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Evaluation of Kentucky Grown Soft Red Winter Wheat with Sensory Evaluation for Bread-making Capabilities and Quality

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THESIS

A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Science in Nutrition and Food Systems in the
College of Agriculture, Food and Environment
at the University of Kentucky

By

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ABSTRACT OF THESIS

Evaluation of Kentucky Grown Soft Red Winter Wheat with Sensory Evaluation for Bread-making Capabilities and Quality

Soft red winter (SRW) wheat is a type of wheat that is best suited to grow in Kentucky. However, due to its low protein content, it is an undesirable flour for bread and is usually used for cakes, cookies, crackers, and pastries. This is problematic because this limits the ability for commercial bakers to have a local source of flour, forcing them to purchase from sources outside the state. In doing so, bakers are sacrificing freshness and quality. It also removes the opportunity to keep profits in Kentucky, contributing to the state's economy. The purpose of this study was to investigate the bread-making ability of 68 different genotypes of SRW wheat grown by the UK Wheat Breeding program and to determine if any one variable used in the study could be used as a predictor for high bread quality. This was done through measurements taken during the baking process and a tasting panel. With only three genotypes having significantly lower height, it was found that the genotypes used in this study were able to produce loaf sizes comparable to commercial wheat used for bread-making. There were also two genotypes that scored significantly higher in the aroma category when compared to the control. However, there were no differences measured in crust and crumb texture, crust and crumb flavor, overall quality of the crust and crumb, and overall quality variables. While bready quality was determined to be acceptable, no independent predictor for bread quality could be determined.

KEYWORDS: Soft Red Winter Wheat, Sensory Evaluation, Baking Quality, Near Infrared Spectroscopy (NIR), Loaf Height, Loaf Diameter

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TABLE OF CONTENTS

List Of Figures

CHAPTER 1. INTRODUCTION

Summary

There are many different varieties of wheat (Triticum aestivum L.) that can be used in bread-making, but not every variety of wheat can be grown in every environment. Most winter wheat used for bread baking is hard red winter wheat (HRW) and is grown primarily in the Midwest (Guercio, 1999). The soft red winter wheat (SRW) is the type of wheat grown in Kentucky. Kentucky farmers harvested 23.9 million bushels of winter wheat from 310,000 acres during 2017. (National Agriculture Statistics Service, 2019).

When comparing types of wheat, one of the first differences observed among wheat types is kernel hardness. Harder wheats form a larger particles size when milled into flour. Larger particle sizes are ideal for bread-making because flour with larger particle sizes has an increased water absorption which is ideal for breadmaking (Scotter, 2004). The smaller particle size of the SRW wheat is more ideal for cakes, pastries, cookies, and crackers. Another difference among types of wheat is the protein content. HRW wheat typically has a higher protein content than SRW wheat; the higher protein content is often associated with higher gluten strength (Bruckner, 2001). Gluten is a combination of the two proteins gliadin and glutenin. The combination of all these properties is what gives HRW wheat an advantage in bread-making. With the trend in selling local, Kentucky wheat growers would like to enhance the profitability of their wheat by selling to local bakeries, but because HRW isn’t be grown in Kentucky, local bakers are forced to purchase flour from mills located outside of the state and grown even further away (Jim Betts, personal communication 2018). This situation denies bakers access to freshly milled flour and removes money from the state's economy.

Statement of the Problem

In this proof of concept research project, many different breeding lines of SRW wheat from the University of Kentucky's breeding program will be evaluated for bread-making qualities in hopes of finding a suitable wheat cultivar that can be grown in Kentucky. Hereafter, the terms "varieties", "cultivars", "strains" and "breeding lines" are used interchangeably. The UK wheat breeding program aims to release improved cultivars of SRW wheat adapted to KY. The project grows about 12-14,000 experimental plots each year at 4-6 locations around Kentucky. These plots are evaluated for agronomic and pest resistance traits and a subset of the breeding lines are evaluated every year at the USDA-ARS Soft Wheat Quality Lab for milling and baking quality (https://www.ars.usda.gov/midwest-area/wooster-oh/corn-soybean-and-wheat-quality-research/docs/swql-home/). For many years, the focus has been on commodity wheat rather than local adaptation and end use specificity. In 2013, however, in response to a local baker, the project began to screen breeding lines for flavor and dough functionality in bread. Despite some SRW wheat not having the gluten strength or protein content that HRW wheat has, it is hypothesized that some SRW wheats have other redeeming attributes that can make them suitable for breadmaking. There are no known varieties of SRW wheat that can produce a quality bread product. This removes the opportunity for Kentucky to have a self-sustainable local bread industry and limits the availability of flour selection for local bakers. Through selective wheat breeding, it may be possible to find or create a quality SRW wheat capable of producing the desired bread-making quality. The purpose of this proof of concept research project is to evaluate many varieties of SRW wheats through basic sensory evaluation and pre- and post-measurements of height and diameter to assess their potential to make bread and fill the unmet need. This project will also give insight on the acceptability of SRW wheat bread and contribute to the knowledge related to the specific Kentucky breeding lines in relation to taste and gluten strength. This research will be beneficial to the University of Kentucky's wheat breeding program as well.

Research Questions:

1. Will flour from an SRW wheat variety produce a loaf size acceptable for commercial use that is comparable to HRW wheat flour?
2. Will there be significant taste differences among the different varietal lines assessed compared to the control?
3. Is there one variable measured in the study that is a better predictor for overall bread quality?

Hypotheses

1. It will be possible to find a SRW wheat variety that has an adequate amount of protein to produce an acceptable loaf size when compared to the HRW wheat flour control.
2. There will be a significant taste difference observed between not only the different breeding lines, but when compared with the HRW wheat control.

3. As loaf volume is a desired attribute of bread-making. It is hypothesized that loaf height or protein will be an acceptable predictor of overall bread quality.

Justification

Currently there is little to no information about the properties of the Kentucky grown wheat other than yield and agronomic performance. This information is key to evaluating whether current breeding lines would be suitable for commercial bread-making. This could contribute to a new cash crop for Kentucky farmers and possibly lead to product development in local bakeries. This is a great opportunity to make Kentucky's bread industry more locally sustainable.

CHAPTER 2. BACKGROUND ON WHEATS USED FOR BREADMAKING

History of Baking Bread

For years, archaeologists believed that humans began making bread about 10,000 years ago. But recent excavations prove that ancient nomads in the Middle East began farming and growing cereals 14,000 years ago. These grains and roots were milled into flour and baked on hot rocks to make a sort of flat bread. (Arranz-Otaegui, 2018). Over the years, leavened varieties appeared and with the industrial age came the roller mill and large batches of bread that resemble our current day soft grocery store loaf.

Three primary innovations created the modern bread loaf: leavening, refined flour, and mechanized slicing.

• **Leavening**

The most common source of commercial bread leavening is yeast (Saccharomyces cerevisiae). Yeast can be found floating in the air. If the yeast finds its way into a flour and water mixture, it will slowly start to grow and cause the dough to rise. In the 1860's scientists began to isolate yeast. By the turn of the 20th century, commercial production of baker's yeast began.

• **Refined flour**

While the earliest bread grains were ground by hand using rocks, this resulted in a coarse whole grain bread, similar to our modern-day pumpernickel. Today, we remove the bran and germ and mill the flour to create a smooth, finely-ground flour, often bleaching the flour for a whiter appearance.

• **Mechanized slicing**

In 1928, a bread-slicing machine was installed into a bread-baking factory. Two years later, 90% of store-bought bread was factory sliced.

Since that time, cereal chemists have been studying the effects of the increasingly complex science of quality in the bread-making process and wheat varieties that are best for the commercial production of bread.

The Chemistry of Bread-Making

Bread is consumed around the world. Statista Research & Analysis, a provider of market research states that in 2019, an estimated revenue from bread sales will be around $2.2 billion dollars. The market is expected to grow annually by 3.6%. Globally, the largest sales (approximately 15%) originate in the US with an average per capita consumption of around 35 pounds. (Statista Research and Analysis Market statistics, 2019).

Typically, bread is a food that is low in protein and fat and high in carbohydrates. By law, calcium, iron, thiamin, and niacin are added to all brown and white flours sold in the United States. But there are five ingredients are an important part of making quality bread. Depending on the desired bread consistency, bread is 60-75% water by weight. Water makes the dough consistent and disperses the ingredients evenly, while also controlling the temperature of the dough. A small amount of fat (up to 3%) aids in softening the texture and supporting the development of gluten. Fat prolongs the keeping qualities of the bread by both inhibiting starch crystallization and preventing the evaporation of water from the loaf. While yeast and salt are added in small amounts (1-2%), they are an essential part of the fermentation process. Yeast acts as the leavening agent, providing the production of carbon dioxide during fermentation that makes the bread rise. Salt regulates the speed of the fermentation, adds flavor and strengthens gluten development. The proportion of these ingredients is all dependent on the flour used in the bread-making. Besides natural sugars that feed the yeast, flour is the source of gluten-forming proteins. Long strands of these proteins initially hold the shape of the bread. Then while in the oven, the starch around the protein sets and forms the loaf. The protein framework gelatinizes and softens, giving yeast bread the characteristic chewy texture. Other ingredients, such as eggs, bread improvers, sugar and milk powder are used to impart various qualities to bread. Figure 1 illustrates the chemistry of bread-making. Commercial bakers use these basics to create their own bread recipes for specific and desired results.

Types of Wheat Used for Bread-making

There are several organizations that are trying to develop, maintain and expand markets to enhance the profitability of US wheat producers; these include the International Wheat Yield Partnership, National Association of Wheat Growers and the US Wheat Associates. Commercial bakers are supported by the American Society of Baking, among others. All these partners are working to find the best varieties of wheat and ingredients to produce quality products at an increased profit.

