SOLVENT RETENTION CAPACITY AND QUALITY PARAMETERS OF WHOLE WHEAT FLOUR FROM HARD RED SPRING WHEAT

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MASTER OF SCIENCE

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ABSTRACT

A relatively new method, solvent retention capacity (SRC), is used to determine flour end-product quality. SRC was designed for soft wheat, which is used for baking cookies. The use of SRC to evaluate Hard Red Spring (HRS) wheat quality has not been conducted extensively. Eight HRS wheat cultivars from four different locations and two crop years were milled into refined and whole wheat flours. The samples were analyzed for phenotype, genotype, and environmental effects on flour composition, dough and bread quality. The SRC method was used to determine correlations between refined and whole wheat flours, and flour quality parameters. Flour quality was significantly ($P<0.05$) affected by cultivars, and the year x location, and year x cultivar interactions. Correlations exist between whole wheat flour and refined flour SRC profiles. Limited correlations exist between whole wheat flour SRC and flour quality. Therefore, SRC is not suitable for whole wheat HRS wheat flour.

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LIST OF ABBREVIATIONS

AACCI……...American Association of Cereal Chemists International

ANOVA…….Analysis of Variance

BU……..Braebender Unit

FDA……Food and Drug Administration

GPI…….Gluten Performance Index

HRS……Hard Red Spring

LAB……Lactic Acid Bacteria

LSD……Least Significant Difference

MB……..Moisture Basis

MTI……Mixing Tolerance Index

NDSU…….North Dakota State University

NIR…….Near-Infrared

SAS…….Statistical Analysis Software

SDS…….Sodium Dodecyl Sulfate

SDSU……..South Dakota State University

SRC…….Solvent Retention Capacity

RVA……Rapid Visco Analyzer

RVU……Rapid Visco Unit

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INTRODUCTION

Solvent Retention Capacity

The purpose of the Solvent Retention Capacity (SRC) method is to determine the contribution of wheat flour constituents on end-product functionality. Currently published research on SRC for Hard Red Spring (HRS) wheat is sparse, since the SRC method was developed for soft wheat. The SRC method has been used to evaluate whole wheat flour from soft white wheat, hard white wheat, and Indian wheat varieties, but not from HRS wheat. Knowing the correlations between SRC and other quality and functionality tests for HRS wheat flour may be useful to the milling and bread baking industries. The SRC results could potentially be used to predict bread loaf volume based on functional polymeric components in flour (Duyvejonck et al, 2012). The main functional polymeric components include glutenins, damaged starch, and water-soluble arabinoxylan (AACCI, 2009). These components are measured by solvent compatibility, which is the weight of the solvent held by the flour sample after centrifugation (AACCI, 2009). The SRC method could potentially replace several labor intensive analytical tests that predict baking performance and flour quality. In addition, SRC does not require highly specialized equipment and methodology is easily learned.

Bread Flour Quality Measures

Wheat flour is used extensively by the food industry to produce products such as: breads, pastries, crackers, cookies, and breakfast cereals. Flour quality is evaluated prior to food production as a way to predict the quality of end products, such as bread. Intrinsic and extrinsic factors affect wheat flour quality. Intrinsic factors include protein content, starch damage, and starch content. Extrinsic factors include wheat storage, milling, and flour storage. Knowing the

quality of flour is economically beneficial because quality relates to the desired end product and manufacturing process (Duyvejonck et al, 2011).

Flour quality is measured during each phase of the bread baking process starting with wheat breeders and ending with bakers. Breeders, millers, and bakers utilize flour quality evaluations for selecting higher quality wheat cultivars with optimal performance related to cultivation, milling, and baking (Kweon et al, 2011). There are several parameters used to define flour quality based on intrinsic and extrinsic factors. Higher quality bread flour is defined by high water absorption, medium mixing requirement, satisfactory mixing tolerance, good loaf volume and yield, and good internal crumb and color (Maghirang et al, 2006). High quality bread flours consist of high gluten strength, damaged starch, and arabinoxylans, which contribute to loaf volume (Kweon et al, 2011).

Hard Red Spring Wheat

Most wheat grown in the United States is the *Triticum aestivum* L. species, which contains two varieties: soft and hard wheat (Delcour et al, 2012). The main differences between the soft and hard wheats are the force required to break the kernels during milling, the protein contents, and the end product uses. Hard wheat protein content ranging between 10 and 17%, and is used for making bread products (Maghirang et al, 2006). Soft wheat contains a protein content between 8 and 11%, and is used to make cakes, cookies, crackers, and pretzels (Delcour et al, 2012). The differences in flour composition between soft and hard wheats will produce different SRC results.

There are three classes of wheat under the hard wheat variety, which includes Hard Red Spring (HRS) wheat. HRS wheat is commonly used for making pan breads, hearth breads, rolls, croissants, bagels, hamburger buns, and pizza crust. HRS wheat is typically grown in North

Dakota, Montana, Minnesota, South Dakota, Idaho, Oregon, and Washington (U.S. Wheat Associates, 2014). Some of the major HRS wheat cultivars grown in the United States include: Barlow, Elgin-ND, Faller, Forefront, Glenn, Linkert, Mott, Prosper, SySoren, and WB Mayville (U.S. Wheat Associates, 2014). Over the past 40 years, North Dakota State University (NDSU) has specifically released 26 HRS wheat cultivars through the NDSU HRS wheat breeding program (Underdahl et al, 2008). Hard Red Spring wheat is a common Midwestern crop, but is also used worldwide. Worldwide flour mills regularly blend HRS wheat with other wheat classes or cultivars as a means to increase the gluten strength of low protein wheat classes (Underdahl et al, 2008).

Blending different flour classes is common in the food industry, since blended flours result in more potential final end products. Flour blends made with HRS wheat are used to make several bread products, such as: yeast breads, hard rolls, whole grain breads, pizza dough crusts, and bagels, and non-bread products such as Chinese type noodles (Underdahl et al, 2008). HRS wheat is used for bread products because of the high flour quality characteristics. According to Chung et al (2003) HRS wheat contains higher protein and gluten contents, kernel hardness, and loaf volume, which are ideal for bread products.

Whole Wheat Flour

The main difference between whole wheat and refined flours is that whole wheat flour contains the kernel bran and germ, but refined flour is only composed of the kernel endosperm. The method for whole wheat flour milling is similar to refined flour milling with the exception of reducing bran and germ particle size and blending with the milled endosperm. Endosperm is composed of mostly starch and functional proteins (Doblado-Maldonado et al, 2013). The bran and germ are composed of vitamins, minerals, non-functional proteins, lipid and fiber (Doblado-

Maldonado et al, 2013). Therefore, whole wheat flour has a better nutritional profile compared to refined flour.

The additional nutrients found in whole wheat flour affect flour and end-product qualities. Whole wheat flour has a higher ash content than refined flour because of the nutrients present in the bran. The higher ash and fiber contents of whole wheat flour interfere with gluten development during bread baking. This interference negatively affects bread loaf volume and crumb texture, and requires modifications to the baking procedure to maintain better bread quality (Plyer and Gorton, 2009). Flour quality parameters change between refined flour and whole wheat flour samples due to differences in flour composition. Quality standards exist for refined HRS wheat flour, but whole wheat flour quality standards have not been developed. The SRC method potentially could be a more efficient procedure for determining refined and whole wheat flour quality. The differences between whole wheat flour and refined flour compositions will have an effect on SRC results.

LITURATURE REVIEW

Hard Red Spring Wheat Quality Measures

Hard Red Spring wheat is typically used as bread flour. Several quality methods can be used to determine end-product functionality of HRS wheat (Table 1). Three methods are typically used to evaluate HRS wheat flour quality. Method one consists of determining the level of flour constituents or properties with the zeleny sedimentation test (Duyvejonck et al, 2012). One of the main flour properties evaluated during the zeleny sedimentation test is gluten protein strength, which is used to predict loaf volume. Rheological tests can be used to indicate dough properties and flour quality, which includes the Brabender Farinograph, Mixograph, and Chopin Alveograph analyses (Duyvejonck et al, 2012). The Farinograph and Mixograph measure water absorption, which indicates either a good or poor baking quality flour (Ram et al, 2005). These two tests are more time consuming, expensive, and labor intensive compared to SRC (Ram et al, 2005). Experimental baking represents the industrial bread baking process on a smaller scale, which can be used to evaluate bread quality from a given flour sample (Duyvejonck et al, 2012). Flour constituents, such as proteins, water absorption, and baking characteristic tests, are most commonly used to determine flour quality.

Table 1: Common Flour Quality Parameters and Current Methods for Hard Red Spring Wheat

Flour Parameter	Official Method	Method Reference
Moisture	Moisture- Air Oven Method	AACCI Method 44-15.02
Total Ash	Basic Ash Method	AACCI Method 08-01.01
Total Protein	Crude Protein- Combustion (Leco)	AACCI Method 46-30.01
Total Wet/Dry Gluten	Wet Gluten/Gluten Index	AACCI Method 38-12.02
Damaged Starch	Starch Damage Assay	AACCI Method 76-13.01
Starch Pasting Profile	Rapid Visco Analyzer	AACCI Method 76-21.01
Resistance to Dough Mixing	Farinograph	AACCI Method 54-21.02
Experimental Baking	Basic Straight Dough Bread Baking	AACCI Method 10-09.01

AACCI= American Association of Cereal Chemists International

The Effect of Genotype and Phenotype on Flour Quality

Genetic and environmental factors affect wheat and flour quality. Plant genetics can be categorized by phenotype and genotype. Phenotypes are observed properties of a plant (i.e. kernel color), which are produced in conjunction with the environment. Genotype represents the genetic composition of a plant, distinguished from its physical appearance. Genetic factors are based on the specific type of wheat cultivar and the genetic traits associated with that cultivar. The environmental factors affecting wheat quality include: soil conditions, weather during the growing season (i.e. rain, drought, heat, etc.), location, and year. Plant breeders estimate each year the impact of environmental conditions interacting with desirable genetic traits to determine the best genotypes (Kaya and Akcura, 2014). Breeding programs allow plant breeders to determine how a specific trait is affected by genotype and environment.

Millers and bakers are mostly concerned with the end-use quality traits of HRS wheat. Spring wheat cultivars' genotypes influence bread baking quality more than environment. The end-use quality traits can be heightened through breeding processes for different growing locations (Simmons et al, 2012). High flour yield and grain uniformity are desirable quality traits for millers, whereas, bakers prefer higher protein content and quality (Simmons et al, 2012).

The SRC method has been used to evaluate soft wheat for determining high quality genotypes. Guttieri et al (2002) found the genotype x environment interaction to be non-significant for soft white spring wheat cultivars. A similar study conducted with 26 different soft spring wheat flour samples found differences in genotypes were more significant than genotype-environmental interactions using the SRC method (Guttieri et al, 2001). The research concluded the selection of genotypes within a specific environment are predicted to produce similar results and observations when grown in multiple and diverse environments (Guttieri et al, 2002).

Solvent Retention Capacity

Solvent Retention Capacity is a relatively new method used to measure wheat flour quality. The SRC method quantifies the swelling behavior of flour polymers (Duyvejonck et al, 2012). Slade and Levine (1994) developed the SRC method, which was implemented as an American Association of Cereal Chemists International (AACCI) approved method (Kweon et al, 2009). The SRC test was originally developed for soft wheat flours used to make products such as cookies and biscuits. However, SRC is becoming more commonly used to test hard wheat flours, such as HRS wheat. Wheat breeders, millers, and bakers are increasingly using SRC to evaluate flour quality (Kweon et al, 2011). SRC tests are being utilized more because the procedure is less labor intensive, requires small sample amounts, and is a rapid test method. SRC is beneficial for wheat breeding systems that use small quantities of flour for predicting flour functionality because SRC only uses small amounts of flour (5 g) to run each test (Xiao et al, 2006).

For the SRC method, four solvents, including water, sucrose, sodium carbonate and lactic acid, are used based on functional polymeric flour components. The solvent to flour ratio is 5:1 w/w, which results in a solvent-retention network instead of extracted supernatant (Kweon et al, 2011). Each solvent is diluted with deionized water, because each flour polymer measured contains different water holding capacities. Water-soluble arabinoxylans have the greatest water holding capacity compared to gluten and damaged starch (Kweon et al, 2011). Each solvent has a minimum of 50% water, therefore, as the amount of flour polymer increases, the swelling increases (Kweon et al, 2011).

The overall water holding capacity of all flour polymers is related to water retention capacity. Water acts as the reference solvent since it can hydrate and swell gluten, damaged

starch, and arabinoxylans of flour (Kweon et al, 2011). The water holding capacity of flour is an important property, which effects processing and finished-product quality (Kweon et al, 2011). Water absorption is an important quality parameter because higher water absorption allows better gluten formation in pan bread. The formation of disulfide bonds, hydrogen bonds, and hydrophobic interactions stabilize the gluten structure during the dough mixing process (Chiang et al, 2006). However, the other three SRC solvents are more compatible with one of the polymeric flour components. The other three solvents exaggerate the swelling of the compatible flour polymers more than the water solvent (Kweon et al, 2011).

The 55% ethanol can be used as an additional solvent due to the gliadins association, but this is not an AACCI approved SRC solvent. Gliadin proteins are not soluble in water, but are soluble in ethanol (Pahesh et al, 2014). The gluten proteins, specifically gliadins, were the most soluble in water/ethanol solvent (50/50 v/v) (Pahesh et al, 2014). The extractable ethanol solvent results in a measurable loss of protein during SRC testing to the supernatant, and de-swells damaged starch and arabinoxylans (Kweon et al, 2011). The ethanol solvent is more appropriate to use instead of deionized water or lactic acid when measuring gliadin content, specifically in flour. The ethanol solvent potentially could be used to predict gliadin protein resistance to extension and dough cohesiveness during dough formation (Declour and Hoseney, 2010).

The pH of each solvent, other than water, is important for compatibility with the three flour polymers. Lactic acid (5%) solvent extracts gluten, specifically glutenin proteins, because the pH of the solvent is similar to the pH (<4.0) generated by lactic acid bacteria (LAB) during the dough fermentation process of bread baking (Kweon et al, 2011). The acidic pH allows glutenins to become functional during dough formation, which affects dough strength and loaf

volume. The gluten network formation and gluten strength of flour is based on the ratio of gliadins to glutenins, which are related to the lactic acid solvent.

Lactic acid SRC correlates with the quality of gluten proteins and relates to bake loaf volume of bread (Kweon et al, 2011). The SRC test for hard winter wheat was discovered as a reliable source for predicting bread loaf volume because lactic acid SRC was correlated with SDS-sedimentation bread volume data (Kweon et al, 2011). The SRC results could be used to predict loaf volume for hard winter wheat flours with similar protein contents. The relationship between lactic acid SRC and SDS-sedimentation could be similar for HRS wheat. Thus, lactic acid SRC potentially could be used to predict loaf volume for HRS wheat.

The gluten network is made up of gliadin and gutenin proteins. Glutenins provide dough resistance to extension, and gliadins provide cohesiveness of dough with little resistance to extension (Parker et al, 2006). The presence or absence of low and high molecular weight glutenins and gliadins dictates wheat protein quality (Suchy et al, 2003). Thus, the distribution of glutenins and gliadins in flour is important for the formation of a strong gluten network. These proteins make up the gluten complex in bread dough, which is important for loaf volume. Glutenins and gliadins interact with water to form gluten, which is required for bread making due to its viscoelastic properties (Kuktaite et al, 2004). Water absorption is an important quality parameter because higher water absorption allows for better gluten formation. The formation of disulfide bonds, hydrogen bonds, and hydrophobic interactions stabilize the gluten structure during the mixing process (Chiang et al, 2006). A stronger gluten network will result in optimum dough expansion during fermentation. During the dough fermentation process, yeast produces carbon dioxide gas and ethanol from sugar (Pyler and Gorton, 2009). Gluten possess a unique gas retention characteristic, allowing the dough to trap the carbon dioxide produced by yeast

during fermentation (Pyler and Gorton, 2009). This process allows dough to expand, resulting in bread crumb formation effecting the final bread crumb quality.

Starch damage occurs during the milling process of flour. Damaged starch and arabinoxylans are both found in the aleurone and bran layers of wheat kernels. These two flour components increase the water holding capacity of flour during dough formation (Kweon et al, 2011). The pH of the sodium carbonate solvent is important for interactions with damaged starch. The higher alkaline pH (~12.0) allows 5% sodium carbonate solvent to exaggerate swelling of damaged starch (Kweon et al, 2011). The pH of the sodium carbonate solvent is greater than the pK value of starch hydroxyl groups causing damaged starch or pregelatinized starch to swell (Kweon et al, 2011). Undamaged or native starch granules will not swell in sodium carbonate solvent, since amylopectin is not released and increasing viscosity (Kweon et al, 2011). The presence of damaged starch is important for dough fermentation, since yeast can use damaged starch to produce carbon dioxide and ethanol (Pyler and Gorton, 2009). If large quantities of yeast food (damaged starch) are present during dough fermentation, then the rate of fermentation will change and possibly result in undesirable bread quality characteristics.

The sucrose solvent is used to extract arabinoxylans from flour samples. Arabinoxylans, also known as pentosans, are non-starch polysaccharides found in an abundance in the cell wall of cereals (Gerbruers et al, 2010). The 50% sucrose solvent has a neutral pH that allows for arabinoxylan swelling and specifically interacts with the xylan backbone of wheat flour arabinoxylans (Kweon et al, 2011). This sucrose solution (50% w/w) was the most compatible with wheat flour arabinoxylans' xylan backbone. The amount of arabinoxylans enlarged by sucrose-water solvent will affect the sucrose SRC value, which indicates water holding capacity.

Arabinoxylans increase the water absorption during dough mixing and can cause separation between gluten and starch affecting dough development (Gerbruers et al, 2010).

All three solvents chemically interact with the flour polymers causing extractions of each specific polymer instead of an overall polymer extraction from water. This allows identification of each polymer's functionality for end-product quality. Solvent Retention Capacity provides a flour functionality profile, based on these solvents that can be used to predict the flour performance during baking applications (Duyvejonck et al, 2011).

The gluten performance index (GPI) is a calculated value determined by lactic acid, sodium carbonate and sucrose SRC values using the equation: GPI= lactic acid SRC/(sodium carbonate SRC + sucrose SRC). The SRC GPI value represents the overall performance of gluten in an environment of other modulating networks (Kweon et al, 2011). Kweon et al (2009) discovered GPI increased about a third of the flour yield range as flour extraction increased. The lactic acid SRC value has an inverse relationship with sodium carbonate and sucrose SRC values. Therefore, as lactic acid SRC decreases, the sodium carbonate plus sucrose SRC increases (Kweon et al, 2011). The overall gluten performance of flour decreases when the lactic acid SRC value is less than the sodium carbonate SRC value.

Whole Wheat Flour and Bread

Whole Wheat Flour Milling and Quality

The whole wheat flour standard of identity according to the Food and Drug Administration (FDA) is defined as food prepared by grinding clean wheat with a particle size ranging between 850 μm and 2.36 mm, and the wheat's natural constituents proportions, except for moisture, must be unaltered (FDA, 2012). Whole wheat flour contains the bran and germ

blended together with endosperm flour in natural-occurring proportions (Doblado-Maldonado et al, 2012).

