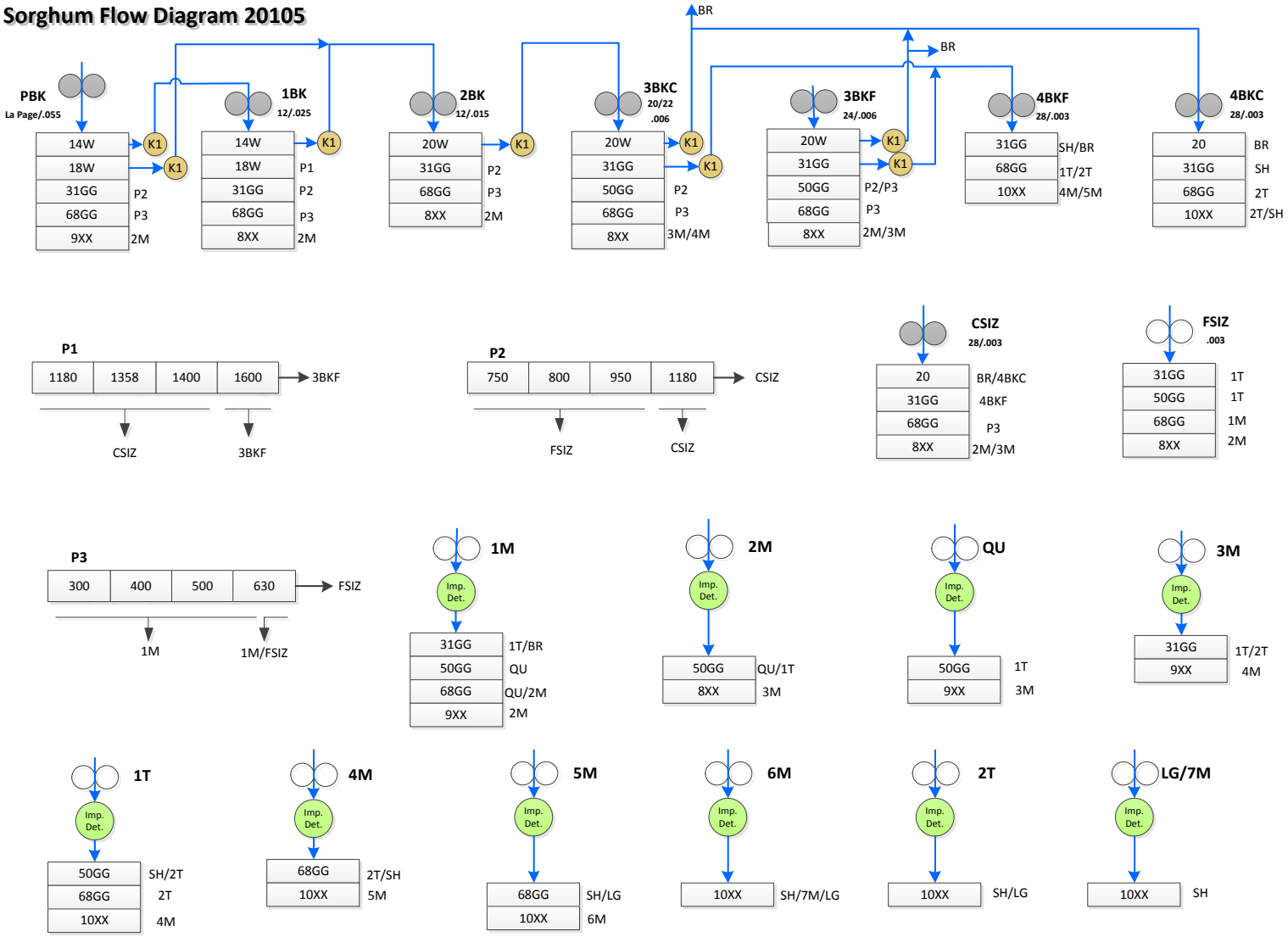

Fig. 2.21 Flow Diagram F20105 (Long reduction system).

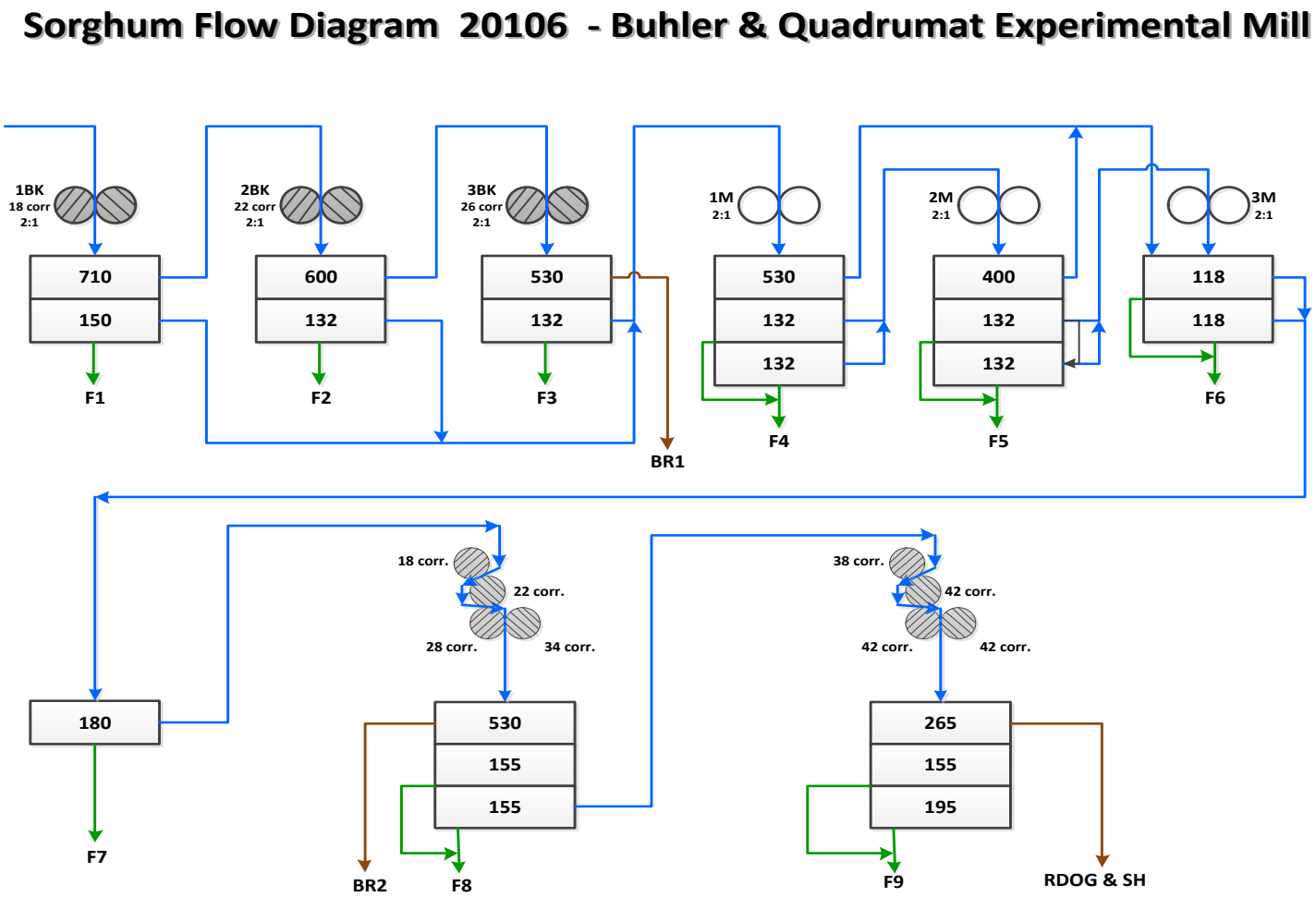

Fig. 2.22 Flow Diagram F20106.

Diagram F20107 – Hammer Mill & Pin Mill

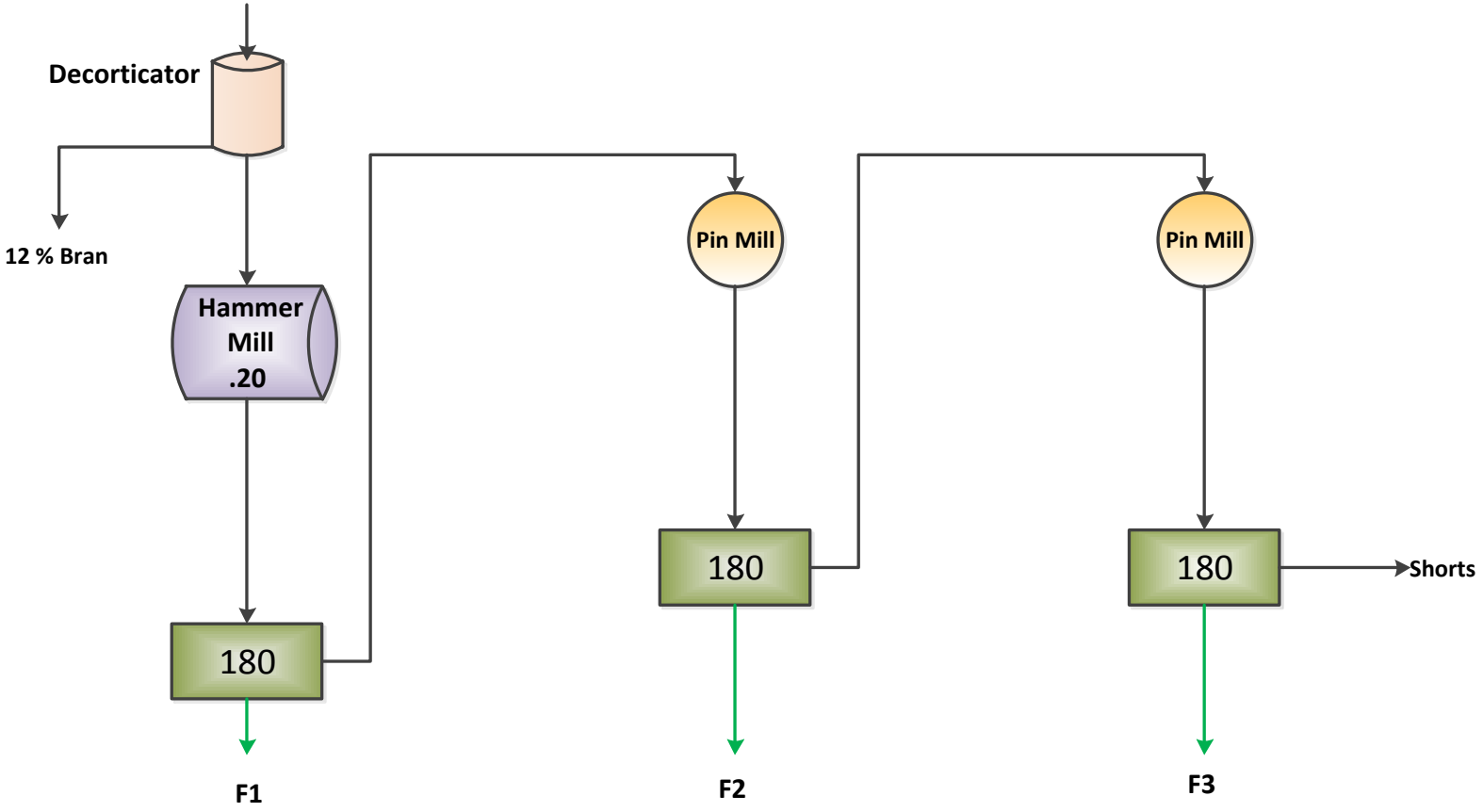

Fig 2.23 Flow Diagram F20107 .