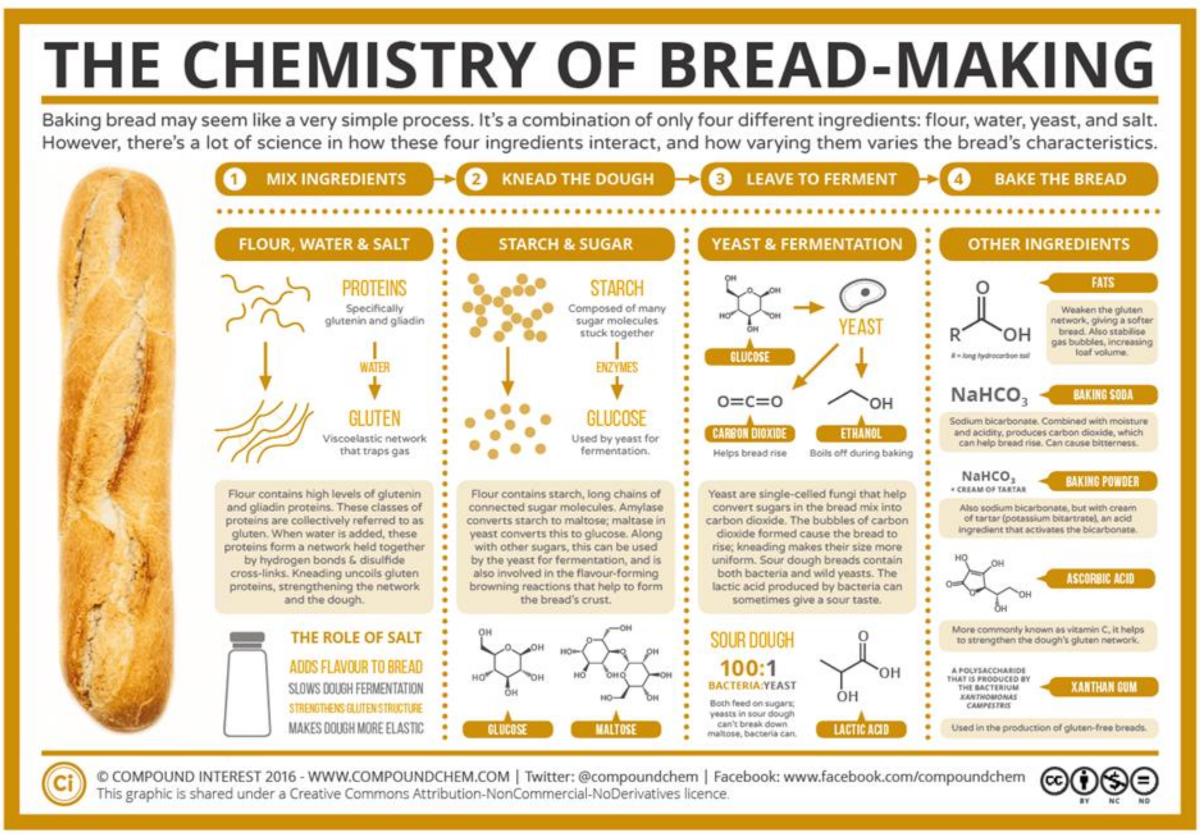

Figure 1. The Chemistry of Bread-making

When it comes to baking, there are different types of wheat flours that come from different types of Common wheats. These are used for bread-making and usually consist of hard red winter (HRW) and hard red spring (HRS) wheat. Another type of wheat that is starting to grow in popularity that has shown promise in bread-making capabilities is hard white winter wheat (HWW) wheat, though it is not grown as widely as HRW wheat. These hard wheats are grown throughout the mid-western part of the United States (Guercio, 1999) and milled in many different locations. The most common wheat grown in the United states is Triticum aestivum L, also called common wheat. (Scotter, 2004)

Bread-Making Properties

There is more to the quality of a great loaf of bread than appearance. Since the 1986 publication of the American Association of Cereal Chemists, Approved Methods of the AACC for Quality Bread products, research has been ongoing to find modernized sensory evaluation methods for quality bread-making. In the 11th edition, online, guidelines are available to assist test bakers in scoring experimental white pan bread. The quality characteristics considered are loaf appearance, crust color, crumb structure, and crumb color. In contrast, a recent article proposes a methodology for the sensory analysis of bread that outlines 46 attributes sorted by sensory groups (17 for visual, nine for odor, 12 for flavor and eight for texture), evaluating crumb and crust separately (Elia, 2011).

Equipment such as a farionograph, alveograph, extensograph, and mixograph, just to name a few, make evaluation expensive and time consuming. But standard sensory methodology leads to not only the best technological quality, but also the ability to consistently meet consumer expectations. Recent advances in bread-making include the application of rheology (the study of flow in response to pressure) of dough. Dough rheology is of particular interest in bread-making because of the effect of elasticity and extensibility of bread dough on final bread qualities (Amjid, 2013).

There is a body of research that looks at all the rheological properties and measurements of dough and gluten. Much time has been spent on determining the rheological properties of dough (Khatkar et al., 2002; Uthayakumaran et al., 2002; Sliwinski et al., 2004a; Chin and Campbell, 2005; Chi et al., 2005; Indrani and Rao, 2007; Skendi et al., 2010) and gluten (Khatkar et al., 2002; Tronsmo et al., 2003; Song and Zheng, 2008). Most application studies find that rheological properties are in direct correlation with optimum bread loaf volume (Tronsmo et al., 2003; Sliwinski et al., 2004b; Dobraszczyk and Salmanowicz, 2008), texture (Uthayakumaran et al., 2002; Vetrimani et al., 2005; Jacob and Leelavathi, 2007; Sudha et al., 2007) and sensory attributes (Bhattacharya et al., 2006; Lazaridou et al., 2007). Sliwinski, et al, 2004b found that rheological properties of dough and gluten are affected by the flour composition (low or high protein content), finding a strong correlation between flour protein content and gluten strength. This collective research supports the need for a higher protein flour to produce a higher quality product.

The flour composition (low or high protein content) is of concern in finding the best varieties of wheat for bread-making in Kentucky. High protein content of bread-making flours traditionally results in high loaf volume. (Bruckner, 2001) HRW and HRS wheats are known for their high protein content (Finney 1987). Since grain protein is primarily used to determine gluten strength (Souza, 2012), HRW and HRS wheats are the gold standard for producing a sizable, quality bread products.

Gluten is a key component that is used for determining whether a flour is suitable for bread-making. Gluten consists of two proteins, gliadin and glutenin (Aziz, 2015) and gluten strength is measured by the capacity of these two proteins to form a gluten network. (Souza, 2012) Naturally, protein content is moderately correlated with loaf volume. (Seabourn, 2012) When baking, CO2 gets captured in the gluten network and causes the product to inflate. There are different ways to asses gluten. Studies in the past have looked at cookie diameter to gauge gluten strength in SRW. An increase in the diameter of cookies was negatively correlated with gluten strength. A study by Souza on selecting soft wheat for end use quality shows that cookie diameter is valuable indicator for soft wheat quality. On the other end of the spectrum, loaf height can also be an indicator for gluten strength. Greater increases in height during baking are positively correlated with gluten strength. It is important to asses gluten strength because gluten strength is a very important component when finding a good bread-making wheat.

Another bread-making property is particle size. Hard wheats yield a larger particle size which is ideal for bread-making (Finney1987). High water absorption is also a desired quality with bread-making. Higher water absorption increases as protein content increases (Scotter, 2004). Water absorption is a direct factor of dough stability and enhances gluten development. All of these factors work together to directly influence the quality of baking products.

Research concerning identification of the proper wheat varieties for quality bread-making continues in many parts of the world. In India, the rheological properties of flour from local wheat varieties were studied. The physiochemical properties of flour such as protein and dry gluten were indicators in predicting product quality as were the rheological properties such as water absorption and dough stability (Ghanate, 2019). Thus, this proof of concept research project will determine which Kentucky varieties are possible contenders for bread-making by commercial bakers.

CHAPTER 3. Background on Kentucky Wheat

Wheat Grown in Kentucky

Wheat is Kentucky's fourth major cash crop behind corn, soybeans, and tobacco. It is a challenging crop to turn a consistent profit. (Herbec 2009) Wheat grown in Kentucky is primarily SRW wheat and is not typically used for bread-making. These soft wheats are more suitable for cookies, cakes, pastries, and crackers. (Baezinger, 1985) Due to their low protein content SRW wheat lacks the ability to reach desired loaf volumes that artisan bakers desire. The soft wheats that are grown in Kentucky in contrast to hard wheat also produce a smaller particle size. Smaller particle size is primary used for softer baked goods like cakes where the particles need to be more uniform. Along with a smaller particle size and low protein content, also comes a low water absorption. With a low water absorption, the baked product has a lower dough stability which is not ideal for bread-making (Finney 1987).

The Need for Kentucky Grown Wheat

Sustainability of small grains is not usually mentioned in sustainable agriculture settings, but there has been an increased interest in some states about localizing grain production to meet the needs of local bakeries. (Hills, 2013) Having access to locally grown wheat suitable for bread-making would make Kentucky bakeries more sustainable and provide sales options closer for growers. Most wheat used for bread-making is grown west of the Mississippi river, in places such as Kansas, Oklahoma, Colorado, Texas, North and South Dakota, and Montana. (Guercio, 2018) This leaves Kentucky bakers without a local source to purchase from.

Kentucky does have several private flour mills but most of the flour is used for their own flour products. In an interview with a local baker, Jim Betts, owner of the Bluegrass Baking Company, stated that the wheat that he uses ultimately comes from Montana and is then shipped to a mill in Illinois before being transported to his bakery. Mr. Betts then stated the importance of having locally grown wheat and having access to fresh milled wheat for baking quality. (J. Betts, Bluegrass Baking, personal communication, November 13, 2018).