The standard method for generating straight-grade flour milling procedure (AACC International, 1999d) is commonly used for whole grain flour (Doblado-Maldonado et al, 2013). The straight-grade flour milling method separates the bran and germ from the endosperm of the wheat kernel. For whole wheat flour, the milling fractions containing the bran and germ are re-milled typically by a conical or hammer mill prior to mixing with the straight-grade endosperm flour (Doblado-Maldonado et al, 2013). During the milling process, wheat kernels are pre-conditioned or tempered prior to grinding to help ease the separation of the bran and germ from the endosperm. Tempering is not an important step in whole wheat flour milling, however, since the bran and germ will not be removed from the final flour product (Doblado-Maldonado et al, 2012).

Within a wheat kernel, majority of nutrients are found in the bran and germ, as opposed to the endosperm. The nutrients found in wheat bran and germ include vitamins, minerals, trace elements, and dietary fiber (Steinfurth et al, 2012). The bran aleurone layer is rich in phosphorous, potassium, magnesium, calcium, iron and zinc (Schmiele et al, 2012). The ash content of whole wheat flour is higher than refined flour due to the higher vitamin and mineral content located in the bran. Whole wheat flour usually contains more protein than refined flour, however, the functional protein content of whole wheat flour is not greater than refined flour. Functional proteins, which are gliadins and glutenins, make up the gluten protein network and are only located in the endosperm (Steinfurth et al, 2012). These functional proteins are important for bread baking quality. The proteins found in the bran include albumin and globulin proteins, which are not gluten forming (Steinfurth et al, 2012).

Whole Wheat Dough Rheology and Bread

The use of whole wheat flour, in comparison to refined flour, has several negative effects on dough rheology and bread quality. The bran and germ specifically worsen dough rheology, decrease bread loaf volume, increase bread crumb hardness, darken bread crumb color, and provide different flavors to whole wheat bread (Demir and Elgun, 2013). A common dough rheological method conducted with refined bread flour is the Farinograph. The Farinograph is used to measure the resistance to dough mixing prior to experimental baking. The Farinograph records several measurements including water absorption. The water absorption of refined flour results mainly from gluten forming proteins, since these gluten proteins can hold as much as three times their weight in water (Schmiele et al, 2012). For whole wheat flour the Farinograph water absorption is caused by fiber, specifically cellulose and hemicellulose, not gluten forming proteins (Schmiele et al, 2012). Therefore, whole wheat flour will have a higher baking water absorption in comparison to refined flour. Since whole wheat flour contains different rheological parameters than refined flour, Schmiele et al (2012), concluded that a need for defined rheological standards exists for whole grain flours in order to attain correlations between dough rheology and bread quality.

Bread produced from whole wheat flour does not result in the same quality characteristics as bread made with refined flour. Whole wheat flour affects dough mixing, fermentation, and baked bread characteristics such as loaf volume, crumb color, and crumb texture. The bran in whole wheat flour affects dough and bread quality. The particle size of the bran is important during the milling of whole wheat flour since the bran particle size has an effect on bread quality. Large bran particles (average particle size 500 μm or more) cause higher water absorption and lower loaf volume (Doblado-Maldonado et al, 2012). Coarse bran particles (greater than 600 μm)

result in bread with a rough crust and gritty texture (Doblado-Maldonado et al, 2012). The particle size of the bran should be re-milled to the same particle size as the milled endosperm for the best results.

Whole wheat flour contains more proteins and dietary fiber than refined flour. The increase in protein and fiber in whole wheat flour causes an increase in water absorption during dough mixing (Steinfurth et al, 2012). Water added during dough mixing is important for hydrating the flour particles and the gluten forming proteins. Without water, dough and gluten formation would not occur. Having the optimal amount of water during dough formation is important for dough properties, such as gluten, which affects the final product quality.

Bran and fiber in whole wheat flour can weaken gluten and decrease the gas retention capacity resulting in lower loaf volume. Gas cells are formed in dough during mixing by incorporation of air, and during fermentation by yeast producing carbon dioxide. The gas cells are trapped in the dough by the starch-protein matrix and the unique gas-holding capacity of the gluten protein network (Steinfurth et al, 2012). Fiber and bran can interfere with the starch protein matrix and gluten network causing non-homogeneous and discontinuous strands, films and membranes (Steinfurth et al, 2012). The fermentation time of whole wheat dough should be reduced since the bran interferes with gas retention capacity. During fermentation yeast converts sugars into alcohol and carbon dioxide, which is trapped in the dough by gluten. The trapped gas causes the dough to expand during fermentation, resulting in baked loaf volume (Pyler and Gorton, 2009). Since bran and fiber interfere with the starch protein matrix and gas retention during mixing and fermentation, the bread loaf volume will decrease as a result.

Solvent Retention Capacity for Whole Wheat Flour

Some researchers have compared whole wheat flour to refined flour using SRC methods including Bettge et al (2002), and Ram et al (2005). Whole wheat flour contains the bran and germ from the wheat kernel. During the milling process, the bran and germ are removed from the endosperm, which is milled into white flour. Flour results in a white color because the bran and germ are typically not milled and blended back with the milled endosperm, unless milling of whole wheat flour is desired. Whole wheat product demands are increasing by consumers, which is why SRC values of whole wheat flour are relevant.

Determining correlations between whole wheat and refined flour SRC profiles are important for the usage of this flour quality test. Higher correlations between whole wheat flour SRC and refined flour SRC indicate this flour quality method also can be used on whole wheat flour (Bettge et al, 2002). Whole wheat flour properties are slightly different than refined flour, which will affect SRC results. Whole wheat flour contains bran, more non-starch carbohydrates and structural proteins compared to refined flour, which can all affect SRC results (Bettge et al, 2002). Whole wheat flour contains the germ of the wheat kernel, which contains more lipid, vitamins, and minerals (ash), which can affect bread quality.

Whole wheat flour resulted in lower lactic acid SRC values, but higher water, sucrose, and sodium carbonate SRC values compared to refined flour (Bettge et al, 2002). The lactic acid, sodium carbonate, and sucrose SRC correlation coefficients were high between whole wheat flours. Whole wheat flour could be used to replace refined flour if the confounding absorption effect of bran on background absorption and bran effects on lactic acid and sucrose SRC are considered.

Whole wheat flour contains more structural proteins and less functional proteins that make up the gluten network. Whole wheat flour has less glutenin and gliadin proteins present causing a lower lactic acid SRC value (Ram et al, 2005). This is important because lactic acid SRC is used to predict the loaf volume during the bread baking process. However, if whole wheat flour is known to have less functional proteins than refined flour, one would expect the final end product, such as bread, to be slightly different as well. Whole wheat flour SRC values have been compared to whole wheat flour Farinograph and Mixograph results. SRC results for whole wheat flour were positively correlated to Farinograph and Mixograph for water absorption and gluten strength. The specific Farinograph and Mixograph values that were compared to SRC include: Farinograph peak time and mixing tolerance index, the Mixograph peak time and peak dough resistance (Ram et al, 2005). Ram et al (2005), reported no significant difference between whole-meal and refined flour SRC profiles.

Justification, Objectives, and Hypothesis

Justification

Growing consumer demands for whole wheat food products have been observed for years. However, whole wheat quality standards are scarce compared to refined flour quality standards. Developing whole wheat quality standards for HRS wheat would benefit the wheat industry. Breeders could use whole wheat and refined HRS wheat flour quality standards to develop varieties that are more versatile to the food industry. The SRC method would be useful to whole wheat HRS wheat flour breeding programs due to the ease and convenience of the procedure. Millers and bakers would be able to use the SRC method as a rapid and easy procedure to determine if their whole wheat flour meets quality specifications. Since the SRC method was developed for soft wheat flour, extensive research studies have been devoted to soft

wheat quality using SRC. However, little research has been conducted using the SRC method for HRS wheat quality, specifically for whole wheat flour.

Objectives

- To determine the effects of genotype, phenotype, and environment on correlations between SRC and flour functionality for refined and whole wheat flours.
- To determine the effects of genotype, phenotype, and environment on flour functionality for refined and whole wheat flours.
- To determine if correlations exist between refined flour SRC and whole wheat flour SRC profiles.

Hypothesis

Location, year, and cultivar will affect flour and end-product quality for both refined and whole wheat flours. The whole wheat flour SRC, flour quality, and baking correlation results will be different than the refined flour.

METHODS AND MATERIALS

Materials

Eight different cultivars of HRS wheat grown in North Dakota were collected. The cultivars were grown in four different locations including Casselton, Carrington, Dickinson and Hettinger in 2013 and 2014. The cultivars used in this experiment are provided in Table 2. These locations, years, and cultivars were chosen based on genotype and phenotype characteristics. The location and crop year are important for crop yield and quality. The crop years, locations, and cultivars used in this experiment had the best growing conditions, yields, flour attributes, and end-product quality in North Dakota. The 2014 crops in the Northern Plains region had ideal weather conditions, which resulted in more favorable harvest (U.S. Wheat Associates, 2014). The HRS wheat cultivars chosen had higher milling and baking quality ratings, which are based on protein content, milling performance, flour parameters, dough characteristics, and baking performance (North Dakota Wheat Commission, 2014).

Table 2: Hard Red Spring Wheat Cultivars used in the Experimental Design

Cultivar	Release Year	Origin	Plant Registration
Barlow	2009	NDSU	Reg. No. CV-1055, PI658018
Elgin	2013	NDSU	N/A
Faller	2007	NDSU	Reg. No. CV-1026, PI648350
Forefront	2012	SDSU	Reg. No. CV-1082, PI664483
Glenn	2005	NDSU	Reg. No. CV-974, PI639273
Mott	2009	NDSU	N/A
Prosper	2011	NDSU	Reg. No. CV-1080, PI662387
SySoren	2011	NDSU	N/A

NDSU: North Dakota State University; SDSU: South Dakota State University; Reg: Registration; No: Number; CV: Cultivar; PI: Seeding Number

Flour Collection Method

Hard Red Spring wheat cultivars were obtained from different regions in North Dakota grown in 2013 and 2014. The wheat samples were milled one location at a time using the Buhler lab mill (MLU 202, CH-9240 Uzwil Switzerland). Therefore, one location was milled and analyzed one at a time to control the aging process of the flour samples. The refined flour, bran, and shorts fractions were saved after the milling process. The refined flour was rebolted using 84 sieve to remove any unwanted materials from the flour. The unwanted material particle size is 170 microns or less and is typically 4-6 grams. The bran and shorts particle sizes had to be reduced to the same particle size as the refined flour. The particle size of the bran and shorts was reduced using a hammer mill with a 0.5 mm screen. Reducing the bran particle size allows for a uniform whole wheat flour mixture, which is important for dough quality. Before blending the refined flour, bran, and shorts to produce whole wheat flour, one needs to determine the amount of each material to use. The percentages of refined flour, bran, and shorts used should meet the requirements for whole wheat flour. The near-infrared method (NIR) was used to find the protein content (14% moisture basis) of each flour sample using the AACCI approved method 39-11.01 (AACC International, 1999h).

Flour Quality Measures

Flour Analysis

Ash and moisture contents were measured using the AACCI approved methods 08-01.01 and 44-15.02, respectively, expressed on a 14% moisture basis (AACC International, 1999a and 1999g). Gluten strength was measured using the AACCI approved method 38-12.02 (AACC International, 2000). The Farinograph method was used to determine water absorption, stability and peak time using the AACCI approved method 54-21.02 (AACC International, 2011). The

arabinoxylan content was measured because it contributes to water absorption of flour during dough formation (Blakeney et al, 1983). The AACCI approved method 76-31.01 was used to determine starch damage (AACC International, 1999c). The AACCI approved method 76-13.01 for total starch content was used (AACC International, 1999i). Rapid Visco-Analyzer (RVA) AACCI approved method 76-21.01 was used to find the pasting profile of the flour samples (AACC International, 1999e).

Bread Baking Analysis

Each flour sample was baked into pup bread loaves using the basic straight-dough AACCI approved method 10-09.01 with a two-hour fermentation (AACC International, 1999b) with modification (α-amylase and instant dry yeast were used instead of malt and compressed yeast, respectively). The bread samples were evaluated on loaf shape and appearance, crust and crumb color, crumb structure, volume by rapeseed displacement, and the bread firmness was measured using the texture analyzer (AACC International, 2012, 2001, and 1999f, respectively).

Solvent Retention Capacity Method

The AACCI approved method 56-11.02 for Solvent Retention Capacity (SRC) was used (AACC International, 2009). The SRC solvents used include deionized water, 50% sucrose, 5% lactic acid, 5% sodium carbonate, and 55% ethanol (Figure 1). The SRC method requires 5 g of flour sample and 25 g of solvent (Figure 2). The flour sample and solvent were mixed in a 50 mL centrifuge tube and placed on an orbital mechanical shaker at 100 RPM for 25 minutes (Figure 2). The samples were then placed into the centrifuge at 1000 RPM, for 15 minutes with the breaker setting off (Figure 2). The samples were removed from the centrifuge, and the excess solvent was drained by placing the tubes at a 90° angle for 10 minutes (Figure 2). The sample

pellets were weighed to determine the sample weight (Figure 2). The SRC values were calculated using the AACCI method equation:

$$\text{SRC\%} = [(\text{pellet (g)}/\text{flour (g)})-1] \times [86/(100-\text{flour moisture})] \times 100 \quad \text{(Eq. 1)}$$

The GPI values were calculated using:

$$\text{GPI} = \text{lactic acid SRC}/(\text{sodium carbonate SRC} + \text{sucrose SRC}) \quad \text{(Eq. 2)}$$

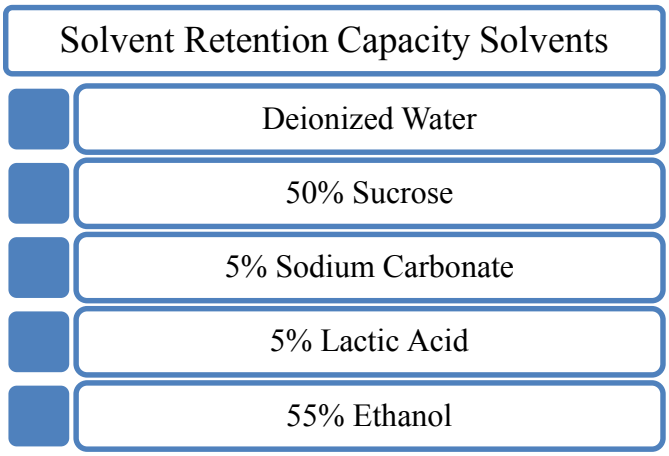

Figure 1: Solvent Retention Capacity Solvents Used in Experiment

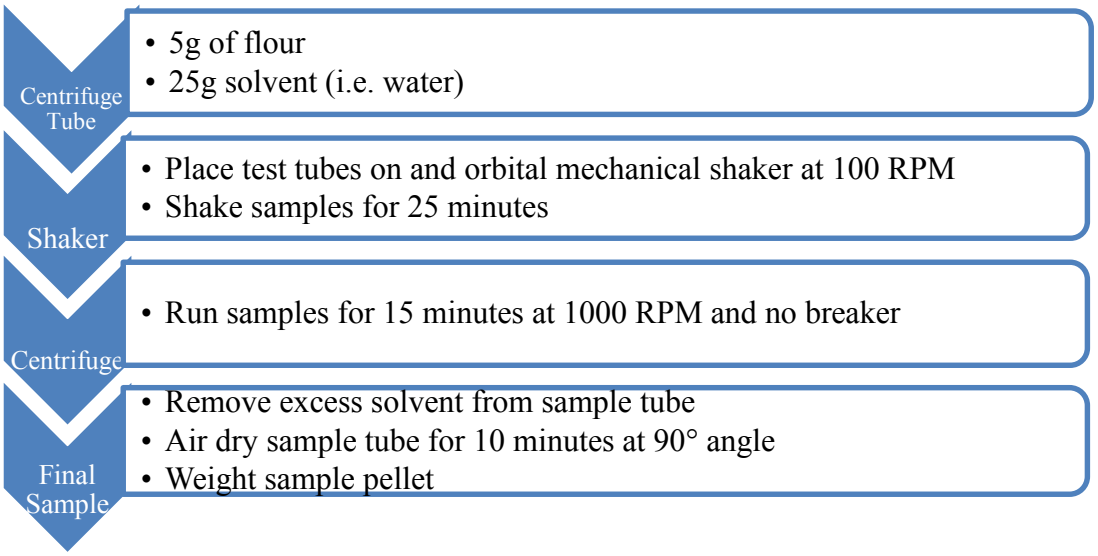

Figure 2: Solvent Retention Capacity Method Procedure Flow Chart

Statistical Analysis

The samples contain eight different HRS wheat cultivars from four different locations in North Dakota grown over two years. Statistical analysis was conducted using the statistical analysis software (SAS) (Version 9.3, SAS Institute; Cary, NC). The "MIXED" procedure in SAS was used to perform the analysis of variance in which the "year x location x cultivar" interaction term was considered the error term. Analysis of variance was used for each set of data collected (Appendix Tables A1-A14). The mean and least significant difference (LSD) values for growing environment (i.e. growing year and location combinations) and genotypes were estimated using "LSMEAN" option in the "MIXED" procedure in SAS with an α 0.05. Correlation coefficients for environment and genotype were calculated using the least square mean value for growing environments and genotypes, respectively.

RESULTS AND DISCUSSION

Flour Composition

Refined Flour

Eight different HRS wheat cultivars from four different locations grown over two years were collected and milled before determining each flour composition. Flour composition studies are commonly used as preliminary measures for predicting end product quality, such as pan bread baking (Tulse et al, 2014). Flour composition measurements include, but are not limited to: ash content, protein content, wet gluten, gluten index, total starch content, starch damage, and arabinoxylan content.

Variations in flour composition of refined flour for the eight different HRS wheat cultivars was observed (Table 3). Ash contents were not significantly (P>0.05) different between each cultivar. The average ash content of HRS wheat falls between 0.40 and 0.60% (Maghirang et al, 2006). The ash contents of the samples were between 0.50 and 0.54%, which falls under the average for HRS wheat (Table 3). Ash content of refined flour is typically low, unless bran contamination has occurred during milling. Ash content consists of inorganic materials that can interfere with gluten functionality during baking.

The total starch contents were not significantly (P>0.05) different between the cultivars (Table 3). Refined flour composition contains large amounts of starch. The total starch values ranged between 72.6 and 74.0% (Table 3). The average range for total starch in HRS wheat flour is between 70 and 77% (Simsek et al, 2010). The endosperm contains the largest amount of starch in a wheat kernel, which explains the large total starch composition of refined flour. The arabinose/xylose ratios, and arabinoxylan content, excluding SySoren, were not significantly (P>0.05) different between each cultivar (Table 3). The arabinoxylan content of HRS wheat on average ranges from 1.9 to 2.3% (Duyvejonck et al, 2011). The arabinoxylan contents of the

different cultivars were between 2.3 and 3.3%, which are slightly higher than the average arabinoxylan content (Table 3).

Significant (P<0.05) variations in protein content exist between cultivars (Table 3). The protein contents ranged from 12.0 to 13.3% (Table 3). The protein content of HRS wheat refined flour typically ranges from 12.0 to 15.0% (Pyler and Gorton, 2009). Higher protein content is desirable for bread flour, because higher protein content indicates more present functional proteins and higher end-product quality (Pyler and Gorton, 2009). The difference in protein contents may be a result of different genotypes between the different cultivars. Faller and Prosper cultivars have slightly lower protein contents compared to the other cultivars (North Dakota Wheat Commissions, 2014).

