WHOLE WHEAT FLOUR MILLING: EFFECTS OF VARIETY AND PARTICLE SIZE

by

JUSTIN B. TURNER

B.S., Kansas State University, 2003

A REPORT

Submitted in partial fulfillment of the requirements for the degree

MASTER OF SCIENCE

Food Science

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2012

Approved by:
Major Professor
Dr. Fadi Aramouni

Abstract

Nutrition from whole grains has become an integral part of a healthy diet. Consumers are focused on adding fiber and whole grains to be healthy and want the benefits of whole grain with the taste and appearance of refined flour. A review of current commercial whole wheat flour in the marketplace indicated many options for food processors to use. However, many of these options required processing changes and added ingredients to provide the consumer with a quality product. A milling and baking study was done to compare commercially and experimentally milled whole wheat flours from both white and red wheat varieties. Both white and red wheat varieties were kept identity preserved. Experimental milling was done with a hammer mill and a roll stand to closely replicate the commercial milling process. Baking was done using a sponge and dough method to closely replicate commercial baking conditions. The results showed both particle size and wheat variety impact bake performance of whole wheat flour. The most significant impact appeared to be dependent on the variety of wheat being milled. The milling process also had an impact. As particle size decreased, bake functionality improved. However, some decreased functionality was seen when particle size became very fine. It was concluded that additional work on a commercial flour mill needed to be done to determine if an optimal particle size for milling whole wheat flour exists. Experimental milling equipment was not adequate enough to replicate particle size distributions of commercial whole wheat mills.

Keywords: **Whole Wheat, Nutrition, Particle Size, Milling, Baking**

Table of Contents

List of Figures

List of Tables

Acknowledgements

I would like to acknowledge all of my friends and family for their continuing encouragement to complete this process. Without their understanding and support, it would not have been possible. Thanks to all for your support.

Dedication

I would like to dedicate this work to my family. Without their support, the long weekends, late nights, and large amounts of work would have been very challenging to handle. I cannot thank them enough

Chapter 1 - Literature Review

Introduction

Current literature on whole wheat is scarce on the milling process of whole wheat, process improvements, and baking quality studies. However, some general work has been done around support areas of this topic. Three general areas of research have been identified: whole grain nutrition and its importance in today's dietary guidelines, baking with fiber and whole grain components, and certain technical aspects of adding fiber into the consumer diet to improve nutrition. These areas support the general knowledge and understanding of milling, nutrition, and baking with fiber products. However, they do not focus directly on how whole wheat flour is milled today, whole wheat particle size and impact on baking quality, and viable solutions to improve whole wheat flour functionality.

By focusing on more specific research on whole-wheat flour milling and whole-grain baking, it is believed that this additional information would provide direction for the wheat milling industry, wheat breeding industry, and baking industry to provide a line of products that would meet the demand for increased fiber in today's consumer diet. A product line that would not diminish baking functionality and still deliver whole wheat nutrition with the functionality of white flour would benefit both the manufacturer and consumer. This, along with a decreased manufacturing cost would potentially make this product more affordable and provide consumers with a lower costing whole grain alternative.

Impacts and Attributes of Milling Techniques

An area of milling that is often overlooked is the different types of mills available to reduce particle size and create unique and differentiated products. The technical manual "Wheat

Flour Milling", Posner and Hibbs (2005), provided a good overview of the grinding process and the machinery involved. The grinding process is the most important step in milling. The way that the kernel is broken impacts the remainder of the grinding and reduction processes. The amount of energy used to break apart the kernel and reduce particle size in conventional flour milling is 50% of the power used in the milling process. The four main forces used in grinding are compression, shear, friction/abrasion, and impact (Posner and Hibbs, 2005).

The stone mill is one of the original mills used for grinding wheat, uses a combination of compression, shear, and abrasion. The grinding action occurs between two stones. The material is fed into the center of the top stone, which is fixed and does not rotate. The bottom stone is driven by a drive mechanism. The grinding gap between the stones is adjusted with a hand adjustment that raises and lowers the stone. The raw wheat material is then ground between the stationary and moving stone and the material is pushed radially to the circumference by grooves and furrows cut into the face of the stone. The ground material is discharged by the rotation motion and is conveyed out by the furrows (Posner and Hibbs, 2005).

The roller mill is the principle grinding machine in a commercial wheat flour mill because of its range of selective grinding and ease of operation. Particles are subject to shear and compression forces, caused by corrugations on the roll surfaces and pressure exerted by the rolls while pulling particles towards the grinding area. The amount of stress applied to the particles during roller milling may be adjusted according to grinding conditions. The rate and uniformity of the flow of stock to the rolls, roll velocities, ratio of speed known as differential, gaps between rolls, and condition of the roll surface impact the type of stress applied.

The hammer mill is a type of impact mill that is most often used as a machine to break flakes and fracture the endosperm, supplementing the roller mill action before sifting. The hammer mill consists of a number of hammers spaced evenly on a rotating rotor. The hammer-rotor chamber is enclosed within a half circle, perforated cylindrical screen, the size of the perforations being dictated by the desired product size. The material enters the top and is reduced in size mostly by impact between the hammers and the wall. It is forced through the perforated screen by hammers, creating heat and friction. This causes the product to be heated up and to lose moisture (Posner and Hibbs, 2005).

Another unique processing step in milling that is being reviewed in today's milling process is wheat pearling. The wheat pearling article by Mousia and others (2003) reviews how removing the outer layer of bran helps with microbial counts and changes particle size of the flour. There may be an optimum to pearling, grinding, and reconstituting back in the pearled wheat bran after hammer milling to control excessive starch damage or to keep granulation more consistent. Pearling also impacts the way wheat kernels are milled, how they shatter differently, and how bran has a negative impact on shelf-life, volume and bake functionality of flour. Heat treatment or stabilization of the bran and germ products may enhance both microbial count reduction and shelf-life stability of these products (Mousia and others, 2003).

Dziski (2008) reviewed methods to reduce energy required for the milling process and a way to improve final product particle size. As the hardness level increases, energy required to mill increases. As the hardness level decreases, energy required for processing decreases. Dry kernels are easier to grind and need less energy. When milling flour, soft wheat has a larger distribution of smaller particles than hard wheat. Dziski (2008) concluded that crushing the kernels before the hammer mill process may decrease the energy needed and change particle size distribution of the final flour. A sieve analysis of their study showed that crushing kernels before grinding had a large influence on particle size distribution on softer wheat. Average particle size of ground material from crushed softer wheat was always lower than the whole kernel grind. When a hammer mill was used, fineness depended on the screen size used. Kernel moisture also had a significant influence. Specific grinding energy was most influenced by crushing before grinding and the moisture content of the kernels. Crushing of kernels compared to impact grinding resulted in less energy being used. However, the degree of fineness or finer particles produced also was lower (Dziski, 2008).

Another common question is how the combination of farming practices and milling technique impacts the performance of whole wheat flour. Kihlberg and others (2004) focused on whole wheat bread and influence of farming, milling, and baking. The study reviewed six samples, all Kosack variety. Three of the samples were grown organically and three grown with conventional methods (Kihlberg and others, 2004). All six wheat samples were each roller-milled, stone-milled, and baked using two different mix times for the bread baking test.

The results showed that conventional versus organic farming contributed to differences as well as the location and variety of the wheat that was grown. Kihlberg and others (2004) examined whether organic or non-organic wheat bakes better bread, showing evidence that samples from organic wheat baked with higher variability than non-organic samples. The discussion justified that final loaf volume is not the only criterion for acceptance.

Not many studies have been done around product quality of organic versus non-organic whole wheat bread. Kihlberg and others (2004) explored this issue by performing both a milling and baking examination of both organic and non-organic Kosack variety samples. Roller milling and stone milling methods were compared to each other for baking functionality as well. Samples were milled, baked, and a sensory analysis was conducted with trained descriptive sensory analysis panel, using hard red winter wheat varieties. For milling, all wheat was tempered to 16% moisture and milled at 100% extraction. For baking, the study had two flour levels for each variable, and two mix times each. The samples were baked in a no-time dough process. The product was baked, immediately frozen, and then evaluated ten days after the bake. The bread was reviewed by a sensory panel, and image analysis was done for review of crumb grain structures (Kihlberg and others, 2004).

Results showed that milling process had the greatest impact on sensory quality over farming technique, mixing, and flour addition. Roller milled wheat had a preferable taste to stone milled samples, with attributes of a higher cereal aroma, roasted notes, crispier crust, and a less sweet flavor. The roller milled samples had higher levels of damaged starch, approximately 7% compared to 3% from stone milled samples (Kihlberg and others, 2004). Also, roller milled samples had approximately 4% higher farinograph absorption levels than stone milled samples. Mixing characteristics were different between roller milled and stone milled samples. Samples that were roller milled showed an improvement with increased mixing tolerance from bake results (Kihlberg and others, 2004). The stone milled samples showed a decrease in performance and final product volumes.

The organic wheat had 0.2% higher ash and slightly lower test weights than the conventional wheat. Damaged starch levels increased by approximately 1% (Kihlberg and others, 2004). Enzyme activity increased with roller milled product. Organic wheat showed larger variations in results than conventional grain varieties (Kihlberg and others, 2004).

One often overlooked aspect of the milling process is the hardness value of the wheat being processed. Osborne and others (2007) reviewed Single Kernel Characterization System (SKCS) analysis on milling potential. This value is used as a quick and efficient way to determine grain rheology in wheat development. These values will impact mill quality performance, how wheat is purchased, how it mills, and the difference between hard and soft wheat. The research showed that the SKCS machine can provide information on wheat varieties in breeding programs without the extensive method of dissection and isolation of bran and germ tissues and provide results to predict commercial milling quality (Osborne and others, 2007).

One of the more popular types of whole wheat flour in the marketplace today is an ultra-fine whole wheat. Hemery and others (2011) conducted a study focused on ultra fine grinding and the milling process and how it impacts nutritive value. Bran has value in terms of its health benefits related to fiber. This fraction represents 15% of the byproduct of wheat flour milling.

Recent studies show that particle size reduction of those fibers can change their functionality from insoluble to soluble fiber types. In studies using hamsters, this reduced the concentration of blood cholesterol, triglycerides, and lipids (Hemery and others, 2011). It is believed that decreasing bran particle size improves digestibility of products and improves the solubility of compounds such as B vitamins and ferulic acid for humans (Hemery and others, 2011).

Hemery and others (2011) also reviewed grinding temperature and how it impacts the granulation of bran produced. Temperatures reviewed were from ambient (25 °C) to cryogenic freezing (-46 °C), showing how grinding characteristics change, and how to make a more finely ground product. For the bran grinding study, two varieties were used, Crousty and Tiger hard red winter varieties. The cryogenic freezing grind created finer particles after two minutes of grinding, however, between two and eight minutes, grind didn’t change particle size significantly (+15%). Grinding at an ambient temperature showed a gradual and continual particle size reduction. Ambient grinding produced particle size distributions with more ultrafine particles

(+16%) and more coarse particles (+18%) than products ground in cryogenic temperatures (Hemery and others, 2011).

Another trial within this study was done to do ultra-fine grinding at both ambient (25 °C) and cryogenic (-46 °C) temperatures. Several grinding steps were done in succession at ambient temperature. The biochemical composition of the bran samples was not found to be significantly changed, except for a noted reduction in amounts of folates and phytic acid. It is possible that some of these compounds were destroyed due to the increased heat present from increased grinding and some were lost in the grinding device. The same process was repeated at the cryogenically cooled temperature (-46 °C). The results show that this cooled grind allowed for finer average particle size with less energy required to process. Also, the cooler temperature may help preserve heat-sensitive compounds such as vitamin E, and B in the process. A finer grind with more available surface area may make these compounds more bio-available and digestible for improved health benefits (Hemery and others, 2011).

Fiber and Whole Grain Baking

There is limited information on whole wheat baking and whole grain products. When the search was widened to include baking with whole-grain components and with soluble and insoluble ingredients, much more information became available. The challenges of baking with fiber and whole grain ingredients are very similar to whole wheat baking.

Shah and others (2006) focused on xylanase enzyme addition to bread for whole wheat baking. This ingredient may be used as a processing aid to enhance whole wheat baking properties as consumer diets evolve and shift to an increase in whole grain consumption. Making these breads is more difficult than standard white pan breads.

The xylanase enzymes create sugars from pentosans to improve fermentation processes in whole wheat breads. This enhances gas production and improves oven spring, loaf volume, shelf life, and crumb structure. It is important to select the correct type of xylanase from isolates that are considered GRAS (Generally Regarded As Safe) (Shaw and others, 2006).

Shaw and others (2006) performed a whole wheat bread bake with 72% absorption on the control sample with no enzyme. With the addition of enzyme, water absorption was reduced by 8%, to 64% in the dough system. A straight dough process with 45 min of fermentation and 45 min of proofing was used. Bread was evaluated for volume, final moisture, and a 100 point sensory evaluation. Bread crumb texture profile was also completed with the control and enzyme added samples. From a commercial baking perspective, this would be a problem and unwanted by commercial bakers. A decrease in dough water absorption would add costs to overall ingredient usage levels of all dry ingredients and added enzyme usage.

In dough mixing, an 8% reduction in absorption was needed when the enzyme was added. More free water was created in the bake process with the enzyme, allowing for improved gluten hydration and better and final volumes, improving from 300 ml for the control sample to 460 ml for the sample containing xylanase enzyme. The final product moisture of the control bread was 32.3% compared to 40.5% moisture of the test sample (Shah and others, 2006). It should be noted that the legal requirement for bread by the Food and Drug Administration is 38% (FDA, 2011a).

Results of sensory testing showed that the bread with added enzyme was favored in all categories of volume, crumb color, texture, grain, appearance, and flavor. The total score from sensory testing was a mean score of 42.6 out of 100 for the control sample, compared to a mean score of 74.4 out of 100 for the sample supplemented with xylanase. The texture profile showed a decrease in crumb firmness, less gumminess, and slightly chewy texture with the enzyme added. The background of the sensory panel was unknown and the level of training was not identified (Shah and others, 2006).

Tait and Galliard (1988) focused on the components of whole wheat flour and their independent and dependent activity on shelf life and functionality over time. The study concluded that lipase activity in whole wheat flour, while in storage, has a negative impact on baking performance. The decreased shelf-life of whole wheat flour is present because of lipid metabolizing enzymes present in the germ and bran. The researchers tried to correlate changes in lipid composition to effects of storage on baking performance. One of the suggested solutions was to develop a test that would easily measure bran lipase activity to give the expected shelf-life of whole wheat flour (Tait and Galliard, 1988).

In the study (Tait and Galliard, 1988) bread was baked from whole wheat flour samples and stored over an eight week period at ambient temperature to determine bake performance over time. Whole meal variable-A in the bake test had a higher lipase activity, resulting in more volume decrease over time, 526 ml after storage. Whole meal variable-B in the bake test had a lower lipase activity, resulting in less volume decrease over time, 146 ml after storage. A very lean baking formula was used to test these samples with no emulsifiers present.

Another series of bake tests were conducted by adding fatty acids, oleic, palmitic, and linoleic acids directly to the freshly milled whole wheat flour. Oleic and linoleic acids added to the freshly milled flour decreased bread volumes. The control sample volume was 1369 ml, compared to 1155 ml volume with the addition of palmitic and linoleic acids (Tait and Galliard, 1988). The addition of palmitic acid showed no change on baked volume.

Another similar study was completed by Barnes and Lowy (1986) to understand which of the components of whole wheat flour: germ, bran, or endosperm, was the most responsible for decreased volume in bread baked from whole wheat flour. Flour was milled and each of the three components of the whole wheat milling process gathered separately. One sample was blended all back together to whole wheat flour, in the proper ratios, and stored at both 20ºC and -20ºC. The rest of the components were stored at the same temperatures over a 27-week period.

The results of this study were unique and different from the previous study. The separated germ, when added back into the whole wheat flour caused no decrease in volume. Flour and bran mixtures showed a 5% decrease in loaf volume over time, but not significant changes. When the bake results were compared to the pre-blended whole wheat flour, the pre-blended flours showed a significant volume loss of 10% over the same storage period (Barnes and Lowy, 1986). From this, it could be concluded that a small level of interaction happens in the bread making procedure. A much larger interaction occurs during storage if all three flour components are combined together. When all three components were combined together, volume loss of 27% was recorded. This had a much larger impact on bake quality than any of the other variables reviewed (Barnes and Lowy, 1986).

Noort and others (2010) focused on the particle size of wheat bran and its impact on bread baking quality. There are contrasting views of how bran particle size impacts bake quality of flour. Some current industry practices used to counteract bran addition include soaking of bran, fermentation, and the addition of vital wheat gluten. Theories such as dilution of gluten, hindrance of the gluten network with bran particles, and enzymes released with reducing properties in whole wheat bread are some common beliefs about how baking quality is reduced in whole wheat flour. Other theories addressing physical changes, water binding ability of whole wheat flour, and gluten agglomeration properties changing with the presence of ferulic acid were discussed (Noort and others, 2010).