There is also an increased need for locally sourced foods to meet the demands of consumers, thought consumers are not the only ones wanting locally sourced foods. Bakers in different settings have also expressed how they would like to have access to locally grown wheat for their products. A study by (Hills, 2016) that took place in Western Washington, looked at what commercial bakers considered “local” and were asked how important it was to them that they were purchasing local. 61% of bakers said that it was important to purchase local (Hills, 2016). With ideas shifting towards purchasing and consuming locally produced food items from locally grown sources, it would be very beneficial to both bakeries and Kentucky’s farmers to find a way to localize grain production.

CHAPTER 4. Sensory Evaluation

Sensory analysis (or sensory evaluation) uses human senses (sight, smell, taste, touch and hearing) for the purposes of evaluating consumer products. Sensory evaluation has been used in the past when evaluating bread and can be used to asses acceptance of products and quality assessment. Sensory evaluation has the potential to identify factors that could lead to product development as well. (Elia, 2011) Many studies have used sensory evaluation to test for differences between red and white wheat baked goods identified levels of consumer acceptance.

A study by (Bakke, 2007) used sensory evaluation to examine the acceptability of whole wheat breads and refined wheat breads and found that tasters were able to tell a difference between refined wheat and whole wheat products. The study also stated that a common sensory barrier was the bitterness of the bread which is why perceived bitterness is measured in this study.

Another study by (Challacombe, 2011) used sensory evaluation to look at consumer acceptance of bread and cracker products made from red and white wheat. Results found that consumers were able to taste a difference between red and white wheat and found that more consumers preferred red wheat over white wheat.

In this proof of concept research project, sensory evaluation will be used to determine the acceptability between different types of SRW wheat to when compared to commercial wheat. Consumer acceptance will play an important role in determining whether the SRW wheats make an acceptable loaf of bread. When using sensory evaluation to assess bread it is important to assess the crumb and crust separately (Elia, 2011). It is also recommended that there is a smaller set of parameters when performing the evaluation. Important parameters for sensory evaluation include appearance, aroma, cut product, and taste (Elia, 2011). With a well-defined set of parameters, sensory evaluation will be a valuable tool in assessing SRW wheats for their ability to produce a quality bread product.

The University of Kentucky Wheat Breeding Program

The website states, “The primary objective of the soft red winter wheat breeding program at the University of Kentucky is to enhance the profitability of wheat production by developing and releasing improved wheat varieties. In Kentucky this means early maturity, lodging resistance, disease resistance, spring freeze tolerance, along with high yield and test weight are among the traits of interest. Year in and year out, diseases are the most yield-limiting factor.” Support for the breeding program is generously provided by the Kentucky Small Grain Promotion Council through a checkoff program. (http://www.uky.edu/Ag/Wheat/wheat_breeding/uk_wheatbreeding.htm)

CHAPTER 5. METHODS

Research Design

The research design for this experiment is a controlled cross-sectional design. In this study 68 breeding lines of SRW wheat were chosen from the UKY Wheat Breeding Program to be evaluated for dough functionality and bread-making ability. Each line was made into a boule of bread, and a control HRW wheat was used for comparison. A boule of bread is the traditional shape of French bread, resembling a squashed ball. Two boules were made from each wheat strain. The dough and finished bread product from each variety of wheat were measured to obtain loaf height and diameter, and pre- and post- baking procedure.

Next, a sensory evaluation was performed on the bread in a tasting forum, using 7 SRW wheat varieties and the control HRW wheat, a standard commercial bread flour. Participants were self-selected to the Erickson Hall kitchen and the Funkhouser kitchen for the assessment. The participants were instructed to rate the aroma of the bread first, then the texture. After, the participants then tasted the bread and rated the flavor of the crust and crumb along with perceived sweetness and bitterness. The participants were instructed to drink water between samples to cleanse their palate. The participants were unaware of the identity of the varieties used for the finished product and the control was blinded and evaluated with the same tasting procedure as the other samples.

Wheat Selection

The wheat used in this study were selected from breeding lines in the UK Wheat Breeding Program. They are selected first at the “head-row” stage, then they are planted in a single row at North Farm in Lexington, Ky. The wheat is then selected based on qualities such as vigor, short stature, straw strength, freedom from disease and early maturity. The next year they were planted into multi-row plots at two locations where they are then screened for the preceding traits as well as grain yield and test weight, a measure of grain quality. The following year, lines with good agronomic potential are put into advanced trials, in 3 replications at 4 locations in KY. It is at this point that the wheat is screened for flavor and dough functionality. All wheat selected for this experiment is SRW wheat, though the hope was that certain lines would have the dough properties required for a quality bread product. A total of 68 varieties of wheat were selected (Figure 2).

Genotype	Name	Pedigree	Genotype	Name	Pedigree
AT 1-6	X11-0039-1-2-5	Pembroke//VA04W-90/KY97C-0508-01-01A-1	AT 4-16	X11-0081-7-5-1	Syngenta W1104//PEMBROKE/USG 3555
AT 1-7	X11-0039-1-7-3	Pembroke//VA04W-90/KY97C-0508-01-01A-1	AT 4-17	X11-0081-8-7-1	Syngenta W1104//PEMBROKE/USG 3555
AT 1-8	X11-0039-1-17-5	Pembroke//VA04W-90/KY97C-0508-01-01A-1	AT 4-20	X11-0089-9-19-3	Syngenta W1104//Excel 234/KY02C-3004-02
AT 1-10	X11-0053-2-19-3	Branson//USG 3555 /KY97C-0508-01-01A-1	AT 4-23	X11-0091-10-14-3	Syngenta W1104//Agripro COKER 9511/USG 3555
AT 1-12	X11-0053-3-9-3	Branson//USG 3555 /KY97C-0508-01-01A-1	AT 4-32	X11-0185-23-7-5	KAS 5058//Excel 234/KY02C-3004-02
AT 1-18	X11-0054-4-12-1	Branson//USG 3555 /Excel 234	AT 5-6	153_UX1105-13-26-7-3	McCormick/UX0771-2-104
AT 1-29	X11-0057-6-14-5	Branson//KY02C-3006-46/PEMBROKE	AT 5-7	153_UX1105-13-26-8-1	McCormick/UX0771-2-104
AT 1-31	X11-0057-7-6-5	Branson//KY02C-3006-46/PEMBROKE	AT 5-12	161_UX1107-6-31-5-3	McCormick/UX0792-7-53
AT 1-33	X11-0057-7-14-3	Branson//KY02C-3006-46/PEMBROKE	AT 5-21	AC-2-7-5-5	KY06C-11-3-10//Pembroke/Excel234
AT 2-11	X11-0010-9-16-3	Pembroke//Agripro COKER 9511/IL04-7942	AT 5-26	AC-5-11-3-3	KY06C-11-3-10//Pembroke/VA01W-558
AT 2-12	X11-0010-9-17-3	Pembroke//Agripro COKER 9511/IL04-7942	AT 5-27	AC-7-7-3-3	KY06C-11-3-10//Pembroke/VA01W-558
AT 2-13	X11-0010-10-9-5	Pembroke//Agripro COKER 9511/IL04-7942	AT 5-28	AC-7-12-5-5	KY06C-11-3-10//Pembroke/VA01W-558
AT 2-15	X11-0010-10-14-1	Pembroke//Agripro COKER 9511/IL04-7942	AT 5-30	AC-8-18-1-1	KY06C-11-3-10//KY97C-0508-01-01A-1/SS MPV-57
AT 2-21	X11-0120-12-3-5	Syngenta W1104//VA06W-558/SS MPV-57	AT 5-31	AC-12-16-1 not on keep list-1	KY06C-11-3-10//Agripro COKER 9511/Pembroke
AT 2-22	X11-0120-12-4-3	Syngenta W1104//VA06W-558/SS MPV-57	AT 5-33	AC-12-16-5 not on keep list-5	KY06C-11-3-10//Agripro COKER 9511/Pembroke
AT 2-29	X11-0225-14-5-3	KAS 5058//IL04-7942/SS MPV-57	MX 1-5	X11-0004-3-8-1	Pembroke//Agripro COKER 9511/Pioneer 25R32
AT 2-36	X11-0249-17-5-5	VA05W-151//Agripro COKER 9511/VA06W-558	MX 1-6	X11-0013-7-14-3	Pembroke//USG 3555 /KY97C-0508-01-01A-1
AT 3-5	X11-0249-17-9-1	VA05W-151//Agripro COKER 9511/VA06W-558	MX 1-7	X11-0017-9-18-3	Pembroke//KY02C-3006-46/PEMBROKE
AT 3-6	X11-0249-17-9-3	VA05W-151//Agripro COKER 9511/VA06W-558	MX 1-8	X11-0017-10-16-3	Pembroke//KY02C-3006-46/PEMBROKE
AT 3-9	X11-0308-19-7-1	KY02C-3004-07//SS MPV-57/Excel 234	MX 1-9	X11-0035-15-3-1	Pembroke//VA04W-90/KY02C-3004-02
AT 3-12	X11-0312-20-6-5	KY02C-3004-07//VA06W-558/PEMBROKE	MX 1-12	X11-0044-19-15-3	Branson//Agripro COKER 9511/Pioneer 25R32
AT 3-15	X11-0326-22-17-5	KY02C-3004-07//USG 3350/KY97C-0508-01-01A-1	MX 1-16	X11-0170-52-3-3	Excel 234//IL04-7942/SS MPV-57
AT 3-17	X11-0357-24-13-5	KY02C-3005-25//VA06W-558/BRANSON	MX 1-17	X11-0170-52-8-3	Excel 234//IL04-7942/SS MPV-57
AT 3-19	X11-0386-26-9-5	KY03C-1237-32//KY97C-0508-01-01A-1/USG 3350	MX 1-19	X11-0205-56-13-3	KAS 5058//KY02C-3006-46/KY97C-0508-01-01A-1
AT 3-22	X11-0395-27-4-5	KY03C-1237-32//Pioneer 25R32/SS MPV-57	MX 1-20	X11-0217-58-7-5	KAS 5058//BRANSON/KY02C-3004-02
AT 3-23	X11-0395-27-9-5	KY03C-1237-32//Pioneer 25R32/SS MPV-57	MX 1-21	X11-0374-104-13-5	KY02C-3005-25//USG 3350/VA04W-90
AT 3-25	X11-0395-27-18-3	KY03C-1237-32//Pioneer 25R32/SS MPV-57	MX 1-23	X11-0384-110-2-1	KY03C-1237-32//KY97C-0508-01-01A-1/Excel 234
AT 3-26	X11-0395-27-19-3	KY03C-1237-32//Pioneer 25R32/SS MPV-57	MX 1-25	X11-0385-112-16-1	KY03C-1237-32//KY97C-0508-01-01A-1/Pioneer 25R32
AT 3-31	X11-0395-28-10-3	KY03C-1237-32//Pioneer 25R32/SS MPV-57	MX 1-26	X11-0385-113-1-1	KY03C-1237-32//KY97C-0508-01-01A-1/Pioneer 25R32
AT 3-33	X11-0395-28-12-5	KY03C-1237-32//Pioneer 25R32/SS MPV-57	MX 1-29	X11-0420-120-13-3	KY03C-1237-32//KY02C-3004-02/SS MPV-57
AT 4-5	X11-0395-28-18-3	KY03C-1237-32//Pioneer 25R32/SS MPV-57	MX 1-31	X11-0464-123-18-5	KY02C-1058-02//Excel 234/SS MPV-57
AT 4-11	X11-3296-39-1-1	Shirley/VA05W-151	MX 1-33	X11-0598-140-6-3	Germplasm-11-3-10//PEMBROKE/USG 3555
AT 4-14	X11-3296-40-1-3	Shirley/VA05W-151	MX 1-39	X12-619-205-5-3	KY03C-1002-02/VA05W-151//KY03C-1002-02
AT 4-15	X11-0003-2-20-3	Pembroke//Excel 234/KY02C-3004-02	MX 1-40	X12-619-205-7-1	KY03C-1002-02/VA05W-151//KY03C-1002-02