For wet gluten content, the cultivars Barlow, Forefront, Glenn, Mott, and SySoren were not significantly (P>0.05) different (Table 3). However, these cultivars were significantly (P<0.05) different from Elgin, Faller, and Prosper (Table 3). The results for gluten index were not the same as wet gluten because gluten index values represent gluten quality and wet gluten values refer to the water-binding capacity of gluten proteins (AACC International, 2000). The gluten index and wet gluten values of HRS wheat are typically 75 to 99 % and 30 to 40%, respectively (Maghirang et al, 2006; Hammed et al, 2015). The gluten index values between cultivars were significantly (P<0.05) different (Table 3). A larger gluten index indicates a stronger gluten, and a larger wet gluten content means more water soluble gluten proteins are present in the flour.

Damaged starch is a result of broken starch granules, which occurs during the milling process. The average amount of damaged starch found in HRS wheat flour is between 5 and 8% (Duyvejonck et al, 2011). The damaged starch contents of the cultivars were between 6.7 and

9.0% (Table 3). The differences in damaged starch are most likely due to differences in kernel hardness. Even though the samples were milled using the same mill conditions, some cultivars may have differences in kernel hardness resulting in more or less starch damage during milling. If softer kernels are milled with the same roll settings and force needed for harder kernels, than more starch damage is expected to occur during endosperm reduction.

The composition results show that the cultivars contain similarities and differences in quality traits that can affect end product quality. The differences in flour composition between cultivars are most likely due to different genotypes.

Table 3: Refined Flour Composition for Hard Red Spring Wheat Cultivars Grown in North Dakota

Cultivar	Ash* (%)	Protein * (%)	Wet Gluten * (%)	Gluten Index	Total Starch † (%)	Damaged Starch‡ (%)	Arabinoxylan ‡ (%)	Arabinose /Xylose Ratio
Barlow	0.52^{a}	13.1^{ab}	34.9^{a}	92.0^{ab}	73.2^{a}	8.8^{a}	2.5^{b}	0.89^{a}
Elgin	0.50^{a}	12.5^{bc}	31.8^{b}	94.7^{a}	73.3^{a}	7.3^{b}	2.5^{b}	0.96^{a}
Faller	0.53^{a}	12.1^{c}	31.1^{b}	94.8^{a}	74.0^{a}	9.0^{a}	2.5^{b}	0.97^{a}
Forefront	0.50^{a}	13.1^{a}	34.7^{a}	90.3^{b}	72.6^{a}	6.8^{b}	2.7^{b}	0.93^{a}
Glenn	0.50^{a}	13.3^{a}	34.8^{a}	94.8^{a}	73.7^{a}	8.7^{a}	2.6^{b}	0.96^{a}
Mott	0.50^{a}	12.9^{ab}	35.1^{a}	86.4^{c}	73.9^{a}	7.4^{b}	2.3^{b}	0.95^{a}
Prosper	0.52^{a}	12.1^{c}	31.5^{b}	93.4^{ab}	73.8^{a}	8.9^{a}	2.3^{b}	0.96^{a}
SySoren	0.54^{a}	13.3^{a}	36.4^{a}	84.3^{c}	72.6^{a}	6.7^{b}	3.3^{a}	0.95^{a}

Values with the same superscript letter are not significantly different (P>0.05). Least significant difference was used for mean separation. * 14% moisture basis, † dry weight basis, ‡ as is moisture basis

Environmental conditions, such as location and year, have an effect on flour composition (Table 4). Hard Red Spring wheat grown in 2013 and 2014 from Casselton, Carrington, Dickenson, and Hettinger, North Dakota were used to determine the effects of environment on flour composition. The Carrington 2013 sample had the highest total protein content and wet gluten content (Table 4). The Carrington sample may have a greater loaf volume and higher

quality pan bread since the protein and gluten results were higher. The Dickinson 2013 sample had the highest total starch content and the lowest damaged starch content (Table 4). A lower damaged starch content is desirable because less starch was damaged during milling, and the present damaged starch will have less of a negative impact on end product quality. Overall samples from the same location but different years, and samples from different locations but the same year had significantly (P<0.05) different flour compositions (Table 4). Therefore, year and location do affect the composition of flour and may further have an effect on flour quality.

Table 4: Refined Flour Composition of Hard Red Spring Wheat Grown in Four Locations over Two Years

Location	Year	Ash* (%)	Protein * (%)	Wet Gluten * (%)	Gluten Index	Total Starch† (%)	Damaged Starch‡ (%)	Arabinoxylan ‡ (%)	Arabinose /Xylose Ratio
Carrington	2013	0.45^{d}	14.2^{a}	38.7^{a}	88.7^{b}	72.1^{c}	7.5^{b}	2.5^{b}	0.96^{ab}
Casselton	2013	0.51^{bc}	12.9^{cd}	32.9^{cd}	91.3^{ab}	73.6^{abc}	8.2^{ab}	2.3^{b}	0.97^{ab}
Dickinson	2013	0.47^{cd}	13.3^{bc}	35.7^{b}	89.8^{b}	74.6^{a}	6.2^{c}	2.4^{b}	0.94^{ab}
Hettinger	2013	0.54^{ab}	13.6^{ab}	35.1^{bc}	89.7^{b}	73.4^{abc}	8.0^{ab}	2.3^{b}	0.97^{a}
Carrington	2014	0.53^{ab}	12.0^{e}	32.7^{cd}	93.8^{a}	74.3^{ab}	8.7^{a}	2.6^{b}	0.96^{ab}
Casselton	2014	0.55^{a}	12.1^{e}	32.9^{cd}	89.1^{b}	72.9^{bc}	8.2^{ab}	2.8^{b}	0.89^{b}
Dickinson	2014	0.52^{ab}	12.0^{e}	29.6^{e}	94.5^{a}	74.0^{ab}	8.2^{ab}	3.4^{a}	0.96^{ab}
Hettinger	2014	0.54^{ab}	12.2^{de}	32.6^{d}	93.5^{a}	72.4^{c}	8.3^{ab}	2.3^{b}	0.94^{ab}

Values with the same superscript letter are not significantly different (P>0.05). Least significant difference was used for mean separation. * 14% moisture basis, † dry weight basis, ‡ as is moisture basis

The flour composition for each cultivar grown in 2013 and 2014 was measured and analyzed for differences (Table 5). Some of the flour characteristics are not significantly (P>0.05) different between different cultivars grown in the same year, or different cultivars grown in different years (Table 5). For total starch, there were no significant (P>0.05) differences between cultivars and years (Table 5). Some of the sample cultivars changed in flour

compositions between years. Several of the cultivars had lower total protein contents and wet gluten values from 2013 to 2014 (Table 5). The changes in protein and gluten contents are undesirable for bread flour, and may cause bread loaf volumes to decrease.

The ash contents, gluten indexes, damaged starch, and arabinoxylan contents, increased from 2013 to 2014 for several cultivars (Table 5). These changes in flour composition may be the result of breeding programs for desirable flour traits, or the result of different environmental growing conditions from different crop years. The weather conditions during the growing season change each year, and can result in flour composition differences. The seasonal conditions were different during 2013 and 2014, with more ideal weather in 2014 (North Dakota Wheat Commission, 2014). These seasonal changes may have contributed to difference in flour composition. Overall, significant (P<0.05) differences in flour composition exist between cultivars and years, which indicates that genotype and environment affect flour properties and flour quality (Table 5).

Table 5: Refined Flour Composition for Hard Red Spring Wheat Cultivars Grown in Different Years

Cultivar	Year	Ash* (%)	Protein * (%)	Wet Gluten* (%)	Gluten Index	Total Starch † (%)	Damaged Starch‡ (%)	Arabinoxylan ‡ (%)	Arabinose /Xylose Ratio
Barlow	2013	0.48^{de}	13.6^{ab}	35.6^{abcd}	93.9^{ab}	73.6^{a}	8.5^{abcd}	2.2^{cd}	0.97^{a}
Elgin	2013	0.47^{e}	13.5^{abc}	35.1^{abcd}	92.5^{ab}	72.6^{a}	6.6^{fgh}	2.7^{abcd}	0.96^{a}
Faller	2013	0.51^{abcde}	12.6^{cd}	32.4^{de}	94.2^{ab}	74.0^{a}	8.5^{abcd}	2.1^{d}	0.97^{a}
Forefront	2013	0.50^{bcde}	13.9^{a}	36.9^{ab}	87.1^{cd}	72.1^{a}	6.1^{h}	2.5^{bcd}	0.92^{ab}
Glenn	2013	0.46^{e}	13.9^{a}	36.5^{abc}	93.2^{ab}	74.0^{a}	8.4^{bcd}	2.2^{cd}	0.98^{a}
Mott	2013	0.50^{bcde}	13.5^{abc}	36.7^{abc}	83.0^{d}	73.8^{a}	7.3^{efg}	2.2^{cd}	0.96^{a}
Prosper	2013	0.49^{cde}	12.8^{bcd}	33.3^{cd}	92.5^{ab}	74.0^{a}	8.1^{cde}	2.0^{d}	0.97^{a}
SySoren	2013	0.53^{abcd}	14.0^{a}	38.1^{a}	82.9^{d}	73.2^{a}	6.4^{gh}	3.3^{ab}	0.95^{a}
Barlow	2014	0.57^{a}	12.5^{d}	34.1^{bcd}	90.0^{bc}	72.9^{a}	9.0^{abc}	2.7^{abcd}	0.81^{b}
Elgin	2014	0.53^{abcd}	11.5^{ef}	28.5^{f}	96.8^{a}	73.9^{a}	7.9^{cde}	2.2^{cd}	0.95^{a}
Faller	2014	0.55^{ab}	11.5^{ef}	29.6^{ef}	95.4^{a}	74.1^{a}	9.4^{ab}	3.0^{abc}	0.97^{a}
Forefront	2014	0.50^{bcde}	12.4^{d}	32.5^{de}	93.4^{ab}	73.0^{a}	7.5^{defg}	2.8^{abcd}	0.95^{a}
Glenn	2014	0.54^{abc}	12.6^{cd}	33.0^{d}	96.3^{a}	73.4^{a}	8.9^{abc}	2.9^{abc}	0.95^{a}
Mott	2014	0.49^{bcde}	12.3^{de}	33.6^{cd}	89.7^{bc}	74.0^{a}	7.6^{def}	2.5^{bcd}	0.95^{a}
Prosper	2014	0.55^{ab}	11.3^{f}	29.6^{ef}	94.3^{ab}	73.8^{a}	9.6^{a}	2.6^{abcd}	0.95^{a}
SySoren	2014	0.55^{ab}	12.5^{d}	34.7^{abcd}	85.8^{cd}	72.0^{a}	7.0^{efgh}	3.3^{a}	0.94^{a}

Values with the same superscript letter are not significantly different (P>0.05). Least significant difference was used for mean separation. * 14% moisture basis, † dry weight basis, ‡ as is moisture basis

Whole Wheat Flour

The HRS wheat cultivars used to measure refined flour composition were also milled as whole wheat flour. Whole wheat flour composition will be slightly different than the composition of refined flour. Unlike the refined flour results, the whole wheat flour compositions were significantly (P<0.05) different between cultivars (Table 6). A few of the cultivars were not significantly (P>0.05) different for specific flour characteristics (Table 6). The wet gluten values of whole wheat flour were similar to the wet gluten values of refined flour, ranging between 30

and 36% (Tables 3 and 6). However, the gluten index values of whole wheat flour appear to be lower than those of refined flour (Tables 3 and 6). The lower gluten index values or weaker gluten networks of whole wheat flours is probably a result of bran composition. The bran contains non-functional proteins and fiber, which can interfere with the gluten-starch matrix causing a weaker gluten (Pyler and Gorton, 2009). The lower gluten index values can be used to predict small bread loaf volume results for whole wheat bread.

The Ash content and protein content typically increase with whole wheat flour. The ash contents of the whole wheat samples were between 1.4 and 1.6% (Table 6). Barlow, Glenn, and SySoren were significantly ($P<0.05$) different from the other cultivars (Table 6). The bran contains more inorganic materials, such as vitamins and minerals, which increases the ash content of the flour. A common range of whole wheat flour ash for HRS wheat is between 1.40 and 1.70% (Bruckner et al, 2001). The differences in ash contents are mostly likely a result of different mineral contents from the different cultivars. Since whole wheat flour was obtain, differences in ash content were not caused by bran contamination like refined flour, but mostly caused by different genotypes.

The protein contents differed between some of the cultivars (Table 6). The Barlow and Mott, Forefront, Glenn, and SySoren, and Faller and Prosper were not significantly ($P>0.05$) different for protein, respectively (Table 6). The protein content of whole wheat flour will be similar to refined flour for HRS wheat, which is usually between 12 to 15% (Doblado-Maldonado et al, 2012). The protein contents of the refined cultivars were between 12.0 and 13.3% (Table 3). The protein contents of the whole wheat cultivars was between 12.7 and 14.1% (Table 6). The difference in protein content between refined and whole wheat flours is the result of different kernel components used to make the flours. Refined flour is milled from only

endosperm, but whole wheat flour is milled from the bran, germ, and endosperm. Since the bran and germ contain proteins, the total protein content will increase from refined to whole wheat flour from the same wheat cultivar.

The arabinoxylan content is expected to increase between refined and whole wheat flours. The arabinoxylan contents for the refined flours were between 2.3 and 3.3% (Table 3). The arabinoxylan contents of the whole wheat flours were between 5.7 and 8.0% (Table 6). Arabinoxylans are found in the cell walls, or the bran layer of a kernel, and whole wheat flour contains the entire wheat kernel. Therefore, the increase in arabinoxylan content from refined to whole wheat flour is expected. The arabinoxylan content of HRS wheat flour has been found between 4.7 and 6.9% (Doblado-Maldonado et al, 2012). The whole wheat flour samples had higher arabinoxylan contents compared to the results found by Doblado-Maldonado et al (2012), which is most likely a result of different genotypes. The Elgin, Faller, and Prosper cultivars were significantly (P<0.05) different from each cultivar for arabinoxylan content (Table 6). The differences in arabinoxylan contents may be a result of genotype differences between cultivars.

The total starch content and damaged starch content differences between cultivars were observed (Table 6). The Barlow, Forefront, Mott, and SySoren cultivars were not significantly (P>0.05) different for total starch content (Table 6). The cultivars Barlow and Faller, and Forefront and SySoren were not significantly (P>0.05) different for damaged starch, respectively (Table 6). Total starch and damaged starch contents of whole wheat flour appear to be lower than the starch values of refined flour (Tables 3 and 6). The total starch and damaged starch contents for refined flour were 72.6 to 74.0% and 6.7 to 9.0%, respectively (Table 3). The total starch and damaged starch contents of whole wheat flour were 59.5 to 63.8% and 5.1 to 7.2%, respectively (Table 6). The decrease in total starch content of whole wheat flour is a result of the bran and

germ diluting the endosperm, or starch portion of the kernel. The damaged starch contents of whole wheat flour samples may have been reduced because of the whole wheat milling process, since the bran does not need to be fully removed from the endosperm. The bran and germ may act as an inhibitor of starch damage or provide protection to the endosperm during milling.

Table 6: Whole Wheat Flour Composition for Hard Red Spring Wheat Cultivars Grown in North Dakota

Cultivar	Ash* (%)	Protein* (%)	Wet Gluten* (%)	Gluten Index	Total Starch† (%)	Damaged Starch‡ (%)	Arabinoxylan ‡ (%)	Arabinose/ Xylose Ratio
Barlow	1.5^{ab}	13.7^{ab}	34.2^{a}	69.8^{bc}	60.9^{bc}	6.6^{abc}	7.3^{ab}	0.96^{a}
Elgin	1.5^{abc}	13.2^{bc}	30.9^{b}	85.1^{a}	59.5^{c}	6.0^{bcd}	8.0^{a}	0.95^{ab}
Faller	1.5^{bcd}	12.8^{c}	31.3^{b}	78.1^{ab}	63.8^{a}	6.4^{abc}	6.5^{bc}	0.95^{ab}
Forefront	1.4^{cd}	13.8^{a}	34.1^{a}	73.0^{bc}	60.6^{bc}	5.4^{d}	7.2^{ab}	0.90^{c}
Glenn	1.5^{ab}	13.9^{a}	34.4^{a}	82.1^{a}	59.7^{c}	6.8^{ab}	7.2^{ab}	0.95^{ab}
Mott	1.6^{a}	13.6^{ab}	34.6^{a}	66.7^{cd}	60.8^{bc}	5.8^{cd}	7.4^{ab}	0.95^{ab}
Prosper	1.4^{d}	12.7^{c}	31.2^{b}	72.9^{bc}	61.8^{ab}	7.2^{a}	5.7^{c}	0.97^{a}
SySoren	1.5^{ab}	14.1^{a}	35.8^{a}	59.5^{d}	60.2^{bc}	5.1^{d}	7.5^{ab}	0.92^{bc}

Values with the same superscript letter are not significantly different (P>0.05). Least significant difference was used for mean separation. * 14% moisture basis, † dry weight basis, ‡ as is moisture basis

Whole wheat flour composition was evaluated for differences in results based on location and year. For arabinose/xylose ratio there were no significant (P>0.05) differences between samples from different locations and different years (Table 7). For ash, protein, and arabinoxylan contents, there were significant (P<0.05) differences between flours in different locations in different years, but there is less variation between different flour samples grown in the same year (Table 7). Overall, there were significant (P<0.05) differences in flour composition for the same locations and different years (Table 7). Majority of the sample locations experienced a decrease

in protein, wet gluten, damaged starch, and arabinoxylan contents from 2013 to 2014 (Table 7). Therefore, one would expect to observe a decrease in bread quality between 2013 and 2014 samples. The environmental conditions were most likely different between the locations and years. The soil conditions and weather during the growing season typically change from year to year and between different locations.

Table 7: Whole Wheat Flour Composition of Hard Red Spring Wheat Grown in Four Locations over Two Years

Location	Year	Ash* (%)	Protein* (%)	Wet Gluten* (%)	Gluten Index	Total Starch † (%)	Damaged Starch ‡ (%)	Arabinoxylan ‡ (%)	Arabinose /Xylose Ratio
Carrington	2013	1.5^{bc}	14.5^{a}	37.7^{a}	73.1^{b}	60.2^{bc}	5.5^{c}	7.3^{b}	0.94^{a}
Casselton	2013	1.5^{bc}	13.4^{b}	32.7^{cd}	76.0^{ab}	61.6^{ab}	6.2^{bc}	6.5^{bc}	0.95^{a}
Dickinson	2013	1.3^{d}	14.0^{a}	35.5^{ab}	77.0^{ab}	61.4^{ab}	6.0^{bc}	6.8^{bc}	0.95^{a}
Hettinger	2013	1.5^{bc}	14.3^{a}	34.6^{bc}	82.4^{a}	60.9^{abc}	6.9^{ab}	7.0^{bc}	0.94^{a}
Carrington	2014	1.5^{b}	12.7^{c}	30.6^{de}	73.9^{ab}	60.8^{abc}	7.4^{a}	6.7^{bc}	0.92^{a}
Casselton	2014	1.7^{a}	12.8^{bc}	32.2^{cde}	53.8^{c}	60.3^{bc}	5.6^{c}	7.7^{ab}	0.94^{a}
Dickinson	2014	1.4^{c}	12.9^{bc}	29.7^{e}	82.3^{a}	59.3^{c}	5.6^{c}	8.7^{a}	0.94^{a}
Hettinger	2014	1.5^{b}	13.1^{bc}	33.3^{bcd}	68.6^{b}	62.6^{a}	6.0^{bc}	6.1^{c}	0.95^{a}

Values with the same superscript letter are not significantly different (P>0.05). Least significant difference was used for mean separation. * 14% moisture basis, † dry weight basis, ‡ as is moisture basis

Cultivars grown in different years were observed for differences in flour compositions (Table 8). Some of the cultivars grown in the same year were not significantly (P>0.05) different for specific flour properties, such as ash, protein, total starch, and arabinoxylan contents (Table 8). A small number of the same cultivars grown in different years were not significantly (P>0.05) different for certain flour characteristics (Table 8). Forefront ash and total starch, Barlow and Mott total starch, Glenn and Mott damaged starch, Faller arabinoxylan, and Elgin, Faller and Prosper arabinose/xylose ratios were not significantly (P>0.05) different between crop years (Table 8). Overall, significant (P<0.05) differences between cultivars and years did exist

for flour composition (Table 8). Genotype and environment may have contributed to these flour composition differences, however, genotype typically has a great effect on flour quality.