2.4 Results and discussion

Sorghum parameters

The sorghum parameters measured by the SKCS system gave the following values: hardness index (HI) was 82.94±22.39, kernel weight (mg) was 20.42±5.15, and the kernel diameter was 2.02 ± 0.32. The proximate analysis from KSU Analytical Laboratory showed for raw sorghum a crude fat content of 3.02±0.09%, an ash content 1.44±0.02, and a crude fiber content of 1.81±0.07%. The relative humidity and temperature in the storage room were 70-75% and 76°F.

Glumes and fines collection in various treatments

The glumes were separated from sorghum kernels with a Impact Forsberg Dehuller (Forsberg's, Inc., Thief River Falls, Minnesota), equipped with two different inner rings (also three different frequencies for each ring were used). All weights of collected fractions were analyzed and compared in order to determine which conditions were more suitable for the purpose of this research work. The collected data are shown in Table 2.1.

Table 2.1. Glumes and fines collection in various treatments (initial sample 1000g)

Ring Material	Mean ± SE [a]		
	Frequency (Hz)	Glumes (g)	Fines (g)
Plastic	15	0.30 ± 0.03b	0.40 ± 0.07bc
	20	0.33 ± 0.02b	0.65 ± 0.10b
	25	0.49 ± 0.02a	2.11 ± 0.11a
Rubber	15	0.19 ± 0.01b	0.09 ± 0.01c
	20	0.31 ± 0.05b	0.32 ± 0.04bc
	25	0.46 ± 0.03a	1.88 ± 0.12a

[a]Means within a column followed by different letters are significantly different ($P < 0.05$, REGWQ test).

The lowest amount of fines collected was obtained when the rubber inner ring was used at 15 Hz (corresponding speed of 862.5 Hz). However, because the results for the rubber inner ring used in combination with the 20Hz motor frequency (1150 rpm) were acceptable (even from the statistical point of view), these settings were chosen.

Effect of Tempering Time (at 3 Tempering Moisture levels) on Hardness Index

The Hardness Index (HI) of tempered sorghum was determined with a SKCS unit, especially calibrated for sorghum by researchers in the Center for Grain and Animal Health Research (USDA-ARS, Manhattan, Kansas). Four measurements were collected for each treatment (Table 2.2)

Table 2.2. Effect of Tempering Time (at 3 Tempering Moisture levels) on Hardness Index

Tempering Time (h)	Hardness Index (Mean ± SE) at tempering moisture		
	14.5%	16.5%	17.5%
0	83.0 ± 1.0 d	82.94 ± 0.96f	82.94 ± 0.96g
2	105.17 ± 0.69a	112.07 ± 1.12a	111.88 ± 0.64a
3	97.07 ± 0.47b	100.50 ± 1.06b	98.24 ± 1.09b
4	94.65 ± 0.81bc	95.01 ± 0.54c	94.17 ± 0.43c
5	94.52 ± 0.44bc	91.48 ± 0.69cd	90.55 ± 0.40cd
6	93.03 ± 1.91bc	92.06 ± 0.35cd	90.13 ± 1.62cde
7	93.30 ± 0.89bc	90.16 ± 0.41de	91.80 ± 1.00e
8	92.02 ± 0.47c	88.95 ± 0.68de	87.39 ± 0.54ef

*Means within a column followed by different letters are significantly different ($P < 0.05$, REGWQ test)

The combination of tempering time and tempering moisture had a strong influence on the evolution of HI (F=7.38; df=14, 61; P-value<0.0001). Close examination of Figure 2.24 shows that the sorghum kernel hardness increased drastically after 2-hours of tempering, especially at 16.5 and 17.5% moisture, and decreases after 3-hours. After 4-hours, the decreasing trend levels off, and hardness becomes more or less constant until 8-hour tempering. Tempering time had a greater effect on the hardness index (F=2.86.46; df=7, 61; *P-value* <0.0001) than did tempering moisture. At each tempering time tested, the difference in hardness between 16.5% and 17.5% moisture sorghum was not statistically significant (P<0.05), and the difference between 14.5% and 16.5% moisture sorghum was not statistically significant (P<0.05) at 4 and 6-hour tempering. No relationship was found between tempering moisture alone and HI (F= 2.14; df=2,61; *P-value* > 0.13).

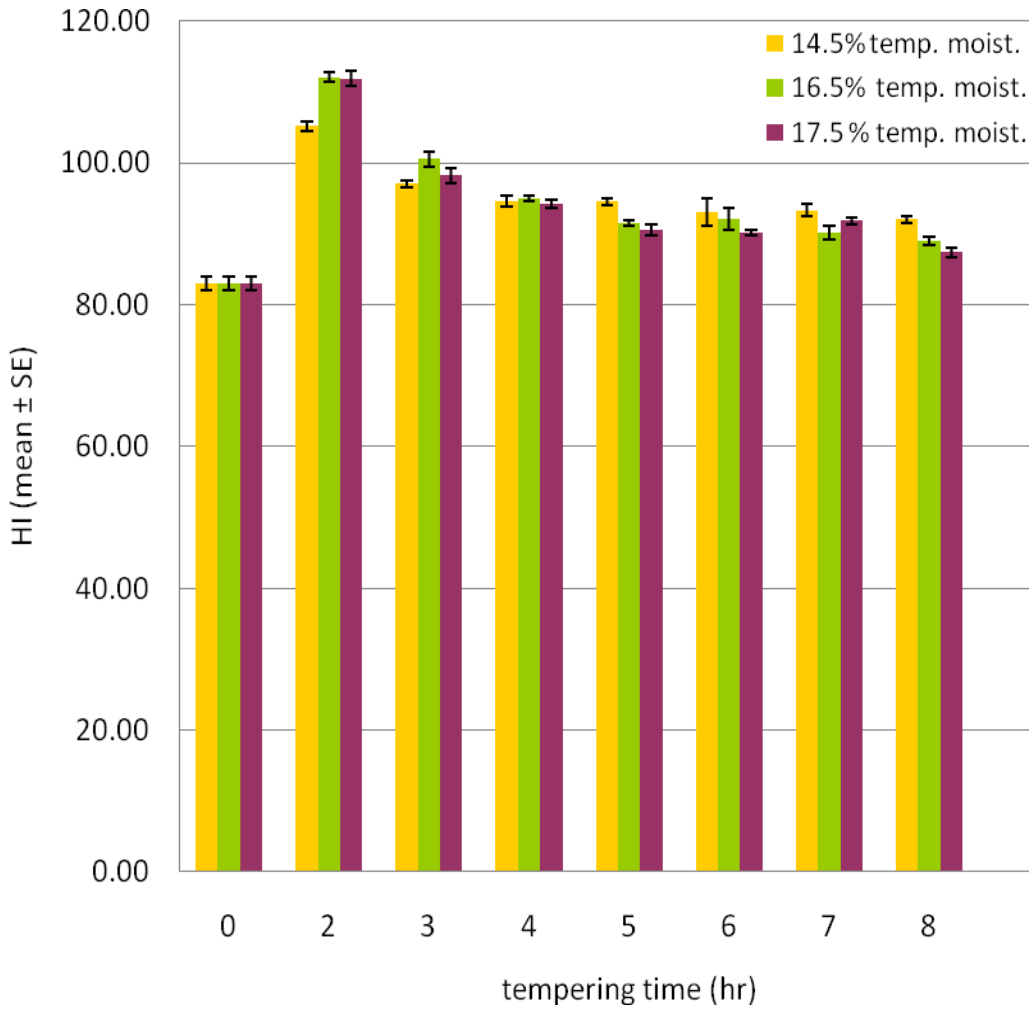

Fig 2.24 Effect of tempering time on Hardness index of sorghum flours tempered at three different moisture contents.

Effect of Tempering Moisture (at constant Tempering Time) on sorghum flour yield

The yield for flour, bran, and shorts at the different tempering time and moistures, are displayed in table 2.3.

Table 2.3. Effect of Tempering Moisture (at constant Tempering Time) on sorghum flour yield.