Figure 2. Genotype Information

Bread Tasting Participants

Participants for the bread tastings were self-selected via convenience sampling. The participants were asked if they would like to participate in a tasting for research. They were recruited from in and around Erickson Hall where the 2nd floor kitchen is located. Later tastings were performed in the Funkhouser building kitchen facility. Each tasting varied in participant size, ranging from 4-15 participants.

Assessment of Protein Content

Near Infrared (NIR) Spectroscopy was performed at the end of the research project obtain protein content. This process was performed by the researcher at UKY Plant sciences building and Seed House in a laboratory using a Perten Instruments, model DA 7250 machine. Other variables measured by this process include moisture, hardness, Flour SE, Flour Yield, Flour Protein, Water SRC, NaCardSRC, Sucrose SRC, LacticSRC, Fusarium-damaged kernels (FDK), and deoxynivalenol (DON).

Sedimentation Coefficient

Sedimentation Coefficient values for 52 of the breeding lines were obtained via secondary data collected from a separate study at the University of Kentucky.

Milling procedure

The wheat samples were brought to a certified kitchen in Erickson Hall at the University of Kentucky for milling. The wheat was milled in a Mockmill 100® in 95g samples. The wheat was milled and then immediately mixed into the dough, using a pre-specified recipe.

Recipe Ingredients and Procedures

Ingredients included a pre-ferment called a "poolish" consisting of 50g all-purpose flour, 50g water, 1/8 tsp instant yeast. The dough included 95g whole wheat flour, 45g all-purpose flour, 4g salt, ¼ tsp yeast and all the poolish. The first step in the process is to create a poolish. A poolish is equal parts water and flour with a small amount of yeast. Poolishes are used to cultivate yeast for the dough. The poolish was made in the morning on the day the dough was made. The poolish was then placed inside an air-tight plastic bag and allowed to mature for 6 hours. This method was chosen to impart yeast into the dough without altering the flavor of the wheat.

After the poolish matured, the dough ingredients were mixed and added to the mixture. This was mixed by hand to form a dough ball. After the dough ball was formed, the dough was folded in on itself six times. The dough then rested for 20 minutes in the plastic bag and was again folded in on itself six times. The folding process was completed one more time to enhance the development of the gluten network. After the dough was folded the third time it was placed back in the bowl and placed in the same plastic bag to be stored in a refrigerator to bulk ferment overnight.

The next morning the dough is removed from the refrigerator and divided as evenly by weight into two dough balls. The dough's height and diameter are then measured with a digital caliper and the dough balls are placed onto parchment paper. The dough balls rested until they reached room temperature. While the bread comes up to temperature the sheet pans used for steam is prepared.

In order to make steam for the baking process, two cotton towels were placed in a half-sized sheet pan and 8 cups of water was added to the pan. The sheet pan was placed in the preheated oven 15 minutes prior to baking the bread. Steam was used in this study replicate a commercial bakery procedure.

After the dough came to room temperature, it was scored and placed on 19in x 13in baking stones in a Frigidaire conventional oven at a temperature of 475°F. Each round of bread baked for 15 minutes and then the sheet pans containing the water and towels were removed. The bread was then baked 15 more minutes. After the bread was baked, it was removed from the oven and placed on cooling racks. The bread rested for 30 minutes and then post-height and diameter measurements were taken. Lastly, the bread was cut into sample pieces for tasting. This baking procedure yielded a total of 16 boules of bread. 14 of the boules used 7 different varieties of SRW wheat with 2 repetitions each. Two of the boules were the HRW wheat control.

Measurements

Measurements were taken two different ways. The first measurement taken was the pre- and post-bake height and diameter in millimeters. The height of the dough was taken where height was at its maximum, excluding protruding peaks made by the loaf ears. Loaf diameter was measured wherever the bread was the widest. Both measurements were taken with a digital caliper to the hundredth of a millimeter. The second measurement was the mass of the dough balls before the baking procedure. Mass was recorded in grams and used to ensure there was no difference between the different boules before baking.

Surveys

The survey (Figure 3) used in this experiment was modeled after a survey used for prior research (Elia, 2011) and a previous survey created by David Van Sanford PHD., then altered to collect data desired by the UKY Wheat Breeding Program. Based on previous research by (Elia, 2011), it was suggested that crumb and crust be evaluated separately. The bread was evaluated on texture, taste, sweetness, bitterness and overall experience for crust and crumb. Aroma scoring was not evaluated separately by crust and crumb. Aroma, texture, taste, and overall experience were scored using a Likert scale ranging from 1 (disliked very much) to 7 (like very much). A score of 4 indicated neither liked nor disliked. Sweetness and bitterness were scored using a four-point scale with 1 meaning no sweet or bitter taste, 2 meaning slightly sweet or bitter taste, 3 moderately sweet or bitter taste, and 4 very sweet or bitter taste. For testing purposes, the variable overall quality was created from the overall quality crust and overall quality crumb from the survey via addition of the two variables and was not included in the survey.

		Texture		Flavor		Overall Experience	
SAMPLE NO.	AROMA	CRUST	CRUMB	CRUST	CRUMB	CRUST	CRUMB
1							
2							
3							
4							
5							
6							
7							
8							

	Sweetness		Bitterness		Tastes/Feels/Smells like… (If Any)
SAMPLE NO.	CRUST	CRUMB	CRUST	CRUMB	
1					
2					
3					
4					
5					
6					
7					
8					

Aroma/Texture/Flavor/Overall Experience
Scale:

7 - Like Very Much
6 - Like Moderately
5 - Like Slightly
4 - Neither Like nor Dislike
3 - Dislike Slightly
2 - Dislike Moderately
1 - Dislike Very Much

Sweetness/Bitterness
Scale:

4 - Very Sweet/Bitter taste

3 - Moderately Sweet/Bitter taste

2 - Slightly Sweet/ Bitter taste

1 - Bland or No Sweet/Bitter taste

Figure 3. Sensory Evaluation Survey

Statistical Analysis

Statistical analysis was performed using IBM SAS 9.4 and SPSS Statistics 24. The first comparisons were made to determine any significant difference between the pre- and post- measurements of loaf height and diameter of each the breeding lines to the control using prebake height and diameter as covariates. The second comparisons made was to test for any significant differences in the sensory evaluation data between the breeding lines and the control. Both were done via one-way ANOVA, then t-tests to determine which genotypes were significantly different. Multiple comparisons were controlled using the Dunnett method.

To determine if there were specific variables that could be used as a predictor for overall bread quality, bivariate correlation was used to determine any correlations between the sensory data. Bivariate correlation was also performed on mean pre and post measurement data, NIR data, and mean overall quality variables (crust, crumb, and overall). Lastly, a smaller scale bivariate correlation was run to determine any correlation between the overall quality variables, mean pre and post measurement, NIR, and sedimentation coefficient data.

CHAPTER 6. RESULTS

Loaf Size Comparisons Genotype to Control

To compare for differences of post-bake height among the genotypes and control, an ANOVA was run to test for significant difference between the least square means. Then t-tests were used to discover which specific genotypes were different. In this test pre-bake height was used as a covariate. The Dunnett method was used to control for multiple comparisons. The results of the t-tests are located in Figure 4. Among the different genotypes, AT 1-8, $t(128)= -7.0919$ $p=0.0021$, AT 3-6, $t(128)= -4.652$ $p=0.0111$, and MX 1-40, $t(128)=-7.64$ $p=0.0006$, tested with a significantly lower post-height when compared to the control. All other genotypes were not significantly different that the control.