Noort and others (2010) reviewed two bran fractions, wheat bran and aleurone. Measurements done on these fractions included particle size, chemical analysis, water binding ability, gluten yield, and farinograph or dough rheology results. Bread bake testing was completed. However, target absorptions used in the bake process were based on farinograph absorption values. A straight dough process with very short fermentation time of 15 min was used.

The baking results showed some unique findings that do not support the previous theories discussed. The addition of the coarse wheat bran had a small impact on loaf volume (-2%), indicating that gluten dilution is a minor factor in baking performance. Noort and others (2010) concluded that fiber particles piercing gas cells to be an unlikely hypothesis. Their results showed that gluten re-aggregation is impacted by the fiber fraction and a better explanation for lower stability of gas cells in the gluten network. As the particle size of the bran added decreased, the bake volumes also decreased, suggesting that there are negative effects related to the increased surface area of the bran being added back into the formula ($\mathrm{p} = 0.004$). The negative influence of smaller bran size may also be due to the aleurone cells being broken and releasing compounds such as enzymes and glutathione, negatively reacting with the gluten proteins. The conclusion was that finer particle size created a greater surface area and more gluten interaction with enzymes and fibers. This created a stiffer and less extensible gluten network that decreased final loaf volume by 15% (Noort and others, 2010).

Ozboy and Koksel (1997) reviewed the impact of coarse wheat bran on baking. Very little is known about differences between bran from various wheat varieties and how it impacts baking performance. They reviewed two Turkish wheat varieties: Bezostaya, a hard red winter variety, 13.4% protein; and Gerek, a soft white wheat variety, 11.4% protein.

Both varieties were milled, and each was added to a bread dough formula at 5, 10, and 15% based on flour weight. In addition, vital wheat gluten was added to the formula at 3, 6, and 9% to compensate for the increased fiber addition. The samples were baked using a lean straight dough process with potassium bromate added at 50 ppm as an oxiding agent. The water absorption used was based off of a farinograph target.

The results of the study were different than expected. The addition of Gerek coarse bran was seen to strengthen the curve of the farinograph at all gluten and bran addition levels. The Gerek coarse bran improved function in Gerek flour. The impact of adding Gerek coarse bran was studied again using a stronger flour. The results showed a slight increase at 5 and 10% addition (Ozboy and Koksel, 1997).

All types of bran added to the different dough showed a decrease in volume of bread baked. Because the flour tested was from two different varieties, there were two volume potentials. Bread volume results were normalized as a result. Ozboy and Koksel (1997) concluded that bran addition of Gerek had positive dough rheology impact based on farinograph results, increasing development times from 4 min with no bran added, up to 10 min with 15% bran added.

Also, the Gerek wheat bran had a smaller impact on bake performance when compared to the Bezostaya variety. The Gerek variety had a 6% higher normalized volume than the Bezostaya when added at levels of 15% to the bread formula (Ozboy and Koksel, 1997). More varieties like Gerek could be used as a fiber source to be added back into fiber breads. The conclusion from the study was based only on the farinograph numbers and less on the baking performance so it is difficult to relate the results to actual baking performance (Ozboy and Koksel, 1997).

Kock and others (1999) reviewed the heat treatment and particle size of different bran types in whole grain bread. This study looked at three bran particle sizes from ten wheat varieties. All of the tests were run with a single base flour of 14% protein. The bran particle sizes tested were >0.75 mm, <1.8 mm, and >1.8 mm. The bran addition levels were 9, 12, and 15% based on flour weight. The objective was to prove the concept that the enzymes present in bran and glutathione present were the main causes of volume reduction when bran is added to wheat flour for commercial bread baking.

To test this, samples were run with both heat-treated and untreated bran from all of the varieties tested. The results showed that heat-treated bran did significantly improve bake performance. Not all 10 varieties of wheat bran performed equally. This would suggest that some physical attribute difference between the wheat varieties impacted performance (Kock and others, 1999).

The testing showed that without heat treatment, coarser bran particles actually performed better and showed a smaller bake volume reduction (92% of control volume with a mean projection size of 3.2 mm) than the smaller bran particles (90% of control volume with a mean projection size of 0.6 mm). However, when heat-treated, bran with a finer particle size (92% of control volume with a mean projection of 0.6 mm) had similar results in loaf volume than coarser bran (92% of control volume with a mean projection of 3.2 mm) (Kock and others, 1999).

From the results, it was concluded that heat treatment improves baking quality of wheat bran by reducing enzyme function. Some of the reduction in bake performance is related to physical properties of the wheat bran related to its origin variety. Heat treatment of finely ground wheat bran (mean projection of 0.6 mm) showed a greater improvement than on coarse bran (mean projection of 3.2 mm). The optimal bran to use for fiber addition to multigrain breads would then be untreated coarse bran, or finely ground, heat-treated bran (Kock and others, 1999).

Some studies focused less on final baking properties and more on rheological tools to predict quality of functionality and baking. Penella and Haros (2008) reviewed the impact of wheat bran and enzyme addition on dough rheological properties by performing analysis on the farinograph and rheofermentometer. There was a brief discussion around baking performance, however, most of the study focused on dough rheology as a key performance indicator of bread baking functionality.

The farinograph test was used to measure dough rheology and was modified to take into account that whole grain dough requires a stiffer dough and higher viscosity to make bread. The target farinograph torque was 700 BU's, 200 BU's higher than the standard farinograph test method used by the American Association of Cereal Chemists. The rheofermentometer was used to measure fermentation rate and dough gas retention ability. The findings showed that the percentage of bran addition and particle size of the bran impacted farinograph properties (Penella and Haros, 2008). Enzyme addition impacted water absorption and decreased the tolerance for the dough to be over mixed. The addition of bran and smaller particle size impacted farinograph water absorption by up to 5%. In contrast, addition of fungal phytase or fungal amylase to the dough decreased farinograph water absorption between 2-8%. As bran size increased, dough development time was longer and it was slower to hydrate.

Dough with smaller bran particle size was less tolerant to mixing, as stability times decreased and mixing tolerance index values, or torque measured 5 min after the peak, was lower. The fine bran particles possibly have more impact on the gluten network. It was discovered that the addition of fungal amylase also created lower tolerances to over-mixing and may not be a good bread improver for fiber and whole wheat dough systems, based on rheofermentometer results. Parameters related to gassing power did not appear to be impacted by bran percentage, bran particle size, or added fungal phytase enzyme. Alpha amylase enzyme was the only independent factor that impacted the amount of CO_2 produced. These results were taken from the rheofermentometer and not verified by a bread baking procedure (Penella and Haros, 2008)

While the usage of whole wheat and whole grains has grown in making high fiber products, another new source for fiber addition is the usage of soluble fiber and alternative fiber sources. Wang and others (2002) focused on the addition of different fiber sources to bread. It expanded the focus outside of whole grains and reviewed many different soluble and insoluble fiber sources and how they impacted final bread quality. The use of sensory panel determined what products and fiber sources were tested to be acceptable.

Wang and others (2002) reviewed results using dough rheology information from a farinograph and viscoelastic properties from the alveograph. Also, dough fermentation properties were measured using the rheofermentometer. They showed that fiber addition increased water absorption, with pea and carob fiber showing similar changes to wheat bran. The results of this study were also unique, as it was concluded that fiber addition had no impact on dough development times, or mixing stabilities (Wang and others, 2002). However, the alveograph results showed a decrease in elasticity as fiber was added. The rheofermentometer results agreed with the findings that proofing and fermentation rates were hindered with added fiber. All of the fibers tested showed consistent results, except for the soluble fiber, inulin. It showed opposite impacts on farinograph properties and extensibilities of dough.

Wang and others (2002) concluded that the usage of other fiber sources instead of wheat bran may have a lesser effect on dough rheology. The bread produced from carob fiber and pea fiber produced a softer crumb texture than when made with wheat bran. Texture Profile Analysis from sensory testing indicated lower scores for the parameters of hardness and chewiness (Wang and others, 2002).

Another similar study was completed by Peressini and Sensidoni (2009). They reviewed the impact of soluble dietary fiber sources in dough rheology and bread making properties of fiber enriched breads. The source of soluble dietary fiber used was inulin. Two types of inulin were used with two degrees of polymerization, DP=10, labeled Inulin ST, and DP=23, labeled Inulin HP. Dough rheology was measured using a farinograph. Dough expansion and fermentation were measured using a rheofermentometer. A sensory evaluation was performed on the baked samples, and bread volumes, moisture, crumb firmness, and color were measured.

The farinograph results showed that water absorption decreased with both types of inulin addition. The control sample had a farinograph water absorption of 54.2%, compared to Inulin ST at 44.5% absorption, and Inulin HP at 51.4% absorption (Peressini and Sensidoni, 2009). Stability and development times increased which indicated that it is possible to replace some of the white flour in a bread formula while maintaining machining tolerances. The water absorption was believed to decrease due to lower molecular weight sugars present in inulin that may reduce dough consistency. During fermentation, dough expansion rate gradually decreased with higher levels of inulin and this decreased the amount of gas retention during proofing (Peressini and Sensidoni, 2009).

Inulin added at above 5% flour replacement resulted in unacceptable sensory scores because the bread tasted too sweet. The inulin source with the lower degree of polymerization performed much better than the higher DP, however, too high of an addition level increased crumb firmness and made the final bread product feel stale according to the sensory feedback. This was possibly the result of the large decrease in water absorption required in the formula to make the product machineable, a 10% decrease from control water absorption. While the addition of inulin may increase dough rheology on a farinograph, it decreases the amount of water that may be added and could potentially reduce shelf life due to an increased staling rate or dry crumb properties (Peressini and Sensidoni, 2009).

Other studies reviewed the influence of bran type and the differences of bake performance between layers of bran. Gan and others (1992) analyzed the impact of different types of bran on bread loaf volume. Their test used different cultivars of wheat and different levels of bran addition rates to its testing. Three different levels of bran pearling were used to replace flour: 2.5%, 7.5%, and 12.5%.

Testing showed that lipase activity between the white flour control and whole meal flour was different. The white flour control tested at 1.64 mg FFA/gram, compared to whole meal flour levels of 2.26 mg FFA/gram (Gan and others, 1992). Also, wheat bran that was heat-treated and enzyme inactivated did not show an improvement in loaf volume and baking performance. From this, it may be concluded that enzymes from the bran fraction may not be a significant contribution to the decrease in baking functionality of whole wheat (Gan and others, 1992).

More work was done using a scanning electron microscope that showed how bran fractions interrupt gas cells and the gluten network present in bread making. This was believed to be the main contributor to irregular crumb grain and less functionality of whole wheat flour. The testing showed that when outer epicarp peelings were used with wheat hair attached, the most significant decrease in performance was observed (Gan and others, 1992).

Nutritional Significance of Whole Wheat/Whole Grain

There is a growing demand for whole grains and whole wheat products to be introduced into today's consumer diet. The nutritional benefits of whole grains have been researched, however, more work will need to be done before all consumers and food companies are aligned. The article titled: *Food Scientists Explore Refined Grains in American Diet*, found in the weekly grain-based foods publication Milling and Baking News, reviews how the whole grains push may not be completely based on conclusive research (Anonymous, 2011b). Some refined grains are different than others in terms of their glycemic index and should not all be viewed as the same. Some components, such as phytate found in whole grains, actually block or reduce the absorption of zinc and iron. Also, refined flour is enriched with iron, calcium, and folic acid. This source of nutrients may be lost and nutrient deficiencies may return if diets are restructured and enrichment standards for whole grain do not change. There is some growing concern among dietitians over the switch to unrefined, non-enriched grains (Anonymous, 2011b).

Another unique article, *In Defense of Dietary Fiber,* discussed whole grains and nutrition (Williams and Warber, 1997). It offered an interesting perspective of whole grain addition to improve dietary fiber intake and how the consumption of whole grain products should be the focus, not dietary fiber intake. A rebuttal from a physician indicated that dietary fiber intake is more important.

Williams and Warber (1997) emphasized that many foods are not whole grain and are rich in fiber, such as refined cereals and breads with fiber added back in from wheat bran. The authors of the article responded saying that both aspects are important because whole grains offer other benefits besides fiber. These included anti-oxidants, phytochemicals, vitamin E, and selenium. If only refined grains and supplements were emphasized in the consumer diet, these benefits would be missed. The authors concluded by explaining the need for a universal definition of whole grain among the food industry (Williams and Warber, 1997).

A study by the Whole Grains Council reviewed a new life for whole grains and discussed challenges and development opportunities (Edge and others, 2005). Whole grains have had resurgence in the consumer diet with the popularity of the Atkins and South Beach diets. These diets both focus on how refined grains in foods impact glycemic index values. There has been a lack of success in educating consumers about whole grains and their benefits even after new health claims have been released. The average American consumer is only consuming one serving of whole grains per day (Edge and others, 2005).

The Whole Grains Council has come up with a consumer friendly definition of whole grains and wants to educate people about the health benefits of consuming whole grains. These health benefits include: reduced risk of cardiovascular diseases, improved response to glucose consumption and reduced risk of type II diabetes, decreased risk of certain cancers, and improved weight management and satiety. Some scientists believe whole grains have more benefits than just fiber and vitamin claims (Edge and others, 2005).

No research has been conducted on how the synergy among bio-active substances works in whole grains. The combination of resistant starches, lipids, antioxidants, phytosterols, and tannins may act in combination to provide a greater nutritional benefit. The Whole Grains Council has identified several areas of focus and studies to explore these health benefits.

The first area of focus is around the current consumption of whole grains. Research is lacking with clinical studies on whole grain intake and long term health benefits on both healthy and unhealthy people. These studies will be able to establish how whole grain consumption improves or impacts the health of both types of consumers.

The next area of research should involve new research and development of whole grain products, including breeding of whole grains, milling and processing techniques, and formulation of whole grain products that will nutritionally benefit the consumer. The development of new grain varieties with milling and processing techniques may allow for the use of whole grain in a new way. There may be new ways to process the outer-grain fractions as an additive ingredient to deliver health benefits to other food products.

The final area of focus by the Whole Grains Council involves educating the consumer. In 2005, 71% of consumers in the United States believed they eat enough whole grains on a daily basis. They are consuming less than one good serving of whole grains per day, or approximately 8-grams. The recommended daily intake is three 16-gram servings daily (Edge and others, 2005).

Limited work has been completed on the potential of the fortification of whole wheat flour. The study by Akhtar and Ashgar (2011) was a good review of conditions that focused on the fortification needs for whole wheat flour in India and other countries where food fortification and vitamin deficiency is a large concern. The study uses the United States white flour fortification program as a model to build from. By using the correct type of enrichment, whole wheat flour may be fortified and still provide adequate nutrients and the benefits of whole grain. The fortification added should not impart unwanted changes to the ingredient or food, such as smell, flavor, color, or texture. The study shows that whole wheat flour may also be a suitable carrier for fortification of vitamins and nutrients.

Several more studies have been performed that compare whole grain nutrition to other commonly perceived nutritional foods such as fruits and vegetables. Liu (2007) explained how phytochemicals and antioxidants present in whole grains are often overlooked compared to fruits and vegetables. The presence of these antioxidant compounds in whole grains was underestimated. Recent research has shown there is more present than previously reported. The beneficial effects with whole grain consumption combine these phytochemicals and fiber to create unique health benefits that are different than fruits and vegetables. The benefits of the bran and germ fraction of whole grains may have a larger impact when consumed on a daily basis and reduce the likelihood of certain chronic diseases such as diabetes and cancer.

In contrast, a study by Gordon and Wrigley (2004) reviewed the new recommendations of adding whole grains into the consumer diet and believed that the nutritional significance of refined grains are understated. Whole grains rich in dietary fiber, phytosterols, vitamins, and antioxidants are being encouraged to be the base of the food guide pyramid for these health benefits. However, refined grains are being misperceived as poor to low nutrition foods and are being viewed as unhealthy for consumers. Whole grains are being promoted as healthy compared to refined grains. There are differences in fiber, vitamins, and nutrients in whole grain compared to refined grains. Despite these differences, enriched refined grains provide good levels of nutrients and vitamins as proven in ingredients such as white rice and white wheat flour.

The United States is unique for the large amount of health claims it promotes, with 14-FDA approved claims (Gordon and Wrigley, 2004). The FDA guidelines require a lengthy scientific or clinical study to support any health claim published. Not all studies done for the claim may statistically support the claim or its benefits. Some studies may show inadequate conclusions, no impact, or a reverse impact (Gordon and Wrigley, 2004).

Gordon and Wrigley (2004) reviewed whole grain nutritional claims petitioned to the FDA. They concluded that current whole grain nutritional claims are primarily focused on whole wheat products. They supported the consumption of a larger variety of whole grains and not to promote a single source of whole grain model for approved FDA nutritional claims.

One article of concern from The Economist, *"Food Deserts: If you build it, they may not come"*, focused on the logistical challenge of distributing healthy food to consumers. Some larger urban areas contain pockets where low-income families are challenged with limited access to healthy foods or grocery stores. These regions are defined as an area where 20% of the residents are below the poverty line and 33% or more live over one mile from a grocery store (Anonymous, 2011a).

The USDA has performed studies on these areas to try to link these areas with no access to fresh produce and food with higher levels of obesity and health problems. The results were interesting and unexpected. They showed that improving access to healthy foods doesn't change consumer behavior. Some United States consumers don't care to eat a balanced diet, while others aren't able to pay the financial difference. Healthy food prices have increased at twice the rate of unhealthy foods over the last four years (Anonymous, 2011a).