		Mean ± SE			
Tempering Moisture	**Tempering Time**	**Total Flour***	**Shorts***	**Bran***	**Loss****
14.5	3	475.60 ± 6.41ab	398.50 ± 3.27a	97.43 ± 0.15d	28.47 ± 3.47
	5	484.47 ± 14.87ab	388.13 ± 8.96a	89.03 ± 1.09e	38.37 ± 5.63
	7	466.17 ± 7.69b	405.50 ± 6.50a	87.17 ± 2.63e	41.17 ± 12.19
16.5	3	497.63 ± 9.45ab	346.93 ± 9.51b	112.63 ± 0.45bc	42.83 ± 3.41
	5	503.63 ± 6.70ab	348.08 ± 5.23b	107.60 ± 1.21c	40.70 ± 5.63
	7	476.90 ± 6.16ab	387.83 ± 6.41a	111.33 ± 3.33bc	23.95 ± 12.17
17.5	3	510.40 ± 7.75a	322.40 ± 3.71b	121.68 ± 0.98a	45.53 ± 10.42
	5	502.38 ± 3.40ab	325.20 ± 2.21b	117.38 ± 0.49ab	55.05 ± 4.45
	7	491.15 ± 7.53ab	335.75 ± 5.75b	115.58 ± 0.45ab	57.53 ± 7.19

*Means within a column followed by different letters are significantly different (P<0.05, REGWQ test).
**P=0.1027

The flour obtained from each of the six milling streams (3 breaks and 3 midds) was collected and analyzed by KSU Analytical Lab. The flour from the first break stream had the highest moisture content, while that of the third midds stream had the lowest. Figure **2.25** shows the moisture distribution of the six flour streams and shorts from the sorghum samples tempered at 14.5, 16.5, and 17.5% moisture. The trend observed in Figure 2.25 of decreasing moisture content with increasing grinding steps (1B through 3M) might be due to the heat accumulated on the milling fractions after each step. The moisture contents of all flour streams were below 15% (w.b.), the upper moisture limit suggested for sorghum flour (Codex Standard for Sorghum Flour, 1989).

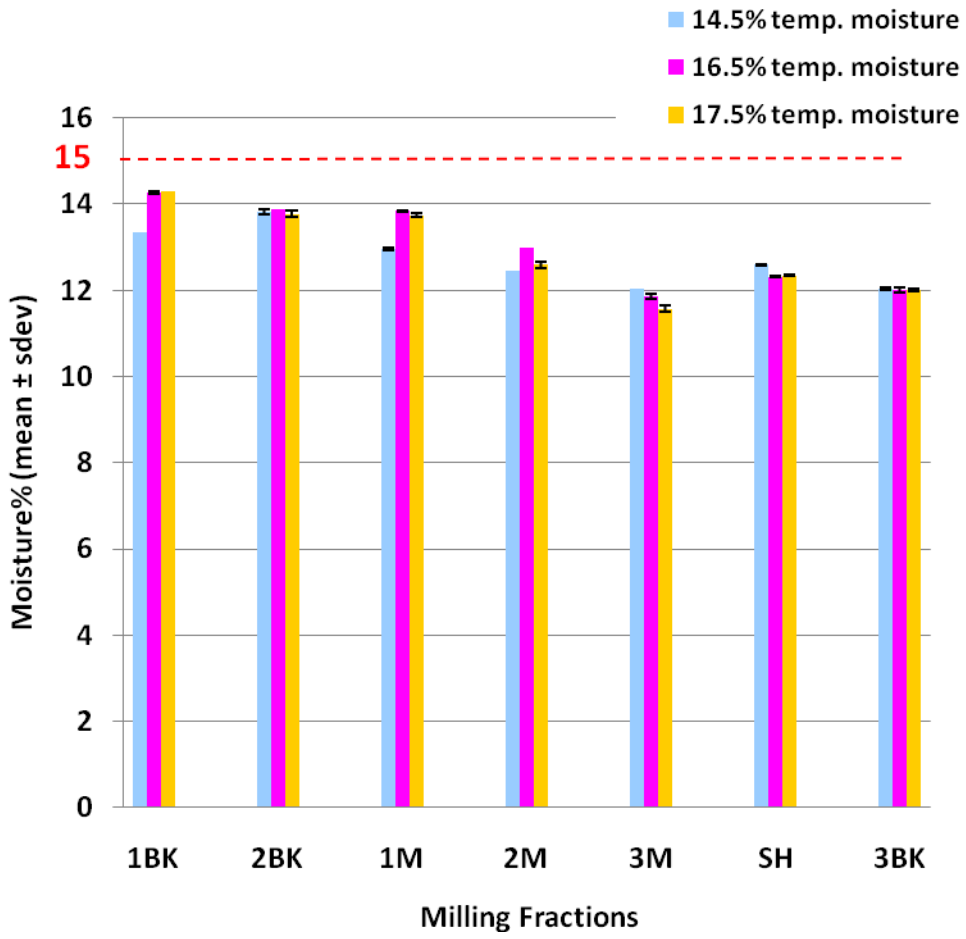

Fig. 2.25 Moisture content of sorghum flour from different milling streams

The crude fat content of the first break flour stream was the lowest. On the other hand, that of third break flour stream was the highest. This can be explained by the structural source (presence or absence of aleurone layer) of the different streams. The flour collected as the first break stream contains the central structures of the sorghum endosperm, mainly the soft endosperm, which contains small amounts of fat. At the third break, corrugated rolls are used to scrap the endosperm that remains attached to the bran. High ash and high fiber content are associated with a higher presence of bran in the flour. The first and second break

and the first midds had the smallest amounts of ashes. Their values of ash content are not statistically different.

The protein content was lowest at the first break flour stream due to the low protein flour which is obtained from the floury endosperm. The protein content of the flour streams increased from 1B to 3M. This was due to the gradual collection of flour from the center part of the kernel, which contains soft endosperm and relatively small amounts of protein, to the periphery of the endosperm, which contains hard endosperm and therefore, relatively large protein content.

As anticipated, it was observed that the particle size decreased from 1Bk to 3M because each grinding step was designed to break the kernel into increasingly smaller pieces.

Effect of Prebreak roll gap on short stocks distribution

The distribution of stocks after testing different Prebreak gaps is given in Table 2.4 and Fig. 2.26.

Table 2.4. Effect of Prebreak roll gap on short stocks distribution.(%)

Prebreak gap (inch)	+14 SSBC* (1580µ)	+18 SSBC* (1190µ)	+31 GG* (630µ)	+10xx* (132µ)	PAN*
0.04	86.42 ± 031c	7.66 ± 0.24a	2.77 ± 0.03a	2.75 ± 0.04a	0.40 ± 0.04a
0.055	92.39 ± 0.21b	4.08 ± 0.07b	1.62 ± 0.05b	1.77 ± 0.11b	0.14 ± 0.00b
0.06	94.02 ± 0.27a	3.03 ± 0.14c	1.34 ± 0.10c	1.49 ± 0.08c	0.11 ± 0.02b

*Mean ± stdev
*Means within a column followed by different letters are significantly different (P < 0.05, REGWQ test).

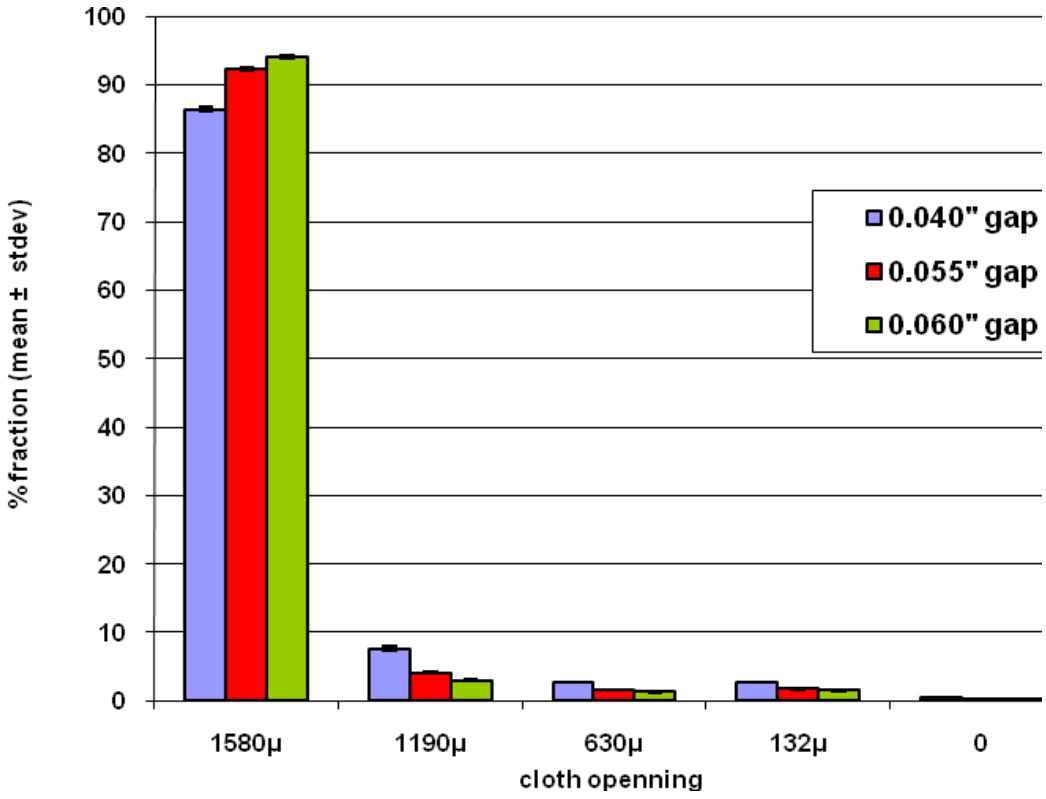

Fig. 2.26 Effect of Prebreak roll gap on stock distribution.

It was determined by visual inspection that, before sifting, unbroken kernels were found in the stocks from 0.060 in roll gap adjustment, and a high degree of broken kernels were in the stocks from 0.040 in roll gap. The optimum stock distribution and texture was obtained when the roll gap was adjusted at 0.055 in.

Effect of different Impact equipment on flattened sorghum shorts

The stock distributions after running shorts (with flattened endosperm in composition), through different equipment, are displayed in Table 2.5 and Fig. 2.27. The goal of this study was to find the most suitable equipment in transforming the flattened endosperm in flour. The high flour yield with low ash, fiber, fat and high Agtron color, was the target of this study.

Table 2.5. Effect of different Impact equipment on flattened sorghum shorts. The values are percentages of total flour (%).