Differences of Genotype Least Squares Means Adjustment for Multiple Comparisons: Dunnett-Hsu							
Genotype	_Genotype	Estimate	Standard Error	DF	t Value	Pr > |t|	Adj P
AT 1-8	Control	-7.0919	1.6401	128	-4.32	<.0001	0.0021*
AT 3-6	Control	-4.6522	1.1998	128	-3.88	0.0002	0.0111*
MX 1-40	Control	-7.6424	1.6519	128	-4.63	<.0001	0.0006*

Figure 4. Significant Genotype and Control Post-Bake Height Comparisons

To compare for differences of post-bake diameter among the genotypes and control an ANOVA was run to test for significant difference between the least square means. Then t-tests were used to discover which specific genotypes were different. In this test pre-diameter was used as a covariate. The Dunnett method again was used to control for multiple comparisons. The results of the t-tests are recorded in Figure 5. Among the different genotypes, AT 1-31, t(128)=10.4615 p=<.0001, AT 1-6, t(128)=10.4615 p=<.0001, AT 1-7, t(128)=9.0730 p=<.0001, AT 2-11, t(128)=7.3740 p=.0349, AT 2-12, t(128)=7.2390 p=.0003, AT 2-21, t(128)=8.1220 p=.0097, AT 2-22, t(128)=7.7262 p=<.0001, AT 2-36, t(128)=7.1713 p=.0547, AT 4-15, t(128)=9.1967 p=.0018, AT 4-17, t(128)=9.5680 p=.0008, AT 4-23, t(128)=9.2930 p=.0016, AT 5-26, t(128)=5.9154 p=.0098, AT 5-27, t(128)=7.4294 p=.0329, AT 5-33, t(128)=11.4179 p=<.0001, AT 5-7, t(128)=7.4747 p=.0271, MX 1-12, t(128)=9.0101 p=.0016, MX 1-17, t(128)=11.3872 p=<.0001, MX 1-19, t(128)=9.5240 p=.0005, MX 1-29, t(128)=11.6379 p=<.0001, MX 1-33, t(128)=7.6802 p=.0187, MX 1-40, t(128)=12.6887 p=<.0001, MX 1-6, t(128)=12.4434 p=<.0001, tested with significantly higher post-diameters when compared to the control. All other genotypes were not significantly different than the control.

Differences of Genotype Least Squares Means Adjustment for Multiple Comparisons: Dunnett-Hsu							
Genotype	**_Genotype**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**	**Adj P**
AT 1-31	Control	10.1998	1.5106	128	6.75	<.0001	<.0001**
AT 1-6	Control	10.4615	2.0479	128	5.11	<.0001	<.0001**
AT 1-7	Control	9.0730	1.5036	128	6.03	<.0001	<.0001**
AT 2-11	Control	7.3740	2.0764	128	3.55	0.0005	0.0349*
AT 2-12	Control	7.2390	1.5067	128	4.80	<.0001	0.0003*
AT 2-21	Control	8.1220	2.0744	128	3.92	0.0001	0.0097*
AT 2-22	Control	7.7262	1.4982	128	5.16	<.0001	<.0001**
AT 2-36	Control	7.1713	2.1005	128	3.41	0.0009	0.0547*
AT 4-15	Control	9.1967	2.1072	128	4.36	<.0001	0.0018*
AT 4-17	Control	9.5680	2.0976	128	4.56	<.0001	0.0008*
AT 4-23	Control	9.2930	2.1162	128	4.39	<.0001	0.0016*
AT 5-26	Control	5.9154	1.5109	128	3.92	0.0001	0.0098*
AT 5-27	Control	7.4294	2.0820	128	3.57	0.0005	0.0329*
AT 5-33	Control	11.4179	2.0464	128	5.58	<.0001	<.0001**
AT 5-7	Control	7.4747	2.0616	128	3.63	0.0004	0.0271*
MX 1-12	Control	9.0101	2.0567	128	4.38	<.0001	0.0016*
MX 1-17	Control	11.3872	2.0596	128	5.53	<.0001	<.0001**
MX 1-19	Control	9.5240	2.0472	128	4.65	<.0001	0.0005*
MX 1-29	Control	11.6379	2.0578	128	5.66	<.0001	<.0001**
MX 1-33	Control	7.6802	2.0576	128	3.73	0.0003	0.0187*
MX 1-40	Control	12.6887	2.0475	128	6.20	<.0001	<.0001**
MX 1-6	Control	12.4434	2.0472	128	6.08	<.0001	<.0001**

Figure 5. Significant Genotype and Control Post-bake Diameter Comparisons

Sensory Evaluation Comparisons Genotype to Control

Differences between aroma values were also tested using an ANOVA to discover differences between the least square means. T-tests were used to discover which specific genotypes were different. The Dunnett method was used to control for multiple comparisons. The results of the t-tests are recorded in Figure 6. Among the different genotypes, AT 1-6, t(643)= 1.5177 p=.0544, AT 5-33, t(643)=1.3229 p=.0229 tested significantly higher for aroma than the control. All other genotypes were not significantly different when compared the control.

Differences of Genotype Least Squares Means Adjustment for Multiple Comparisons: Dunnett							
Genotype	Genotype	Estimate	Standard Error	DF	t Value	Pr > |t|	Adj P
AT 1-6	Control	1.5177	0.4522	643	3.36	0.0008	0.0544*
AT 5-33	Control	1.3229	0.3676	643	3.60	0.0003	0.0229*

Figure 6. Significant Genotype and Control Aroma Comparisons

ANOVA was used for the other variables from the sensory data. There were no significant differences found between the genotypes and control in crust texture F(68)=.99 p=.4926, crumb texture F(68)=1.18 p=.1635, crust flavor F(68)=0.96 p=0.5664, crumb flavor F(68)=0.96 p=.5755, crust overall F(68)=1.06 p=.3615, crumb overall F(68)= 0.87 p=.7525, overall quality F(68)= 0.97 p=.5513, crust sweetness F(68)=1.02 p=.4456, crumb sweetness F(68)= 1.12 p=.2448, crumb bitterness F(68)= 0.82 p=.8449, or crust bitterness F(68)= 0.81 p=.8621.

Sensory Evaluation Correlations

To test for correlations between the sensory evaluation data, a bivariate correlation was performed. The results from the correlation are located in Figure 7. N ranged from 680 to 713 due to invalid or missing data. There were many moderate positive correlations including aroma and crust flavor r(710)=.417, p=<.0001, aroma and crust overall r(704)=.445, p=<.0001, aroma and crumb overall r(704)=.443, p=<.0001, aroma and overall quality r(706)=.468, p=<.0001, crust texture and crust flavor r(711)=.430, p=<.0001, crust texture and overall quality r(707)=.668, p=<.0001, crumb texture and crumb flavor $r(711)=.592$, $p=<.0001$, and crumb flavor overall quality $r(707)=.782$, $p=<.0001$.

There were also multiple strong positive correlations including crust texture and crust $r(705)=.731$, $p=<.0001$, crumb texture and crumb overall $r(705)=.712$, $p=<.0001$, crumb texture and overall quality $r(707)=.661$, $p=<.0001$, crumb and crust bitterness strong positively correlated, $r(684)=.794$, $p=<.000$, crumb and crust sweetness strong positively correlated, $r(689)=.794$, $p=<.0001$.

Lastly, there was a very strong positive correlation between crumb flavor and crumb overall $r(705)=.837$, $p=<.0001$.

Correlations

		Aroma	Crust Texture	Crumb Texture	Crust Flavor	Crumb Flavor	Crust Overall	Crumb Overall	Overall Quality	Crust Sweetness	Crumb Sweetness	Crust Bitterness	Crumb Bitterness
Aroma	Pearson Correlation	1	.395**	.385**	.417**	.379**	.445**	.443**	.468**	.186**	.190**	-.068	-.067
	Sig. (2-tailed)		.000	.000	.000	.000	.000	.000	.000	.000	.000	.074	.080
	N	712	712	712	712	712	706	706	708	689	691	686	686
Crust Texture	Pearson Correlation	.395**	1	.578**	.591**	.430**	.731**	.530**	.668**	.113**	.093*	-.101**	-.093*
	Sig. (2-tailed)	.000		.000	.000	.000	.000	.000	.000	.003	.014	.008	.015
	N	712	713	713	713	713	707	707	709	690	692	687	687
Crumb Texture	Pearson Correlation	.385**	.578**	1	.431**	.592**	.540**	.712**	.661**	.151**	.191**	-.020	-.062
	Sig. (2-tailed)	.000	.000		.000	.000	.000	.000	.000	.000	.000	.609	.104
	N	712	713	713	713	713	707	707	709	690	692	687	687
Crust Flavor	Pearson Correlation	.417**	.591**	.431**	1	.691**	.814**	.628**	.766**	.185**	.154**	-.118**	-.100**
	Sig. (2-tailed)	.000	.000	.000		.000	.000	.000	.000	.000	.000	.002	.008
	N	712	713	713	713	713	707	707	709	690	692	687	687
Crumb Flavor	Pearson Correlation	.379**	.430**	.592**	.691**	1	.643**	.837**	.782**	.173**	.228**	-.097*	-.121**
	Sig. (2-tailed)	.000	.000	.000	.000		.000	.000	.000	.000	.000	.011	.001
	N	712	713	713	713	713	707	707	709	690	692	687	687
Crust Overall	Pearson Correlation	.445**	.731**	.540**	.814**	.643**	1	.745**	.937**	.190**	.158**	-.128**	-.103**
	Sig. (2-tailed)	.000	.000	.000	.000	.000		.000	.000	.000	.000	.001	.007
	N	706	707	707	707	707	707	707	707	684	686	681	681
Crumb Overall	Pearson Correlation	.443**	.530**	.712**	.628**	.837**	.745**	1	.931**	.215**	.243**	-.076*	-.097*
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000		.000	.000	.000	.047	.011
	N	706	707	707	707	707	707	707	707	684	686	681	681
Overall Quality	Pearson Correlation	.468**	.668**	.661**	.766**	.782**	.937**	.931**	1	.223**	.221**	-.115**	-.113**
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000		.000	.000	.003	.003
	N	708	709	709	709	709	707	707	709	686	688	683	683
Crust Sweetness	Pearson Correlation	.186**	.113**	.151**	.185**	.173**	.190**	.215**	.223**	1	.794**	.023	.086*
	Sig. (2-tailed)	.000	.003	.000	.000	.000	.000	.000	.000		.000	.558	.025
	N	689	690	690	690	690	684	684	686	691	691	678	680
Crumb Sweetness	Pearson Correlation	.190**	.093*	.191**	.154**	.228**	.158**	.243**	.221**	.794**	1	.079*	.073
	Sig. (2-tailed)	.000	.014	.000	.000	.000	.000	.000	.000	.000		.038	.056
	N	691	692	692	692	692	686	686	688	691	693	680	680
Crust Bitterness	Pearson Correlation	-.068	-.101**	-.020	-.118**	-.097*	-.128**	-.076*	-.115**	.023	.079*	1	.794**
	Sig. (2-tailed)	.074	.008	.609	.002	.011	.001	.047	.003	.558	.038		.000
	N	686	687	687	687	687	681	681	683	678	680	688	686
Crumb Bitterness	Pearson Correlation	-.067	-.093*	-.062	-.100**	-.121**	-.103**	-.097*	-.113**	.086*	.073	.794**	1
	Sig. (2-tailed)	.080	.015	.104	.008	.001	.007	.011	.003	.025	.056	.000	
	N	686	687	687	687	687	681	681	683	680	680	686	688