Justification of Research

More research is needed to be done to develop whole grain and whole wheat flour quality and products acceptable for consumers. The first important step is to review the current whole wheat flours available in the market place today. They currently offer unique and different types of granulation that come from a few different hard, soft, white, and red wheat varieties. Functional characteristics need to be reviewed by baking cross-section samples currently available in U.S. market and comparing the water absorption, loaf volume, and particle size distribution between flours.

The next step in this process is to review the current available information on baking functionality relative to granulation distribution, variety of wheat used, and which types have the greatest positive impact to performance. This may be accomplished by independently milling identity-preserved white and red wheat. Both wheat varieties will be milled to a fine whole wheat granulation, an optimum whole wheat granulation, and an ultrafine whole wheat granulation. The samples will be baked and compared to each other for final attributes.

Finally, these results should be reviewed. The goal of the findings are to find optimal range for granulation size for whole-wheat flour and provide some estimated benefit of savings for baking manufacturers on reduced usage of vital wheat gluten, dough conditioners, and shelf-life extension. Some of these estimated cost savings may come from reduced ingredient usage, increased processing efficiencies, and additional water absorption.

Chapter 2 - Experimental Whole Wheat Milling and Baking Research

Materials and Methods

Several resources were used to obtain the necessary materials for the experiments performed. From a commercial milling side, samples of commercially milled whole wheat flour were obtained from JM Swank, Gregory Foods, Horizon Milling, and the South Dakota Wheat Commission.

Table 1: Wheat and Flour Sample Suppliers

Sample Name:	Supplier:	City:	State:
Medium Whole Wheat Flour, North Dakota Mills	Gregory Foods	Eagan	MN
Coarse Whole Wheat Flour, Bay State Milling	Gregory Foods	Eagan	MN
ConAgra Fine Whole Wheat Flour	J.M. Swank	North Liberty	IA
ConAgra Medium Whole Wheat Flour	J.M. Swank	North Liberty	IA
ConAgra Ultragrain Whole Wheat Flour	J.M. Swank	North Liberty	IA
Progressive Baker Fine Whole Wheat Flour	Horizon Milling	Mankato	MN
Progressive Baker Wheat Select White Whole Wheat Flour	Horizon Milling	Mankato	MN
Alice Fine Whole Wheat Flour	South Dakota Wheat Comission	Pierre	SD
936 Red Wheat Variety	Westbred	Bozeman	MT
Snowcrest White Wheat Variety	Westbred	Bozeman	MT
Capstone White Wheat Variety	Westbred	Bozeman	MT
Paloma White Wheat Variety	Westbred	Bozeman	MT
Alice White Wheat Variety	South Dakota Wheat Comission	Pierre	SD

Grinding

Four different grinding methods were used with the goal of obtaining a coarse, medium, fine, and extra-fine granulation out of each wheat sample.

Table 2: Grinding Equipment

Equipment Name:	Model:	Supplier:	City:	State:
Hammer Mill	PX-MFC-90 D	Kinematica	Bohemia	NY
Roll Stand	Custom	Sid's Corrugation	Wichita	KS

- Coarse grind was obtained by running the hammer mill at 4,000 rpm’s, with a 3.0 mm screen size.
- Medium grind was obtained by running the hammer mill at 6,000 rpm’s with a 3.0 mm screen size
- Fine grind was obtained with a multi-step process. Kernels were run through the hammer mill at 6,000 rpm’s, with a 3.0 mm screen size. The stock was then taken and run through corrugated break roll stand with the front roll set at 392 rpm’s and the back roll set at 266 rpm’s. This method was created to closely resemble a commercial fine whole wheat milling process.
- Extra fine grind was obtained with a multi-step process. Kernels were run through the hammer mill at 6,000 rpm’s, with a 3.0 mm screen size. The stock was then taken and run through corrugated break roll stand with the front roll set at 392 rpm’s and the back roll set at 266 rpm’s. To create the extra fine product, the milled stock was then taken and placed in a sifter box and sifted for 3 min. The remaining stock with a particle size of equal to or greater than 414 microns was taken and put through a regrind to the hammer mill. The over’s stock was reground through the hammer mill at 6,000 rpm’s through a 1.0 mm screen. This stock was then recombined with the thru’s from the

sifting process in a flour blender for 5 min to evenly redistribute the product. This method was created to attempt to create an extra-fine grind whole wheat flour that had finer particle size than commercial fine whole wheat flour.

Bake Formulation and Procedure

Table 3: Bake Formulation Ingredients

Bake Formula Ingredients:			
Ingredient Name:	**Supplier:**	**City:**	**State:**
Whole Wheat Flour	Variable, see sample names for specific samples		
Water	Horizon Milling Bake Lab/City of Minnetonka	Minnetonka	MN
Yeast Food 2232	AB Mauri Bakery Ingredients	Fenton	MO
Malted Barley Flour	J.M. Swank	North Liberty	IA
Vital Wheat Gluten	Cargill B.V.	Morrow	GA
Yeast, fresh compressed	American Yeast Sales Corp	Memphis	TN
Salt, fine blend-TCP PP	Cargill Salt	Hutchinson	KS
Sugar, United Fine Granulated	United Sugars Corporation	Fridley	MN
Master Chef All Purpose Shortening	Cargill Dressings, Sauces, and Oils	Sidney	OH

Table 4: Bake Equipment

Bake Area Equipment:			
Equipment Name:	**Supplier:**	**City:**	**State:**
Hobart 10 Quart C-100 Mixer	Hobart Manufacturing	Akron	OH
Reed Retail Oven	Reed Ovens	Kansas City	MO
National Manufacturing Proof and Fermentation Cabinet	National Manufacturing	Lincoln	NE
Peerless Straight Grain Molder	Peerless Manufacturing	Sidney	OH
Wooden Benchtop and Drawer	Custom, Ira Oak	Minnetonka	MN

Table 5: Whole Wheat Bake Formula

Bake Process Formula:			
Sponge Ingredients:	Quantity:	Dough Ingredients:	Quantity:
Whole Wheat Flour	420 g	Whole Wheat Flour	60 g
Water	330 ml	Salt	4.0 g
Yeast Food	3.5 g	Granulated Sugar	20.0 g
Malted Barley Flour	1.0 g	Baker's Shortening	8.0 g
Vital Wheat Gluten	30 g	Water	40 ml
Yeast, Fresh Compressed	33 g		

Bake Procedure

The procedure used was a sponge and dough bake method. The first step to the process was to mix the sponge. The sponge ingredients were deposited into a Hobart 10-quart, C100 mixer and mixed for 1 min on low speed, then 2 min on 2nd speed. The sponge mass was then removed and scaled into 2, 270 g pieces and placed into 2 separate containers, a sponge for a short mix time of 7 min, and a sponge for a long mix time of 9 min The sponges were then placed into a fermentation cabinet for 3.5 hours at 29.44 ºC and 85% humidity.

After 3.5 hours, the sponges were removed from fermentation cabinet. They were removed from their troughs and added back in with the dough side ingredients. The short mix sponge and long mix sponge samples were added individually to two different mixers. Next, the short mix samples were mixed for 1 min on low speed, and then 7 min on 2nd speed. The long mix samples were also mixed for 1 min on low speed, and then 9 min on 2nd speed.

Once the samples completed the mixing cycles, they were removed from the mixers and individually scored for a mixing score. The dough’s were then placed into the fermentation cabinet to rest for 30 min at 29.44 ºC and 85% humidity.

After the resting period, the samples were removed and divided and rounded into 2, 175 g pieces. While these samples were divided and rounded, they were given a benching or dough handling score by the person running the test. After rounding, the samples were placed into an intermediate proofing drawer, at ambient temperature and humidity, and left to rest for 15 min

Once the resting period was complete, the samples were run through the Peerless straight grain molder and panned into a pup loaf pan. Each sample scaled two dough pieces, so each mix time and variable had duplicate samples. These samples were given a makeup score as they were being panned. The panned samples were then placed into a proofing cabinet set at 40.6 ºC and 85% humidity.

The samples were proofed to the height of a template or a maximum of 70 min. Any samples that did not proof to height in the 70 min were removed and placed into the oven for baking. Each sample was removed according to the criteria and baked at 204.4 ºC for 19 min in the Reed Oven.

Once the baking cycle was complete, the samples were removed from the oven and de-panned. They were then placed on porous trays and allowed to cool for 20 min before being placed into a bread box container. The samples were then measured for height of the baked loaf in cm the following day after the bread has cooled and been cut for scoring.

Interpretation of Baking Results

The interpretation of bake results required scoring the samples at different points along the baking process. The three areas of focus were mixing score, dough handling score, and loaf height. Each measurement helped determine how a sample might process in a commercial bakery at commercial processing speed and stress.

The mixing and dough handling scores were based on subjective scores. The subjective scores were assigned based on the scorer’s experience and participation in a monthly cross-check program. This cross check program calibrated each participant using control samples that have previously been scored and agreed upon by the check-sample participants. The agreement by committee allowed participants to score samples consistently among each other.

To align on scoring agreement, a sample with a known score is prepared and baked. Each participant of the cross-check actively scores both the short and long mix time sample as it is pulled from the mixer. Next, the sample is scored for dough handling and panning by each participant. The samples are then baked and the finished bread is reviewed the following day. Scores, comments, and the final appearance of the baked bread are compared and reviewed among participants. Any deviations from the group score are noted and cross-check participants are certified based on their results.

Mixing Score

The mixing score was measured immediately after the sample had completed the remixing process. The sample was pulled from the mixer and placed in a dough trough. The sample was then pulled by two hands up to shoulder height and stretched to display the developed gluten web. A numerical score was then assigned based on a subjective scoring method listed (Table 6).

Table 6: Mixing Score Description

Mixing Score Scale:	Description of Score:
85	Much stronger than optimum for bread baking
80	Stronger than optimum for bread baking
75	Slightly stronger than optimum for bread baking
65	Optimum for bread baking
60	Softer, but in optimum range for bread baking
55	Softer than optimumfor bread baking
45	Weaker than optimum for bread baking
40	Too extensible for bread baking
below 40	Undesirable for bread baking

Dough Handling Score

The dough handling score (Table 7) was measured when the sample was divided and rounded into a scaled dough piece. A numerical score was then assigned based on a subjective scoring method listed.

Table 7: Benching Score Description

Benching Score Scale:	Description of Score:
11	Above optimal, stronger than needed for commercial processing
10	Optimal, good for commercial processing with minimal problems
9	Good, slightly softer, however, still good for commercial processing
6	Mellow, softer, adequate for some commercial processes
5	Soft, adequate for processing at low speeds, extensible

Loaf Height

Loaf height was measured to the highest point of the crown of the finished baked sample. The height was measured after the baked sample was cooled and cut the following day for scoring. Height was measured in centimeters using a ruler and measuring from the base to the crown.

Bake Design and Scoring Ballot

The bake test created for this experiment measured both a combination of qualitative and quantitative measures (Figure 2-1).

Figure 2-1: Bake Scoring Ballot

Baking Score Ballot:	
Criteria:	Score Possible:
Volume:	20
Grain:	20
Texture:	15
Color:	5
Absorption:	5
Mixing Tolerance:	15
Dough Handling	10
Make Up:	10
Total Bread Score:	Possible score out of 100 points:
Mixing Strength:	Separate score from previous day

The qualitative measures involved giving samples a score directly out of mixing in the dough form, a score for how the dough handled at make-up and panning, and finally written comments as to how the dough felt and if absorption was an issue in the dough phase through tacky or wet comments. The two main quantitative measures during the bake test measured the proofing time of the sample as well as the final bread height in centimeters. Three series of bake tests were performed on combinations of experimentally milled wheat samples and commercial whole wheat samples.

The first bake test was set up to test one identity-preserved variety of white wheat and one identity-preserved variety of red wheat experimentally milled to the same granulations to compare baking performance for both types of wheat. In addition, samples of commercially milled white and red whole wheat flours were run at the same time to compare against the experimentally milled flours to determine if processing differences had significant impacts on bake functionality and dough handling.

The second bake test was set up to understand how different granulations of commercial whole wheat flour samples would perform in the bake test method designed for this testing. Commercial samples with granulation ranging from coarse to extra-fine whole wheat were reviewed. In addition, experimentally milled samples from two different wheat varieties with the same granulation were tested.

The third bake test was designed to compare four different identity preserved white wheat varieties. Each of the samples were milled to the same granulations and baked with the same procedure. These samples were milled and baked within the same timeframe to eliminate the variable of oxidation or aging on flour performance. The results from this bake were based on differences between wheat varieties and not processing.

Granulation Procedure

The particle size and granulation were measured with a Ro-Tap and a Cilas particle size machine (Table 8). The Ro-Tap machine was used as a traditional type of measurement for whole grain or whole-wheat granulation. Many of the commercial whole-wheat specifications are written on the basis of this testing. This testing method is, however, limited in the ability to measure fine to very fine particles. One of the common issues with this test is excessive amounts of product remain on a sieve, preventing the flow of smaller particles through and into the correct final size sieve. With this limitation, it was difficult to measure subtle differences between granulation of products.

Another form of testing particle size of fine products such as flour or powder is the Cilas 1064 particle size machine. This machine is able to measure very subtle changes in overall particle size and offers both a visual and statistical distribution of the mean average particle size of samples. The limitations of this machine are in the ability to measure larger particles such as coarse bran or germ. This is why the combination of measurement with both testing methods became necessary to adequately cover the range of products produced from the experimental milling processes. By using a combination of both methods, the differences between fine to very finely ground samples was quantified.

Ro-Tap Model E Procedure

Table 8: Granulation Equipment Suppliers

Granulation Equipment:			
Equipment Name:	**Supplier:**	**City:**	**State:**
WS Tyler Ro-Tap E	Precision Eforming	Cortland	NY
Cilas 1064 Particle Analyzer	Cilas	Madison	WI
Brass Sieves, US20, 40, 60, 80, 100, Pan	Precision Eforming	Cortland	NY
Rubber Balls, 2 per Sieve	Precision Eforming	Cortland	NY

Procedure

The first step to running a Ro-Tap procedure is to weigh out 100 g of sample in a pourable container. Next, push up two stoppers on Ro-Tap and remove the top cover. Ensure sieves are clean and stacked correctly with the largest sieve on top (US 20 wire) and smallest wire placed at the bottom of the stack (US 100 wire), followed by the pan.

Two rubber balls should be placed on each sieve except the top, US 20 wire. Next, pour the 100 g weighed sample into top sieve using a brush to remove all the flour from the container. Replace the top cover making sure it is centered on top tray. Push down on the two stoppers on the side of the instrument making sure the top cover stays even on both sides. Twist stoppers to the right to tighten properly, keeping pressure equal on both the left and right side.

The timer should be set for 3 min, fine analysis setting. Press the start button to begin the test. Once the machine has cycled and the test is complete, loosen stoppers along the side of the machine. Push up and remove the top cover. Remove all 6 sieves keeping them stacked. Tap entire stack 2 or 3 times hard to loosen any remaining flour fines around the edges of the sieves.

Next, place the empty container on the scale for weighing and tare the scale. Remove first sieve (US 20 wire) and pour flour the over's into the container. Tap the side of the sieve several times with brush to remove all the flour from the edges. Use the brush to sweep out any remaining flour. Tap empty sieve on the counter a couple times to remove flour dust. Turn upside down, set aside. Document weight of the flour collected from the sieve.

Remove 2 rubber balls from the next sieve (US 40 wire), dust off and place on the US 20 wire sieve. Repeat this process for remaining sieves, weighing the over's for each sieve, including the pan**.** When complete, turn entire stack right side up and place back on the base of the Ro-Tap.

Cilas 1064 Dry Particle Size Procedure

A sample is slowly added to machine at a target concentration of 100. The machine integrates two sequenced laser sources positioned at angles of 0° and 45° to produce a diffraction pattern analyzed on a 64 channel silicon detector. Through the software, the distribution curve is represented by 100 classes over the range from 0.30 to 500 μm for dry analysis.

Results and Discussion

Bake Testing Results

The first bake test performed showed some functional differences between wheat types and yielded relevant data (Table 9). The results from both the red and white wheat varieties showed a strong relationship of particle size versus loaf height. As particle size decreased, loaf height of both wheat varieties increased (Figure 2-2 and Figure 2-3).

This correlation contradicted findings from a study completed by Noort and others (2010). Their study indicated that the addition of coarse bran particles had minor impact on final bake volumes and gluten dilution played a minor role in functional changes in flour with added bran. Their conclusion believed as bran particle size decreased, glutathione levels increased from damaged aleurone cells, creating a less extensible and weaker gluten network (Noort and others, 2010).

The population size of this bake test was limited to 4 samples in each set. Because of this limitation, it was difficult to draw many statistical conclusions from the data related to granulation versus volume.