Sieve / Equip.	>355µ*	355 µ-240µ*	240 µ-180µ*	180 µ-132µ*	<132 µ*	LOSS*
Control- No Impact	48.70 ± 0.40a	20.52 ± 0.05b	12.37 ± 0.58c	14.49 ± 1.00e	3.61 ± 0.22c	0.31 ± 0.32b
Impact Forsberg (3162rpm)	30.76 ± 0.46b	26.00 ± 0.80a	15.58 ± 0.51bc	19.50 ± 0.95d	5.72 ± 0.32c	2.44 ± 1.14b
Pin Mill Low speed (2875rpm)	4.91 ± 0.11d	20.42 ± 1.75b	15.77 ± 3.22bc	40.38 ± 0.46b	17.50 ± 1.52a	1.02 ± 1.10b
Pin Mill Hi Speed (3625rpm)	2.93 ± 0.03e	14.03 ± 1.00c	20.38 ± 0.11a	44.31 ± 1.75a	17.31 ± 1.01a	1.04 ± 0.88b
Impact Detacher Robinson (3600rpm)	11.89 ± 0.19c	24.51 ± 1.07a	17.50 ± 0.99ab	28.31 ± 0.52c	9.41 ± 0.99b	8.38 ± 2.32e

*Mean ± stdev

*Means within a column followed by different letters are significantly different (P<0.05, REGWQ test).

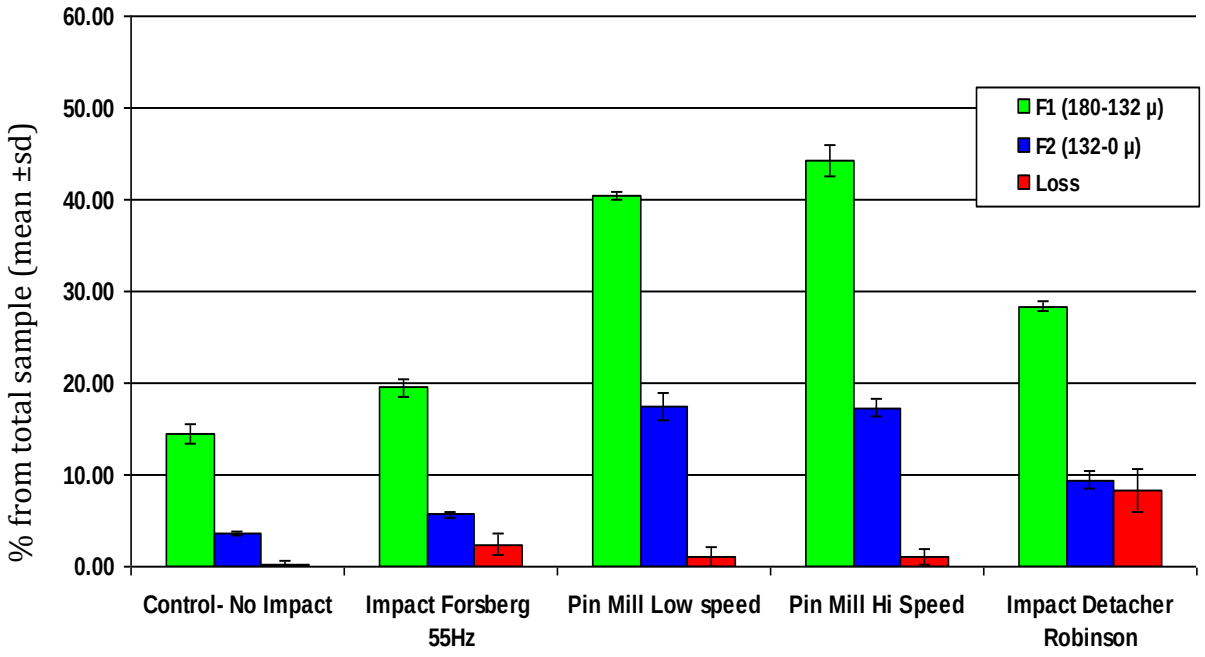

Fig. 2.27 Effect of Impact equipment on flattened sorghum shorts.

Proximate analysis for both types of flour (F1:180-132 microns; F2<132 microns) obtained after each treatment were conducted by the KSU Analytical lab. The results are displayed in Tables 2.6 and 2.7. A granulation curve for each reduced shorts stock was plotted in Fig 2.28.

Table 2.6. Proximate analysis of Flour 1 (180-132μ).

Treatment	% Crude fat (d.b.)*	% Ash (d.b.)*	% Crude fiber (d.b.)*	Moisture (w.b.)*	Moisture (d.b.)*	Agtron Color*
Control	1.96 ± 0.04c	1.00 ± 0.01c	1.00 ± 0.11a	12.25 ± 0.03a	13.96 ± 0.03a	35.67 ± 1.15a
Impact Forsberg	2.17 ± 0.01b	1.06 ± 0.01a	0.99 ± 0.06a	12.18 ± 0.02b	13.87 ± 0.03b	32.00 ± 0.00b
Pin Mill Low Speed	2.10 ± 0.02b	1.00 ± 0.01c	0.86 ± 0.05a	12.13 ± 0.03b	13.80 ± 0.04b	32.00 ± 1.00b
Pin Mill High Speed	2.32 ± 0.03a	1.03 ± 0.01b	0.83 ± 0.05a	12.03 ± 0.03c	13.68 ± 0.04c	34.33 ± 0.58a
Impact Detacher	2.11 ± 0.04b	1.06 ± 0.01a	0.92 ± 0.05a	11.79 ± 0.01d	13.37 ± 0.02d	34.67 ± 0.58a

*Mean ± sdev
*Means within a column followed by different letters are significantly different (P < 0.05, REGWQ test).

Table 2.7. Proximate analysis of Flour 2 (<132μ).

Treatment	% Crude fat (d.b.)	% Ash (d.b.)	% Crude fiber (d.b.)	Moisture (w.b.)	Moisture (d.b.)	Agtron Color
Control	2.68 ± 0.01c	1.67 ± 0.02a	0.86 ± 0.04a	11.77 ± 0.11d	13.33 ± 0.14d	40.00 ± 1.00c
Impact Forsberg	2.80 ± 0.04b	1.65 ± 0.02a	0.82 ± 0.07a	12.12 ± 0.03b	13.79 ± 0.04b	40.33 ± 1.15c
Pin Mill Low Speed	2.98 ± 0.02a	1.58 ± 0.01c	0.67 ± 0.06b	12.16 ± 0.01ab	13.84 ± 0.02ab	44.00 ± 0.00b
Pin Mill High Speed	2.79 ± 0.01b	1.53 ± 0.00d	0.62 ± 0.03b	12.26 ± 0.02a	13.97 ± 0.02a	44.00 ± 0.00b
Impact Detacher	2.85 ± 0.06b	1.62 ± 0.01b	0.61 ± 0.06b	11.91 ± 0.03c	13.51 ± 0.04c	46.33 ± 0.58a

*Mean ± sdev
*Means within a column followed by different letters are significantly different (P < 0.05, REGWQ test).

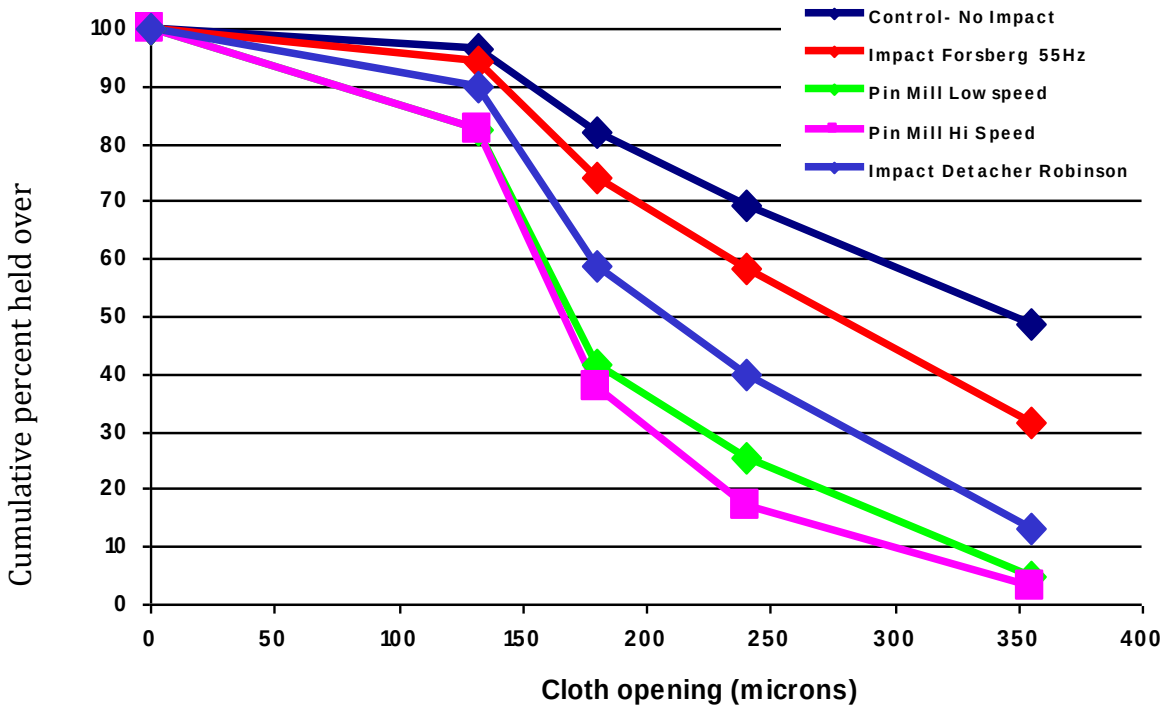

Fig. 2.28 Granulation curves for flattened sorghum shorts after/before Impact action.

The finest granulation curve of shorts was obtained after using the pin mill and the coarsest granulation curve was obtained with the Impact Forsberg machine (fig. 2.28 and tab. 2.5). It can be concluded after analyzing this data that the best flour yield was obtained with the pin mill equipment (high speed 3625 rpm; table 2.5 and fig. 2.27). The proximate analysis of the midds from this particular equipment shows that they contain relatively low levels of fat, ash, and fiber (Table 2.6 and 2.7). The relatively large loss of collected shorts (Table 2.5 and Fig 2.27) observed when the Robinson Impact Detacher was used may have been caused by the steps farther along in the process. The processing flow did not include a filtration/separation step for the stream exiting the cyclone attached to the Impact Detacher. This step would

have allowed the recovery of fine particles. In spite of this loss, it can be said that the Robinson Impact Detacher is a feasible option to accomplish the detaching operation on sorghum flattened midds (it was supposed that a big part of the loosed material was flour). Also, a pin mill connected to a separation cyclone/filter can be used in the laboratory version of this Flow Diagram.