Table 8: Whole Wheat Flour Composition for Hard Red Spring Wheat Cultivars Grown in Different Years

Cultivar	Year	Ash* (%)	Protein * (%)	Wet Gluten* (%)	Gluten Index	Total Starch † (%)	Damaged Starch‡ (%)	Arabinoxylan ‡ (%)	Arabinose /Xylose Ratio
Barlow	2013	1.5^{efg}	14.2^{ab}	35.7^{abc}	71.1^{cde}	61.2^{bc}	6.6^{abcd}	7.4^{abc}	0.99^{a}
Elgin	2013	1.4^{fg}	14.1^{abc}	34.0^{abc}	87.1^{a}	60.5^{bc}	5.8^{bcdef}	6.9^{bcd}	0.95^{abc}
Faller	2013	1.5^{efg}	13.3^{bcd}	32.9^{bcd}	84.5^{a}	64.7^{a}	7.0^{ab}	6.4^{bcd}	0.95^{abc}
Forefront	2013	1.4^{efg}	14.5^{a}	36.0^{ab}	69.7^{de}	60.4^{bc}	5.2^{def}	7.6^{abc}	0.91^{cde}
Glenn	2013	1.4^{efg}	14.4^{a}	36.3^{ab}	78.5^{abcd}	60.7^{bc}	6.7^{abc}	6.9^{bcd}	0.94^{bcd}
Mott	2013	1.5^{abcde}	14.1^{ab}	35.9^{abc}	77.0^{abcd}	60.5^{bc}	5.8^{bcdef}	7.1^{bcd}	0.94^{bcd}
Prosper	2013	1.4^{g}	13.2^{cd}	32.9^{bcd}	82.0^{abc}	60.7^{bc}	7.0^{ab}	5.8^{cd}	0.96^{ab}
SySoren	2013	1.5^{abcde}	14.7^{a}	37.1^{a}	67.7^{def}	59.8^{c}	5.1^{ef}	7.1^{bcd}	0.95^{abc}
Barlow	2014	1.6^{abcd}	13.2^{de}	32.4^{bcd}	68.4^{de}	60.5^{bc}	6.5^{abcde}	7.2^{bcd}	0.94^{abcd}
Elgin	2014	1.6^{a}	12.2^{f}	27.8^{e}	83.1^{ab}	58.5^{c}	6.2^{abcdef}	9.0^{a}	0.96^{abc}
Faller	2014	1.5^{cde}	12.3^{ef}	29.7^{de}	71.7^{bcde}	62.9^{ab}	5.9^{bcdef}	6.6^{bcd}	0.96^{abc}
Forefront	2014	1.4^{efg}	13.1^{de}	32.1^{cd}	76.8^{abcd}	60.8^{bc}	5.5^{cdef}	6.8^{bcd}	0.89^{e}
Glenn	2014	1.6^{abc}	13.4^{bcd}	32.5^{bcd}	85.7^{a}	58.6^{c}	6.9^{abc}	7.5^{abc}	0.96^{abc}
Mott	2014	1.6^{ab}	13.0^{def}	33.3^{abcd}	56.4^{fg}	61.8^{bc}	5.9^{bcdef}	7.7^{ab}	0.96^{abc}
Prosper	2014	1.5^{def}	12.2^{f}	29.4^{de}	63.8^{ef}	63.0^{ab}	7.3^{a}	5.6^{d}	0.97^{ab}
SySoren	2014	1.5^{bcde}	13.4^{bcd}	34.5^{abc}	51.3^{g}	60.7^{bc}	5.0^{f}	7.9^{ab}	0.90^{de}

Values with the same superscript letter are not significantly different (P>0.05). Least significant difference was used for mean separation. * 14% moisture basis, † dry weight basis, ‡ as is moisture basis.

Dough and Bread Quality

Refined Flour

Starch composition of flour is important for bread baking quality for several reasons including: providing yeast food, interactions with gluten matrix to form loaf crumb, and effects on crumb texture and firmness. Some similarities and differences, based on significance (P<0.05), exist between pasting profiles of the different HRS wheat cultivars (Table 9). The

Rapid Visco-Analyzer (RVA) was used to produce fast starch pasting profile results for the flour samples. The important parameters recorded in a RVA pasting profile include: pasting viscosity, breakdown, final viscosity, and pasting time, which are illustrated in Figure 3. This method was originally designed to measure sprout damage in wheat caused by high levels of α-amylase, which affects bread baking quality (Deffenbaugh and Walker, 1989).

Elgin, Faller, Glenn, and Prosper were not significantly (P>0.05) different for peak viscosity (Table 9). Peak viscosity measures the water binding capacity of starch during heating (Julianti et al, 2015). The water binding capacity of starch is important for starch gelatinization, since water, heat, and force are necessary for starch granules to swell and gelatinize (Deffenbaugh and Walker, 1989). Gelatinized starch is important during the baking process, because α-amylase present in the dough can convert gelatinized starch molecules to dextrins, which can be hydrolyzed by yeast during fermentation (Pyler and Gorton, 2009). Gelatinization of starch granules is necessary during the baking process to produce a desirable bread crumb structure. From the previously mentioned list of cultivars, only Faller, Glenn, and Prosper were not significantly (P>0.05) different for starch breakdown (Table 9). The breakdown parameter indicates the ease of collapsing swollen granules (Julianti et al, 2015). During the breakdown phase the starch granules rupture due to excess swelling, and soluble amylose is released (Saunders et al, 2011). This process causes the flour material to gel and the viscosity to increase, which is why starch can be used as a thickening agent.

The Elgin, Faller, and Prosper cultivars were not significantly (P>0.05) different for final viscosity or setback (Table 9). During the setback phase, ruptured starch granules re-associate to form a gel-network known as a retrogradation process (Julianti et al, 2015). Some researchers

hypothesize that retrograded or recrystallized starch molecules cause crumb firmness during storage (Pyler and Gorton, 2009). The final viscosity indicates the gelatinization of the re-ordered starch molecules (Julianti et al, 2015). The RVA results indicate that starch pasting profiles are not the same for each HRS wheat cultivar, therefore, the differences in starch quality are most likely a result of different genotypes.

Table 9: Pasting Profile for Different Cultivars of Refined Hard Red Spring Wheat Flour

Cultivar	Peak Viscosity (RVU)	Breakdown (RVU)	Final Viscosity (RVU)	Setback (RVU)	Peak Time (min)
Barlow	176.6^{c}	86.2^{bc}	168.4^{c}	78.1^{c}	5.9^{d}
Elgin	209.3^{a}	89.8^{b}	209.9^{a}	90.2^{a}	6.2^{a}
Faller	215.8^{a}	98.0^{a}	209.6^{a}	91.8^{a}	6.2^{b}
Forefront	190.7^{b}	81.7^{c}	197.5^{ab}	87.7^{ab}	6.1^{b}
Glenn	215.1^{a}	102.6^{a}	192.5^{b}	80.0^{bc}	6.1^{b}
Mott	185.4^{bc}	82.4^{c}	191.3^{b}	80.6^{bc}	6.0^{cd}
Prosper	215.2^{a}	98.0^{a}	207.5^{a}	90.2^{a}	6.1^{bc}
SySoren	183.2^{bc}	76.0^{d}	199.8^{ab}	92.6^{a}	6.0^{bc}

Values with the same superscript letter are not significantly different (P>0.05). Least significant difference was used for mean separation. RVU: rapid visco units

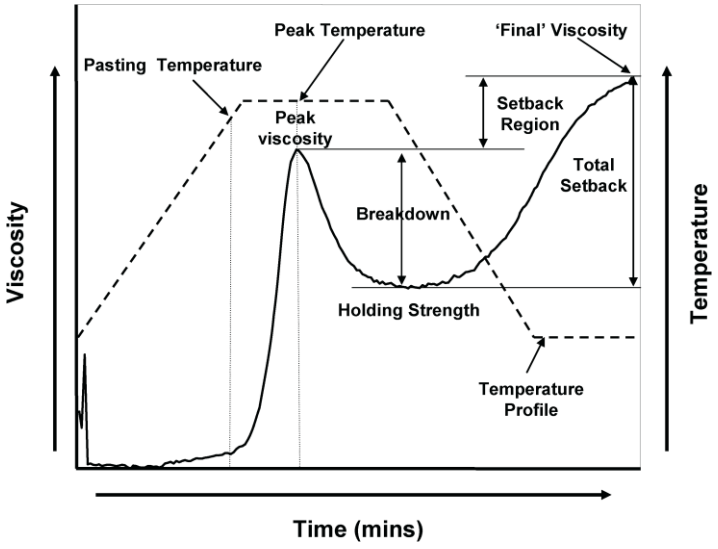

Figure 3: The Parameters Recorded from a RVA Pasting Profile (Saunders et al, 2011)

The pasting parameters for HRS wheat grown in different locations over two years were observed (Table 10). The samples grown in the same year from different locations were more similar than the respective sample locations from a different year (Table 10). Even though the samples were grown in four different locations, the samples from the same year experienced similar seasonal conditions during the growing season, and may have had similar starch properties. The Dickinson sample from 2014 was the only peak viscosity value significantly (P<0.05) different from 2014 (Table 10). For the breakdown parameter, the Hettinger sample was significantly (P<0.05) different from the other samples in 2014 (Table 10). The setback values between years at the Carrington and Casselton locations were not significantly (P>0.05) different (Table 10). The Hettinger location was the only sample significantly (P<0.05) different for final viscosity in 2013 (Table 10). The peak times from the Carrington and Hettinger samples were not significantly (P>0.05) different between years (Table 10). Overall the pasting profiles were significantly (P<0.05) different between the same location, but different years (Table 10). Therefore, environmental factors of year and location do affect the pasting parameters of starch.

Table 10: Pasting Profiles for Refined Hard Red Spring Wheat Grown in Different Locations over Two Years

Location	Year	Peak Viscosity (RVU)	Breakdown (RVU)	Final Viscosity (RVU)	Setback (RVU)	Peak Time (min)
Carrington	2013	209.1^{b}	90.5^{b}	212.1^{b}	85.9^{b}	6.1^{a}
Casselton	2013	195.6^{bc}	93.9^{b}	187.4^{d}	85.6^{b}	5.9^{b}
Dickinson	2013	208.7^{b}	89.6^{bc}	209.1^{bc}	89.9^{b}	6.1^{a}
Hettinger	2013	240.9^{a}	108.8^{a}	233.4^{a}	100.4^{a}	6.1^{a}
Carrington	2014	194.3^{c}	82.4^{d}	197.3^{cd}	85.3^{b}	6.1^{a}
Casselton	2014	192.9^{c}	83.1^{d}	197.2^{cd}	87.5^{b}	6.0^{a}
Dickinson	2014	157.9^{d}	81.6^{d}	151.0^{e}	74.7^{c}	5.9^{b}
Hettinger	2014	191.9^{c}	84.9^{cd}	188.8^{d}	81.8^{bc}	6.1^{a}

Values with the same superscript letter are not significantly different (P>0.05). Least significant difference was used for mean separation. RVU: rapid visco units

Different cultivars grown during the same year had similar starch qualities, but the respective cultivars grown in a different year had different starch properties (Table 11). A few cultivars grown in the same year were not significantly (P>0.05) different in peak viscosity, breakdown, final viscosity, and peak time (Table 11). Therefore, less variation in starch quality exists between different cultivars from the same crop year. The genotypes for starch quality may be similar between the different cultivars from the same year. Breeding for different starch qualities in bread flour would not be useful, since starch is important for bread crumb and texture development. The pasting profiles for the same cultivars grown in different years were significantly (P<0.05) different for the majority of the RVA parameters (Table 11). The starch quality differences for cultivars grown in different years may be the result of different breeding programs or different growing conditions. The growing conditions were different between 2013 and 2014, which can result in different flour compositions and quality results (North Dakota Wheat Commissions, 2014). Since seasonal conditions are known to affect flour quality along with genetics, crop surveys are necessary for determining the flour quality profiles from different cultivars gown in different locations each year. The starch pasting parameters recorded in Table 11 demonstrate the effects of genotype and environmental factors on starch quality.

Table 11: Pasting Profiles of Different Refined Hard Red Spring Wheat Cultivars Grown over Two Years

Cultivar	Year	Peak Viscosity (RVU)	Breakdown (RVU)	Final Viscosity (RVU)	Setback (RVU)	Peak Time (min)
Barlow	2013	191.6^{cd}	92.9^{c}	180.7^{de}	82.0^{defg}	5.9^{de}
Elgin	2013	222.4^{ab}	95.4^{c}	220.6^{a}	93.6^{abcd}	6.1^{ab}
Faller	2013	228.4^{a}	104.9^{b}	220.7^{a}	97.3^{ab}	6.1^{bc}
Forefront	2013	199.6^{cd}	85.4^{def}	207.6^{ab}	91.6^{abcde}	6.1^{bc}
Glenn	2013	234.7^{a}	114.5^{a}	205.4^{abc}	85.2^{cdefg}	6.0^{bc}
Mott	2013	207.5^{bc}	88.1^{cde}	214.7^{ab}	80.0^{efg}	6.1^{bc}
Prosper	2013	227.3^{a}	103.0^{b}	218.6^{a}	94.4^{abc}	6.1^{bc}
SySoren	2013	197.2^{cd}	81.4^{efgh}	215.6^{ab}	99.8^{a}	6.0^{cd}
Barlow	2014	161.5^{f}	79.6^{fgh}	156.1^{f}	74.2^{g}	5.9^{e}
Elgin	2014	196.3^{cd}	84.2^{defg}	198.8^{bcd}	86.7^{bcde}	6.2^{a}
Faller	2014	203.2^{bc}	91.0^{cd}	198.5^{bcd}	86.3^{bcdef}	6.1^{abc}
Forefront	2014	181.8^{de}	78.0^{gh}	187.5^{cd}	83.7^{cdefg}	6.1^{bc}
Glenn	2014	195.5^{cd}	90.7^{cd}	179.6^{de}	74.8^{fg}	6.1^{abc}
Mott	2014	163.3^{ef}	76.7^{hi}	167.8^{ef}	81.3^{efg}	5.9^{e}
Prosper	2014	203.2^{bc}	93.0^{c}	196.3^{bcd}	86.0^{bcdefg}	6.0^{bc}
SySoren	2014	169.2^{ef}	70.6^{i}	184.0^{de}	85.4^{bcdefg}	6.0^{cd}

Values with the same superscript letter are not significantly different (P>0.05). Least significant difference was used for mean separation. RVU: rapid visco units

Farinograph data is used to determine the quality of dough prior to pan bread baking, and can be used to predict bread quality. The important Farinograph parameters are water absorption, peak time, stability, and mixing tolerance index (MTI). Barlow and Glenn had the highest Farinograph water absorptions and were significantly ($P<0.05$) different from the other cultivars (Table 12). Water absorption is caused by proteins, including gluten proteins, damaged starch, and arabinoxylans, which all have water holding retention properties (Pyler and Gorton, 2009). The water absorption value is used as a starting point for determining the amount of water needed during the dough mixing stage of pan bread baking.

Some cultivars were not significantly ($P>0.05$) different for peak time, which means these samples will have similar dough mixing times based on gluten development (Table 12). Peak time indicates the length of time needed to fully develop the gluten within the dough. The Farinograph stability for Faller, Prosper, and SySoren are not significantly ($P>0.05$) different, therefore, these cultivars have similar gluten strengthens (Table 12).The stability represents the gluten strength of a flour; a longer stability means the dough has a higher gluten strength and the dough is more flexibility with mixing time (Pyler and Gorton, 2009). Glenn had the longest stability, or strongest gluten, and Barlow had the shortest stability, or weakest gluten (Table 12). Since stability indicates gluten strength, one would predict a greater loaf volume for the Glenn sample and a smaller loaf volume for the Barlow sample.

Barlow and Mott had the longest MTI values and Glenn had the shortest MTI value (Table 12). Dough with a higher MTI value has a higher tolerance for over mixing, so the dough can experience a longer mixing time without the breakdown of gluten. Once gluten begins to break down, the dough becomes sticky, hard to machine, and the overall dough/bread quality decreases. The peak time and MTI Farinograph parameters can be used to determine the

appropriate mixing time of a flour sample during bread baking. The Farinograph results show significant (P<0.05) differences between different cultivars, which is caused by different genotypes.

Table 12: Refined Flour Farinograph Profiles for Different Cultivars of Hard Red Spring Wheat

Cultivar	Absorption (14% MB)	Peak Time (min)	Stability (min)	MTI (BU)
Barlow	65.3^{a}	6.5^{ab}	7.2^{d}	36.6^{a}
Elgin	63.3^{b}	6.5^{ab}	8.6^{ab}	30.7^{bcd}
Faller	62.7^{bcd}	5.8^{bc}	8.2^{bcd}	32.6^{abc}
Forefront	61.8^{d}	7.0^{a}	8.5^{abc}	29.6^{cd}
Glenn	64.5^{a}	6.9^{a}	9.6^{a}	26.1^{d}
Mott	62.2^{cd}	6.1^{bc}	7.3^{cd}	36.7^{a}
Prosper	62.9^{bc}	5.6^{c}	7.8^{bcd}	35.4^{ab}
SySoren	62.8^{bc}	6.4^{ab}	7.8^{bcd}	30.4^{bcd}

Values with the same superscript letter are not significantly different (P>0.05). Least significant difference was used for mean separation. MB: moisture basis; MTI: mixing tolerance index; BU: Braebender unit

Samples grown in different locations during different years produced similar Farinograph results (Table 13). The sample grown in Carrington in 2013 had the highest water absorption, and the sample grown in Dickinson in 2014 had the lowest water absorption (Table 13). The absorptions for Casselton and Hettinger from 2013 and 2014 were not significantly (P>0.05) different (Table 13). Samples with similar Farinograph absorptions, most likely have similar flour compositions due to water retention capacity properties.

The Peak times for the samples from Dickinson and Hettinger 2013 and the sample from Hettinger 2014 were not significantly (P>0.05) different (Table 13). The 2014 samples from Carrington, Casselton, and Dickinson had the lowest peak times, and the 2013 Carrington sample had the highest peak time (Table 13). Therefore, the time required during dough mixing to fully develop the gluten network will change between some of the samples. The sample from Carrington 2013 had the longest stability, but one of the lowest MTI values (Table 13). A longer

stability does not always result in a higher MTI value, because a stronger gluten does not always result in higher tolerance to over mixing. The 2014 Casselton sample had the lowest stability and the highest MTI values (Table 13). The Farinograph results display the effects of environmental conditions on dough quality. Different samples grown in different locations and/or years can still have similar dough qualities due to similar genotypes and growing conditions.