Table 9: Loaf Height, Mixing, and Dough Handling Scores of Bake Test 1; A Comparison of Commercial versus Experimentally Milled Samples

Sample	Mixing Time (min.)	Mixing Score (mix score scale)	Bench Score (bench score scale)	Bench Comments	Proof Time (min)	Height (cm)
X-mill 936 coarse, red, 7 min.	7	60	9	stiff, putty	43	8.8
X-mill 936 coarse, red, 9 min.	9	35	10	putty	43	8.3
X-mill 936 medium, red, 7 min.	7	60	10	good	44	9.3
X-mill 936 medium, red, 9 min.	9	45	10	good	48	9.1
X-mill 936 fine, red, 7 min.	7	65	11	great	43	9.5
X-mill 936 fine, red, 9 min.	9	40	10	soft	48	8.9
X-mill 936 x-fine, red, 7 min.	7	55	10	very good	47	9.7
X-mill 936 x-fine, red, 9 min.	9	40	10	softer, sl. Tky	48	9
X-mill Alice coarse, white, 7 min.	7	55	9	tacky, extensible	49	9.2
X-mill Alice coarse, white, 9 min.	9	20	5	putty, poor, tacky	53	7.4
X-mill Alice medium, white, 7 min.	7	55	5	pliable	54	8.9
X-mill Alice medium, white, 9 min.	9	35	5	pliable, tacky	54	8
X-mill Alice fine, white, 7 min.	7	55	10	soft	51	9.4
X-mill Alice fine, white, 9 min.	9	35	6	tacky, extensible	53	7.8
X-mill Alice x-fine, white, 7 min.	7	60	10	soft	48	9.2
X-mill Alice x-fine, white, 9 min.	9	35	9	soft, extensible	51	8.5
Ultragrain, white control, 7 min.	7	55	10	putty	43	8.9
Ultragrain, white control, 9 min.	9	35	10	putty, dry	46	8.4
P.Baker, fine, red control, 7 min.	7	65	11	great, gassy	41	9.6
P.Baker, fine, red control, 9 min.	9	60	10	great	51	9

Mixing Score Scale:	Description of Score:
85	Much stronger than optimum for bread baking
80	Stronger than optimum for bread baking
75	Slightly stronger than optimum for bread baking
65	Optimum for bread baking
60	Softer, but in optimum range for bread baking
55	Softer than optimumfor bread baking
45	Weaker than optimum for bread baking
40	Too extensible for bread baking
below 40	Undesirable for bread baking

Benching Score Scale:	Description of Score:
11	Above optimal, stronger than needed for commercial processing
10	Optimal, good for commercial processing with minimal problems
9	Good, slightly softer, however, still good for commercial processing
6	Mellow, softer, adequate for some commercial processes
5	Soft, adequate for processing at low speeds, extensible

Figure 2-2: Loaf Height versus Granulation of 936 Red Whole Wheat, Experimentally Milled Sample

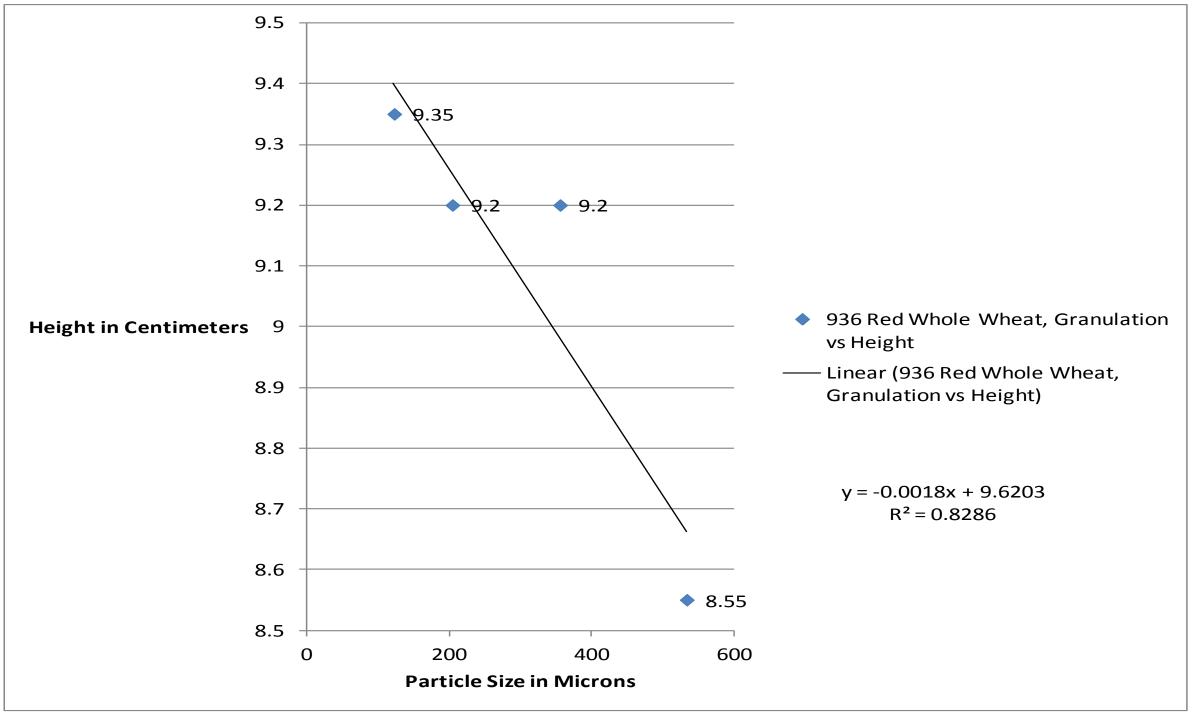
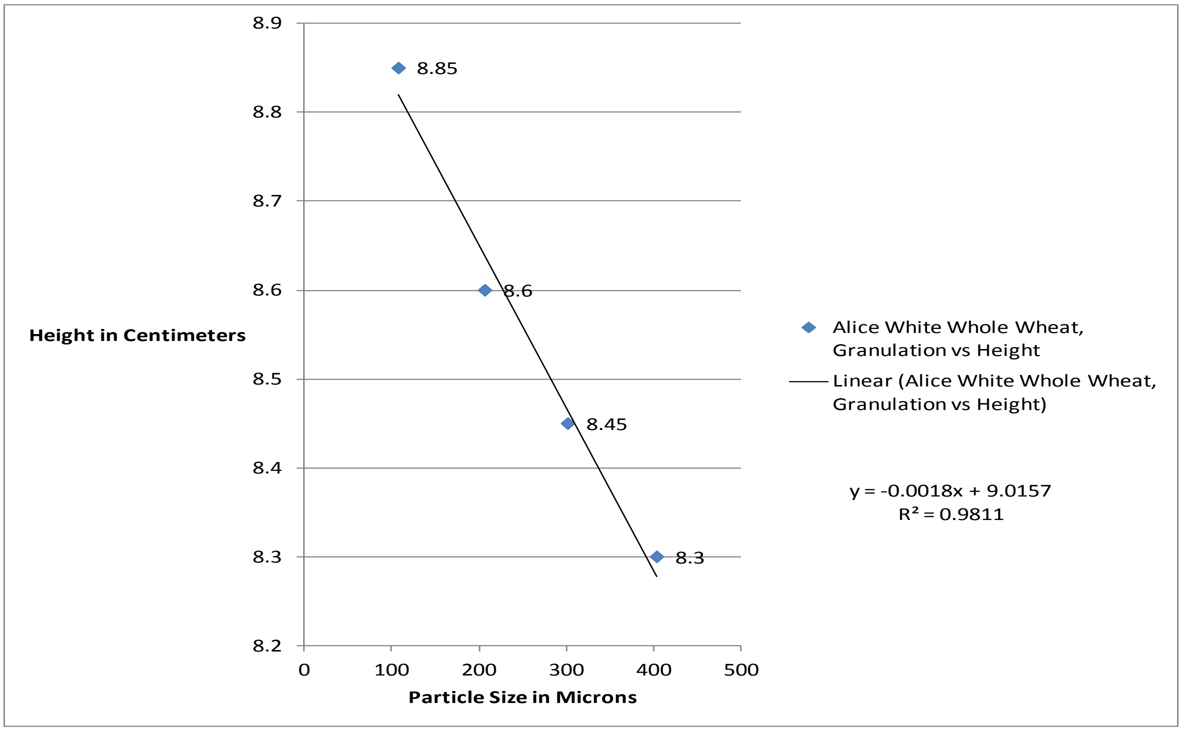


Figure 2-3: Loaf Height vs. Granulation of Alice White Whole Wheat, Experimentally Milled Sample



The results of the experimentally milled samples when compared to the commercially milled samples did not show any visible differences in functionality or bake volume. The red wheat commercial sample performed very similarly to the fine and extra fine whole wheat samples that were experimentally milled. The white wheat commercial sample actually had a very slightly lower volume than the experimentally milled sample, but the results didn't appear to be significant.

The comparison of red wheat to white wheat samples indicated that red wheat samples had consistently higher final bake height than the white wheat samples in all granulation types (Figure 2-4 and Figure 2-5). This result contradicts a study completed by Ozboy and Koksel in 1997. In this study, white and red coarse wheat bran were added to flour samples and tested for dough rheology and baking performance. The samples that had the white bran added had improved dough rheology and bake volumes compared to red bran addition (Ozboy and Koksel, 1997).

The bake results did not take into account the age of the commercial samples compared to the freshly-milled experimental samples. Studies completed by Tait and Galliard (1988), and Barnes and Lowy (1986) reviewed shelf life of whole wheat flour and indicated diminished functionality as whole wheat flour ages. These factors were not accounted for in comparing results and may have impacted final bake data.

Figure 2-4: 936 Red Whole Wheat, Experimentally Milled Sample, Loaf Height Results by Grind Type

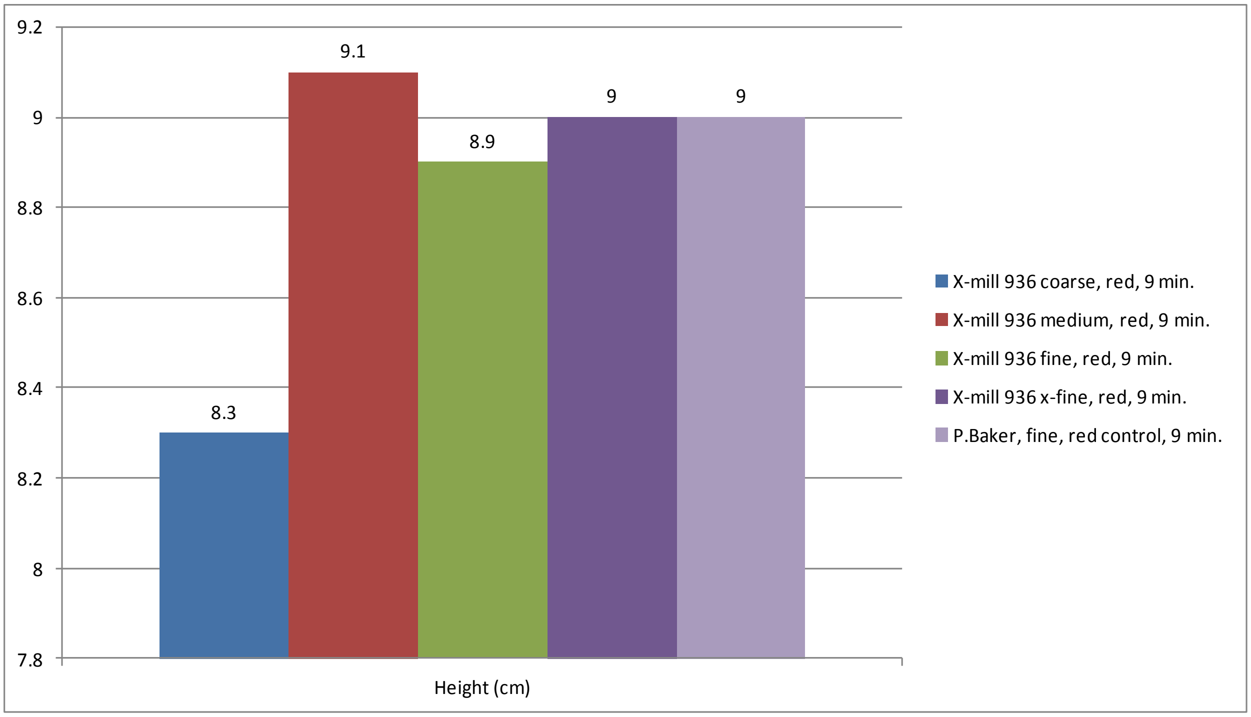


Figure 2-5: Alice White Whole Wheat, Experimentally Milled Sample, Loaf Height Results by Grind Type