Flours evaluation

The flours obtained from the Diagram F20105 (Long Reduction System), F20106 (Buhler-Quadrumat short laboratory flow) and F20107 (Hammer/Pin milling) were identified as: 148, 210, and 200, respectively. Another commercial white sorghum flour (sample ID=144) provided by a private producer was tested and used as a check to compare the other flour samples. The flour, sample ID=148, was considered as control (it was the principal objective of this research).

Proximate analysis (crude fat, moisture, ash, and crude fiber) on flours was performed by KSU Analytical laboratory. The following tests were done at the CGAHR, USDA-ARS facility, Manhattan, KS: particle size distribution, starch damage, total starch, and baking. The bread C-Cell and Mixolab analysis were performed in the KSU flour and dough testing laboratory. The Agtron color and flour blending were done in KSU Ross Milling Laboratory.

The results obtained are displayed in Tables 2.8-2.14 and in Figures 2.29-2.31.

Table 2.8. Yield by fraction and loss after milling by three different flows.

Sample	Diagram	(%) (Mean ± SE)			
		Flour (%)*	Shorts (%)*	Bran (%)*	Loss (%)*
148	**F20105**	71.31 ± 0.77b	9.06 ± 0.32b	12.00 ± 0.12a	7.63 ± 0.87a
200	**F20107**	75.98 ± 0.46a	7.97 ± 0.31c	12.00 ± 0.00a	4.05 ± 0.76a
210	**F20106**	69.43 ± 0.70b	12.03 ± 0.06a	11.40 ± 0.68a	7.14 ± 1.24a

*Means within a column followed by different letters are significantly different (P < 0.05, REGWQ test).

Table 2.9. Proximate analysis of sorghum flours produced by three different milling procedures

Diagram	Sample	% Crude fat (d.b.)*	% Ash (d.b.)*	% Crude fiber (d.b.)*	Moisture (w.b.)*
F20105	**148**	1.43 ± 0.03b	0.74 ± 0.01b	0.51 ± 0.04c	13.13 ± 0.04b
Com.	**144**	1.47 ± 0.02b	0.69 ± 0.01c	0.51 ± 0.03c	11.19 ± 0.05d
F20107	**200**	2.77 ± 0.04a	1.21 ± 0.01a	0.75 ± 0.03a	13.53 ± 0.02a
F20106	**210**	1.42 ± 0.02b	0.76 ± 0.02b	0.60 ± 0.03b	13.01 ± 0.07c

*Mean ± sdev
*Means within a column followed by different letters are significantly different (P < 0.05, REGWQ test).

Table 2.10. Comparison of different sorghum flours based on color parameters.

Diagram	Sample	Mean ± SE			
		L-value	a-value	b-value	Agtron Color
F20105	**148**	89.28 ± 0.01b	-0.93 ± 0.01b	9.53 ± 0.01c	44.33 ± 0.58b
Com.	**144**	85.65 ± 0.01d	1.49 ± 0.03d	10.2 ± 0.01a	6.33 ± 0.58d
F20107	**200**	87.31 ± 0.01c	-0.72 ± 0.01c	11.89 ± 0.00b	22.33 ± 1.53c
F20106	**210**	90.6 ± 0.01a	-1.04 ± 0.01a	8.91 ± 0.01d	50.00 ± 1.00a

*Means within a column followed by different letters are significantly different (P < 0.05, REGWQ test).

The milling procedure described in Diagram F20107 produced the largest flour yield of the three procedures used. However, contents of fat, ash, and fiber contents were highest for the flour (Table 2.9). This is undesirable in white sorghum flour. The flour yield from diagram 20105 and 20106 were similar (Table 2.8), and they also had the best color (Table 2.10). The fat, ash and fiber contents differed very little among flour samples 148, 144, and 210, and in some cases, these differences were not statistically significant ($P<0.05$, Table 2.11).

Table 2.11. Flour characterization based on four parameters.

	Mean ± SE			
Sample ID	**% Total Starch (d.b.)**	**Particle size (d_{90})**	**% Starch Damage**	**% Protein (d.b.)**
148	86.05 ± 1.19 a	191.03 ± 0.02 a	12.50 ± 0.33 b	9.47 ± 0.02 c
144	83.94 ± 1.16 a	191.28 ± 0.10 a	12.48 ± 0.26 b	10.36 ± 0.04 a
200	82.14 ± 0.90 a	180.37 ± 0.90 b	6.10 ± 0.10 c	9.69 ± 0.04 b
210	84.47 ± 0.99 a	179.09 ± 0.04 b	19.55 ± 0.28 a	8.96 ± 0.03 d

*Means within a column followed by different letters are significantly different ($P < 0.05$, REGWQ test).

The percentage of starch damage was similar for the samples 148 and 144, and also these flours had same particle size distribution as well. The milling procedure that used both the Buhler and Quadrumat Mill (sample 210),produced the highest amount of damaged starch in the flour, while the lowest was attained by the hammer mill followed by pin mill (samples 210 and 200, respectively; Table 2.12). The lowest protein content was found in sample 210 and the highest level was found in commercial sample 144.

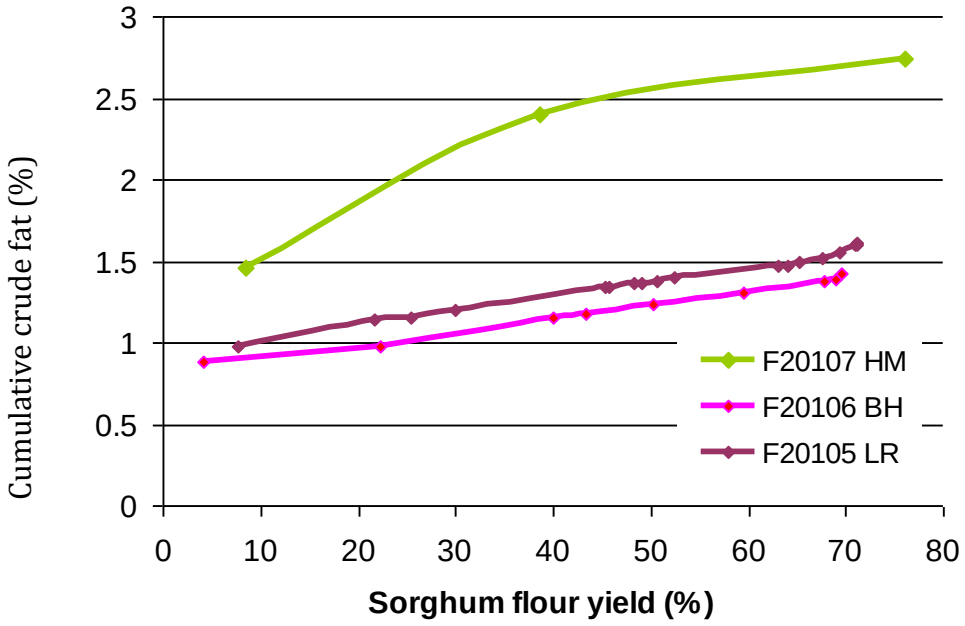

Fig. 2.29 Cumulative crude fat (%) vs. yield (%) of sorghum flours produced with three different milling procedures

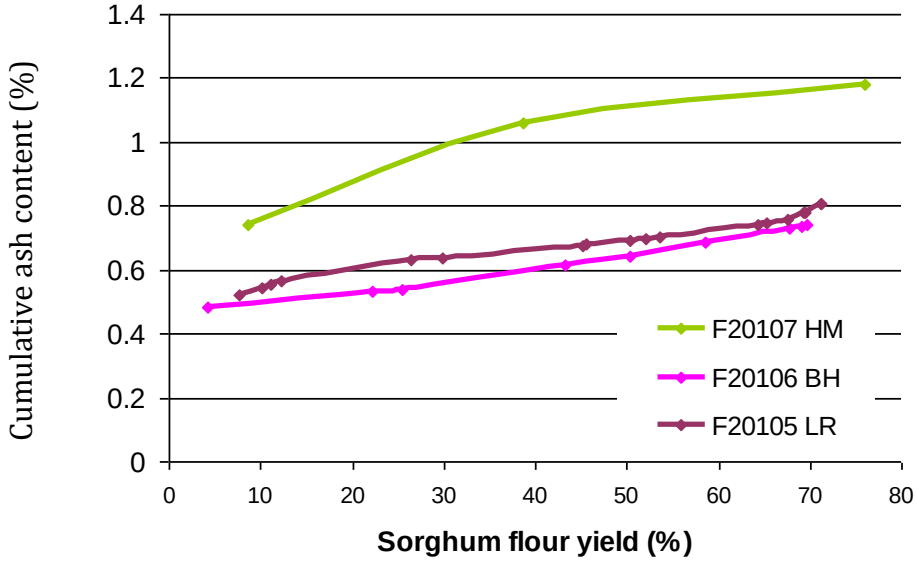

Fig. 2.30 Cumulative ash (%) vs. yield (%) of sorghum flours produced with three different milling procedures

The cumulative curves of fat and ash content for the samples 148 and 210 were very similar (Figs. 2.29 and 2.30, respectively). However, the slope was very small throughout the range of sorghum flour yield tested (5-75%). This indicated that the marginal gain of fat and ash content with every unit of sorghum flour produced was very small for both F20105 and F20106. It can be shown from these figures and from the proximate analysis of the resulting flours that these milling procedures were effective in reducing the particle size of endosperm and separating it from the bran and germ (Table 2.11). This finding made the use of a short laboratory flow, specifically F20106, as a check for the long reduction system more relevant. Nevertheless, the high degree of damaged starch associated with flour from short diagram F20106 should be considered as a drawback of its utilization (Table 2.11).

Mixolab flour evaluation

The three sets of sorghum flour produced by the milling procedures from Diagrams F20105, F20106, and F20107, plus commercial flour, AD, were tested using the Mixolab (Chopin Technologies, Villeneuve la Garenne, France).

The Mixolab protocols "Chopin+" and "Dilek+" were implemented with final dough masses of 75 and 90 g, respectively. The "Chopin+" protocol was successful in testing wheat flour properties, while "Dilek+" had been used with good results for testing two commercial sorghum flours BM (whole sorghum flour, Bob Red Mill, Oregon), and AD. Unfortunately, in both cases the C1 consistency fell outside of tolerance levels, and a new Mixolab protocol had to be created (Dr. Hulya Dogan).