Table 13: Refined Flour Farinograph Profiles for Hard Red Spring Wheat Grown in Different Locations over Different Years

Location	Year	Absorption (14% MB)	Peak Time (min)	Stability (min)	MTI (BU)
Carrington	2013	65.7^{a}	7.3^{a}	9.3^{a}	24.9^{d}
Casselton	2013	62.8^{c}	6.5^{b}	8.0^{bcd}	33.4^{b}
Dickinson	2013	64.4^{b}	6.9^{ab}	9.0^{ab}	27.6^{d}
Hettinger	2013	62.9^{c}	7.2^{ab}	8.8^{abc}	33.2^{bc}
Carrington	2014	64.4^{b}	5.5^{c}	7.4^{d}	33.6^{b}
Casselton	2014	62.6^{c}	5.5^{c}	6.2^{e}	41.7^{a}
Dickinson	2014	60.2^{d}	5.2^{c}	8.7^{abc}	27.7^{cd}
Hettinger	2014	62.5^{c}	6.5^{ab}	7.6^{cd}	36.0^{b}

Values with the same superscript letter are not significantly different (P>0.05). Least significant difference was used for mean separation. MB: moisture basis; MTI: mixing tolerance index; BU: Braebender unit

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The Farinograph results for the different cultivars grown in 2013 and 2014 were significantly (P<0.05) different for the majority of the cultivars (Table 14). The Barlow sample grown in 2013 had the highest water absorption, and the Mott and Forefront samples from 2014 had the lowest absorptions (Table 14). The absorption values appear to decrease from 2013 to 2014 for most of the cultivars, which may have been the result of different flour compositions. The flour composition is affected by genotypes and environmental conditions. Therefore, the genotypes or the seasonal conditions changed from 2013 to 2014.

For peak time, the cultivars grown in 2013 were significantly (P<0.05) different than the respective cultivars grown in 2014 (Table 14). The cultivars from 2014 had similar peak time

results (Table 14). From 2014, the cultivars Barlow, Elgin, Glenn, and SySoren were not significantly (P>0.05) different for peak times (Table 14). Several cultivars from 2014 were not significantly (P>0.05) different for stability (Table 14). The changes in peak time may be related to changes in gluten quality, since the peak time parameter indicates the amount of time need to fully develop gluten.

The Farinograph stability values changed from 2013 to 2014 for majority of the cultivars. This indicates that the gluten strengths of the flours changed over one year. The 2014 cultivars Elgin and Mott were the only samples significantly (P<0.05) different for stability from each sample (Table 14). The Glenn sample from 2013 had the longest stability and shortest MTI value (Table 14). Majority of the 2013 cultivars were significantly (P<0.05) different than the 2014 cultivars for MTI values (Table 14). Overall, year and cultivar do affect dough quality. Since the cultivars from different years had different Farinograph results, the changes in growing conditions most likely contributed to these observations.

Table 14: Refined Flour Faringoraph Profiles for Different Hard Red Spring Wheat Cultivars Grown in Different Years

Cultivar	Year	Absorption (14% MB)	Peak Time (min)	Stability (min)	MTI (BU)
Barlow	2013	66.1^{a}	7.2^{ab}	7.8^{bcde}	33.5^{bcd}
Elgin	2013	64.4^{bcd}	7.3^{ab}	8.8^{abc}	29.0^{cde}
Faller	2013	63.6^{cde}	6.5^{bc}	9.4^{ab}	28.5^{de}
Forefront	2013	62.2^{fg}	7.3^{ab}	8.3^{bcde}	30.0^{cde}
Glenn	2013	65.0^{ab}	7.9^{a}	10.4^{a}	25.5^{e}
Mott	2013	63.1^{def}	6.8^{bc}	7.6^{cde}	36.7^{abc}
Prosper	2013	64.0^{bcd}	6.0^{cd}	8.9^{abc}	28.5^{de}
SySoren	2013	63.1^{def}	6.8^{abc}	8.9^{abc}	26.5^{de}
Barlow	2014	64.6^{bc}	5.8^{cd}	6.6^{e}	39.7^{ab}
Elgin	2014	62.2^{fg}	5.7^{cd}	8.3^{bcde}	32.5^{bcde}
Faller	2014	61.8^{fg}	5.0^{d}	6.9^{e}	36.7^{abc}
Forefront	2014	61.4^{g}	6.6^{bc}	8.8^{abcd}	29.2^{cde}
Glenn	2014	64.0^{bcd}	5.9^{cd}	8.7^{abcd}	26.7^{de}
Mott	2014	61.4^{g}	5.3^{d}	7.1^{de}	36.7^{abc}
Prosper	2014	61.8^{fg}	5.2^{d}	6.7^{e}	42.2^{a}
SySoren	2014	62.4^{efg}	6.0^{cd}	6.8^{e}	34.2^{bcd}

Values with the same superscript letter are not significantly different (P>0.05). Least significant difference was used for mean separation. MB: moisture basis; MTI: mixing tolerance index; BU: Braebender unit

Test baking, such as pup loaf pan bread baking, is commonly used to determine ingredient functionality. Bread baking quality factors include: water absorption, mixing time, mixing tolerance, fermentation tolerance, loaf volume, external appearances, and internal appearances (Pyler and Gorton, 2009).

The Faller cultivar was the only sample significantly (P<0.05) different for baking absorption (Table 15). The bread quality results for refined flour indicates that absorptions for Barlow and Glenn, and Prosper and SySoren were not significantly (P>0.05) different, respectively (Table 15). These similarities in baking absorption also were seen in Farinograph absorptions (Table 12). The water absorption is measured during dough mixing, and is dependent on flour composition (protein, starch damage, etc.), flour moisture, methods and equipment used,

and desired end product characteristics (Pyler and Gorton, 2009). The flour compositions for these cultivars were significantly (P<0.05) different (Table 3). Therefore, flour composition results should not be used to estimate baking absorption.

The dough mixing time is the amount of time required to fully develop the gluten network of flour. A stronger gluten content is indicated by a long mixing time. The dough mixing times during baking were not strongly affected by genotype since six of the eight samples were not significantly (P>0.05) different (Table 15). The Glenn cultivar had the longest Farinograph stability value (Table 12), and the longest dough mixing time during bread baking (Table 15). The Farinograph stability and dough mixing times appear to be related and could be used to determine the gluten strength. The Farinograph stability parameter potentially could be used to predict the dough mixing time during baking.

Loaf volume and specific loaf volume are bread quality parameters used to determine the gluten quality of a given flour. Loaf volume is dependent on gluten proteins, because gluten proteins allow dough to become elastic and extensible causing ease in dough expansion (Pyler and Gorton, 2009). The Faller, Forefront, and SySoren samples were not significantly (P>0.05) different in loaf volumes (Table 15). The cultivars Forefront and SySoren, and Mott and Prosper were not significantly (P>0.05) different for specific loaf volume (Table 15). During fermentation yeast converts sugars into carbon dioxide gas and ethanol, resulting in dough expansion (Pyler and Gorton, 2009). Gluten contains the unique gas retention property, which traps the gas cells in the dough causing the dough to rise during proofing and causes an increase in loaf volume (Pyler and Gorton, 2009). During baking, the ethanol dissolves and the gas evaporates, but the bread loaf volume remains. Therefore, gluten development of bread dough is important for the final quality of bread.

The starch content of flour is important for bread quality. Starch gelatinization begins during proofing and continues during baking. The gelatinization of starch helps make dough more flexible during expansion, and protects the loaf volume and shape during cooling (Pyler and Gorton, 2009). Starch retrogradation may affect the crumb firmness during storage, known as crumb staling (Pyler and Gorton, 2009). The texture analyzer was used to measure the crumb firmness, which was not significantly (P>0.05) different for all eight cultivar samples (Table 15). Therefore, genotype does not affect crumb texture.

Symmetry, crust color, crumb grain, and crumb color are subjective measures based on a 0-10 scale, 0 being the lowest quality value and 10 being the highest quality value. These values for the different cultivars were similar, since most of the samples were not significantly (P>0.05) different (Table 15). Overall, genotype had little effect on the dough and loaf quality during pan bread baking. Therefore, the different cultivars have similar genotypes resulting in similar end-product quality traits.

Table 15: Refined Flour Bread Quality of Different Hard Red Spring Wheat Cultivars

	Dough		Bread Loaf						
Cultivar	Absorption (%)	Mixing Time (min)	Loaf Volume (cc)	Specific Volume (cc/g)	Symmetry*	Crust Color*	Crumb Grain*	Crumb Color*	Firmness (g)
Barlow	71.9^{a}	3.8^{b}	1168.1^{a}	8.9^{a}	7.1^{b}	9.2^{b}	5.9^{c}	7.7^{ab}	64.3^{a}
Elgin	71.1^{ab}	3.8^{ab}	1091.2^{b}	8.1^{d}	7.8^{ab}	9.9^{a}	6.9^{ab}	6.9^{d}	69.0^{a}
Faller	69.2^{c}	3.7^{b}	1123.7^{ab}	8.5^{abc}	7.7^{ab}	9.6^{ab}	6.9^{ab}	8.1^{a}	76.6^{a}
Forefront	69.7^{bc}	3.6^{b}	1121.9^{ab}	8.5^{bcd}	7.8^{ab}	10.0^{a}	6.8^{ab}	7.5^{bc}	71.2^{a}
Glenn	72.2^{a}	4.2^{a}	1165.6^{a}	8.8^{ab}	7.3^{b}	9.2^{b}	6.7^{ab}	7.6^{ab}	67.1^{a}
Mott	70.1^{bc}	3.7^{b}	1087.5^{b}	8.2^{cd}	8.1^{a}	9.7^{ab}	7.2^{a}	7.6^{bc}	71.1^{a}
Prosper	70.8^{abc}	3.8^{b}	1105.6^{b}	8.3^{cd}	7.6^{ab}	9.7^{ab}	6.5^{bc}	7.9^{ab}	71.2^{a}
SySoren	70.8^{abc}	3.7^{b}	1126.2^{ab}	8.5^{bcd}	7.7^{ab}	9.6^{ab}	6.8^{ab}	7.1^{cd}	74.7^{a}

Values with the same superscript letter are not significantly different (P>0.05). Least significant difference was used for mean separation. *Values are subject based on a scale from 0 to 10, 0= low quality, 10= high quality

The dough and loaf quality results from experimental bread baking indicates that the baking absorptions were significantly (P<0.05) different between the same cultivars from 2013 and 2014 (Table 16). The environmental conditions during 2013 were different during 2014, which most likely caused the differences in bread quality. For dough mixing times, the same cultivars grown in different years were significantly (P<0.05) different (Table 16). The cultivars grown in 2013 are more similar, and the cultivars grown in 2014 were significantly (P<0.05) different (Table 16). Similar results for loaf volume and specific volume were recorded for samples from different locations and years (Table 16). However, there does not appear to be a trend between locations over two years or between locations from the same year. Several of the samples from 2013 and 2014 were not significantly (P>0.05) different for firmness (Table 16). Therefore, the differences in seasonal conditions between years did not affect crumb texture.

The subjective bread quality results display some significant (P<0.05) differences between sample location and year (Table 16). The sample location and year had no effect on crumb grain (Table 16). The crust color results were similar to the crumb grain results, therefore, location and year have less effect on crust color (Table 16). For crumb color results, the locations within each year are more similar (Table 16). The 2014 Carrington samples was the only sample significantly (P<0.05) different for crumb color (Table 16).The Casselton samples from 2013 and 2014 were not significantly (P>0.05) different for loaf symmetry (Table 16). The other sample locations and years had relatively similar results for loaf symmetry (Table 16).

Table 16: Refined Flour Bread Quality for Hard Red Spring Wheat Grown in Different Locations during Different Years

		Dough				Bread Loaf				
Location	Year	Absorption (%)	Mixing Time (min)	Loaf Volume (cc)	Specific Volume (cc/g)	Symmetry*	Crust Color*	Crumb Grain*	Crumb Color*	Firmness (g)
Carrington	2013	72.8^{ab}	3.7^{bc}	1119.4^{bcd}	8.3^{cd}	7.0^{c}	9.7^{a}	6.6^{a}	7.8^{a}	75.6^{ab}
Casselton	2013	68.6^{c}	3.8^{bc}	1073.1^{d}	8.1^{d}	7.4^{bc}	9.7^{a}	6.5^{a}	7.6^{ab}	88.6^{a}
Dickinson	2013	71.7^{ab}	3.6^{c}	1142.5^{ab}	8.5^{bc}	7.5^{abc}	9.9^{a}	6.7^{a}	7.9^{a}	64.1^{bc}
Hettinger	2013	68.7^{c}	3.7^{bc}	1130.6^{ab}	8.8^{ab}	7.5^{abc}	9.6^{a}	6.7^{a}	7.7^{ab}	75.8^{ab}
Carrington	2014	73.1^{a}	3.6^{c}	1083.1^{cd}	8.1^{d}	8.1^{a}	9.0^{b}	6.7^{a}	7.7^{ab}	70.4^{abc}
Casselton	2014	71.2^{b}	3.5^{c}	1111.2^{bcd}	8.5^{c}	7.4^{bc}	9.4^{ab}	6.6^{a}	7.2^{b}	74.4^{ab}
Dickinson	2014	68.0^{c}	4.5^{a}	1171.9^{a}	9.0^{a}	8.2^{a}	9.9^{a}	7.1^{a}	7.3^{b}	60.4^{bc}
Hettinger	2014	71.7^{ab}	3.9^{b}	1128.1^{abc}	8.5^{bc}	8.0^{ab}	9.9^{a}	6.7^{a}	7.2^{b}	55.7^{c}

Values with the same superscript letter are not significantly different (P>0.05). Least significant difference was used for mean separation. *Values are subject based on a scale from 0 to 10, 0= low quality, 10= high quality

Table 17: Refined Flour Bread Quality of Different Hard Red Spring Wheat Cultivars Grown in Different Years

		Dough		Bread Loaf						
Cultivar	Year	Absorption (%)	Mixing Time (min)	Loaf Volume (cc)	Specific Volume (cc/g)	Symmetry*	Crust Color*	Crumb Grain*	Crumb Color*	Firmness (g)
Barlow	2013	71.5^{abcd}	3.7^{abc}	1153.7^{abc}	8.8^{ab}	6.5^{d}	9.2^{ab}	6.0^{cd}	8.0^{abc}	76.3^{ab}
Elgin	2013	70.7^{bcd}	3.6^{bc}	1088.7^{cd}	8.1^{c}	8.2^{ab}	9.7^{a}	6.7^{abc}	7.0^{e}	72.1^{ab}
Faller	2013	70.5^{bcd}	3.7^{abc}	1148.7^{abc}	8.7^{ab}	7.2^{bcd}	9.7^{a}	6.7^{abc}	8.4^{a}	76.5^{ab}
Forefront	2013	69.2^{de}	3.4^{c}	1107.5^{bcd}	8.4^{bc}	7.2^{bcd}	10.0^{a}	6.7^{abc}	7.7^{abcd}	75.9^{ab}
Glenn	2013	71.2^{abcd}	4.1^{a}	1176.2^{ab}	8.8^{ab}	6.7^{cd}	10.0^{a}	7.0^{ab}	7.7^{abcd}	83.0^{a}
Mott	2013	70.2^{bcde}	3.6^{c}	1076.2^{d}	8.1^{c}	7.7^{abc}	9.7^{a}	7.0^{ab}	7.7^{abcd}	71.5^{ab}
Prosper	2013	70.7^{bcd}	3.8^{abc}	1105.0^{bcd}	8.2^{c}	7.5^{abcd}	9.7^{a}	6.2^{bcd}	8.1^{ab}	71.1^{ab}
SySoren	2013	69.8^{cde}	3.6^{bc}	1135.0^{abcd}	8.5^{bc}	7.5^{abcd}	9.7^{a}	6.7^{abc}	7.2^{de}	81.9^{a}
Barlow	2014	72.4^{ab}	3.9^{abc}	1182.5^{a}	9.0^{a}	7.7^{abc}	9.2^{ab}	5.9^{d}	7.5^{bcde}	52.2^{b}
Elgin	2014	71.5^{abcd}	4.1^{ab}	1093.7^{cd}	8.2^{c}	7.4^{abcd}	10.0^{a}	7.0^{ab}	6.9^{e}	66.0^{ab}
Faller	2014	67.9^{e}	3.7^{abc}	1098.7^{cd}	8.4^{bc}	8.1^{ab}	9.5^{a}	7.0^{ab}	7.7^{abcd}	76.6^{ab}
Forefront	2014	70.2^{bcde}	3.8^{abc}	1136.2^{abcd}	8.6^{abc}	8.4^{a}	10.0^{a}	6.9^{ab}	7.2^{de}	66.4^{ab}
Glenn	2014	73.2^{a}	4.2^{a}	1155.0^{abc}	8.7^{ab}	7.9^{ab}	8.5^{b}	6.4^{bcd}	7.5^{bcde}	51.1^{b}
Mott	2014	70.0^{cde}	3.7^{abc}	1098.7^{cd}	8.4^{bc}	8.4^{a}	9.7^{a}	7.5^{a}	7.4^{cde}	70.6^{ab}
Prosper	2014	70.9^{abcd}	3.8^{abc}	1106.2^{bcd}	8.4^{bc}	7.6^{abc}	9.7^{a}	6.7^{abc}	7.7^{abcd}	71.4^{ab}
SySoren	2014	71.8^{abc}	3.7^{abc}	1117.5^{abcd}	8.5^{abc}	7.9^{ab}	9.5^{a}	6.9^{ab}	7.0^{e}	67.5^{ab}

Values with the same superscript letter are not significantly different (P>0.05). Least significant difference was used for mean separation. *Values are subject based on a scale from 0 to 10, 0= low quality, 10= high quality

Since the baking results for the different cultivars were similar (Table 15), the results for different cultivars grown in different years are expected to be similar (Table 17). The baking results for the cultivar x year interaction indicates that baking absorption was significantly (P<0.05) different for the same cultivars grown in different years (Table 17). There was, however, no significant (P>0.05) difference between some cultivars within the same year and with other cultivars from a different year (Table 17). For dough mixing time, several cultivars were relatively similar for both crop years. The cultivars Barlow, Faller, Glenn, and Prosper were not significantly (P>0.05) different in 2013 and 2014 for mixing time (Table 17). Overall, the mixing time results were similar between cultivars from the same year (Table 17). The loaf volume and specific loaf volume results were relatively similar. For loaf volume, the Elgin, Prosper, and SySoren cultivars were not significantly (P>0.05) different for 2013 and 2014 (Table 17). For specific volume, only the Elgin and Glenn cultivars were not significantly (P>0.05) different between crop years (Table 17). Majority of the crumb firmness results were not significant (P>0.05) between cultivars and years (Table 17).

For the subjective bread quality results, the majority of the samples were not significantly (P>0.05) different for crust color (Table 17). For loaf symmetry, crumb color, and crumb grain, the results between the same cultivar from different years were significantly (P<0.05) different, except for Elgin crumb color (Table 17). Overall, the cultivar x year interaction does have some effect on bread quality results (Table 17). Since cultivars grown in the same years had more similar bread quality results, the cultivar genotypes may have changes between 2013 and 2014. However, the seasonal conditions were different in 2013 and 2014, so environmental conditions could have caused the bread quality differences.