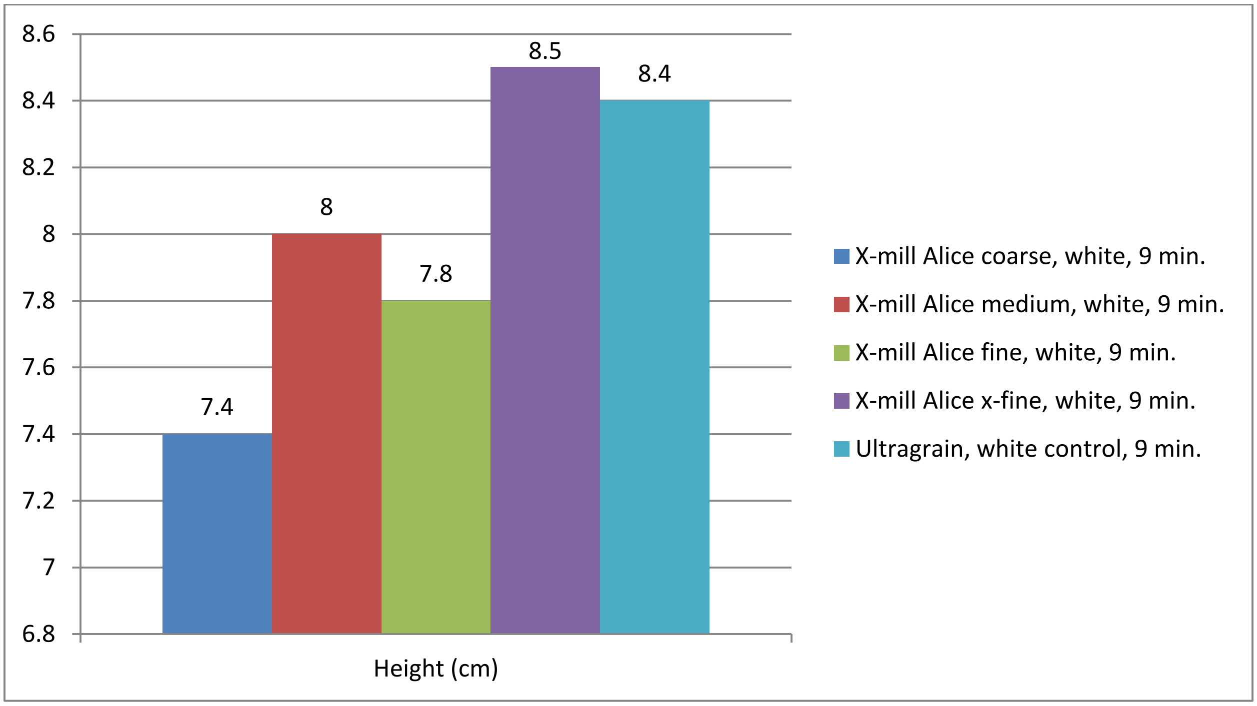


Figure 2-6: Photos of Red Wheat Whole Wheat (WW), 936 Variety, 7 Min Mix Time

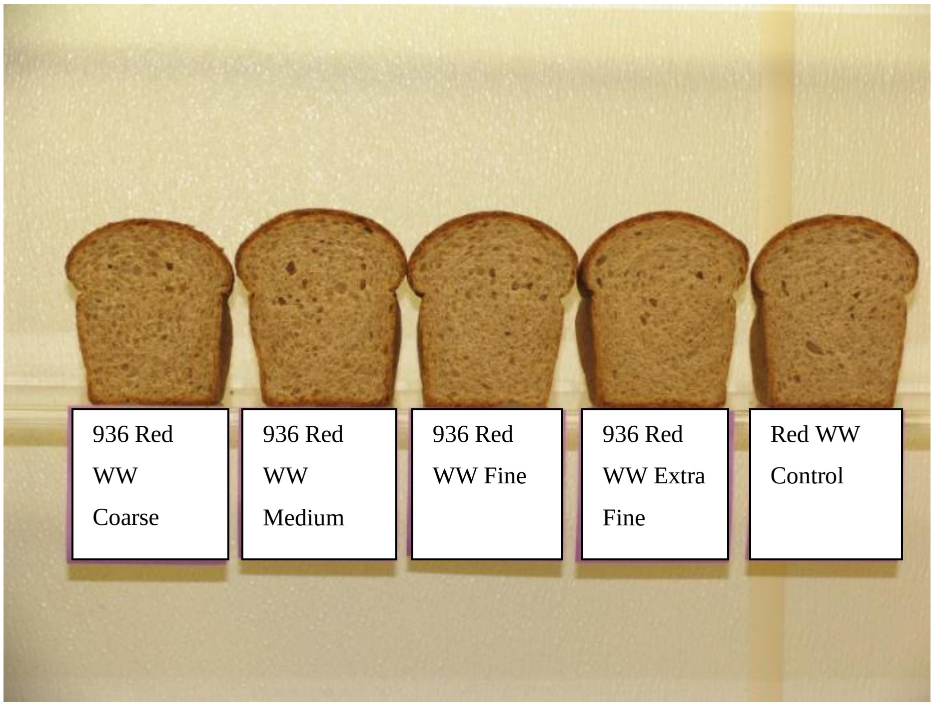


Figure 2-7: Photo of Red Wheat Whole Wheat (WW), 936 Variety, 9 Min Mix Time

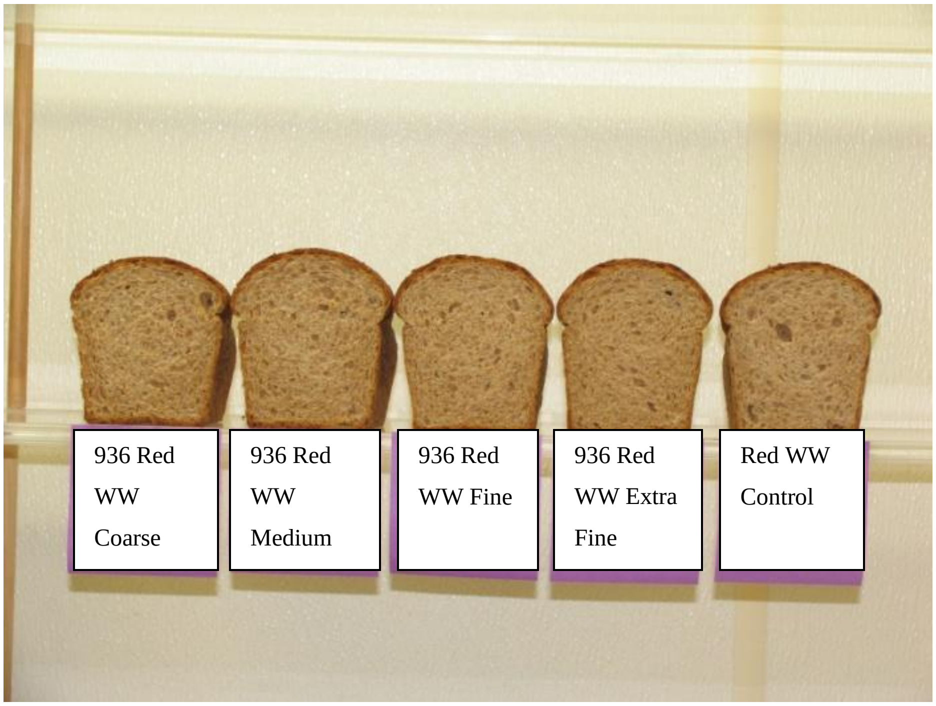


Figure 2-8: Photo of White Whole Wheat (WW), Alice Variety, 7 Min Mix Time

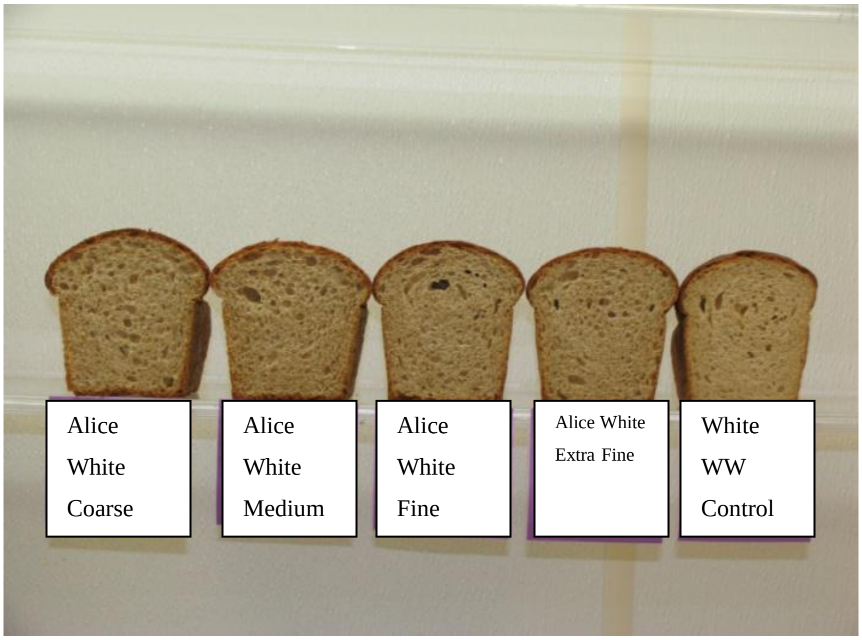
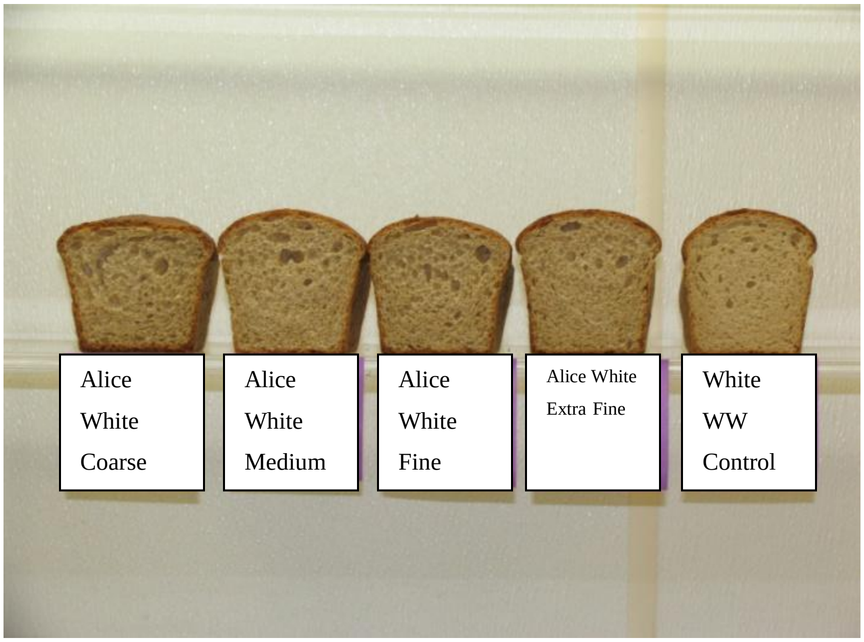


Figure 2-9: Photo of White Whole Wheat (WW), Alice Variety, 9 Min Mix Time



The second bake test was designed to review all of the commercial whole wheat samples. They were tested against each other to compare bake functionality, dough handling, and final product volume of the various granulations available on the market today.

Table 10: Loaf Height, Mixing, and Dough Handling Results of Bake Test 2; A Comparison of White Wheat Varieties and Commercially Milled Samples

Sample	Mixing Time (min.)	Mixing Score (mix score scale)	Bench Score (bench score scale)	Bench Comments	Proof Time (min)	Height (cm)
X-mill Capstone, white, fine, 7 min.	7	45	10	soft	51	9.2
X-mill Capstone, white, fine, 9 min.	9	40	9	sl tacky, pliable	53	8.9
X-mill Paloma, white, fine, 7 min.	7	60	10	good, gassy	46	10.1
X-mill Paloma, white, fine, 9 min.	9	55	10	soft, sl extensible	46	9.7
X-mill Snowcrest, white, fine, 7 min.	7	60	10	good	44	10.3
X-mill Snowcrest, white, fine, 9 min.	9	60	10	good	44	10
Commercial Coarse WW, red, 7 min.	7	60	9	soft, sl tacky	61	9.8
Commercial Coarse WW, red, 9 min.	9	45	8	tacky, extensible	66	8.9
Medium WW, red commercial A, 7 min.	7	60	10	soft	49	9.4
Medium WW, red commercial A, 9 min.	9	55	10	soft	49	9.1
Medium WW, red, commercial B, 7 min.	7	60	9	soft	50	9.1
Medium WW, red, commercial B, 9 min.	9	55	8	ft, tacky, extensible	64	7.8
Fine WW, red, commercial B, 7 min.	7	60	9	soft, extensible	50	8.3
Fine WW, red, commercial B, 9 min.	9	55	8	oft, very extensible	59	8
Wheat Select, fine, White commercial A, 7 min.	7	60	11	great, gassy	51	10.5
Wheat Select, fine, White commercial A, 9 min.	9	60	10	good	56	10

Mixing Score Scale:	Description of Score:
85	Much stronger than optimum for bread baking
80	Stronger than optimum for bread baking
75	Slightly stronger than optimum for bread baking
65	Optimum for bread baking
60	Softer, but in optimum range for bread baking
55	Softer than optimumfor bread baking
45	Weaker than optimum for bread baking
40	Too extensible for bread baking
below 40	Undesirable for bread baking

Benching Score Scale:	Description of Score:
11	Above optimal, stronger than needed for commercial processing
10	Optimal, good for commercial processing with minimal problems
9	Good, slightly softer, however, still good for commercial processing
6	Mellow, softer, adequate for some commercial processes
5	Soft, adequate for processing at low speeds, extensible

In addition to the commercial samples, three different varieties of hard white wheat were examined. Each one of these varieties was identity preserved and experimentally milled to a fine granulation that was intended to replicate commercially milled fine whole wheat. These identity preserved varieties were baked over a two day period due to bake test sample limitations. These samples were processed in a controlled setting to determine if granulation or wheat variety was a more important factor in functionality and if the extra-fine grinding step reduced final product functionality in the bake process.

After baking all of the commercial samples it was difficult to initially see any differences in functionality of such wide range of products tested. A solution for this was to plot the bake volume versus the granulation of each sample. The results showed little to no relationship between particle sizes of the whole wheat flour tested to the resulted final product volumes (Figure 2-10).

The commercial samples were comprised of unknown wheat originations and unknown age of samples. Tait and Galliard (1988) and Barnes and Lowy (1986) both indicated that storage and sample age contributes to final loaf volume and functionality.

Some of the coarser granulation products out performed the fine to very fine granulation products in loaf height. While surprising, these results agree with a study performed by Penella and Haros (2008). In this study, it was concluded that fine bran added to flour had more of a mixing tolerance impact than coarse bran. As levels of fine bran increased, farinograph mixing tolerance decreased significantly compared to the same addition level of coarse bran (Penella and Haros, 2008).

The results would indicate that final product bake quality may be less dependent on the whole wheat flour granulation and processing. Instead, the proper wheat mix or combination of wheat varieties that have better baking properties may be the more significant factor in functionality.

The impact of variety on results with the same granulation was also reviewed by looking at three identity-preserved white wheat's of Capstone, Paloma, and Snowcrest. The Paloma and Snowcrest varieties showed much improved loaf height compared to the Capstone variety. A study completed by Kock and others (1999) agreed with these findings. This study reviewed 10 different varieties of wheat and performed heat treatment to eliminate enzymatic differences in the bran reviewed. It concluded that bake performance was related to physical attribute differences between varieties (Kock and others, 1999). It was very apparent after viewing these results that wheat variety or type is significantly related to differences in bake quality between samples if milled in the same way to the same particle size and granulation (Figures 2-12 to 2-16).

Figure 2-10: Commercial Sample Bakes, Comparison of Average Granulation versus Loaf Height