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Figure 7. Sensory Data Correlation Table

Measurement and NIR Data Correlations

NIR data was also analyzed using a bivariate correlation and tabulated in Figure 8. To check for correlations between quality variables from the sensory evaluation the means were taken and added to the NIR and measurement data. Same as before, there were many correlations associated with the data (N=68). Moderate positive correlations included moisture and hardness r(66)=.573, p=<.0001, moisture and flour protein r(66)=.557, p=<.0001, moisture and waterSRC r(66)=.456, p=<.0001, moisture and NaCarbSRC r(66)=.422, p=<.0001, protein and lacticSRC r(66)=-.457, p=<.0001, protein and crust overall r(66)=.460, p=<.0001, protein and crumb overall r(66)=.414, p=<.0001, protein and overall quality r(66)=.465, p=<.0001, hardness and lacticSRC r(66)=.463, p=<.0001, flour SE and flour yield, r(66)=.442, p=<.0001, flour protein and crust overall r(66)=.505, p=<.0001, flour protein and crumb overall r(66)=.410, p=<.0001, waterSRC and sucroseSRC r(66)=.459, p=<.0001, and NaCarbSRC and sucroseSRC r(66)=.529, p=<.0001.

There were also many strong positive correlations among variables like Moisture and lacticSRC r(66)=.735, p=<.000, protein and sucroseSRC r(66)=.598, p=<.0001, flour SE and NaCardSRC r(66)=-.706, p=<.0001, flour protein and sucroseSRC r(66)=.631, p=<.0001.

The final positive correlations observed were very strong correlations. These include protein and flour protein r(66)=.971, p=<.0001, hardness and flour SE r(66)=-.811, p=<.0001 hardness and waterSRC r(66)=.882, p=<.0001, hardness and NaCarbSRC r(66)=.846, p=<.0001, flour SE and waterSRC r(66)=-.806, p=<.0001, waterSRC and NaCarbSRC r(66)=.969, p=<.0001.

There were also a few moderate negative correlations and one strong negative correlation and they are as follows, moisture and protein $r(66)=-.510$, $p=<.0001$, moisture and crust overall $r(66)=-.413$, $p=<.0001$, flour protein and lacticSRC $r(66)=-.438$, $p=<.0001$ hardness and flour yield $r(66)=-.688$, $p=<.0001$.

Correlations

		Mean Post-bake Height	Mean Post-bake Diameter	Moisture	Protein	Hardness	Flour_SE	Flour_Yield	Flour_Protein	WaterSRC	NaCarbSRC	SucroseSRC	LacticSRC	FDK	DON	Mean(Crust Overall)	Mean(Crumb Overall)	Mean(Overall Quality)
Mean Post-bake Height	Pearson Correlation	1	-.175	.203	-.083	-.059	.103	.169	-.095	-.073	-.049	-.332**	.276*	-.165	-.308*	-.190	-.129	-.172
	Sig. (2-tailed)		.154	.096	.502	.632	.404	.168	.443	.555	.690	.006	.023	.180	.011	.120	.293	.162
	N	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68
Mean Post-bake Diameter	Pearson Correlation	-.175	1	-.281*	.211	-.100	-.023	-.091	.265*	-.139	-.104	.231	-.191	-.034	.173	.385**	.289*	.361**
	Sig. (2-tailed)	.154		.020	.083	.415	.852	.462	.029	.259	.398	.058	.119	.781	.159	.001	.017	.003
	N	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68
Moisture	Pearson Correlation	.203	-.281*	1	-.510**	.573**	-.307*	-.145	-.557**	.456**	.422**	-.306*	.735**	-.009	-.463**	-.413**	-.324**	-.394**
	Sig. (2-tailed)	.096	.020		.000	.000	.011	.239	.000	.000	.000	.011	.000	.939	.000	.000	.007	.001
	N	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68
Protein	Pearson Correlation	-.083	.211	-.510**	1	-.092	.008	-.358**	.971**	-.081	-.032	.598**	-.457**	.105	.664**	.460**	.414**	.465**
	Sig. (2-tailed)	.502	.083	.000		.456	.949	.003	.000	.513	.797	.000	.000	.394	.000	.000	.000	.000
	N	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68
Hardness	Pearson Correlation	-.059	-.100	.573**	-.092	1	-.811**	-.688**	-.029	.882**	.846**	.390**	.463**	.551**	.192	-.047	-.142	-.098
	Sig. (2-tailed)	.632	.415	.000	.456		.000	.000	.815	.000	.000	.001	.000	.000	.117	.705	.247	.429
	N	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68
Flour_SE	Pearson Correlation	.103	-.023	-.307*	.008	-.811**	1	.442**	-.074	-.806**	-.706**	-.393**	-.305*	-.380**	-.243*	-.087	-.048	-.073
	Sig. (2-tailed)	.404	.852	.011	.949	.000		.000	.551	.000	.000	.001	.012	.001	.046	.482	.695	.555
	N	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68
Flour_Yield	Pearson Correlation	.169	-.091	-.145	-.358**	-.688**	.442**	1	-.374**	-.618**	-.659**	-.667**	-.117	-.613**	-.443**	-.091	.021	-.040
	Sig. (2-tailed)	.168	.462	.239	.003	.000	.000		.002	.000	.000	.000	.342	.000	.000	.462	.862	.745
	N	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68
Flour_Protein	Pearson Correlation	-.095	.265*	-.557**	.971**	-.029	-.074	-.374**	1	-.062	-.015	.631**	-.438**	.116	.653**	.505**	.410**	.489**
	Sig. (2-tailed)	.443	.029	.000	.000	.815	.551	.002		.616	.901	.000	.000	.344	.000	.000	.001	.000
	N	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68
WaterSRC	Pearson Correlation	-.073	-.139	.456**	-.081	.882**	-.806**	-.618**	-.062	1	.969**	.459**	.305*	.534**	.197	-.032	-.108	-.072
	Sig. (2-tailed)	.555	.259	.000	.513	.000	.000	.000	.616		.000	.000	.011	.000	.108	.793	.382	.558
	N	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68
NaCarbSRC	Pearson Correlation	-.049	-.104	.422**	-.032	.846**	-.706**	-.659**	-.015	.969**	1	.529**	.280*	.518**	.202	-.008	-.122	-.066
	Sig. (2-tailed)	.690	.398	.000	.797	.000	.000	.000	.901	.000		.000	.021	.000	.099	.947	.321	.594
	N	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68
SucroseSRC	Pearson Correlation	-.332**	.231	-.306*	.598**	.390**	-.393**	-.667**	.631**	.459**	.529**	1	-.348**	.405**	.669**	.344**	.251*	.318**
	Sig. (2-tailed)	.006	.058	.011	.000	.001	.001	.000	.000	.000	.000		.004	.001	.000	.004	.039	.008
	N	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68
LacticSRC	Pearson Correlation	.276*	-.191	.735**	-.457**	.463**	-.305*	-.117	-.438**	.305*	.280*	-.348**	1	-.012	-.581**	-.379**	-.363**	-.394**
	Sig. (2-tailed)	.023	.119	.000	.000	.000	.012	.342	.000	.011	.021	.004		.920	.000	.001	.002	.001
	N	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68
FDK	Pearson Correlation	-.165	-.034	-.009	.105	.551**	-.380**	-.613**	.116	.534**	.518**	.405**	-.012	1	.593**	.153	.091	.131
	Sig. (2-tailed)	.180	.781	.939	.394	.000	.001	.000	.344	.000	.000	.001	.920		.000	.213	.461	.286
	N	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68
DON	Pearson Correlation	-.308*	.173	-.463**	.664**	.192	-.243*	-.443**	.653**	.197	.202	.669**	-.581**	.593**	1	.429**	.373**	.428**
	Sig. (2-tailed)	.011	.159	.000	.000	.117	.046	.000	.000	.108	.099	.000	.000	.000		.000	.002	.000
	N	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68
Mean(Crust Overall)	Pearson Correlation	-.190	.385**	-.413**	.460**	-.047	-.087	-.091	.505**	-.032	-.008	.344**	-.379**	.153	.429**	1	.772**	.948**
	Sig. (2-tailed)	.120	.001	.000	.000	.705	.482	.462	.000	.793	.947	.004	.001	.213	.000		.000	.000
	N	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68
Mean(Crumb Overall)	Pearson Correlation	-.129	.289*	-.324**	.414**	-.142	-.048	.021	.410**	-.108	-.122	.251*	-.363**	.091	.373**	.772**	1	.934**
	Sig. (2-tailed)	.293	.017	.007	.000	.247	.695	.862	.001	.382	.321	.039	.002	.461	.002	.000		.000
	N	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68
Mean(Overall Quality)	Pearson Correlation	-.172	.361**	-.394**	.465**	-.098	-.073	-.040	.489**	-.072	-.066	.318**	-.394**	.131	.428**	.948**	.934**	1
	Sig. (2-tailed)	.162	.003	.001	.000	.429	.555	.745	.000	.558	.594	.008	.001	.286	.000	.000	.000	
	N	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Figure 8. Measurement and NIR Data Correlation Table

Lastly, a final bivariate correlation (Figure 9) was run on a smaller scale (N=52), and the sedimentation correlation was combined with available NIR, measurement, and quality data. There was only one moderate correlation between sedimentation coefficient and SucroseSRC $r(66)=-.415$, $p=<.0001$.