Whole Wheat Flour

The RVA was used to record the starch pasting profiles for whole wheat flour samples. The whole wheat flour RVA results are more significantly (P<0.05) different between cultivars than the results for refined flour (Tables 9 and 18). The pasting profiles for different HRS wheat cultivars were overall significantly (P<0.05) different (Table 18). Some cultivars were similar for specific RVA parameters. For peak viscosity, Barlow and Mott, Elgin and Forefront, and Faller and Prosper were not significantly (P>0.05) different, respectively (Table 18). The cultivars Barlow, Mott, and SySoren were not significantly (P>0.05) different for breakdown, and Prosper was not significantly (P>0.05) different from Faller or Glenn for starch breakdown (Table 18). The final viscosity results for Forefront, Prosper, and SySoren were not significantly (P>0.05) different (Table 18). For setback and peak time, Faller and Forefront, and Elgin and Glenn were not significantly (P>0.05) different, respectively (Table 18). The overall starch pasting properties do vary by cultivar for whole wheat flour, which is most likely the result of different genetics.

Table 18: Whole Wheat Flour Pasting Profiles for Different Hard Red Spring Wheat Cultivars

Cultivar	Peak Viscosity (RVU)	Breakdown (RVU)	Final Viscosity (RVU)	Setback (RVU)	Peak Time (min)
Barlow	117.1^{d}	58.9^{e}	126.4^{e}	68.22^{e}	5.7^{e}
Elgin	142.3^{bc}	68.4^{c}	153.2^{bc}	79.30^{bcd}	5.8^{ab}
Faller	152.4^{a}	72.0^{b}	164.3^{a}	83.99^{ab}	5.8^{a}
Forefront	139.9^{bc}	64.4^{d}	158.1^{ab}	82.68^{ab}	5.8^{bcd}
Glenn	146.0^{ab}	76.4^{a}	144.4^{cd}	74.74^{d}	5.8^{ab}
Mott	123.0^{d}	57.6^{e}	141.4^{d}	76.07^{cd}	5.7^{de}
Prosper	151.2^{a}	72.9^{ab}	159.5^{ab}	81.11^{abc}	5.8^{abc}
SySoren	134.9^{c}	58.7^{e}	162.6^{ab}	86.40^{a}	5.8^{cd}

Values with the same superscript letter are not significantly different (P>0.05). Least significant difference was used for mean separation. RVU: rapid visco unit

For the starch pasting profiles for whole wheat flour, location appears to have a greater effect than year for significant (P<0.05) differences between samples (Table 19). For peak viscosity, Hettinger 2013 and Dickinson 2014 were the only samples that were significantly (P<0.05) different (Table 19). For starch breakdown, all samples were significantly (P<0.05) different from the same location but different years, except for Casselton 2014, which was not significantly (P>0.05) different from Casselton 2013 (Table 19). Similarities in final viscosity results were observed, but significant (P<0.05) difference between the same locations from different years exists (Table 19). For peak time, the Carrington and Hettinger samples were not affected by year, since these values were not significantly (P>0.05) different, respectively (Table 19). Overall, location and year do affect whole wheat flour starch quality. The different environmental conditions during 2013 and 2014 did affect whole wheat flour starch quality.

Table 19: Whole Wheat Flour Pasting Profiles for Hard Red Spring Wheat Grown in Different Locations and Years

Location	Year	Peak Viscosity (RVU)	Breakdown (RVU)	Final Viscosity (RVU)	Setback (RVU)	Peak Time (min)
Carrington	2013	134.1^{b}	61.1^{c}	150.0^{bc}	76.9^{cd}	5.8^{ab}
Casselton	2013	135.1^{b}	66.4^{b}	138.7^{d}	70.0^{e}	5.7^{bc}
Dickinson	2013	138.8^{b}	64.7^{b}	147.7^{cd}	73.6^{de}	5.8^{a}
Hettinger	2013	175.8^{a}	83.7^{a}	188.9^{a}	96.9^{a}	5.8^{a}
Carrington	2014	139.3^{b}	64.8^{b}	159.6^{b}	85.1^{b}	5.8^{ab}
Casselton	2014	139.2^{b}	63.2^{bc}	157.0^{bc}	81.0^{bc}	5.8^{a}
Dickinson	2014	108.8^{c}	59.7^{c}	119.9^{e}	70.8^{e}	5.7^{c}
Hettinger	2014	135.7^{b}	65.7^{b}	148.0^{cd}	78.0^{cd}	5.8^{a}

Values with the same superscript letter are not significantly different (P>0.05). Least significant difference was used for mean separation. RVU: rapid visco unit

The majority of the results for whole wheat pasting profiles for different cultivars and years were significantly (P<0.05) different (Table 20). For final viscosity, the Faller and Prosper cultivars were not significantly (P>0.05) different between 2013 and 2014 (Table 20). The Barlow and Prosper cultivars were not significantly (P>0.05) different between years for setback and peak time, respectively (Table 20). For each RVA parameter, significant (P<0.05) differences exists between different cultivars from the same and different years (Table 20). Therefore, different genotypes and environmental conditions contributed to whole wheat flour starch quality.

Table 20: Whole Wheat Flour Pasting Profiles for Different Hard Red Spring Wheat Cultivars Grown in Different Years

Cultivar	Year	Peak Viscosity (RVU)	Breakdown (RVU)	Final Viscosity (RVU)	Setback (RVU)	Peak Time (min)
Barlow	2013	124.9^{g}	62.9^{d}	131.6^{ef}	69.61^{f}	5.7^{def}
Elgin	2013	152.3^{abc}	71.8^{b}	160.6^{abc}	80.01^{bcde}	5.8^{ab}
Faller	2013	156.4^{ab}	73.2^{b}	163.7^{ab}	80.53^{bcde}	5.8^{ab}
Forefront	2013	144.8^{bcde}	66.3^{cd}	161.9^{ab}	83.46^{abc}	5.7^{abcde}
Glenn	2013	153.9^{abc}	78.5^{a}	150.3^{bcd}	74.91^{def}	5.9^{a}
Mott	2013	133.9^{efg}	61.9^{d}	149.9^{bcd}	78.23^{cde}	5.7^{cdef}
Prosper	2013	157.3^{a}	74.9^{ab}	161.4^{abc}	78.98^{cde}	5.8^{abc}
SySoren	2013	144.2^{cdef}	62.0^{d}	171.5^{a}	89.22^{a}	5.8^{bcde}
Barlow	2014	109.3^{h}	54.9^{e}	121.3^{f}	66.83^{f}	5.7^{f}
Elgin	2014	132.2^{fg}	65.0^{d}	145.8^{cde}	78.58^{cde}	5.8^{abc}
Faller	2014	148.4^{abcd}	70.8^{bc}	165.0^{ab}	87.45^{ab}	5.9^{a}
Forefront	2014	135.0^{efg}	62.5^{d}	154.3^{bc}	81.90^{abcde}	5.8^{abcd}
Glenn	2014	138.2^{def}	74.2^{ab}	138.5^{de}	74.58^{ef}	5.8^{abc}
Mott	2014	112.2^{h}	53.2^{e}	132.9^{ef}	73.91^{ef}	5.7^{ef}
Prosper	2014	145.2^{bcde}	70.9^{bc}	157.5^{abc}	83.23^{abcd}	5.8^{abc}
SySoren	2014	125.6^{g}	55.3^{e}	153.8^{bcd}	83.58^{abc}	5.7^{abcde}

Values with the same superscript letter are not significantly different (P>0.05). Least significant difference was used for mean separation. RVU: rapid visco units

The bran and germ composition of each cultivar may have caused differences in whole wheat flour Farinograph results. The fiber content of whole wheat flour increases from refined flour, which caused an increase in water absorption between refined and whole wheat flours (Tables 12 and 21). Farinograph results for whole wheat flour cultivars indicates that several cultivars have similar results for specific Farinograph parameters (Table 21). For water absorption, Barlow and Glenn had the highest values (Table 21). Elgin and SySoren, and Faller, Mott, and Prosper were not significantly (P>0.05) different for water absorption, respectively (Table 21). The differences in water absorption values may be the result of different protein, arabinoxylan and damaged starch contents, since these components all contribute to water absorption. Glenn had the longest peak time value (Table 21). Barlow, Elgin, Forefront, and SySoren were not significantly (P>0.05) different for peak times (Table 21). These four cultivars will have similar dough mixing times during baking based on peak time results.

For stability, Elgin and Mott, Glenn and SySoren, and Faller and Prosper were not significantly (P>0.05) different, respectively (Table 21). Cultivars with similar Farinograph stability results have similar gluten strengths. Higher Farinograph stability values indicate higher quality bread loaves based on gluten strength. Faller and Prosper had the longest MTI values and Forefront and SySoren had the shortest MTI values, which indicate a stronger and weaker dough mixing tolerance, respectively (Table 21). Barlow and Mott were not significantly (P>0.05) different for MTI, and neither were Elgin and Glenn (Table 21). Genotype had some effect on whole wheat flour dough quality based on Farinograph profiles. The peak times, stability values and MTI values, may have been affected by the fiber content of whole wheat flour, since some of these parameters decreased for whole wheat flour (Tables 12 and 21). A decrease in Farinograph

peak time and stability from refined to whole wheat flour is expected since the fiber in whole wheat flour interferes with gluten development (Pyler and Gorton, 2009).

Table 21: Whole Wheat Flour Farinograph Profiles for Different Cultivars of Hard Red Spring Wheat

Cultivar	Absorption (14% MB)	Peak Time (min)	Stability (min)	MTI (BU)
Barlow	71.7^{a}	5.8^{ab}	7.3^{bc}	30.4^{ab}
Elgin	69.7^{b}	5.8^{ab}	7.9^{abc}	27.0^{bc}
Faller	68.9^{bc}	5.5^{b}	6.6^{c}	35.6^{a}
Forefront	68.1^{c}	5.8^{ab}	8.6^{a}	23.4^{c}
Glenn	70.8^{a}	6.0^{a}	8.1^{ab}	28.1^{bc}
Mott	68.8^{bc}	5.5^{b}	7.3^{abc}	30.6^{ab}
Prosper	69.0^{bc}	5.5^{b}	6.6^{c}	34.0^{a}
SySoren	69.6^{b}	5.6^{ab}	8.1^{ab}	23.1^{c}

Values with the same superscript letter are not significantly different (P>0.05). Least significant difference was used for mean separation. MB: moisture basis; MTI: mixing tolerance index; BU: Braebender unit

Environmental factors appear to have a greater effect on whole wheat flour dough quality as compared to cultivars (Table 22). There are more variations in the water absorption results for different locations and years (Table 22). The Carrington sample from 2013 had the highest water absorption, and was similar to the water absorption from the 2014 Carrington sample (Table 22). Samples from Casselton 2013, Dickinson 2014, and Hettinger 2014 were not significantly (P>0.05) different for water absorption (Table 22). Differences in water absorption are caused by differences in flour composition, which is affected by different genotypes or environmental conditions.

The environmental conditions of the samples did affect gluten quality. The Dickinson 2013 sample had the longest peak time and the Casselton 2014 sample had the shortest peak time (Table 22). The peak times are similar between some of the samples, however, samples from different locations and years were significantly (P<0.05) different (Table 22). The Carrington 2013 sample had the longest stability but the shortest MTI value, and the Casselton 2014 sample

had the shortest stability and longest MTI value (Table 22). The stability values were significantly (P<0.05) different between locations from the same year, and the same locations from different years (Table 22). The MTI values for Hettinger samples from 2013 and 2014 were not significantly (P>0.05) different (Table 22). Therefore, environmental factors did not affect the dough mixing tolerance for the whole wheat flour samples from Hettinger. The environmental conditions for the different locations and years most likely caused the differences in dough quality, since the Farinograph results for different cultivars were more similar.

Table 22: Whole Wheat Flour Farinograph Profiles for Hard Red Spring Wheat Grown in Different Locations and Years

Location	Year	Absorption (14% MB)	Peak Time (min)	Stability (min)	MTI (BU)
Carrington	2013	71.0^{a}	6.4^{ab}	9.7^{a}	19.5^{e}
Casselton	2013	68.6^{d}	5.5^{de}	7.1^{cd}	28.9^{cd}
Dickinson	2013	70.2^{abc}	6.5^{a}	8.7^{ab}	24.5^{de}
Hettinger	2013	69.8^{bc}	6.0^{bc}	8.0^{bc}	26.6^{cd}
Carrington	2014	70.7^{ab}	5.0^{ef}	6.2^{de}	34.5^{ab}
Casselton	2014	69.8^{cd}	4.7^{f}	5.2^{e}	39.1^{a}
Dickinson	2014	68.5^{d}	5.9^{bcd}	7.9^{bc}	30.7^{bc}
Hettinger	2014	68.6^{d}	5.6^{cd}	7.5^{bcd}	28.4^{cd}

Values with the same superscript letter are not significantly different (P>0.05). Least significant difference was used for mean separation. MB: moisture basis; MTI: mixing tolerance index; BU: Braebender unit

The Farinograph water absorption data for different whole wheat flour cultivars grown in different years indicates that the cultivars grown in 2013 were significantly (P<0.05) different from each other and from the same cultivars grown in 2014 (Table 23). For peak time and stability, the cultivars grown within the same year are similar (Table 23). The cultivars grown in 2013 were significantly (P<0.05) different than the cultivars grown in 2014, respectively, for peak time and stability (Table 23). The dough mixing tolerance of whole wheat flour cultivars is affected by year, because the MTI values for the different cultivars were significantly (P<0.05) different for the respective cultivars from 2013 and 2014 (Table 23). The crop year appears to

have a greater effect on whole wheat flour dough quality as compared to cultivar. The seasonal conditions changing from year to year may have resulted in dough quality differences between the cultivars.

Table 23: Whole Wheat Flour Farinograph Profiles for Different Hard Red Spring Wheat Cultivars Grown in Different Years

Cultivar	Year	Absorption (14% MB)	Peak Time (min)	Stability (min)	MTI (BU)
Barlow	2013	71.9^{a}	6.1^{abcd}	8.2^{bcde}	26.5^{cde}
Elgin	2013	70.4^{bcd}	6.4^{a}	9.2^{ab}	20.7^{ef}
Faller	2013	69.5^{cdef}	5.7^{bcde}	6.8^{defg}	33.0^{abc}
Forefront	2013	69.0^{g}	6.1^{abcd}	9.1^{abc}	21.0^{ef}
Glenn	2013	70.7^{abcd}	6.2^{abc}	8.3^{abcd}	24.0^{de}
Mott	2013	69.2^{defg}	6.1^{abcd}	8.1^{bcdef}	28.0^{bcde}
Prosper	2013	69.5^{cdef}	5.8^{abcde}	7.3^{cdefg}	29.7^{bcd}
SySoren	2013	69.8^{cde}	6.3^{ab}	10.2^{a}	16.0^{f}
Barlow	2014	71.4^{ab}	5.5^{cdef}	6.3^{fg}	34.2^{ab}
Elgin	2014	68.9^{efg}	5.2^{ef}	6.6^{defg}	33.2^{abc}
Faller	2014	68.3^{fg}	5.2^{ef}	6.4^{efg}	38.2^{a}
Forefront	2014	68.3^{fg}	5.4^{def}	8.1^{bcdef}	25.7^{cde}
Glenn	2014	70.9^{abc}	5.9^{abcde}	7.8^{bcdefg}	32.2^{abc}
Mott	2014	68.3^{efg}	4.9^{f}	6.5^{defg}	33.2^{abc}
Prosper	2014	68.4^{efg}	5.2^{ef}	6.0^{g}	38.2^{a}
SySoren	2014	69.4^{defg}	4.9^{f}	5.9^{g}	30.2^{bcd}

Values with the same superscript letter are not significantly different (P>0.05). Least significant difference was used for mean separation. MB: moisture basis; MTI: mixing tolerance index; BU: Braebender unit

The baking quality results for several of the different HRS wheat cultivars were similar. For baking absorption, the Barlow, Eglin, and SySoren cultivars were not significantly (P>0.05) different (Table 24). The Faller, Mott, and Prosper samples were not significantly (P>0.05) different for baking absorption either (Table 24). The differences in flour composition did not greatly affect the baking absorptions of the whole wheat flour samples, since the absorptions were similar between several samples.

For dough mixing time, Barlow was the only sample significantly (P<0.05) different from the other cultivars (Table 24). The Mott sample was not significantly (P>0.05) different for mixing time with any of the cultivars (Table 24). The different cultivar genotypes do not appear to affect gluten development times during dough mixing. The loaf volume and specific volume results were relatively alike. For loaf volume, Barlow, Glenn, and Prosper were not significantly (P>0.05) different, and neither were Elgin, Faller, Forefront, and SySoren (Table 24). Barlow and Glenn, and Elgin, Faller, and Forefront were not significantly (P>0.05) different for specific loaf volume, respectively (Table 24). The different cultivar genotypes did not greatly affect the overall gluten quality between the different samples. For crumb firmness, only Glenn and Prosper were not significantly (P>0.05) different (Table 24).

For loaf symmetry and crust and crumb characteristics, the cultivar samples were relatively similar. For symmetry, Elgin, Faller, Forefront, and SySoren were not significantly (P>0.05) different from each other, nor the other cultivars (Table 24). SySoren and Mott were not significantly (P>0.05) different from Barlow, Elgin, Faller or Forefront for crust color (Table 24). No significance (P>0.05) in crumb grain was found between cultivars (Table 24). For crumb color, Faller and Glenn were not significantly (P>0.05) different from the rest of the cultivars (Table 24). The whole wheat bread quality was not strongly influenced by the specific cultivars. The different genotypes from the cultivars did not affect bread quality, much like the refined flour bread quality results.

Table 24: Whole Wheat Flour Bread Quality of Different Hard Red Spring Wheat Cultivars

	Dough				Bread				
Cultivar	Absorption (%)	Mixing Time (min)	Loaf Volume (cc)	Specific Volume (cc/g)	Symmetry*	Crust Color*	Crumb Grain*	Crumb Color*	Firmness (g)
Barlow	87.8^{bc}	3.7^{b}	850.6^{a}	5.9^{ab}	6.9^{a}	9.6^{a}	6.3^{a}	7.7^{a}	103.8^{e}
Elgin	87.6^{bc}	4.1^{a}	793.7^{ab}	5.6^{abc}	6.7^{ab}	9.6^{a}	6.7^{a}	7.7^{a}	146.0^{bcd}
Faller	83.9^{c}	4.1^{a}	804.4^{ab}	5.7^{abc}	6.1^{ab}	9.9^{a}	6.9^{a}	7.6^{ab}	131.4^{cde}
Forefront	96.4^{a}	4.0^{a}	797.5^{ab}	5.6^{abc}	6.6^{ab}	9.9^{a}	6.5^{a}	7.9^{a}	175.3^{ab}
Glenn	93.8^{ab}	4.1^{a}	833.1^{a}	5.9^{ab}	7.0^{a}	9.1^{bc}	6.8^{a}	7.6^{ab}	109.2^{de}
Mott	86.7^{c}	3.9^{ab}	738.7^{b}	5.2^{c}	5.8^{b}	9.5^{ab}	6.3^{a}	7.1^{b}	186.4^{a}
Prosper	83.3^{c}	4.0^{a}	845.0^{a}	6.1^{a}	6.9^{a}	8.9^{c}	6.9^{a}	7.6^{a}	119.7^{de}
SySoren	88.9^{bc}	4.0^{a}	800.0^{ab}	5.5^{bc}	6.4^{ab}	9.5^{ab}	7.0^{a}	7.7^{a}	167.8^{abc}

Values with the same superscript letter are not significantly different (P>0.05). Least significant difference was used for mean separation. *Values are subject based on a scale from 0 to 10, 0= low quality, 10= high quality

The whole wheat bread quality results indicate that similarities exist between locations within the same year and between different years for whole wheat bread (Table 25). For baking absorption, the 2013 locations were significantly (P<0.05) different than the locations from 2014 (Table 25). The 2013 Casselton and Dickinson samples were not significantly (P>0.05) different from Carrington or Hettinger for absorption (Table 25). From the 2014, the Hettinger and Dickinson samples were significantly (P<0.05) different from Carrington and Casselton for water absorption (Table 25). Different environmental conditions from the different years and locations did have some effect on baking absorption. For dough mixing time the only sample location from 2013 and 2014 that was not significantly (P>0.05) different was Casselton (Table 25). Therefore, environmental factors did not strongly influence gluten development. For loaf volume, specific volume, and firmness there was little to no significance (P>0.05) between locations and years (Table 25). The environmental factors did not affect gluten quality overall.