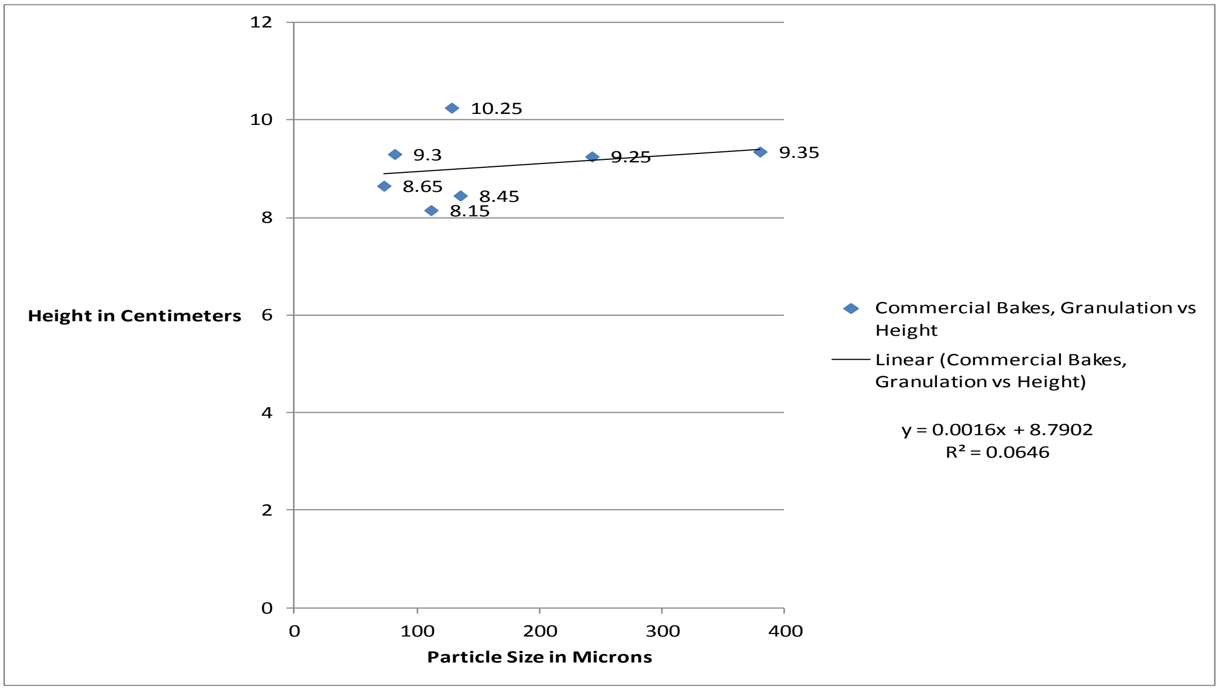


Figure 2-11: Commercial Samples, Loaf Height Results by Sample Type

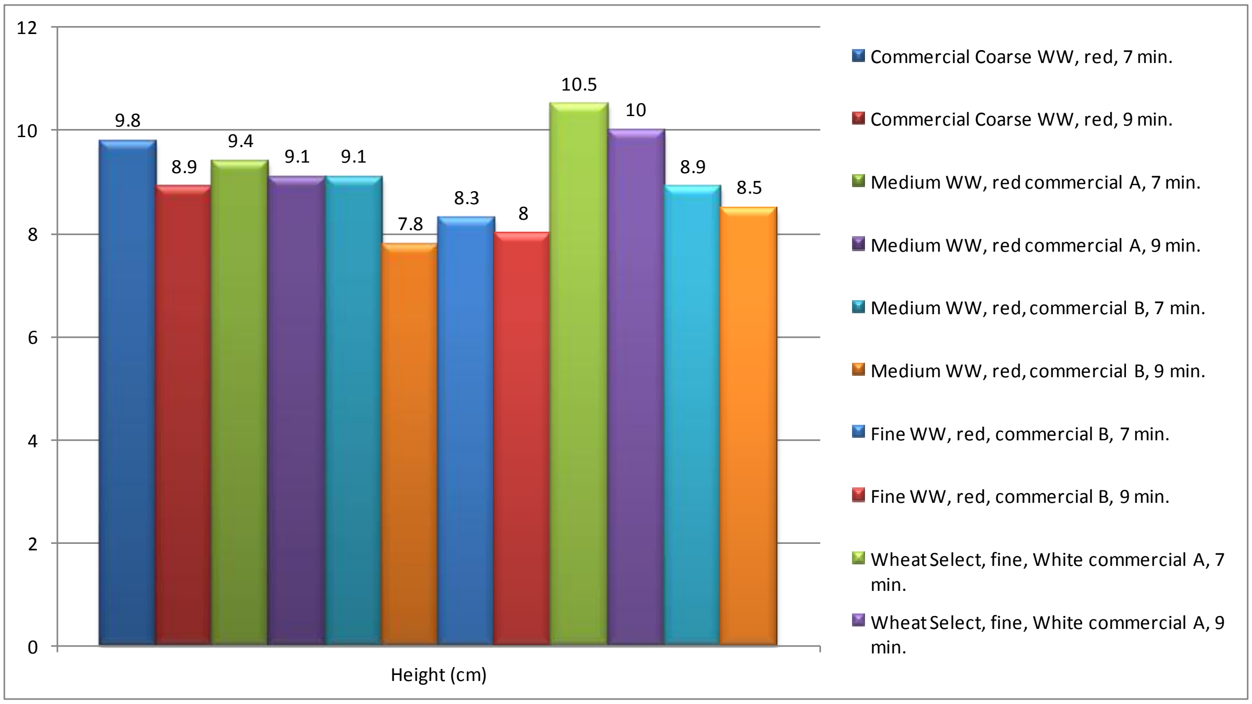


Figure 2-12: Identity Preserved White Wheat Varieties, Loaf Height Results

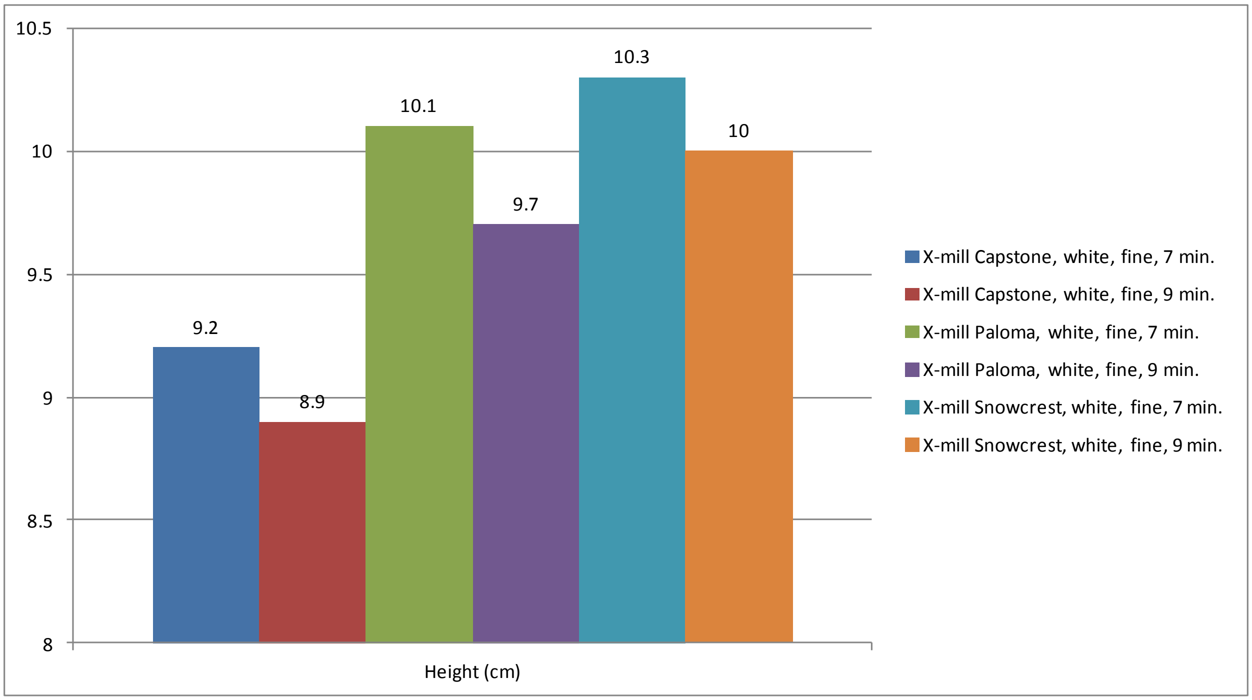


Figure 2-13: Photo of Commercial Bake Samples, ConAgra Medium Whole Wheat, ConAgra Fine Whole Wheat (WW)

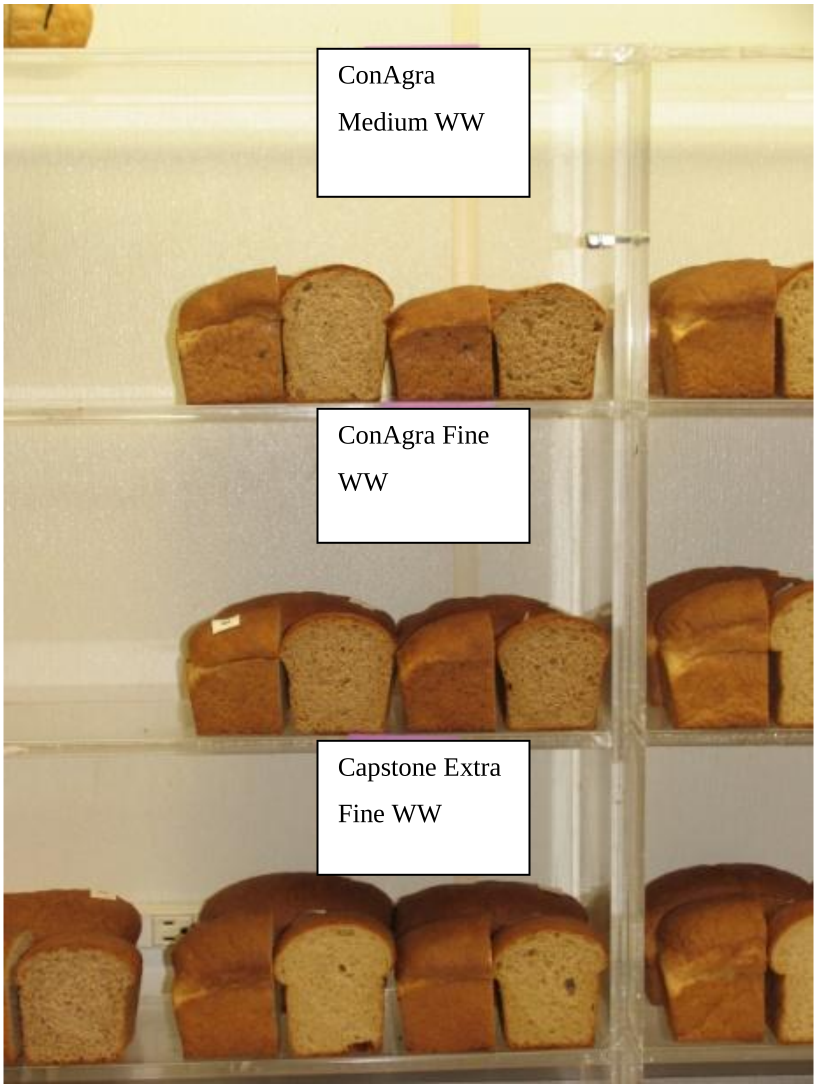


Figure 2-14: Photos of Commercial Bake Samples, Bay State Coarse Whole Wheat, North Dakota Mills Medium Whole Wheat (WW)

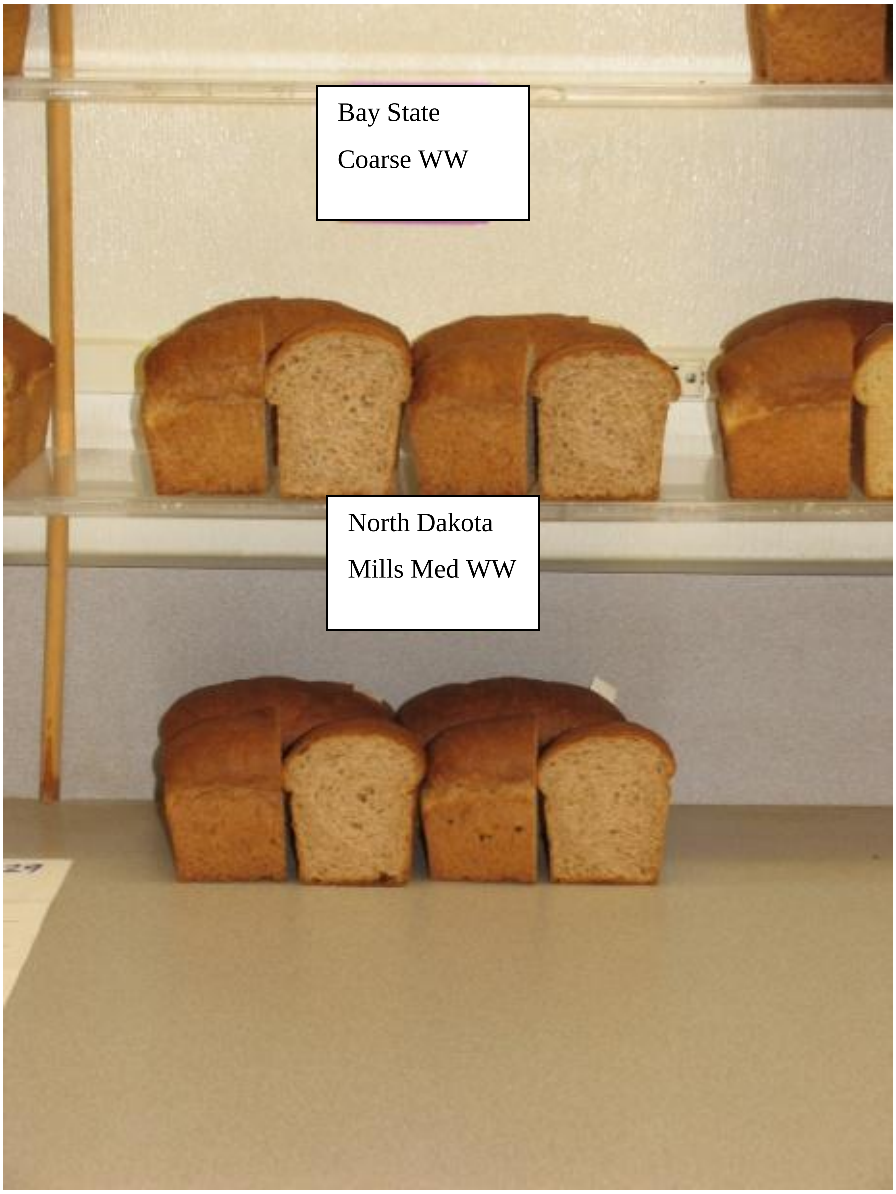


Figure 2-15: Photo of Commercial Bake Samples, White Whole Wheat (Wheat Select), Red Whole Wheat (WW) (Progressive Baker Fine Whole Wheat)

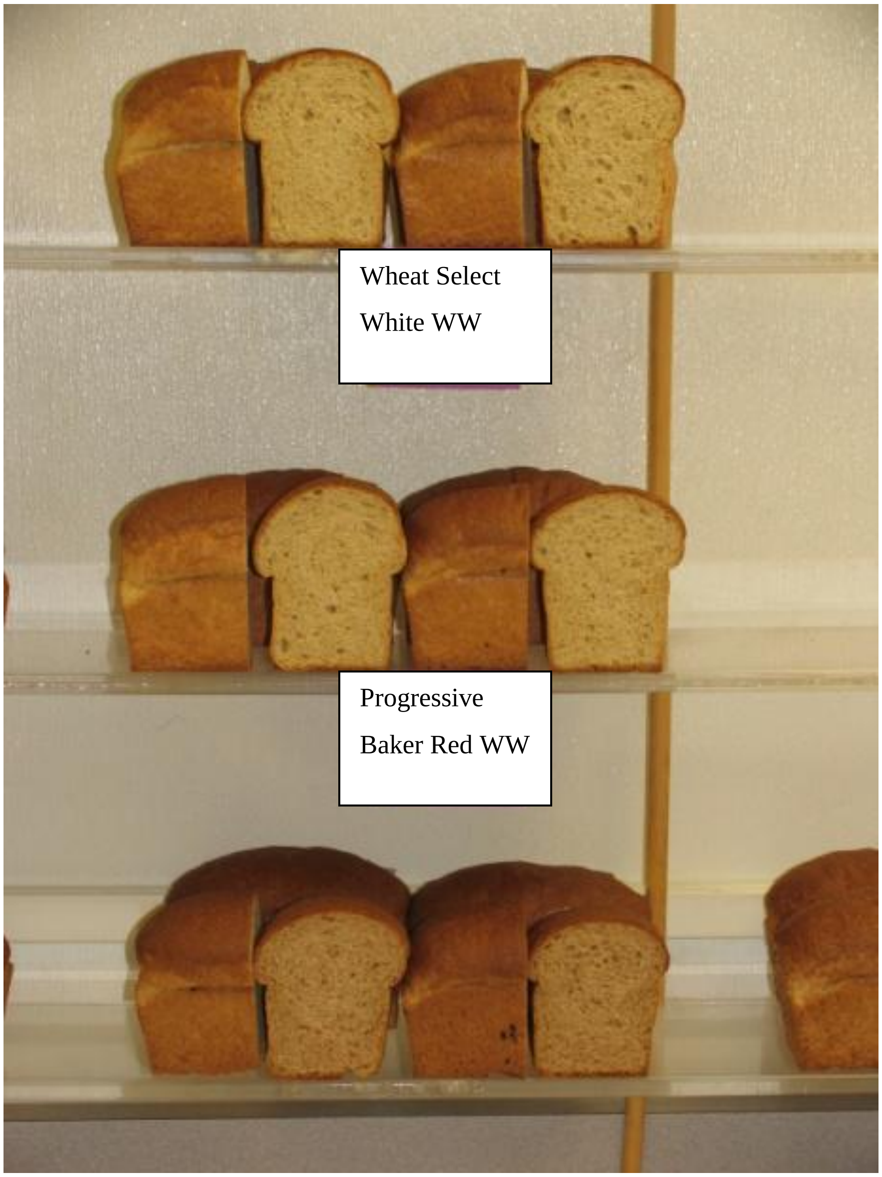
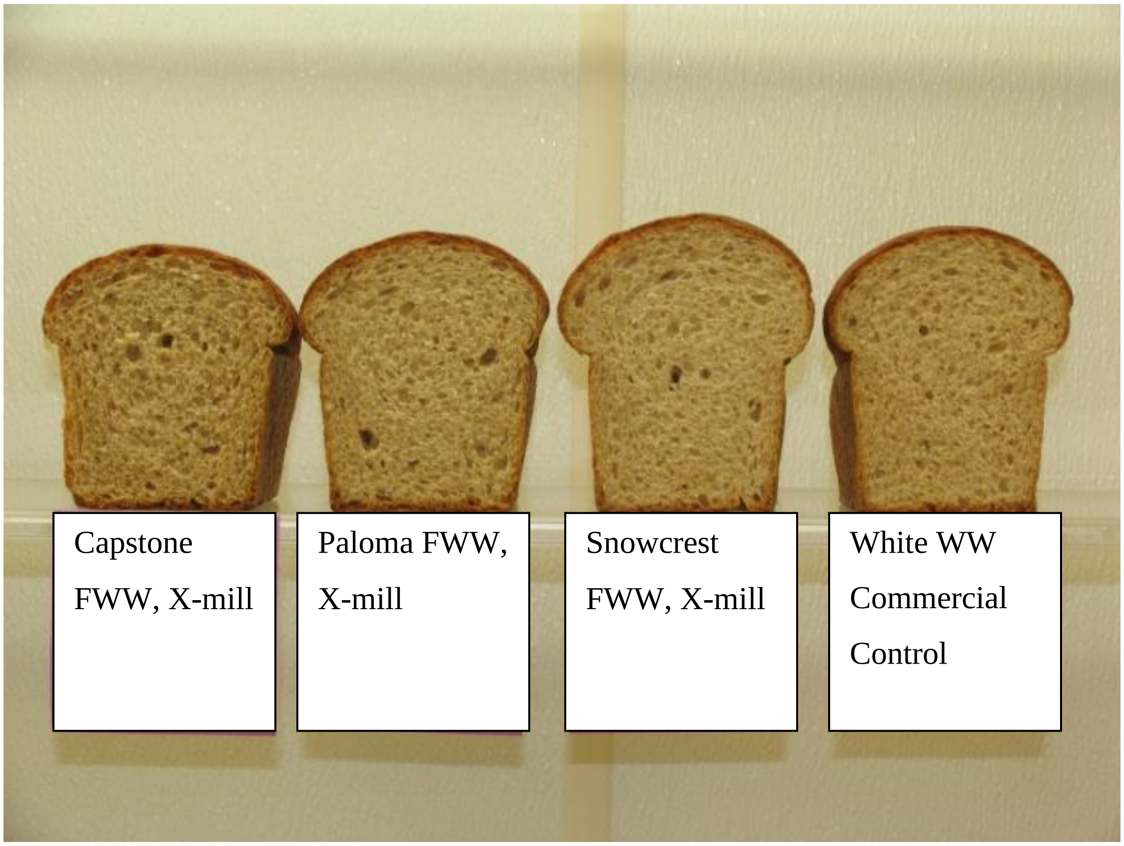


Figure 2-16: Photo of White Whole Wheat Variety (WW) Comparison: Capstone, Paloma, Snowcrest, Experimentally Milled and Identity Preserved Varieties

:



The third bake test was designed to continue work from part of the second bake test and compare four different identity preserved wheat varieties. Each of these samples were processed to the same granulation and milled the same way. The only difference between samples was the variety of wheat used. A commercial extra-fine white whole wheat sample was baked along these samples as a reference point (Table 11).

The results confirmed the preliminary work done from bake 2, stating that the difference in wheat variety appeared to be more significant for final product quality than processing. The results showed significant difference between varieties that were milled the same day, with the same process (Figure 2-18). These results agree with a study by Kock and others (1999). This study reviewed 10 wheat varieties and noted differences related to variety type and physical attributes.

The order from highest to lowest performer was Snowcrest, Paloma, Capstone, and then Alice. The commercial sample, Ultragrain performed in between the Capstone variety and Alice, so the lower 50% of the samples.