The new Mixolab protocol was named “h”. The samples were prepared as follows. The dough mass used was 100 grams and the target consistency was 1.1 Nm (+/- 0.05 Nm). The dough weights were measured with a Mettler-Toledo scale (model PL 3002, max. 3100 g; d=0.01 g), produced by Mettler-Toledo Group in China. The moisture content of the different types of flour was measured in triplicates by the convection oven method at the KSU Analytical Lab. After the samples were prepared, their flour properties were tested with the Mixolab using the protocol “h”, whose conditions are detailed in Table 2.12. The water absorption was kept at 115% for each sample.

Table 2.12 Mixolab- Protocol “h”

Parameter	**Setting**
Kneading speed	80rpm
Target torque(C1)	1.1Nm
Dough mass	100g
Tank temperature	30 C
Temperature 1st level	30 C
Duration 1st level	8min
Temperature 2nd level	90 C
1st temperature gradient	15min / 4 C
Duration 2nd level	7min
2nd temperature gradient	10min / -4 C
Temperature 3rd level	50 C
Duration 3rd level	5 min
Total analysis time	45min

The Mixolab properties of flours from Diagrams F20105 (148), F20106 (200), and F20107 (210), plus commercial flour AD (144) are shown in Figure 2.31. There were visible differences, from a qualitative point of view, in the mixing and pasting behavior of these samples. The batter of samples 144 and 148 were more stable after gelatinization. The flour sample 200 had the best stability (the lowest slope α, between C_1 and C_2) during the mixing time. This flour also had the best proofing and baking behavior. The highest amount of water was added to sample 210, while the lowest was added to sample 200 (Table 2.15). Concomitantly with water addition, peak dough viscosity is higher for sample 210 and lowest for sample 200 due to high and low, respectively, starch damage (Tables 2.11 and Figure 2.31).

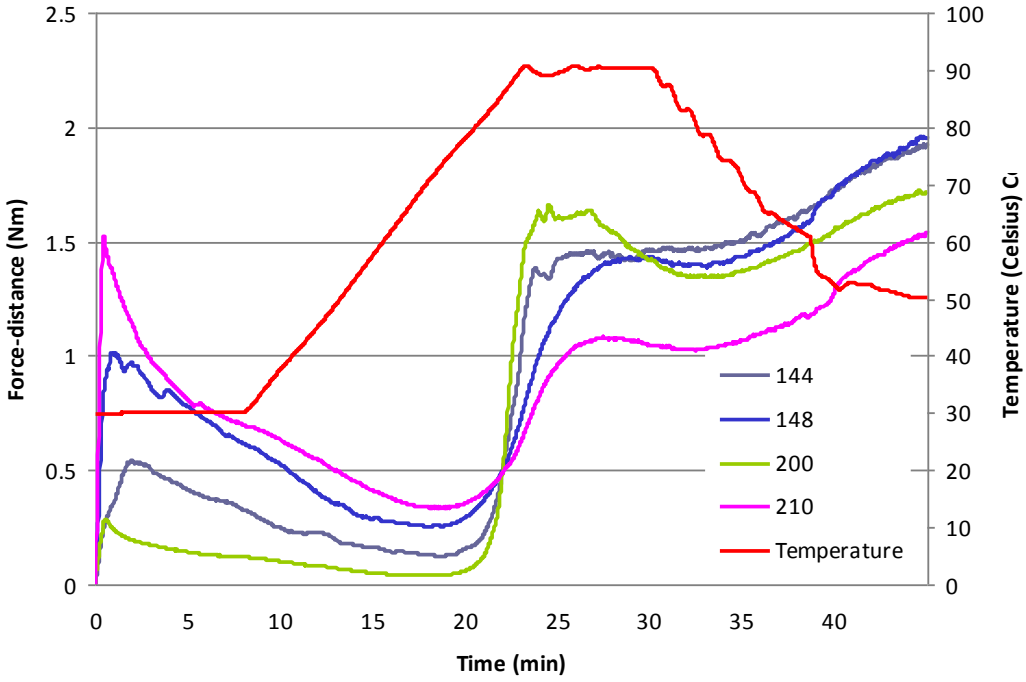

Fig. 2.31 Mixolab characteristics of sorghum flours.

Bread evaluation

In order to evaluate the bread properties, the first step was to standardize the amount of water added to the flour control sample 148 to make batter and then, the Shober procedure was followed(table 2.13 and fig.2.32). The standard viscosity chosen for this study was corresponding at 28000g*sec for the Area F-T. This was provided by 115 mL of water added to 100 g flour (70 g sorghum control sample flour and 30 g potato starch) for achieving the desired viscosity. The remaining sorghum flour samples (144, 200, and 210) had to be optimized for added water in order to reach the batter viscosity of sample 148 (Table 2.14).

Table 2.13. Standardization of amount of water added to sorghum flour to produce batter

Sample	Water added%	Avg. Spec Vol. (cc/g)	SDev
148-F20105	110	2.616	0.038
	115	2.732	0.043
	120	2.823	0.038

Table 2.14. Water added to the different sorghum flours produced and specific volumes of their breads

Diagram	Sample ID	Water Added*	Spec. Volume (cc/g)**
F20105	148	115	2.73 ± 0.043b
Com.	144	99.8	2.80 ± 0.023ab
F20107	200	84.7	2.89 ± 0.065a
F20106	210	122	2.78 ± 0.027b

*%Water added to 70% sorghum flour and 30% potato starch (Schober method for sorghum bread)
*Means within a column followed by different letters are significantly different (P < 0.05, REGWQ test).

In addition to the amount of added water to the different sorghum flours, Table 2.15 shows their corresponding bread specific volume. This showed good progress (based especially on different milling techniques used) (fig2.33 and 2.34) from the previously reported data on this research topic (Frederick, 2009).

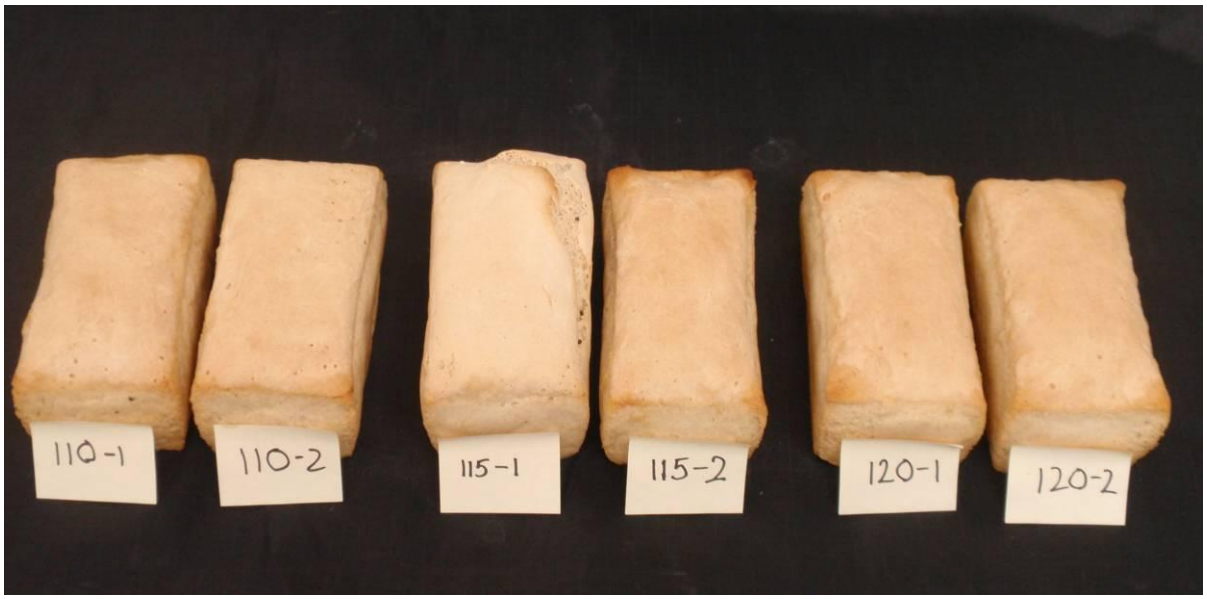

Fig. 2.32 Bread evaluation for water standardization

Fig. 2.33 Sorghum bread evaluation – side view (sample 200; loaf 1)

Fig. 2.34 Sorghum bread evaluation –front end view (sample 200; loaf 1)

2.5 Conclusions

A long reduction system which included Impact detaching techniques produced white sorghum flour with high extraction rate and good quality flour (compared with the existing flour on the market), baking, and bread properties. An Impact dehulling machine and a Prebreak roller mill were effective in preparing the sorghum kernels before first break.

The shattering effect of the fragile sorghum bran was avoided by implementing air separation of bran from endosperm before each Break. A purification system effectively cleaned and sorted the sorghum grits by size.

The Diagrams F20105, F20106, and F20107 can be used successfully in their current form or with small adjustments at the laboratory level for obtaining flour from different sorghum hybrids. These Diagrams also fill a gap in the currently available milling literature. They can be scaled up in the sorghum processing industry.

Chapter 3. Evaluation of sorghum flour with different protein content (short preliminary study)

3.1 Introduction

One of the big challenges in the gluten-free world is to find the right formula for wheat-free sorghum bread (Taylor et al., 2006). A very small amount of research related with the sorghum proteins behavior during breadmaking, compared with other grains, has been done in the past. It was founded that using sourdough to degrade sorghum proteins improved crumb grain of gluten free sorghum breads (Schober et al, 2007). The hypothesis that isolated mill streams with low protein content will produce better sorghum bread is the rationale of developing this short preliminary study.

Unlike wheat flour, high protein content is not a desirable characteristic in sorghum flours. This is due to the difference in the composition of proteins of both wheat and sorghum. Wheat has gluten proteins which provide viscoelastic properties to dough, but these type of proteins are absent in the sorghum kernel.