There were little variations in the data results for loaf shape, crust and crumb color or crumb grain between samples (Table 25). For loaf symmetry, the Carrington, Dickinson, and Hettinger 2013 samples and the Carrington, Casselton, and Hettinger 2014 samples were not significantly (P>0.05) different, respectively (Table 25). Dickinson and Casselton were the only two locations with significant (P<0.05) difference between years for crust color (Table 25). Carrington and Casselton from 2013 and 2014 had no significant (P>0.05) differences in crumb color (Table 25). For crumb grain, Casselton was the only location with significant (P<0.05) difference between crop years (Table 25). Location and year did have some effect on whole wheat bread quality, which means the environment can affect end-product quality with only a one year different.

Table 25: Whole Wheat Flour Bread Quality for Hard Red Spring Wheat from Different Locations and Years

		Dough		Bread						
Location	Year	Absorption (%)	Mixing Time (min)	Loaf Volume (cc)	Specific Volume (cc/g)	Symmetry*	Crust Color*	Crumb Grain*	Crumb Color*	Firmness (g)
Carrington	2013	79.5^{cd}	3.7^{cd}	798.1^{a}	5.5^{ab}	6.9^{a}	9.4^{abc}	6.7^{ab}	7.7^{a}	141.2^{a}
Casselton	2013	75.8^{d}	4.0^{b}	779.4^{a}	5.5^{b}	6.2^{ab}	9.6^{ab}	7.0^{a}	7.9^{a}	146.0^{a}
Dickinson	2013	78.9^{cd}	3.6^{d}	841.2^{a}	5.9^{ab}	6.7^{a}	9.2^{bc}	7.0^{a}	7.7^{ab}	153.3^{a}
Hettinger	2013	76.7^{d}	3.7^{d}	849.4^{a}	6.0^{a}	6.6^{a}	9.7^{a}	6.5^{ab}	7.6^{ab}	123.1^{a}
Carrington	2014	93.1^{b}	4.0^{bc}	791.2^{a}	5.5^{ab}	6.9^{a}	9.7^{a}	6.6^{ab}	7.7^{a}	155.6^{a}
Casselton	2014	84.0^{c}	4.2^{b}	803.7^{a}	5.8^{ab}	6.7^{a}	9.0^{c}	6.2^{b}	7.9^{a}	151.4^{a}
Dickinson	2014	108.2^{a}	4.7^{a}	786.9^{a}	5.6^{ab}	5.4^{b}	9.7^{a}	6.7^{ab}	7.1^{c}	136.9^{a}
Hettinger	2014	112.2^{a}	4.1^{b}	813.1^{a}	5.7^{ab}	7.0^{a}	9.5^{ab}	6.6^{ab}	7.2^{bc}	132.0^{a}

Values with the same superscript letter are not significantly different (P>0.05). Least significant difference was used for mean separation. *Values are subject based on a scale from 0 to 10, 0= low quality, 10= high quality

The results for whole wheat bread quality indicates that several cultivars from different years were not significantly (P>0.05) different (Table 26). For water absorption and mixing time, majority of the cultivars were not significantly (P>0.05) different within a year (Table 26). For baking absorption, there were no significant (P>0.05) difference between cultivars for 2013, but the 2013 cultivars were significantly (P<0.05) different from the 2014 cultivars (Table 26). The results for mixing time are similar to the absorption results. The cultivars from 2013 are not significantly (P>0.05) different, and neither are the cultivars from 2014, respectively (Table 26). However, the 2013 and 2014 samples were significantly (P<0.05) different for the respective cultivars (Table 26). Elgin, Forefront, Glenn, Mott, Prosper and SySoren loaf volumes were not significantly (P>0.05) different from 2013 to 2014 (Table 26). The specific volumes of Elgin, Glenn, and Mott samples were not significantly (P>0.05) different between 2013 and 2014 (Table 26). For crumb firmness, the Barlow samples from 2013 and 2014 were not significantly (P>0.05) different (Table 26).

The subjective bread quality measures for the cultivar x year interaction were more alike than the other bread quality parameters. For symmetry and crumb grain the samples from the same cultivar but different years were not significantly (P>0.05) different (Table 26). For crust and crumb color, the Mott and SySoren, and the Glenn and SySoren values were not significantly (P>0.05) different for 2013 and 2014 (Table 26). Overall, the whole wheat bread quality was affected by genotype and phenotype. However, there appears to be less of an effect on whole wheat bread as compared to refined bread quality. The cultivars had similar end product qualities for whole wheat flour within a specific year, and between years for some cultivars. Therefore, the genotypes important for end product quality do not greatly change each year.

Table 26: Whole Wheat Flour Bread Quality of Different Hard Red Spring Wheat Cultivars Grown in Different Years

		Dough		Bread						
Cultivar	Year	Absorption (%)	Mixing Time (min)	Loaf Volume (cc)	Specific Volume (cc/g)	Symmetry*	Crust Color*	Crumb Grain*	Crumb Color*	Firmness (g)
Barlow	2013	78.9^{d}	3.6^{c}	865.0^{a}	6.0^{abc}	6.7^{ab}	9.7^{ab}	6.5^{ab}	8.0^{a}	101.9^{de}
Elgin	2013	78.4^{d}	3.8^{c}	808.7^{ab}	5.6^{abcd}	6.7^{ab}	9.5^{abc}	6.7^{ab}	8.0^{a}	152.7^{abcde}
Faller	2013	77.1^{d}	3.9^{bc}	870.0^{a}	6.1^{ab}	6.5^{ab}	10.0^{a}	7.0^{ab}	7.9^{ab}	99.0^{e}
Forefront	2013	76.5^{d}	3.7^{c}	766.2^{ab}	5.4^{bcd}	6.5^{ab}	9.7^{ab}	6.5^{ab}	8.0^{a}	171.9^{abc}
Glenn	2013	77.6^{d}	3.8^{c}	828.7^{ab}	5.8^{abcd}	7.2^{a}	9.2^{bcd}	7.0^{ab}	7.5^{abc}	117.2^{cde}
Mott	2013	77.9^{d}	3.6^{c}	745.0^{b}	5.1^{d}	5.7^{b}	9.5^{abc}	6.5^{ab}	7.0^{c}	197.4^{a}
Prosper	2013	76.9^{d}	3.7^{c}	872.5^{a}	6.3^{a}	7.0^{ab}	8.7^{d}	7.2^{a}	7.7^{ab}	107.0^{de}
SySoren	2013	78.4^{d}	3.6^{c}	780.0^{ab}	5.4^{bcd}	6.5^{ab}	9.5^{abc}	7.0^{ab}	7.7^{ab}	180.2^{ab}
Barlow	2014	96.7^{bc}	3.7^{c}	836.2^{ab}	5.9^{abcd}	7.0^{ab}	9.5^{abc}	6.1^{b}	7.5^{abc}	105.6^{de}
Elgin	2014	96.7^{bc}	4.4^{a}	778.7^{ab}	5.5^{abcd}	6.7^{ab}	9.7^{ab}	6.7^{ab}	7.5^{abc}	139.4^{bcde}
Faller	2014	90.7^{bc}	4.2^{ab}	738.7^{b}	5.3^{cd}	5.7^{b}	9.7^{ab}	6.7^{ab}	7.2^{bc}	163.9^{abc}
Forefront	2014	116.2^{a}	4.3^{a}	828.7^{ab}	5.8^{abcd}	6.7^{ab}	10.0^{a}	6.5^{ab}	7.7^{ab}	178.7^{ab}
Glenn	2014	110.0^{a}	4.4^{a}	837.5^{ab}	5.9^{abcd}	6.7^{ab}	9.0^{cd}	6.6^{ab}	7.6^{abc}	101.1^{de}
Mott	2014	95.5^{bc}	4.2^{ab}	732.5^{b}	5.2^{d}	5.9^{ab}	9.5^{abc}	6.1^{b}	7.2^{bc}	175.3^{ab}
Prosper	2014	89.7^{c}	4.3^{a}	817.5^{ab}	5.9^{abcd}	6.7^{ab}	9.0^{cd}	6.5^{ab}	7.5^{abc}	132.4^{bcde}
SySoren	2014	99.5^{b}	4.3^{a}	820.0^{ab}	5.7^{abcd}	6.5^{ab}	9.5^{abc}	7.0^{ab}	7.7^{ab}	155.3^{abcd}

Values with the same superscript letter are not significantly different (P>0.05). Least significant difference was used for mean separation. *Values are subject based on a scale from 0 to 10, 0= low quality, 10= high quality

Solvent Retention Capacity

Refined Flour

Solvent Retention Capacity profiles were measured for refined HRS wheat flour from different cultivars, locations, and crop years. The SRC solvents used were deionized water, sodium carbonate (5%), ethanol (55%), sucrose (50%), and lactic acid (5%). The SRC results and gluten performance index (GPI) for different HRS wheat cultivars were observed (Table 27). The cultivars display similarities for the different SRC parameters.

The Glenn and Prosper cultivars were the only samples not significantly ($P>0.05$) different for the water SRC (Table 27). Samples with similar water SRC results have similar water holding capacity properties, which was observed in the flour composition data (Table 3). The water holding capacity properties are dependent on protein, damaged starch, and arabinoxylan contents. Since the other cultivars were significantly ($P<0.05$) different for the water SRC value, the water holding capacity of these flours was affected differently by each flour composition.

Several of the cultivars had similar sodium carbonate SRC results. For sodium carbonate SRC, the Barlow and SySoren were not significantly ($P>0.05$) different (Table 27). The Elgin, Faller, Glenn, and Prosper cultivars were not significantly ($P>0.05$) different for the sodium carbonate SRC (Table 27). Sodium carbonate solvent extracts damaged starch from the flour sample; therefore, samples with similar sodium carbonate SRC values most likely have similar damaged starch contents. Many the samples with similar sodium carbonate SRC results also had similar damaged starch contents (Table 3). Therefore, the sodium carbonate SRC values were related to the damaged starch composition.

There was no significant (P>0.05) differences in ethanol SRC values for the different cultivars (Table 27). Therefore, the gliadin contents would be relatively similar between the different samples (Table 27). The glutenin protein contents of the different cultivars is also expected to be similar since the lactic acid SRC results were not significantly (P>0.05) different for Elgin, Faller, and Forefront, or between Mott and Prosper (Table 27). The Elgin and Faller cultivars had similar wet gluten and gluten index values, which are effected by glutenin and gliadin proteins (Table 3). For these two cultivars, the lactic acid and ethanol SRC values were related to the gluten quality parameters of flour. According to Xiao et al (2006) the lactic acid SRC was correlated with gluten protein quality, and was consistent with predicted bread loaf volumes. The lactic acid value for Glenn was the highest (Table 27). A larger lactic acid SRC value may indicate that this sample will have a higher loaf volume during experimental bread baking (Kweon et al, 2011).

The Barlow, Forefront and Mott cultivars were significantly (P<0.05) different for the sucrose SRC (Table 27). The Faller, Glenn, and Prosper cultivars were not significantly (P>0.05) different for sucrose SRC (Table 27). The arabinoxylan content of these three cultivars were also not significantly (P>0.05) different, which is measured with the sucrose SRC solvent (Table 3). However, the sucrose SRC solvent may not be the most reliable for determining arabinoxylan content, since the SySoren cultivar was the only sample with a significantly (P<0.05) different arabinoxylan content (Table 3). Therefore, one would expect the SySoren sample to have the only significantly (P<0.05) different sucrose SRC value.

The GPI values were not significantly (P>0.05) different for Barlow, Elgin, and Faller, and Prosper and SySoren, respectively (Table 27). The GPI values indicate the gluten performance in flour containing other modulating networks. Therefore, the gluten performance

of these samples are dependent on the other flour components that could interfere with gluten development and strength. The SRC profiles were affected by the different cultivar genotypes. However, some of the cultivars were relatively the same for different SRC parameters, which means these cultivars most likely have relatively the same respective flour compositions.

Table 27: Refined Flour Solvent Retention Capacity Profiles for Different Hard Red Spring Wheat Cultivars

	Solvents					
Cultivar	Water (%)	Sodium Carbonate (%)	Lactic Acid (%)	Sucrose (%)	Ethanol (%)	GPI
Barlow	82.8^{a}	110.5^{ab}	159.1^{b}	117.2^{a}	70.9^{a}	0.70^{bc}
Elgin	79.5^{bc}	115.5^{a}	156.2^{bc}	111.0^{bc}	74.6^{a}	0.69^{bc}
Faller	79.8^{b}	111.6^{a}	156.2^{bc}	114.4^{ab}	74.4^{a}	0.70^{bc}
Forefront	74.1^{e}	103.0^{b}	156.2^{bc}	104.0^{d}	73.0^{a}	0.76^{a}
Glenn	81.5^{ab}	113.1^{a}	164.2^{a}	115.4^{ab}	73.5^{a}	0.72^{b}
Mott	76.9^{cd}	103.0^{b}	152.3^{c}	109.1^{c}	73.8^{a}	0.73^{ab}
Prosper	81.0^{ab}	114.3^{a}	153.8^{c}	114.0^{ab}	73.8^{a}	0.68^{c}
SySoren	75.2^{de}	107.5^{ab}	147.1^{d}	107.8^{cd}	75.1^{a}	0.68^{c}

Values with the same superscript letter are not significantly different (P>0.05). Least significant difference was used for mean separation. GPI: Gluten Performance Index.

The solvent retention capacity profiles were affected more by environmental conditions than cultivar genetics. For the water SRC, there were significant (P<0.05) differences between the same locations but different years (Table 28). The locations within the same year are more alike (Table 28). From 2013, the Carrington sample was the only water SRC value significantly (P<0.05) different (Table 28). Therefore, the water holding capacities of the flours from different locations were not affected by environmental conditions in 2013. The 2014 samples may have been affected by environmental conditions for flour water holding capacities, since the Dickinson and Hettinger were the only sample locations not significantly (P>0.05) different for the water SRC (Table 28).

For the sodium carbonate SRC, the locations within 2013 had similar arabinoxylan contents, since Carrington was the only location significantly (P<0.05) different (Table 28). The

2013 locations were significantly (P<0.05) different from the 2014 locations for the sodium carbonate SRC (Table 28). The Carrington and Hettinger 2014 locations were the only samples not significantly (P>0.05) different for the sodium carbonate SRC (Table 28). The environmental conditions between the different locations had a strong effect on the sodium carbonate SRC results for 2014, much like the water SRC results.

The Carrington 2013 and the Dickinson 2014 samples were not significantly (P>0.05) different for lactic acid SRC, so these two samples most likely have the same glutenin contents (Table 28). The differences in lactic acid SRC values indicates that the gluten structure and strength changed between sample locations and years. The environmental conditions between different locations in 2013 and 2014 had a greater effect on the lactic acid SRC values in comparison to the water and sodium carbonate SRC values.

The Carrington 2013, Dickinson 2014, and Hettinger 2014, samples were not significantly (P>0.05) different for the sucrose SRC (Table 28). These samples were not affected by location and year for arabinoxylan content. The 2013 samples were all significantly (P<0.05) different for the Sucrose SRC (Table 28). The different environmental locations had a greater effect on the sucrose SRC results for 2013 samples. The environmental conditions were different in 2014, since the results for the sucrose SRC were not the same as the 2013 results.

For the GPI values, the Casselton 2013 and 2014, and Dickinson 2013 and 2014 were not significantly (P>0.05) different, respectively (Table 28). Therefore, the gluten performance of the samples from Casselton and Dickinson did not change between 2013 and 2014. However, the gluten performances of the other samples did changed between years, so the seasonal conditions had an effect on the gluten network of these flours. Year and location had an effect on SRC

values for refined flour. Year appears to have had a greater effect on SRC measures, since samples from the same location were not similar between years for most SRC solvents.

Table 28: Refined Flour Solvent Retention Capacity Profiles for Hard Red Spring Wheat Grown in Different Locations and Years

		Solvent					
Location	Year	Water (%)	Sodium Carbonate (%)	Lactic Acid (%)	Sucrose (%)	Ethanol (%)	GPI
Carrington	2013	75.2^{bc}	95.3^{cd}	137.9^{e}	99.1^{e}	78.7^{c}	0.71^{b}
Casselton	2013	87.2^{a}	130.9^{a}	159.8^{d}	121.0^{c}	87.7^{a}	0.63^{c}
Dickinson	2013	86.0^{a}	123.9^{a}	182.7^{a}	132.8^{b}	82.5^{bc}	0.72^{b}
Hettinger	2013	85.6^{a}	124.8^{a}	167.9^{b}	139.5^{a}	85.7^{ab}	0.64^{c}
Carrington	2014	76.3^{b}	103.9^{b}	163.1^{cd}	104.3^{d}	84.1^{ab}	0.78^{a}
Casselton	2014	74.5^{bc}	101.4^{bc}	127.6^{f}	100.1^{de}	59.5^{d}	0.63^{c}
Dickinson	2014	72.7^{c}	93.0^{d}	140.1^{e}	97.8^{e}	53.3^{e}	0.74^{b}
Hettinger	2014	73.1^{c}	105.2^{b}	165.8^{bc}	98.2^{e}	57.6^{de}	0.82^{a}

Values with the same superscript letter are not significantly different (P>0.05). Least significant difference was used for mean separation. GPI: Gluten Performance Index

Cultivars from the same year were more similar in SRC profiles compared to the same cultivars from a different year (Table 29). For each SRC solvent and GPI value, all of the cultivars were significantly (P<0.05) different from 2013 and 2014 (Table 29). This indicates that the genotypes for these eight cultivars did change from 2013 to 2014 based on SRC results. For the ethanol SRC, most of the 2013 cultivars were not significantly (P>0.05) different, and none of the 2014 cultivars were significantly (P>0.05) different (Table 29). These samples would be expected to have similar gliadin contents since there is little variation in the ethanol SRC results. The gliadin protein contents of these cultivars changed between 2013 and 2014 as indicated by the ethanol SRC results (Table 28).

The other SRC solvents displayed more differences between cultivars and years as compared to the ethanol SRC results (Table 28). In 2013, the Elgin, Faller, and Glenn cultivars

were not significantly (P>0.05) different for the water SRC (Table 28). The cultivars from 2014 were more similar for water SRC values, since Forefront was the only sample significantly (P<0.05) different for the water SRC (Table 28). The sodium carbonate SRC results were similar to the water SRC results. In 2013, the cultivars Elgin and Glenn, and Faller and Prosper were not significantly (P>0.05) different for the sodium carbonate SRC, respectively (Table 28). In 2014, the cultivars Barlow, Glenn, and SySoren were the only samples not significantly (P>0.05) different for the sodium carbonate SRC (Table 28). Therefore, the different cultivars had similar genotypes in 2013 and 2014, respectively, based on the water and sodium carbonate SRC results.