Table 11: Loaf Height, Mixing, and Dough Handling Results of Bake Test 3, A Comparison of White Wheat Varieties, Extra-Fine Grinding Step

Sample	Mixing Time (min.)	Mixing Score (mix score scale)	Bench Score (bench score scale)	Bench Comments	Proof Time (min)	Height (cm)	Difference between X-fine and fine (Height in cm)
X-mill Snowcrest, white, X-fine, 7 min.	7	65	11	great	42	10.6	10.6
X-mill Snowcrest, white, X-fine, 9 min.	9	60	10	good, soft	40	10	10
X-mill Capstone, white, X-fine, 7 min.	7	55	10	soft	44	9.3	1
X-mill Capstone, white, X-fine, 9 min.	9	40	9	pliable	49	8.5	0.5
X-mill Paloma, white, X-fine, 7 min.	7	65	10	great, very good	41	10	-0.5
X-mill Paloma, white, X-fine, 9 min.	9	55	10	slightly pliable	41	9.4	-0.6
Commercial, white, Ultragrain, 7 min.	7	55	9	extensible	41	8.9	
Commercial, white, Ultragrain, 9 min.	9	40	6	putty, pliable	44	8.5	
X-mill Alice, white, X-fine, 7 min.	7	80	9	dry, pliable	44	8.5	
X-mill Alice, white, X-fine, 9 min.	9	60	10	soft, pliable	52	6.7	

Mixing Score Scale:	Description of Score:
85	Much stronger than optimum for bread baking
80	Stronger than optimum for bread baking
75	Slightly stronger than optimum for bread baking
65	Optimum for bread baking
60	Softer, but in optimum range for bread baking
55	Softer than optimumfor bread baking
45	Weaker than optimum for bread baking
40	Too extensible for bread baking
below 40	Undesirable for bread baking

Benching Score Scale:	Description of Score:
11	Above optimal, stronger than needed for commercial processing
10	Optimal, good for commercial processing with minimal problems
9	Good, slightly softer, however, still good for commercial processing
6	Mellow, softer, adequate for some commercial processes
5	Soft, adequate for processing at low speeds, extensible

Figure 2-17: Identity Preserved White Wheat Varieties, Comparison of Particle Size and Loaf Height Result from Bake 3

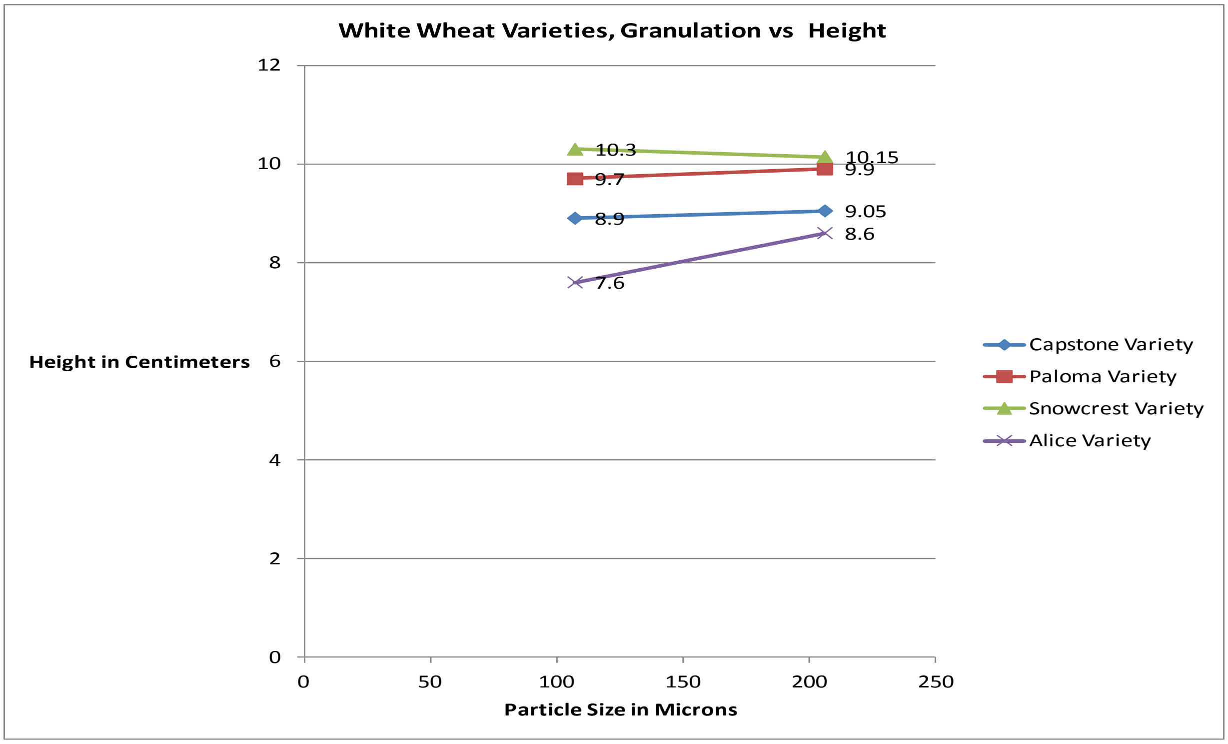
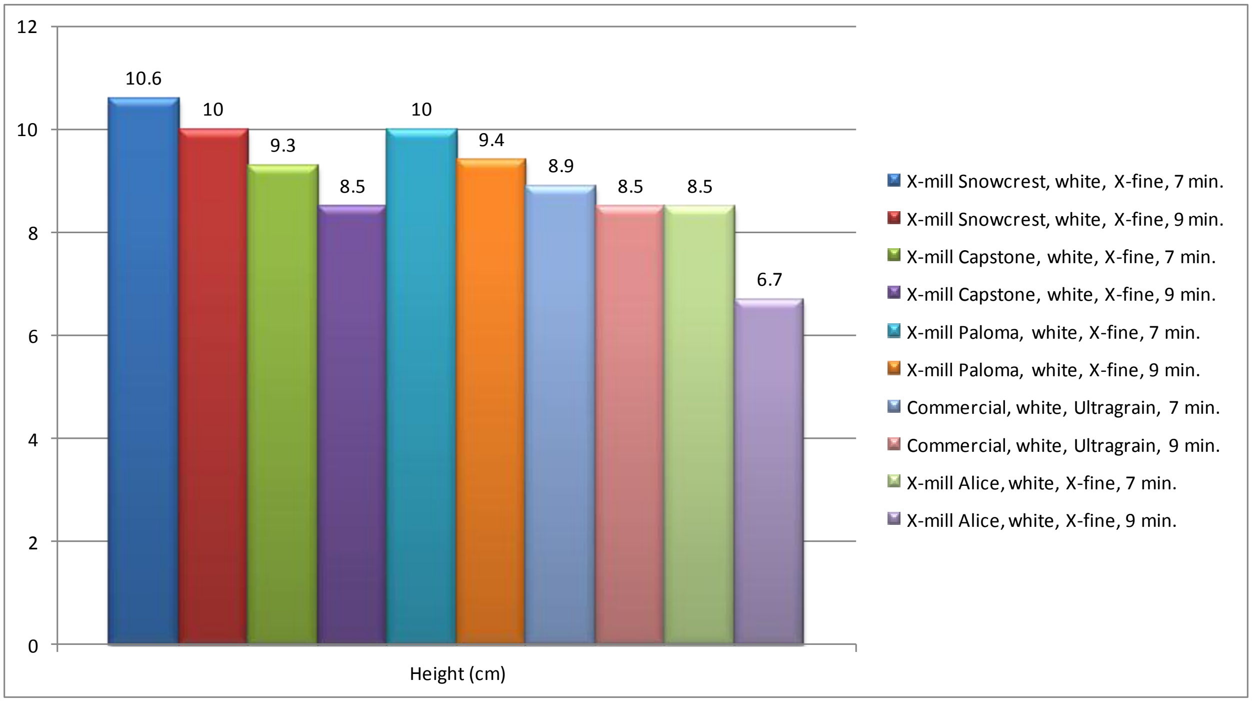


Figure 2-18: Identity Preserved White Wheat Varieties, Comparison of Loaf Height Results of Short versus Long Mixing Times from Bake 3



Another important understanding was to determine if the extra processing, or the extra-fine granulation created significant benefits or decreased functionality from the fine granulation processing. The results of this comparison were mixed. The Snowcrest variety showed a slight increase in volume from the extra fine granulation up from an average of 10.1 cm to 10.3 cm. The Capstone and Paloma varieties actually showed a slight decrease in volume with the extra-fine granulation (Figure 2-19).

Results from the Capstone and Paloma varieties agreed with studies performed by Noort and others (2010) and Kock and others (1999). Both studies indicated a correlation between finer bran particles and increased bake volume reduction. The height decrease appeared in the long mix times, possibly indicating a mixing tolerance issue. Because the 3rd bake only reviewed 3 varieties with extra fine granulation, it was difficult to make any statistical conclusions from these results.

Figure 2-19: Identity Preserved White Wheat Varieties, Comparison of Difference in Loaf Height of Fine vs. Extra-Fine Grinding Processing

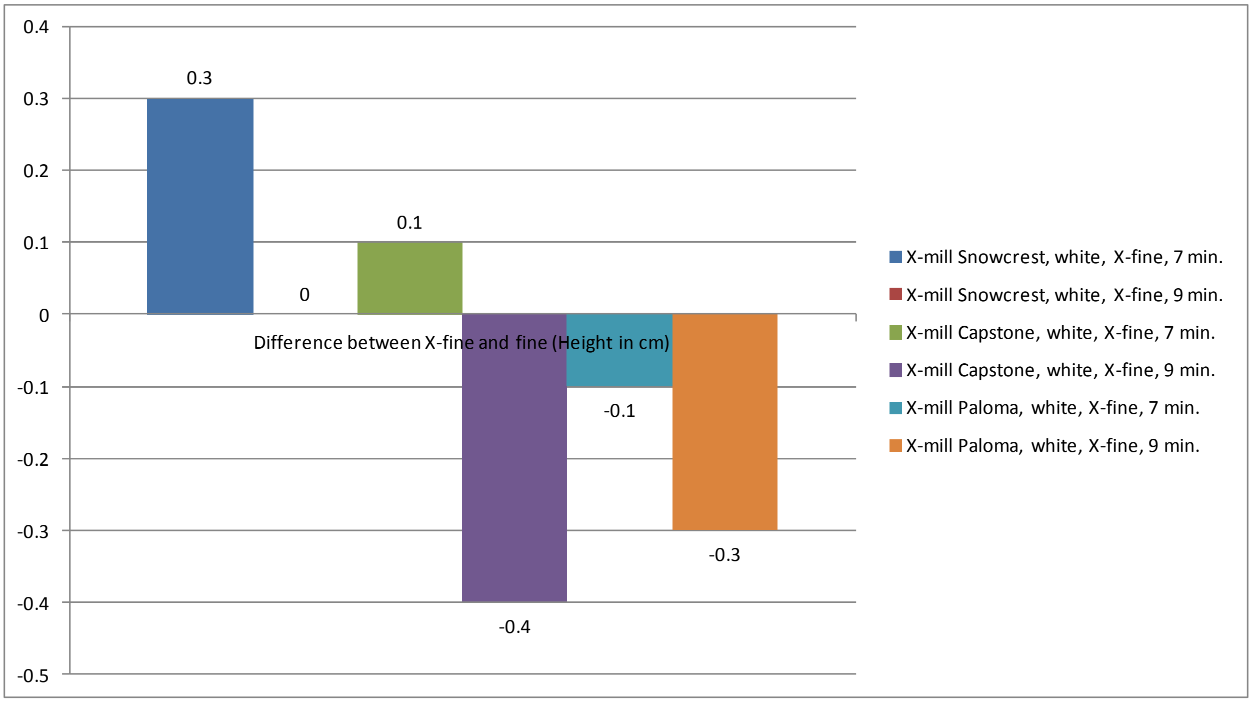


Figure 2-20: Photos of Bake 3 Results, 7 Min Mix Time

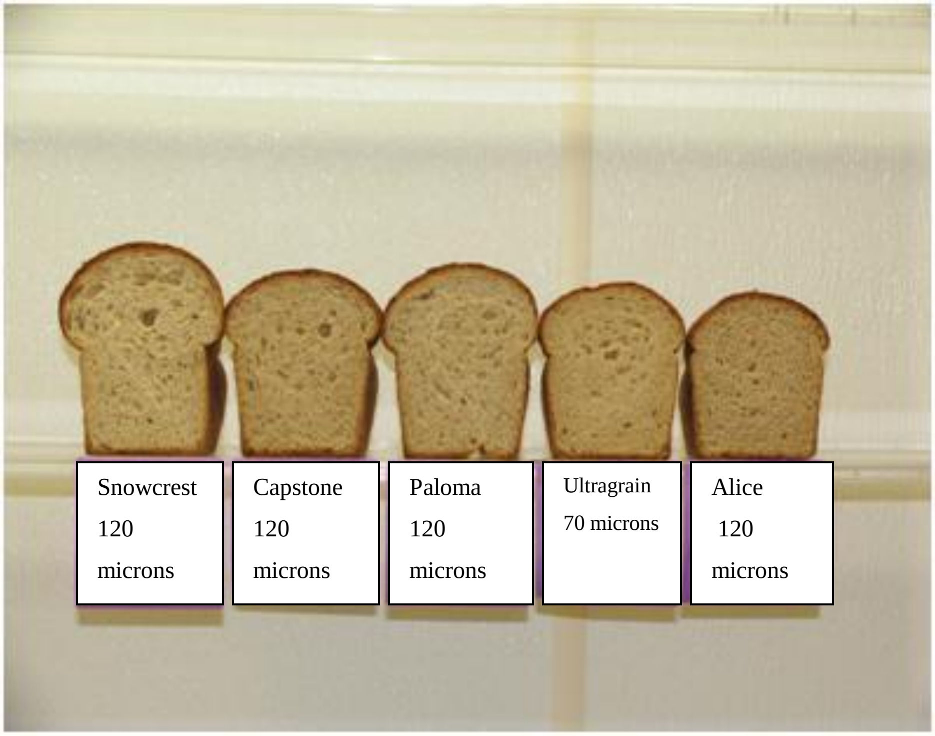
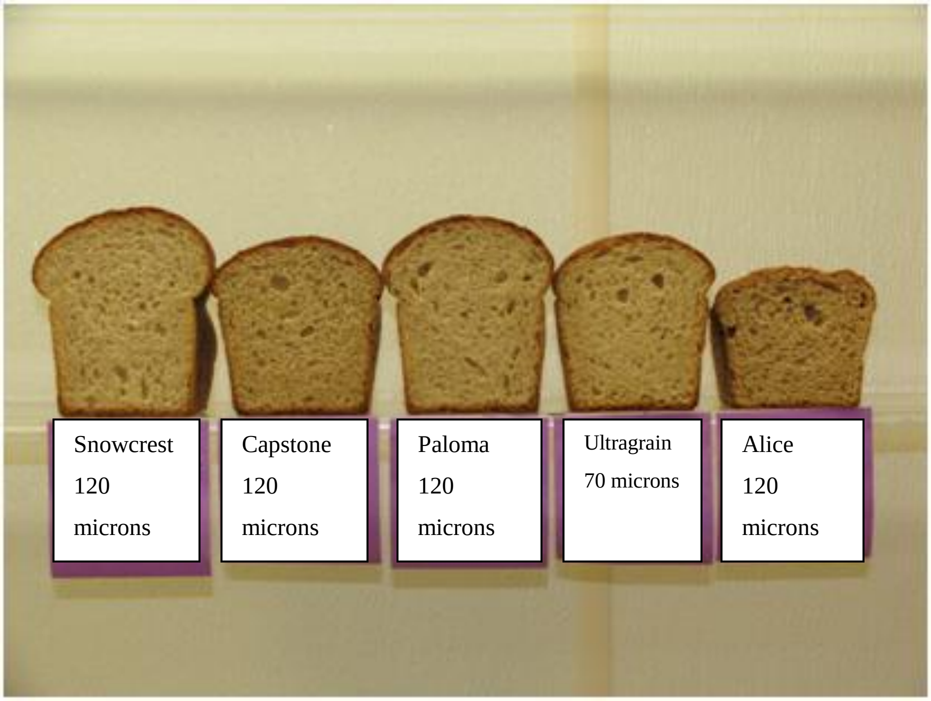


Figure 2-21: Photo of Bake 3 results, 9 Min Mix Time



Milling Study and Granulation Results

The commercial whole wheat flour samples reviewed had a wide range of particle sizes. The labeled fine, medium, or coarse whole wheat flours do not have a strict legal definition for particle size. The current definition of whole wheat flour as defined by the U.S. Food and Drug Administration for granulation is: “not less than 90 percent passes through a 2.36 mm (US No. 8) sieve and not less than 50 percent passes through an 850 micron (US No. 20) sieve (FDA, 2011b).”

As a result, the average diameter of the fine whole wheat flour’s tested ranged from 128 microns down to 72.9 microns. Five of the seven commercial samples reviewed were able to be run through the Cilas 1064 particle size machine to determine the mean diameter particle size with 95% accuracy. The remaining two samples, however, were too coarse to be run through this machine, so their average particle size was estimated by using the Ro-Tap granulation results and calculating a rough weighted average particle size.

The initial assumption was coarse, medium, fine, and extra fine whole wheat flour could be produced in an experimental mill using a hammer mill and a roll stand to closely reproduce the commercial whole wheat milling process. After further analysis from particle size testing, the results show it is very difficult to replicate this process on a smaller scale. The distribution of particle size was the most difficult characteristic to match. Coarse and medium whole wheat’s could be somewhat replicated, but fine and extra fine whole wheat particle sizes were not easily copied from a lab scale process.