The sorghum kernel contains kafirins in the endosperm. Kafirins are secreted by the endoplasmic reticulum, and deposited and accumulated in the lumen of the endosperm cells. They form protein bodies which vary in size from 0.1-1 μm. These proteins are mostly composed of hydrophobic amino acids, and glutamic acid. A particular group of Kafirins contains small but significant amounts of the sulfur-containing amino acid, cisteine (El Nour et al, 1998). Because of their composition and chemistry, sorghum endosperm proteins do not

contribute to the creation of viscoelastic dough. There are many differences between wheat gluten and chemical composition of kafirins. This explains the inadequate behavior of sorghum proteins in breadmaking systems. Part of this limitation may be the lack of mobility for kafirins due to encapsulations in protein structures (Bugusu et al, 2001).

However, there is recent evidence on the potential of sorghum proteins for bread making. Hamaker et al (2003) have studied the viscoelastic behavior of maize storage protein as well as extended sorghum protein structures that appear to form during cooking.

3.2 Materials and methods

Five sorghum flours with different protein contents were collected from milling the White food grade sorghum variety Fontanelle 1000 with a Buhler Experimental Mill (MLU-202, Uzwil, Switzerland). The settings adjustments for this equipment were different from the ones used for wheat milling, and have been already detailed in the chapter: Tempering. All flours were blended 30 minutes prior to testing to assure good homogeneity. The sample ID's were: 101, 102, 103, 104, and 105, which correspond to flour collected from the 1BK, 2BK, 1M, 2M, and 3M streams, respectively. The protein content of the samples increases with every additional reduction step (table 3.2).

The tests performed were the same described in the previous chapter. The proximate analysis, flour properties, baking tests, and bread evaluation were done in triplicates for each sample.

The results obtained are displayed in the Tables 3.1-3.7 and in Figure 3.1.

Table 3.1. Proximate analysis of different sorghum flours.

Sample ID	Mean ± SE			
	% Fat (d.b.)*	% Ash (d.b.)*	% Fiber (d.b.)*	% Moisture (w.b.)
101	0.72 ± 0.01 d	0.48 ± 0.01 c	0.32 ± 0.00 ab	14.09 ± 0.01 a
102	1.46 ± 0.02 a	0.58 ± 0.01 a	0.36 ± 0.01 a	13.65 ± 0.01 b
103	1.18 ± 0.02 b	0.53 ± 0.01 b	0.32 ± 0.02 ab	13.45 ± 0.02 c
104	1.09 ± 0.02 c	0.57 ± 0.01 a	0.28 ± 0.01 b	13.02 ± 0.02 d
105	1.08 ± 0.01 c	0.57 ± 0.01 a	0.28 ± 0.02 b	12.92 ± 0.01 e

***Means within a column followed by different letters are significantly different (*P* < 0.05, REGWQ test)**

Table 3.2. Starch damage, protein content and total starch of different sorghum flours

Sample ID	Mean ± SE		
	% Starch Damage*	% Protein (d.b.)	% Total Starch (d.b.)
101	2.28 ± 0.00 e	4.48 ± 0.05 e	77.62 ± 2.14
102	3.60 ± 0.03 d	5.98 ± 0.01 d	84.82 ± 1.50
103	9.16 ± 0.04 c	6.89 ± 0.04 c	82.61 ± 2.11
104	15.13 ± 0.13 b	7.94 ± 0.10 b	82.35 ± 1.39
105	21.74 ± 0.24 a	8.92 ± 0.05 a	83.19 ± 1.11

***Means within a column followed by different letters are significantly different (*P* < 0.05, REGWQ test**

Table 3.3 Color parameters measured on five different sorghum flours

Sample	L- Value*	a-Value*	b-Value*
101	**91.96 ± 0.01a**	**-1.11 ± 0.05ac**	**6.89 ± 0.02d**
102	**90.59 ± 0.04d**	**-1.05 ± 0.06a**	**8.21 ± 0.02b**
103	**91.48 ± 0.01b**	**-1.18 ± 0.03c**	**8.32 ± 0.01a**
104	**91.35 ± 0.03c**	**-1.16 ± 0.03c**	**8.29 ± 0.01a**
105	**91.33 ± 0.01c**	**-1.08 ± 0.03a**	**8.15 ± 0.02c**

***Means within a column followed by different letters are significantly different (*P* < 0.05, REGWQ test)**

The sample 101 had the lowest fat content while the sample 102 had the highest (Table 3.1). The ash content, starch damage, and protein content gradually increased from sample 101 to 105 (Tables 3.1 and 3.2). The sorghum protein doesn't contribute to batter properties. Increasing of damaged starch is a condition which affects negatively the behavior of sorghum batter.

The color analysis for these flours showed acceptable values for all the samples. The L-value was above 90, a very good color for all samples (Table 3.3). The starch damage values ranged from 2.28 (sample 101) to 21.74 (sample 105), and the protein content ranged from 4.48 (sample 101) to 8.92 (sample 105, Table 3.2).

Water standardization

The procedure described in the previous chapter was used to standardize the amount of added water. The batter viscosity selected before for water standardization of previous tested flours was utilized. All these analysis and the baking were done at CGAHR, USDA-ARS, Manhattan, KS. The amount of water added to the 100 g flour mixture (sorghum flour 70% and potato starch 30%) was as low as 86 (sample 101) and as high as 132(sample 105)(Table 3.4)

Table 3.4. Amount of water added to sorghum flours and the specific volumes of their breads.

Sample	Water Added*	Specific Volume (cc/g)**
101	**86**	**2.85 ± 0.029a**
102	**90**	**2.83 ± 0.047a**
103	**98**	**2.91 ± 0.029a**
104	**112**	**2.86 ± 0.032a**
105	**132**	**2.69 ± 0.052b**

* % water added to 70%flour and 30%patato starch (Shober Method - Sorghum Bread)
** Mean ± sdev. Means within a column followed by different letters are significantly different (P < 0.05, REGWQ test).

Baking and bread evaluation

The Schober method presented in chapter 1 was used in baking of these flour samples. The results displayed in Table 3.4 showed a good specific volume for these flours(compared with the Frederick's research/2009). The lowest specific volume (2.69 cc/g) was recorded for the sample 105 (8.92% protein content and 21.74% starch damage). The specific volume of bread from the samples 101, 102, 103, and 104 were not statistically different and ranged between 2.83 and 2.91 cc/g. The starch damage for the flour samples 101, and 102 was relatively low (2.27 and 3.60% respectively), but significant higher for the others. The protein content for the flour samples 101-104 was low (it ranged between 4.48-6.89% db).

The bread crust color was very pale (whitest) at the samples 101 and 102. The L-values for these samples were 82.80 and 80.34, respectively. The crust became more red-colored on the samples while the protein content and the starch damage of the sorghum flour increased (Table 3.2). The a-value for the sample 105 was 2.89 (Table 3.5). This phenomenon can be associated with an insufficient Mallard reaction in the first baked samples (very low starch damage and low protein content).

The crumb evaluation with the C-Cell equipment is reported in Table 3.6. The highest value for slide brightness was observed at sample 104 (162.21). Also an upward trend was noticed in wall thickness (range: 0.44-0.53), and cell diameter (range: 1.96-2.89) during baking of samples 101 to 105. At the same time, a downward trend was observed for number of cells/cm^2 (range: 63.73-49.23).

Table 3.5. Color parameters evaluated for sorghum flour breads crust

Sample ID	Mean ± SE		
	L-Value*	a – Value*	B – Value*
101	82.80 ± 0.29a	0.31 ± 0.11c	21.82 ± 0.38c
102	80.34 ± 0.24a	1.22 ± 0.15b	24.65 ± 0.33b
103	76.57 ± 0.63b	1.11 ± 0.14b	22.28 ± 0.64c
104	73.88 ± 1.53b	0.37± 0.23c	21.69 ± 0.82c
105	67.90 ± 0.97c	2.89 ± 0.23a	28.72 ± 0.59a

*Means within a column followed by different letters are significantly different (P < 0.05, REGWQ test).

Table 3.6. C-Cell bread evaluation factors for the different sorghum flours.

Sample ID	Mean ± SE				
	Slice Brightness*	Cells /cm^2*	Wall Thickness / mm*	Cell Diameter / mm*	Cell Volume*
101	154.27 ± 0.55b	63.73 ± 0.84a	0.44 ± 0.002d	1.96 ± 0.04d	6.14 ± 0.15d
102	153.79 ± 0.26b	59.84 ± 0.44b	0.45 ± 0.002d	1.87 ± 0.02d	6.01 ± 0.10d
103	154.74 ± 0.67b	56.56 ± 0.67c	0.48 ± 0.002c	2.12 ± 0.03c	7.00 ± 0.14c
104	162.21 ± 0.98a	54.67 ± 0.85c	0.49 ± 0.00b	2.40 ± 0.05b	7.91 ± 0.19b
105	153.29 ± 0.54b	49.23 ± 0.61d	0.53 ± 0.003a	2.89 ± 0.05a	10.11 ± 0.23a

*Means within a column followed by different letters are significantly different (P < 0.05, REGWQ test).