Correlations

		Mean Post-bake Height	Mean Post-bake Diameter	Sed. Vol (mL)	Moisture	Protein	Hardness	Flour_SE	Flour_Yield	Flour_Protein	WaterSRC	NaCarbSRC	SucroseSRC	LacticSRC	FDK	DON	Mean(Crust Overall)	Mean(Crumb Overall)	Mean(Overall Quality)
Mean Post-bake Height	Pearson Correlation	1	-.241	.242	.175	-.203	-.171	.204	.300*	-.219	-.183	-.143	-.418**	.243	-.231	-.344*	-.254	-.242	-.266
	Sig. (2-tailed)		.085	.084	.214	.150	.226	.147	.031	.119	.194	.313	.002	.083	.099	.013	.069	.084	.057
	N	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52
Mean Post-bake Diameter	Pearson Correlation	-.241	1	-.087	-.245	.193	.046	-.115	-.214	.265	-.001	.042	.296*	-.232	.046	.200	.379**	.288*	.360**
	Sig. (2-tailed)	.085		.540	.081	.170	.748	.416	.128	.057	.993	.768	.033	.098	.749	.154	.006	.038	.009
	N	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52
Sed. Vol (mL)	Pearson Correlation	.242	-.087	1	.336*	-.376**	.009	.000	.273*	-.360**	-.098	-.173	-.415**	.125	-.324*	-.386**	-.084	-.093	-.094
	Sig. (2-tailed)	.084	.540		.015	.006	.952	.998	.050	.009	.491	.221	.002	.377	.019	.005	.555	.510	.505
	N	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52
Moisture	Pearson Correlation	.175	-.245	.336*	1	-.561**	.547**	-.309*	-.072	-.596**	.404**	.358**	-.312*	.760**	-.089	-.490**	-.345*	-.289*	-.342*
	Sig. (2-tailed)	.214	.081	.015		.000	.000	.026	.614	.000	.003	.009	.024	.000	.531	.000	.012	.038	.013
	N	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52
Protein	Pearson Correlation	-.203	.193	-.376**	-.561**	1	-.103	.044	-.367**	.970**	-.083	-.008	.629**	-.526**	.153	.707**	.524**	.457**	.528**
	Sig. (2-tailed)	.150	.170	.006	.000		.466	.759	.007	.000	.558	.955	.000	.000	.279	.000	.000	.001	.000
	N	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52
Hardness	Pearson Correlation	-.171	.046	.009	.547**	-.103	1	-.811**	-.664**	-.034	.862**	.820**	.439**	.409**	.511**	.208	.056	-.095	-.015
	Sig. (2-tailed)	.226	.748	.952	.000	.466		.000	.000	.810	.000	.000	.001	.003	.000	.140	.691	.505	.918
	N	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52
Flour_SE	Pearson Correlation	.204	-.115	.000	-.309*	.044	-.811**	1	.391**	-.033	-.796**	-.686**	-.413**	-.247	-.354*	-.257	-.134	-.096	-.124
	Sig. (2-tailed)	.147	.416	.998	.026	.759	.000		.004	.815	.000	.000	.002	.078	.010	.066	.343	.500	.380
	N	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52
Flour_Yield	Pearson Correlation	.300*	-.214	.273*	-.072	-.367**	-.664**	.391**	1	-.388**	-.583**	-.636**	-.700**	-.043	-.643**	-.491**	-.223	-.027	-.141
	Sig. (2-tailed)	.031	.128	.050	.614	.007	.000	.004		.004	.000	.000	.000	.762	.000	.000	.112	.850	.318
	N	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52
Flour_Protein	Pearson Correlation	-.219	.265	-.360**	-.596**	.970**	-.034	-.033	-.388**	1	-.066	.009	.660**	-.510**	.152	.689**	.551**	.428**	.529**
	Sig. (2-tailed)	.119	.057	.009	.000	.000	.810	.815	.004		.644	.948	.000	.000	.283	.000	.000	.002	.000
	N	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52
WaterSRC	Pearson Correlation	-.183	-.001	-.098	.404**	-.083	.862**	-.796**	-.583**	-.066	1	.966**	.519**	.233	.521**	.233	.082	-.034	.030
	Sig. (2-tailed)	.194	.993	.491	.003	.558	.000	.000	.000	.644		.000	.000	.096	.000	.096	.564	.812	.832
	N	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52
NaCarbSRC	Pearson Correlation	-.143	.042	-.173	.358**	-.008	.820**	-.686**	-.636**	.009	.966**	1	.588**	.211	.503**	.238	.122	-.040	.050
	Sig. (2-tailed)	.313	.768	.221	.009	.955	.000	.000	.000	.948	.000		.000	.133	.000	.090	.390	.778	.726
	N	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52
SucroseSRC	Pearson Correlation	-.418**	.296*	-.415**	-.312*	.629**	.439**	-.413**	-.700**	.660**	.519**	.588**	1	-.380**	.463**	.713**	.395**	.276*	.364**
	Sig. (2-tailed)	.002	.033	.002	.024	.000	.001	.002	.000	.000	.000	.000		.005	.001	.000	.004	.048	.008
	N	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52
LacticSRC	Pearson Correlation	.243	-.232	.125	.760**	-.526**	.409**	-.247	-.043	-.510**	.233	.211	-.380**	1	-.105	-.635**	-.429**	-.449**	-.470**
	Sig. (2-tailed)	.083	.098	.377	.000	.000	.003	.078	.762	.000	.096	.133	.005		.460	.000	.001	.001	.000
	N	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52
FDK	Pearson Correlation	-.231	.046	-.324*	-.089	.153	.511**	-.354*	-.643**	.152	.521**	.503**	.463**	-.105	1	.610**	.201	.132	.181
	Sig. (2-tailed)	.099	.749	.019	.531	.279	.000	.010	.000	.283	.000	.000	.001	.460		.000	.153	.351	.199
	N	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52
DON	Pearson Correlation	-.344*	.200	-.386**	-.490**	.707**	.208	-.257	-.491**	.689**	.233	.238	.713**	-.635**	.610**	1	.461**	.433**	.480**
	Sig. (2-tailed)	.013	.154	.005	.000	.000	.140	.066	.000	.000	.096	.090	.000	.000	.000		.001	.001	.000
	N	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52
Mean(Crust Overall)	Pearson Correlation	-.254	.379**	-.084	-.345*	.524**	.056	-.134	-.223	.551**	.082	.122	.395**	-.429**	.201	.461**	1	.744**	.943**
	Sig. (2-tailed)	.069	.006	.555	.012	.000	.691	.343	.112	.000	.564	.390	.004	.001	.153	.001		.000	.000
	N	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52
Mean(Crumb Overall)	Pearson Correlation	-.242	.288*	-.093	-.289*	.457**	-.095	-.096	-.027	.428**	-.034	-.040	.276*	-.449**	.132	.433**	.744**	1	.924**
	Sig. (2-tailed)	.084	.038	.510	.038	.001	.505	.500	.850	.002	.812	.778	.048	.001	.351	.001	.000		.000
	N	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52
Mean(Overall Quality)	Pearson Correlation	-.266	.360**	-.094	-.342*	.528**	-.015	-.124	-.141	.529**	.030	.050	.364**	-.470**	.181	.480**	.943**	.924**	1
	Sig. (2-tailed)	.057	.009	.505	.013	.000	.918	.380	.318	.000	.832	.726	.008	.000	.199	.000	.000	.000	
	N	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Figure 9. Correlations Between Genotypes with Measurement, NIR, and Sedimentation Coefficient Data

CHAPTER 7. DISCUSSION

The purpose of this study is to investigate the ability of SRW wheat to create a quality bread product when compared to a standard commercial bread flour. Aim number one was to determine if a SRW wheat could produce an adequate loaf size when compared to the commercial flour. Nearly all the different genotypes were able to produce a loaf size that was deemed not significantly different from the control. There were no genotypes that were able to outperform the control and three of the sixty-eight genotypes (AT 1-8, AT 3-6, and MX 1-40) that had a measured post-bake height significantly less than the control. However, when working with SRW wheat, no difference could be considered significant because the belief that SRW wheat is less desirable when it comes to bread-making. There different findings are evident when examining the post-bake diameter variables. Out of the 68 genotypes tested, 23 of the genotypes had a significantly larger post-bake diameter measurement (Figure 5). This is not surprising knowing the relationship between diameter, protein, and gluten strength. Only one genotype (MX 1-40) had a significantly higher post-bake diameter and a significantly lower post-bake height. With these results the hypothesis can be accepted.

The goal of aim two was to find a significant taste between the different genotypes and the control. There were not any significant differences measured in any of the variables: crust and crumb flavor, crust and crumb sweetness, and crust and crumb bitterness. There were also no significant differences in the crumb quality, crust quality, and overall quality, which all had a taste component factored into the score. In this case the hypothesis is rejected as none of the flavor scores tested significantly different as predicted.

However, in this instance, a test of non-significance can be considered positive because of the perceived quality of SRW wheat.