The mean diameter for the lab scale fine grind whole wheat was approximately 200 microns. This mean particle size was approximately 80-120 microns larger than the commercial samples labeled as fine whole wheat. The main difference between the two types of samples was the amount of large particles above 200 microns present in the experimentally milled fine grind compared to the commercially milled samples containing a large amount of particles below 100 microns.

The experimental milling process for this granulation used the hammer mill to break open the wheat and reduce particle size initially. The broken and ground wheat pieces were then run through a roll stand with the primary purpose of separating the endosperm off of the ground wheat pieces to reduce some of the larger bran pieces. No sifting or re-grinding was done in this process. The flour produced from this type of process was closer to a commercial medium whole wheat granulation.

The lab scale milling process was able to create a product with a similar mean diameter to commercial fine whole wheat by adding a sifting and re-grinding step. The mean diameter particle size obtained from this process ranged between 107-122 microns, which was similar to some of the coarser commercial fine whole wheat’s.

The added step of re-grinding did not occur until after the stock had been run through the hammer mill and roll stand. The fine grind product was collected and run through a stock sifter, removing the particles greater than 414 microns and regrinding through the hammer mill. The hammer mill was equipped with a 1.0 mm screen for this regrind. After the stock was reground, it was reconstituted back into the remaining product and blended for 5 minutes in a flour blender to create a homogenous blend, making sure none of the bran was removed from the process.

This type of process reduced the coarse bran particles of stock to a finer particle sizes, however, it was unable to reduce the medium to fine particles created from the initial milling process to a finer size. This type of re-processing and regrinding showed the limitations of the experimental milling process. To create a finer granulation product it would be necessary to have more sifting and a hammer mill or roll stand capable of reducing medium particles to a fine particle size. While regrinding bran stock, the hammer mill would often choke or the stock feeding rate would be too fast or slow for the grinding process to be consistent.

While the product created from this lab scale process had similar mean diameter particle size, the distribution of particles was still significantly different than a commercial mill, as noted by the particle size testing. More fine particles were created with this added processing, however, the smooth and even distribution of particles from a commercial process was not able to be replicated. With the limited equipment available, it was not possible to replicate an extra-fine grind whole wheat granulation like the commercial Ultragrain sample has. As a result, it was unable to be determined if products with a very fine granulation such as this one have been processed to a level of fineness that decreases final product bake functionality.

Conclusion

The study and work completed involved many of the current whole wheat flours available in the market place today from a variety of the larger commercial miller's in the United States. A good sampling of products were reviewed with different granulations from coarse to extra-fine whole wheat. The majority of the commercially milled flours tested were produced from red wheat's, however, two of the products were made from white wheat's.

This cross-section of flour samples would appear to be representative of what is seen in today's marketplace. The majority of whole-wheat or whole grain products sold in the baking section of grocery stores are made from red whole wheat. The reason for this is most likely due to the availability of hard white wheat and the extra costing involved with sourcing, procurement, transportation, and identity preservation of these varieties. The extra costs involved in creating a supply chain for hard white wheat products are something that most consumers would not pay more for.

The functional characteristics as well as the particle size and granulation were reviewed on all samples through bake testing and two different particle size determinations. The results of the experimental milling of the identity preserved varieties and baking of commercial samples had two significant findings. First, it was discovered that product milled more coarsely had lower loaf height’s, more open grain, and were drier to the touch, possibly impacting sensory attributes. Also, bread from both white and red wheat varieties showed an increase in loaf volume as particle size decreased with further milling and particle size reduction.

However, Noort and others (2010) discussion would appear to support our findings with fine and extra-fine granulation products. Results from both commercially milled products and experimentally milled products show similar conclusions that when particle size becomes very fine, less than 110 microns, baking functionality can decrease.

The commercially milled Ultragrain product had the finest mean particle size at approximately 70 microns. This product showed characteristics of a stiffer, less extensible gluten network and lower final product loaf volumes. Comments from the makeup and mixing of dough’s from this flour often described the dough as pliable, putty, and dry. In addition, some of the extra-fine grind samples produced from the experimental milling process actually showed a loaf volume reduction from the fine grinding, 200 micron particle size, to the extra-fine processing, 110 micron particle size. The results from the experimentally milled products were somewhat inconclusive, as not all extra-fine grind products showed a decrease in final bake volumes or dough handling issues.

In summary, it would appear that both granulation of whole wheat flour and wheat variety type used are directly related to flour functionality and baking quality. The abbreviated study performed using four separate white wheat varieties indicated that wheat variety type could potentially be more significant for final product functionality than granulation or processing. More studies are needed in this area to better understand these findings.

Whole wheat processing, or granulation, also have significant impact on final product functionality. There would appear to be an optimal granulation for whole-wheat functionality as baking performance and dough handling improved with the fine and extra-fine whole wheat's tested. The experimental milling process, however, does not match a commercially milled whole wheat product closely. The limitations in the experimental milling process were determined by equipment available and ability to regrind coarse and medium bran pieces into fine and very fine particle sizes. It was not possible to effectively sift and regrind product in a lab scale without losing part of the bran due to equipment failure. To effectively determine optimal whole wheat granulation size, further work would need to be completed on a larger experimental mill scale or a small commercial mill with improved process controls.

Chapter 3 - References

Akhtar S, Ashgar A. 2011. Mineral fortification of whole wheat flour. In: Flour and Breads and their Fortification in Health and Disease Prevention. New York: Elsevier. p 263-71.

Anonymous. 2011a. Food Deserts: If you build it, they may not come. The Economist 8741:31.

Anonymous. 2011b. Food scientists explore refined grains role in American diet. Milling and Baking News 90:1-18.

Barnes PJ, Lowy GDA. 1986. The effect on baking quality of interaction between milling fractions during the storage of wholemeal flour. J Cereal Sci 4:225-32.

Dziski D. 2008. The crushing of wheat kernels and its consequence on the grinding process. Powder Tech 185:181-86.

Edge M, Jones JM, Marquart L. 2005. A new life for whole grains. J Amer Dietetic Assoc 105:1856-60.

FDA. 2011a. 21 CFR 136.100. Bread, rolls, and buns. Fed. Reg. 21.

FDA. 2011b. 21 CFR 137.200. Whole wheat flour. Fed. Reg. 21.

Gan Z, Galliard T, Ellis PR, Angold RE, Vaughan JG. 1992. Effect of the outer bran layers on the loaf volume of wheat bread. J Cereal Sci 15:151-63.

Gordon DT, Wrigley C. 2004. Whole-grain versus refined products. In: Wrigley C, Corke H, Walker CE, editors. Encyclopedia of grain science. New York: Elsevier p 424-29.

Hemery Y, Chaurand M, Holopainen U, Lampi AM, Lehtinen P, Puronen V, Sadoudi A, Rouau X. 2011. Potential of dry fractionation of wheat bran for the development of food ingredients, part I: Influence of ultra-fine grinding. J Cereal Sci 53:1-8.

Kihlberg I, Johansson L, Kohler A, Risvik E. 2004. Sensory qualities of whole wheat pan bread-influence of farming system, milling and baking technique. J Cereal Sci 39:67-84.

Kock S, Taylor J, and Taylor, JRN. 1999. Effect of heat treatment and particle size of different brans on loaf volume of brown bread. Lebenesm.-Wiss. U.-Technol 32:349-56.

Liu RH. 2007. Whole grain phytochemicals and health. J Cereal Sci 46:207-19.

Mousia Z, Edherley S, Pandiella SS, Webb C. 2003. Effect of wheat pearling on flour quality. Food Research Intnl 37:449-59.

Noort MWJ, Haaster D, Hemery Y, Schols HA, Hamer RJ. 2010. The effect of particle size of wheat bran fractions on bread quality-Evidence for fibre-protein interactions. J Cereal Sci 52:59-64.

Osborne BG, Henry RJ, Southan MD. 2007. Assessment of commercial milling potential of hard wheat by measurement of the rheological properties of whole grain. J Cereal Sci 45:122-27.

Ozboy O, Koksel H. 1997. Unexpected strengthening effects of a coarse wheat bran on dough rheological properties and baking quality. J Cereal Sci 25:77-82.

Penella JMS, Haros CCM. 2008. Effect of wheat bran and enzyme addition on dough functional performance and phytic acid levels in bread. J Cereal Sci 48:715-21.

Peressini D, Sensidoni A. 2009. Effect of soluble dietary fibre addition on rheological and breadmaking properties of wheat doughs. J Cereal Sci 49:190-201.

Posner ES, Hibbs AN. 2005. Wheat Flour Milling. 2nd ed. St. Paul, MN. AACC. p 125-53.

Shah AR, Shah RK, Madamwar D. 2006. Improvement of the quality of whole wheat bread by supplementation of xylanase from *Aspergillus foetidus*. Bioresource Technology 97:2047-53.

Tait SPC, Galliard T. 1988. Effect on baking quality of changes in lipid composition during wholemeal storage. J Cereal Sci 8:125-37.

Wang J, Rossell CM, Beneditio de Barber C. 2002. Effect of the addition of different fibres on wheat dough performance and bread quality. Food Chem 79:221-26..

Williams C L, Warber LTC JP. 1997. In defense of dietary fiber. JADA 97:248.

Appendix A - Experimental Milling

Figure A-1: Photo of Experimental Hammer Mill Used for Initial Grinding

Figure A-2: Hammer Mill, Settings at 6,000 R.P.M.'s

Figure A-3: Photo of Hammer Mill Screen Sizes, 3.0 mm, 2.0 mm, and 1.0 mm from Left to Right

Figure A-4: Photo of Experimental Roll Stand

Figure A-5: Roll Stand Speed Settings

Figure A-6: Photo of 22 Stainless Steel Bolting Cloth, Coarse Stock

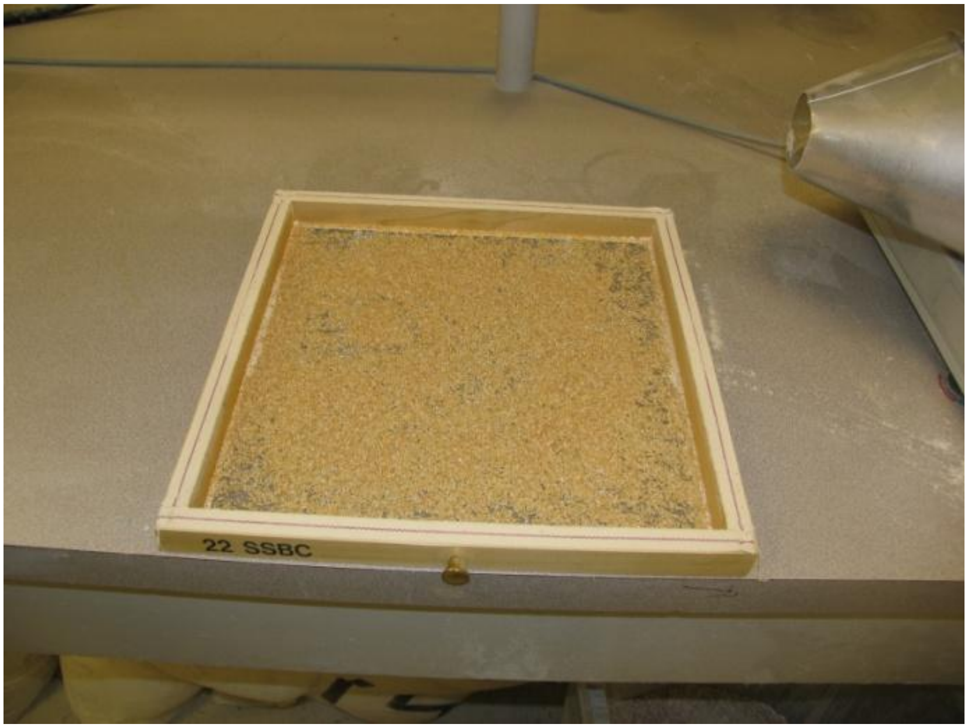


Figure A-7: Photo of 24 Stainless Steel Bolting Cloth, Coarse Stock

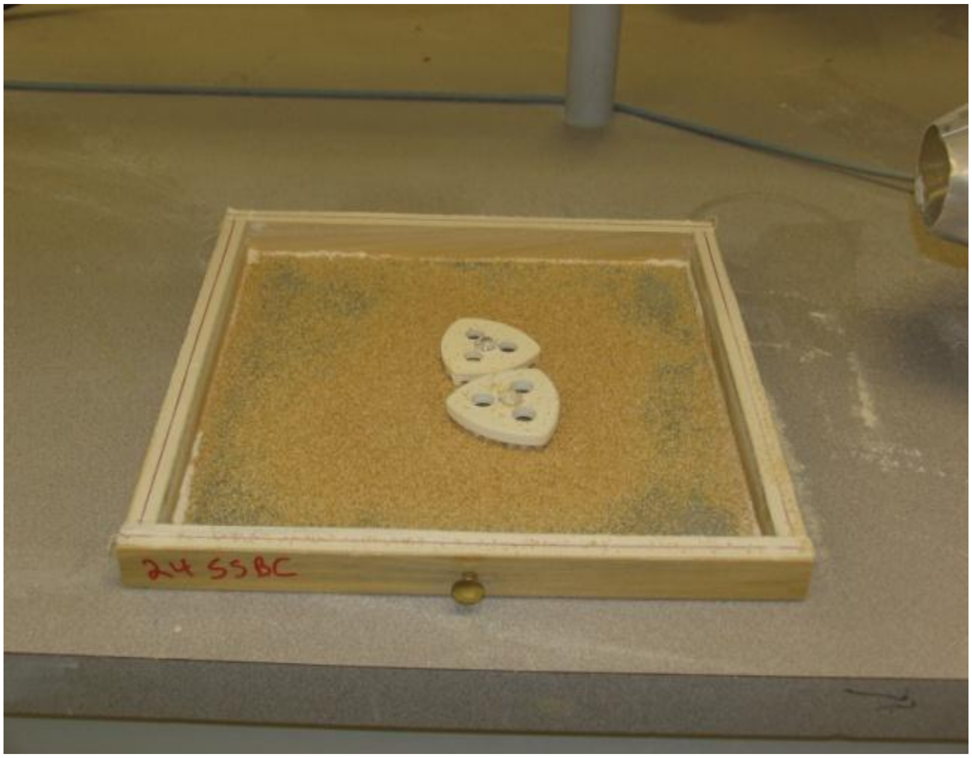


Figure A-8: Photo of 28 Stainless Steel Bolting Cloth, Medium Stock

Figure A-9: Photo of 48 Stainless Steel Bolting Cloth, Fine Stock

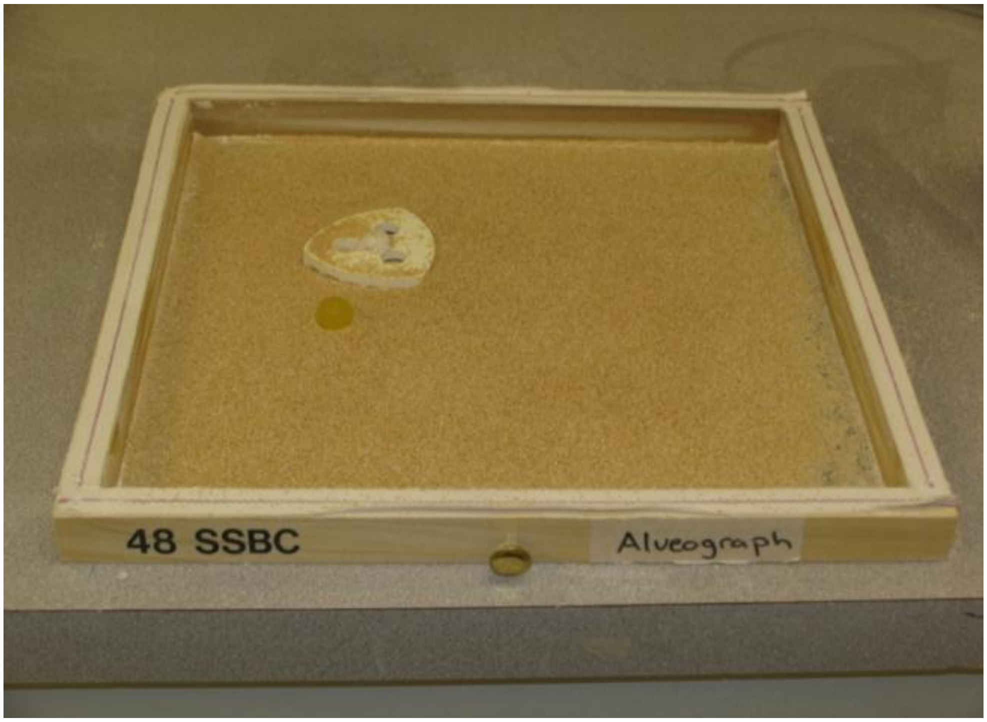


Figure A-10: Photo of Combined Stock of Over's From Sifting

Figure A-11: Photo of Stock Not Reground, Thru's

Figure A-12: Ro Tap Granulations of Commercial Whole Wheat Samples (WW)