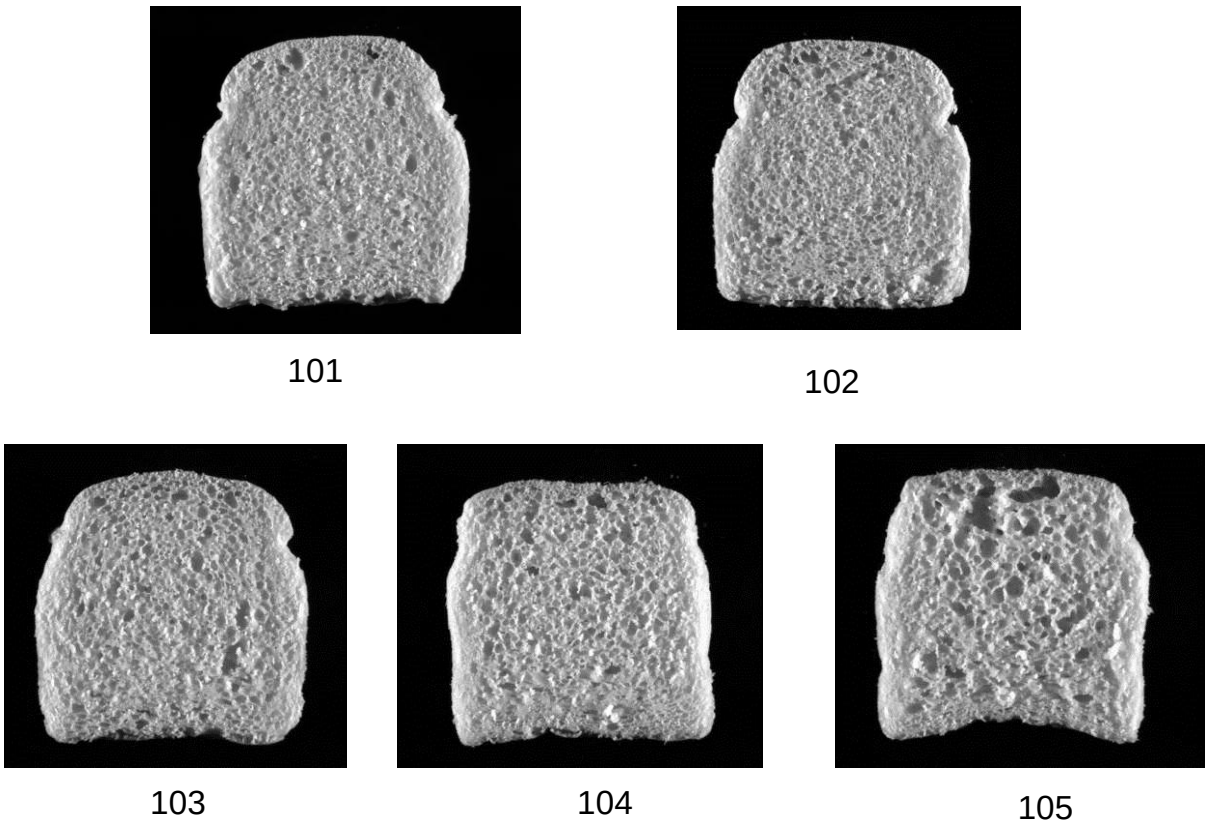

Fig. 3.1 Crumb appearance of the bread made with the different sorghum flours.

3.3 Results and Discussion

A Pearson correlation coefficient matrix between the flour, baking and bread properties is shown in Table 3.7.

Table 3.7 Effect of sorghum flour parameters on bread characteristics (sample 101-105)

Parameters correlation			Bread Characterization									
			Specific Volume	Water addition	Slice Bright.	Cells / cm^2	Wall thickness	Cell diameter	Cell volume	Crumb Color		
										L-value	a-value	b-value
Flour Param.	Starch Damage		-0.592	0.989	0.228	-0.919	0.977	0.956	0.959	-0.926	0.595	0.506
			0.020	<.0001	0.414	<.0001	<.0001	<.0001	<.0001	<.0001	0.019	0.054
	Protein		-0.494	0.939	0.268	-0.941	0.931	0.860	0.877	-0.919	0.620	0.520
			0.061	<.0001	0.335	<.0001	<.0001	<.0001	<.0001	<.0001	0.014	0.047
	Crude Fat		-0.034	0.038	-0.042	-0.226	0.020	-0.109	-0.058	-0.157	0.308	0.269
			0.905	0.893	0.882	0.418	0.944	0.700	0.837	0.575	0.264	0.332
	Ash		-0.424	0.563	0.246	-0.603	0.511	0.453	0.477	-0.569	0.443	0.422
			0.116	0.029	0.377	0.017	0.052	0.090	0.072	0.027	0.098	0.117
	Total Starch		-0.386	0.342	-0.007	-0.550	0.359	0.297	0.333	-0.404	0.424	0.397
			0.155	0.212	0.980	0.034	0.189	0.282	0.225	0.135	0.116	0.143
	Particle size		0.602	-0.941	-0.185	0.939	-0.916	-0.863	-0.884	0.921	-0.678	-0.604
			0.018	<.0001	0.509	<.0001	<.0001	<.0001	<.0001	<.0001	0.006	0.017
	Color	L-value	0.166	-0.047	0.071	0.191	0.018	0.094	0.050	0.120	-0.319	-0.366
			0.555	0.867	0.802	0.496	0.950	0.739	0.860	0.671	0.247	0.180
		a-value	-0.648	0.011	-0.467	0.057	-0.101	-0.019	0.010	-0.015	0.381	0.502
			0.009	0.968	0.079	0.841	0.720	0.947	0.972	0.957	0.161	0.056
		b-value	-0.061	0.473	0.250	-0.640	0.494	0.334	0.371	-0.567	0.389	0.270
			0.830	0.075	0.368	0.010	0.061	0.223	0.174	0.028	0.152	0.331

correlation between parameters strong correlation between parameters

The protein content in the flour was found strongly positive correlated with the amount of added water to batter (to reach the standardized viscosity), wall thickness, cell diameter, and cell volume ($\rho>0.85$; $P<0.0001$), and strongly negative correlated with the number of cells/cm^2 and L-value of the bread crust ($-0.95>\rho>-0.91$; $P<0.0001$). It was also correlated

with the a-value and b-value of the bread crust (ρ=0.620, P< 0.014 and ρ=0.520, P< 0.047, respectively).

A strong positive correlation was found between starch damage in the flour and added water to batter (to reach the standardized viscosity), wall thickness, cell diameter, and cell volume (ρ >0.9; P<0.0001). On the other hand, a strong negative correlation was found between the amount of starch damage in the flour and number of cells/cm^2, and L-value of the bread crust (-0.93>ρ>-0.90; P< 0.0001). Also, a negative correlation was observed between starch damage in the flour and specific volume of the bread (ρ=-0.592; P< 0.02), and a positive correlation between starch damage and a-value of bread crust (ρ=0.595; P< 0.02).

The particle size of the flour was strongly negative correlated with the amount of water added to the batter, cell wall thickness, cell diameter and cell volume (-0.95>ρ>-0.86; P<0.0001). A positive strong correlation was found between particle size and crust L-value and number of cells/cm^2 of the bread (ρ>0.92; P<0.0001). Also, the particle size of the flour was weakly correlated with specific volume of the bread (ρ=0.60, P<0.018) and bread crust a- and b-value (ρ=-0.678, P<0.006; ρ=-0.604, P<0.017, respectively).

Other correlations (not strong) between flour and bread properties are displayed in the Table 2.24. No correlation was found between crude fat content and L-value of flour and bread. Also, the slice brightness was not correlated with any of the flour properties investigated in this study.

3.4 Conclusion

It was found in this preliminary research that sorghum flour protein, starch damage and particle size, are strong correlated with some parameters of gluten-free bread (water added to the batter, cell wall thickness, cell diameter, cell volume, crust L-value, number of cells/cm^2).This research points out that not only the starch damage and particle size of sorghum flours may affect strongly the bread characteristics.

The protein content of sorghum flour may also be very important in gluten-free breadmaking and other prospective need to be evaluated in future research. Also the work for developing new productive sorghum hybrids (with a higher balance between floury and glassy endosperm), need to be in trend with their milling and breadmaking performances. The differences in bread quality from this preliminary experiment had shown that the milling procedures can be used to manipulate the composition of the flour and impact bread quality.

3.5 Literature cited

Bugusu, B.A., Campanella, O., Hamaker, B.R. 2001. Improvement of sorghum-wheat composite dough rheological properties and breadmaking quality through zein addition. Cereal Chemistry 78:31-35

El Nour, I.N.A., Peruffo, A.D., Curioni, A. 1998. Characterization of sorghum kafirins in relation to their cross-linking behavior. Journal of cereal science 28(2): 197-207.

Hamaker, B. R., and Bugusu, B.A.. 2003. Overview: Sorghum proteins and food quality. In: Proc. AFRIPRO Workshop on the Proteins of Sorghum and Millets: Enhancing Nutritional and Functional Properties for Africa. P. S. Belton and J. R. N. Taylor, eds. Pretoria, South Africa. Available at http://www.afripro.org.uk/papers/Paper08Hamaker.pdf..

Oria, M.; Hamaker, B.; Shull, J. 1995. Resistance of sorghum α, β, and γ-Kafirins to pepsin digestion. J. Agric. Food Chem. 43:2148-2153.

Schober, T.J., Bean, S., Boyle, D.L. 2007. Gluten-free sorghum bread improved by sourdough fermentation: Biochemical, rheological and microstructural background. Journal of Agricultural and Food Chemistry. 55:5137-5146.

Taylor, J.R., Schober, T.J., Bean, S. 2006. Novel and non-food uses for sorghum and millets. Journal of Cereal Science. 44(3):252-271.

Chapter 4 Future work

These are some suggestions that have been made for future research work:

Flow diagram development:

- Adapted filtration/separation equipment (filter/ separation cyclone) can be attached to the Impact mill in Diagram F20105 in order to improve sorghum flour yield and quality. This would reduce the loss of fine fraction resulted after the action of the impact detacher equipment on flattened sorghum endosperm.

- Rapid screening for starch damage and crude fat on the flour streams are necessary to make faster progress the development and improvement of diagrams. The enzymatic and wet chemistry methods used in this study to measure these two parameters were lengthy, and this slowed the diagram development process.

- Different setting adjustments can be implemented in the reduction rolls and a purifier can be added to the Diagram F20106 in order to improve sorghum flour yield and quality.

- Higher levels of decortication can be tested in the flow diagram F20107. The maximum level tried was 12% in this research work. The following levels can be tested: 16, 18 and 20% in order to separate more germ and bran from the endosperm. The resulting flours streams would need to be analyzed for ash and fat content, which are proxy for bran, and germ contamination, respectively.

- The lack of quality standards for sorghum flour among processors and end users makes it difficult for millers to set appropriate milling goals. There is need for specific quality requirements for sorghum flour that would be processed into bread, cake mixes, muffins, pancakes, and other products.

Sorghum breadmaking:

- The optimum protein content in sorghum flour which would yield good quality bread is still to be determined. An experiment can be designed where % starch damage and particle size remain constant but protein content is varied. This can be achieved by adding protein isolate to a flour stream with known % starch damage and particle size. Alternatively, different sorghum types containing different levels of protein content can be used. These can be milled with the same equipment to cause the similar levels of starch damage.

- Sorghum bran can be used to increase the nutritional and health benefits of sorghum/wheat breads. Sorghum bran has high levels of antioxidants which would help market these breads. Two approaches can be taken to develop these formulas: either using whole sorghum flour or addition of sorghum bran to flour mixes.