Lastly, aim three investigated whether a single variable could be used as a predictor for overall bread quality with the hypothesis being that loaf volume and protein are strong predictors of overall quality because these are desired traits. There were several moderate to very strong correlations between variables and either crust quality, crumb quality, and overall quality. Figure 10 shows the strongest correlations between the assessed variables. The crust and crumb texture and crust and crumb flavor variables were more strongly associated with their respective crust and crumb overall values than any other quality variable. This could indicate that the crust and crumb textures could be strong indicators of the quality of the crust and the crumb. However, aroma was moderately correlated with overall quality. There were also correlations between the NIR data and the mean quality variables shown in Figure 11. As predicted protein and flour protein was moderately positively correlated with the overall quality, but the correlations were not as strong as the flavor variables. There was one moderate negative correlation between moisture and mean crust quality. The hypothesis in this case is rejected because even though there was a correlation between protein and overall quality there was not a correlation between post-bake height and quality variables. Even though the second and third hypothesis were rejected the results from this study still contribute insight that can alter the perceived baking and flavor quality of SRW wheat.

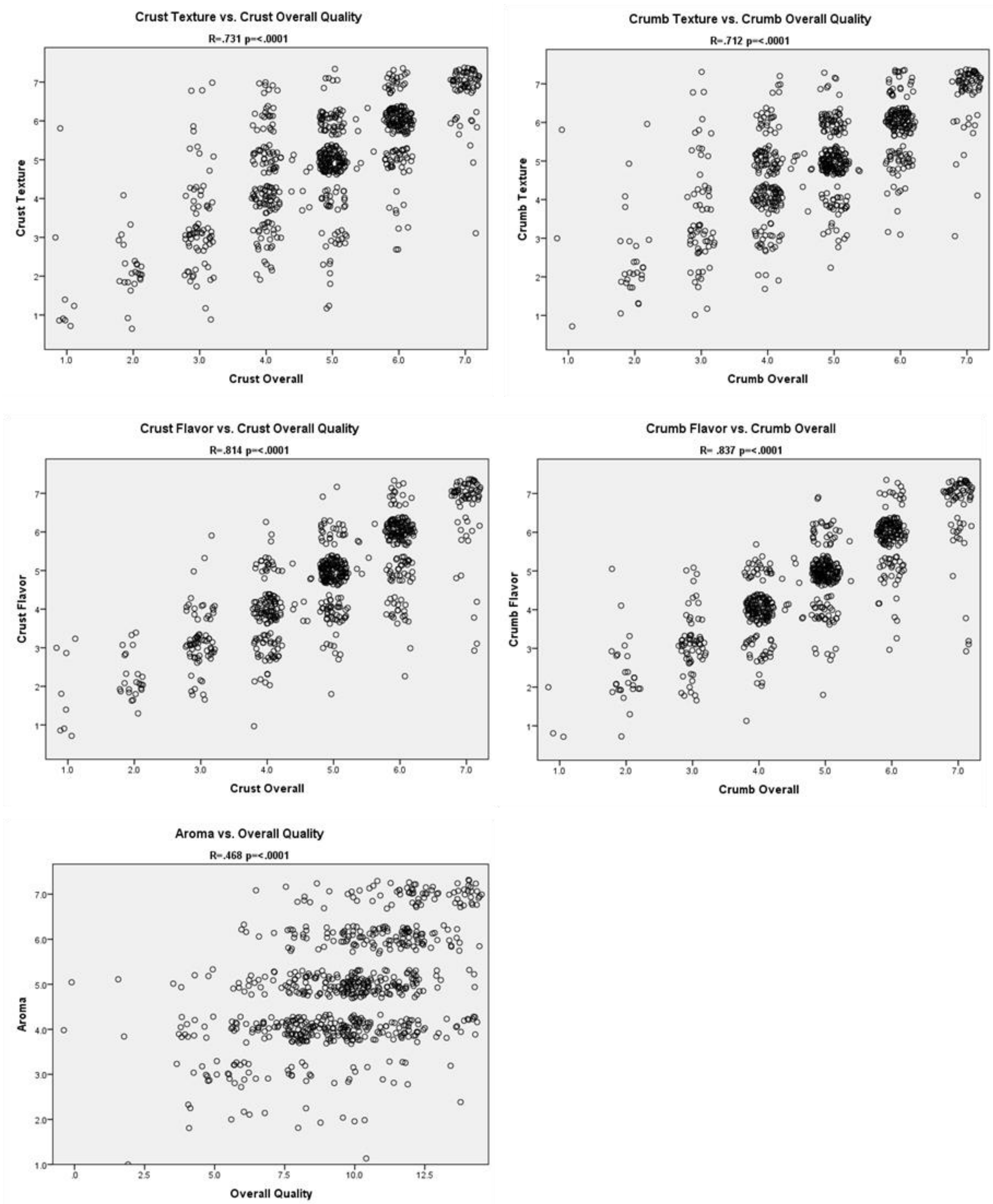

Figure 10. Sensory variables Correlated with Quality Variables

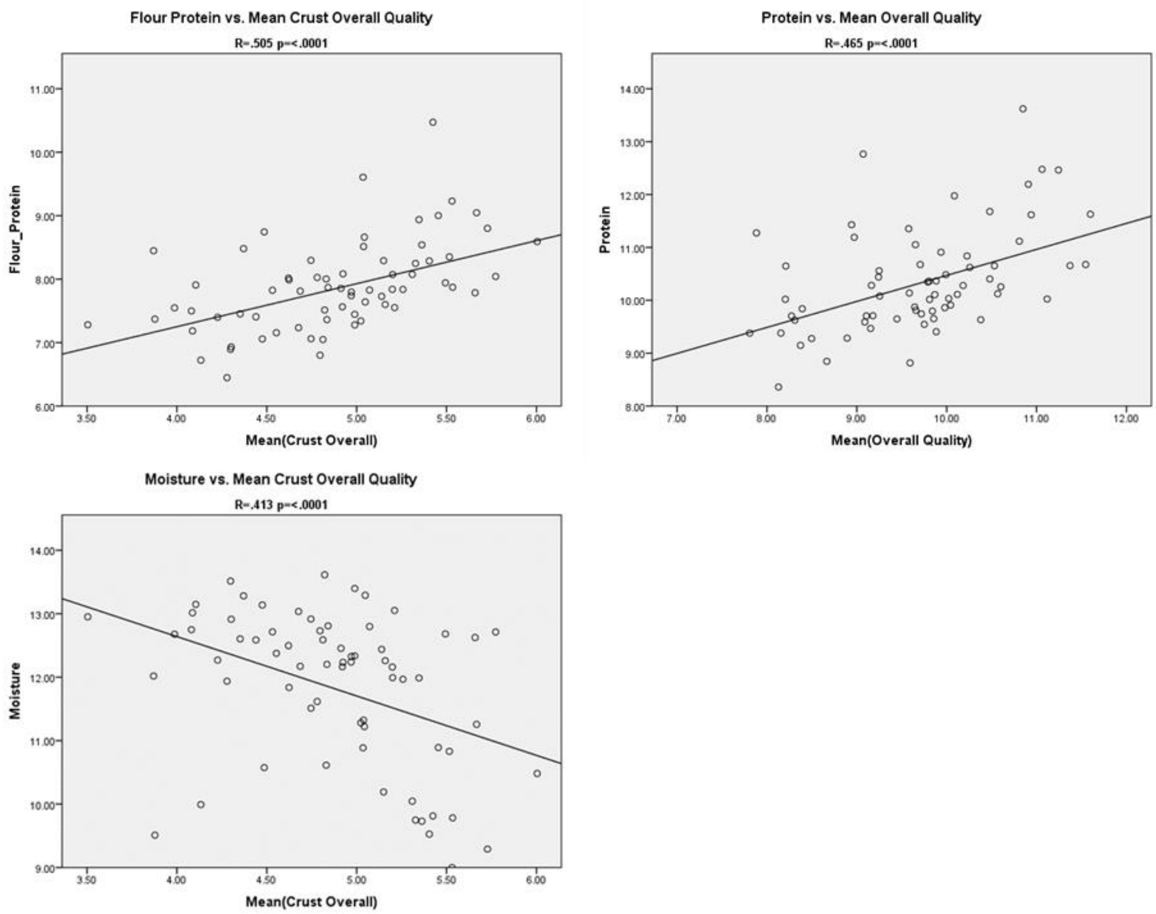

Figure 11. NIR Variables Correlated with Quality Variables

Limitations and Future Steps

There are a few limitations of this study. With limited funding and access to equipment, more advanced methods used to evaluate bread were inaccessible. Also, the selection process for tastings was very sporadic and the tastings were not a very consistent sample size. On the other hand, there are many strengths to this study.

Some innovative aspects to this study include insight into bread acceptability by consumers that could be used for future research. This is also one of the first experiments that evaluates bread quality in relation to flavor. Not only does this study look at flavor preferences of SRW wheat it also uses the quality variables and looks at correlations between them and other variables such as NIR data and sedimentation coefficients. This study is also one of the first studies to evaluate the ability to find a locally sourced flour for practical applications for bakers, by using a recipe designed to mimic standard baking practices such as application of steam, mixed ratios of whole wheat and bread flour, and scoring.

Future studies could focus more on repetition and increased sample sizes. Some of the tasting data is limited by have limited tasters. The measurement data was also taken from the baking of two boules and with increased repetitions more accurate data could arise. It could also be beneficial to have a constant tasting panel to ensure that each genotype is evaluated the same way and removes variance between random participants.

Conclusion:

This proof of concept idea of evaluating the baking performance and sensory evaluations of SRW has positive outcomes. It is potentially beneficial in selecting possible genotypes to produce for commercial bakers and producing potential data that could be used by the UK wheat breeding program. It has also given some insight into important factors when exploring quality amongst baking products and it has shown that texture, flavor and aroma all contribute to the perceived quality of tasters.

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