The lactic acid and sucrose SRC results were different than the results for the other solvents. The 2013 cultivars Elgin and Prosper were the only samples not significantly (P>0.05) different for the lactic acid SRC (Table 28). In 2014, the Faller and Prosper cultivars were the only samples not significantly (P>0.05) different for the lactic acid SRC (Table 28). The 2013 and 2014 results for the lactic acid SRC indicates that the gluten quality changed between different cultivars within each year, which may be the results of different genotypes. For the sucrose SRC, The Glenn and Prosper 2013 cultivars, and the Elgin and SySoren 2014 cultivars were the only samples not significantly (P>0.05) different, respectively (Table 28). The sucrose SRC results also indicate that the flour compositions or genotypes changed between cultivars within each year.

The GPI values appear to increase between 2013 and 2014 (Table 28). In 2013, the Barlow, Elgin and Faller cultivars were not significantly (P>0.05) different for the GPI results (Table 28). In 2014, the only cultivars not significantly (P>0.05) different for GPI were Barlow and Glenn (Table 28). The gluten performances of the cultivars were different for majority of the flour samples, which may be the result of different flour compositions. The environmental

conditions differed between 2013 and 2014, which may have contributed to the differences in SRC results. These results suggest that different cultivars from the same crop year were more similar in flour composition and possibly end-product quality.

Table 29: Refined Flour Solvent Retention Profiles for Different Hard Red Spring Wheat Cultivars Grown in Different Years

		Solvent					
Cultivar	Year	Water (%)	Sodium Carbonate (%)	Lactic Acid (%)	Sucrose (%)	Ethanol (%)	GPI (%)
Barlow	2013	88.0^{a}	119.9^{abc}	164.3^{abc}	130.0^{a}	78.1^{b}	0.66^{gh}
Elgin	2013	84.3^{ab}	121.8^{ab}	161.6^{bc}	122.8^{bcd}	85.0^{ab}	0.66^{gh}
Faller	2013	85.3^{ab}	126.6^{a}	166.6^{ab}	128.8^{ab}	85.7^{a}	0.66^{gh}
Forefront	2013	78.0^{cde}	107.3^{defg}	160.1^{cd}	113.7^{e}	84.6^{ab}	0.73^{bcde}
Glenn	2013	85.2^{ab}	122.7^{ab}	170.4^{a}	124.7^{abc}	81.5^{ab}	0.69^{efg}
Mott	2013	81.6^{bc}	112.4^{bcd}	158.1^{cde}	121.5^{cd}	84.3^{ab}	0.68^{efgh}
Prosper	2013	87.4^{a}	128.2^{a}	162.2^{bc}	126.7^{abc}	83.9^{ab}	0.64^{h}
SySoren	2013	78.5^{cd}	110.8^{bcde}	153.3^{ef}	116.7^{de}	86.2^{a}	0.68^{fgh}
Barlow	2014	77.7^{de}	101.2^{defgh}	153.9^{def}	104.4^{fg}	63.7^{c}	0.75^{abc}
Elgin	2014	74.6^{ef}	109.1^{cdef}	150.7^{fgh}	99.1^{ghi}	64.1^{c}	0.72^{bcdef}
Faller	2014	74.3^{ef}	96.6^{gh}	145.8^{hi}	100.1^{fghi}	63.2^{c}	0.74^{bcd}
Forefront	2014	70.3^{g}	98.6^{fgh}	152.3^{efg}	94.3^{i}	61.5^{c}	0.79^{a}
Glenn	2014	77.8^{de}	103.4^{defgh}	158.0^{cde}	106.1^{f}	65.5^{c}	0.75^{abc}
Mott	2014	72.2^{fg}	93.5^{h}	146.4^{ghi}	96.7^{hi}	63.4^{c}	0.77^{ab}
Prosper	2014	74.7^{ef}	100.4^{efgh}	145.4^{hi}	101.4^{fgh}	63.7^{c}	0.72^{cdef}
SySoren	2014	71.9^{fg}	104.2^{defgh}	140.9^{i}	98.8^{ghi}	64.1^{c}	0.69^{defg}

Values with the same superscript letter are not significantly different (P>0.05). Least significant difference was used for mean separation. GPI: Gluten Performance Index.

Whole Wheat Flour

Cultivar genetics did not have a strong influence on SRC profiles for whole wheat flour (Table 30). For lactic acid SRC there was no significant (P>0.05) difference between cultivars (Table 30). Similar lactic acid SRC values indicate similar gluten strength and bread loaf volumes. Similar results for wet gluten values were observed in the whole wheat flour composition data (Table 6). Since the lactic acid solvent can be used to predict loaf volumes of

bread flours, these eight cultivars are expected to have similar bread loaf volume results based on the lactic acid SRC data.

The Prosper and the Mott cultivars had the highest and lowest water SRC values, respectively (Figure 10). For the water SRC data, Barlow and Glenn were the only cultivars not significantly (P>0.05) different (Table 30). This indicates that the Barlow and Glenn samples have similar water holding capacities, which are based on flour composition. The Barlow and Glenn whole wheat flours did have similar flour composition results, which appears to be associated with the water SRC data (Tables 6 and 30). Differences in water SRC values result from differences in protein content, damaged starch, and/or arabinoxylan contents.

The Forefront cultivar had the lowest sodium carbonate and sucrose SRC values (Table 30). Lower sucrose and sodium carbonate SRC results indicate less damaged starch and arabinoxylan content in the Forefront sample compared to the other cultivars. The Forefront sample did have one of the lowest damaged starch contents and the lowest arabinose-xylose ratio for whole wheat flour composition (Table 6). For the sodium carbonate SRC results, the Barlow, Forefront and Mott cultivars were the only samples significantly (P<0.05) different (Table 30). For the sucrose SRC results, the Elgin, Forefront, Mott, and SySoren cultivars were the only samples significantly (P<0.05) different (Table 30). The Elgin cultivar was the only sample significantly (P<0.05) different for the ethanol SRC (Table 30). The sodium carbonate, sucrose, and ethanol SRC results indicate that the damaged starch, arabinoxylan, and gliadin contents were similar for majority of the whole wheat flour cultivars.

Forefront had the highest GPI value and Glenn had the lowest GPI value (Table 30). The Elgin, Faller, Prosper, and SySoren cultivars were not significantly (P>0.05) different for GPI values (Table 30). Therefore, the gluten performances of these cultivars were similar in an

environment containing other modulating networks. The slight differences in SRC values that exist between cultivars may be due to genetic variations. Since majority of the cultivars had similar SRC results, the cultivars, therefore, had similar genotypes and flour compositions.

Table 30: Whole Wheat Flour Solvent Retention Capacity Profiles for Different Hard Red Spring Wheat Cultivars

	Solvent					
Cultivar	Water (%)	Sodium Carbonate (%)	Lactic Acid (%)	Sucrose (%)	Ethanol (%)	GPI
Barlow	91.6^{ab}	124.9^{a}	111.9^{a}	120.7^{ab}	90.9^{ab}	0.46^{bc}
Elgin	90.2^{abc}	119.4^{ab}	110.9^{a}	122.7^{a}	93.2^{a}	0.46^{abc}
Faller	90.1^{bc}	121.1^{ab}	111.5^{a}	120.0^{abc}	91.2^{ab}	0.46^{abc}
Forefront	88.0^{cd}	111.6^{c}	109.1^{a}	115.0^{d}	90.1^{b}	0.48^{a}
Glenn	91.4^{ab}	122.1^{ab}	109.6^{a}	121.3^{ab}	92.2^{ab}	0.45^{c}
Mott	87.5^{d}	118.1^{b}	110.9^{a}	116.7^{cd}	91.2^{ab}	0.47^{ab}
Prosper	92.6^{a}	121.9^{ab}	112.3^{a}	119.8^{abc}	90.5^{b}	0.47^{abc}
SySoren	89.8^{bcd}	122.7^{ab}	111.4^{a}	118.6^{bcd}	91.0^{ab}	0.46^{abc}

Values with the same superscript letter are not significantly different (P>0.05). Least significant difference was used for mean separation. GPI: Gluten Performance Index

The SRC profile results for whole wheat flour grown in four different locations over two years were observed (Table 31). For the water SRC, the locations within 2014 were not significantly (P>0.05) different, and these results were lower than the values from 2013 with Carrington as the only exception (Table 31). The majority of the location samples had lower water holding capacities in 2013 compared to 2014, based on the water SRC results (Table 31). Therefore, change in protein content, arabinoxylan content, and/or damaged starch occurred from 2013 to 2014. The changes in flour composition between 2013 and 2014 may be the result of different seasonal conditions.

For sodium carbonate, Carrington was the only location with no significant (P>0.05) difference from 2013 to 2014 (Table 31). Therefore, the damaged starch content from the Carrington sample did not change between years, based on the sodium carbonate SRC results. For the sodium carbonate SRC results, the Carrington 2013 and the Hettinger 2014 samples were significantly (P<0.05) different from the other samples in the respective years (Table 31). This indicates that majority of the samples within a year had similar damaged starch contents. Since starch damage mainly occurs during the milling process, the milling conditions in 2013 may have been different in 2014, based on the sodium carbonate SRC results.

For lactic acid, sucrose, and ethanol, the respective locations from 2013 and 2014 were all significantly (P<0.05) different (Table 31). In 2014, all of the samples were significantly (P<0.05) different for the lactic acid SRC (Table 31). The bread loaf volumes of the 2014 samples are expected to be different based on the lactic acid SRC results. In 2013, the Dickinson and Hettinger samples were not significantly (P>0.05) different for the sucrose SRC (Table 31). In 2014, the Casselton and Dickinson samples were not significantly (P>0.05) different for the sucrose SRC (Table 31). The sucrose SRC results indicate that some samples were not affected by environmental conditions for arabinoxylan contents within a given year. In 2013, the ethanol SRC results were significantly (P<0.05) different between all four locations (Table 31). In 2014, however, the Carrington and Hettinger sample locations were the only ethanol SRC values significantly (P<0.05) different (Table 31). The ethanol SRC results display gliadin content differences between locations in 2013, which may be the result of environmental conditions.

The GPI values from 2014 appear to be lower than the values from 2013 except for the Carrington and Hettinger sample locations (Table 31). In 2013, the Casselton sample was significantly (P<0.05) different from the sample GPI values (Table 31). In 2014, all samples

locations display significantly (P<0.05) different GPI values (Table 31). The environmental conditions in 2013 had less effect on gluten performance as compared to 2014, based on GPI results. The environmental conditions from 2013 to 2014 must have been different since the SRC profiles were affected by the location and year interaction.

Table 31: Whole Wheat Flour Solvent Retention Capacity Profiles for Hard Red Spring Wheat Grown in Different Locations and Years

		Solvent					
Location	Year	Water (%)	Sodium Carbonate (%)	Lactic Acid (%)	Sucrose (%)	Ethanol (%)	GPI
Carrington	2013	84.17^{c}	111.53^{b}	96.81^{d}	109.22^{cd}	97.18^{b}	0.44^{d}
Casselton	2013	102.88^{a}	135.43^{a}	126.13^{a}	131.88^{b}	100.80^{a}	0.47^{c}
Dickinson	2013	99.38^{b}	139.13^{a}	121.99^{ab}	140.09^{a}	96.79^{bc}	0.44^{d}
Hettinger	2013	100.71^{ab}	134.95^{a}	123.12^{ab}	142.33^{a}	98.99^{ab}	0.44^{d}
Carrington	2014	85.04^{c}	114.35^{b}	115.57^{c}	111.80^{c}	94.41^{c}	0.51^{b}
Casselton	2014	82.86^{c}	111.21^{b}	95.45^{d}	107.33^{de}	71.95^{d}	0.44^{d}
Dickinson	2014	82.61^{c}	110.54^{b}	89.68^{e}	107.13^{de}	71.87^{d}	0.41^{e}
Hettinger	2014	83.49^{c}	104.70^{c}	118.99^{bc}	105.06^{e}	98.52^{ab}	0.57^{a}

Values with the same superscript letter are not significantly different (P>0.05). Least significant difference was used for mean separation. GPI: Gluten Performance Index

The whole wheat flour SRC profiles for different HRS wheat cultivars grown in two different years indicates that cultivars from the same crop year are significantly (P<0.05) different than the respective cultivars from a different crop year (Table 32). Therefore, the seasonal conditions and/or different genotypes may have contributed to the SRC results. In 2013, the Mott and Prosper cultivars were the only samples significantly (P<0.05) different for the water SRC (Table 32). In 2014, the Forefront, Glenn, and SySoren were the only cultivars significantly (P<0.05) different for the water SRC (Table 32). The water holding capacities of the different cultivars did not differ between majority of the samples in 2013 and 2014, based on

the water SRC results. Therefore, genotypes within a given year did not affect water holding capacity of flour.

For the sodium carbonate SRC, the results in 2013 were different than the results in 2014 (Table 32). The Forefront and Mott cultivars were the only 2013 samples with significantly (P<0.05) different sodium carbonate SRC values (Table 32). In 2014, Faller, Forefront, Prosper, and SySoren cultivars had significantly (P<0.05) different sodium carbonate SRC values (Table 32). Differences in genotypes or milling conditions between 2013 and 2014 may be the cause of the sodium carbonate SRC results, since these factors can affect damaged starch content.

For the lactic acid SRC, the cultivars from 2013 and 2014 are not significantly (P>0.05) different, respectively (Table 32). Therefore, the samples within the same year have similar glutenin contents. The samples with 2013 and 2014, respectively, are expected to have similar bread loaf volumes based on the lactic acid SRC results. The ethanol SRC results for the cultivars from 2013 are not significantly (P>0.05) different, which means these cultivars have similar gliadin contents (Table 32). In 2014, the only cultivar with a significantly (P<0.05) different ethanol SRC value was Elgin (Table 32). Therefore, the ethanol SRC results were not strongly affected by the cultivar x year interaction.

Overall the SRC profiles of the different cultivars from 2014 appear to be lower than the SRC profiles from 2013 (Table 32). The flour compositions from 2013 to 2014 must have changed based on the SRC profile differences, which was probably a result of different genotypes or seasonal conditions. The trend for GPI values appears to be the opposite of the SRC results, because overall there is an increase in GPI values from 2013 to 2014 (Table 32). The gluten performance for these specific cultivars increased, which may have also resulted from flour composition differences between years. Since majority of the cultivars within a given year

produced similar SRC results, genotype does not affect SRC data as much as year does. The genotypes may have changed between 2013 and 2014 for these eight cultivars, or the different environmental conditions from 2013 to 2014 had a strong effect on SRC results.

Table 32: Whole Wheat Flour Solvent Retention Capacity Profiles for Different Hard Red Spring Wheat Cultivars Grown in Two Years

		Solvent					
Cultivar	Year	Water (%)	Sodium Carbonate (%)	Lactic Acid (%)	Sucrose (%)	Ethanol (%)	GPI
Barlow	2013	98.4^{ab}	135.7^{a}	118.3^{a}	132.6^{ab}	98.6^{a}	0.44^{c}
Elgin	2013	95.9^{bc}	129.5^{ab}	116.0^{a}	131.2^{ab}	99.1^{a}	0.45^{c}
Faller	2013	98.6^{ab}	136.6^{a}	119.2^{a}	134.4^{a}	96.8^{a}	0.44^{c}
Forefront	2013	95.1^{bc}	119.3^{cd}	114.9^{a}	125.9^{c}	98.0^{a}	0.47^{abc}
Glenn	2013	97.1^{ab}	130.2^{ab}	117.2^{a}	132.4^{ab}	99.7^{a}	0.45^{c}
Mott	2013	93.2^{c}	126.6^{bc}	116.1^{a}	128.3^{bc}	97.6^{a}	0.46^{bc}
Prosper	2013	100.1^{a}	132.2^{ab}	118.8^{a}	133.5^{ab}	98.2^{a}	0.45^{c}
SySoren	2013	95.8^{bc}	131.8^{ab}	115.5^{a}	128.7^{bc}	99.4^{a}	0.44^{c}
Barlow	2014	84.7^{de}	114.0^{de}	105.5^{b}	108.9^{ef}	83.2^{c}	0.47^{abc}
Elgin	2014	84.4^{de}	109.4^{efg}	105.7^{b}	114.3^{d}	87.3^{b}	0.47^{abc}
Faller	2014	81.7^{ef}	105.6^{fg}	103.9^{b}	105.6^{ef}	85.6^{bc}	0.49^{a}
Forefront	2014	80.8^{f}	103.9^{g}	103.3^{b}	104.1^{f}	82.2^{c}	0.50^{a}
Glenn	2014	85.7^{d}	114.0^{de}	102.0^{b}	110.1^{de}	84.7^{bc}	0.46^{bc}
Mott	2014	81.7^{ef}	109.6^{efg}	105.7^{b}	105.0^{ef}	84.9^{bc}	0.49^{a}
Prosper	2014	85.1^{de}	111.5^{defg}	105.9^{b}	106.2^{ef}	82.9^{c}	0.49^{ab}
SySoren	2014	83.8^{def}	113.6^{def}	107.2^{b}	108.5^{ef}	82.5^{c}	0.48^{ab}

Values with the same superscript letter are not significantly different (P>0.05). Least significant difference was used for mean separation. GPI: Gluten Performance Index

Refined and Whole Wheat Flour Correlations

Phenotype, genotype, and environmental factors were taken into account when determining correlations between refined and whole wheat flour SRC profiles. All three factors did have an effect on correlations between refined and whole wheat flours (Tables 33-35). Phenotype appears to have the greatest effect on SRC correlations since most of the results were

significant (P<0.0001) between flour types (Table 33). Even though the phenotype results displayed more correlations between flour types in comparison to genotype and environment, the majority of the genotype and environmental correlation coefficients were greater (Tables 34 and 35). Therefore, genotype and environmental factors had the greatest effect on SRC correlations between refined flour and whole wheat flour. Since the different environmental locations were already taken into an account with the correlations for genotype, the genotype factor, therefore, had the greatest effect on correlations between refined and whole wheat four SRC profiles.

Table 33: Correlations for Phenotype between Refined and Whole Wheat Flours for Solvent Retention Capacity

		Refined Flour					
		Water	Sodium Carbonate	Lactic Acid	Sucrose	Ethanol	GPI
Whole Wheat Flour	Water	0.895***	0.839***	0.602***	0.892***	0.680***	-0.485***
	Sodium Carbonate	0.890***	0.777***	0.554***	0.890***	0.657***	-0.509***
	Lactic Acid	0.635***	0.748***	0.788***	0.652***	0.612***	-0.049^{NS}
	Sucrose	0.864***	0.792***	0.642***	0.937***	0.669***	-0.450***
	Ethanol	0.479***	0.486***	0.640***	0.447***	0.683***	0.100^{NS}
	GPI	-0.243^{NS}	0.009^{NS}	0.291*	-0.256*	-0.038^{NS}	0.515***

***P<0.0001, ***P<0.001, *P<0.05, NS: Non Significant, GPI: Gluten Performance Index

The refined flour water SRC was significantly (P<0.05) correlated with the whole wheat water SRC (Table 34). The refined flour water SRC was significantly (P<0.05) correlated with the whole wheat flour sodium carbonate SRC, lactic acid SRC, sucrose SRC, and GPI value, but the correlation coefficient values were lower than the water SRC value (Table 34). This correlation indicates that the water SRC solvent can be used for both refined and whole wheat flours to predict the overall water holding capacity. Ram et al (2005) conducted a study using SRC to evaluate whole wheat and refined flours using Indian wheat varieties, and found a

significant positive correlation between whole wheat and refined flours for the water SRC solvent.

The refined flour and whole wheat flour were not significantly (P>0.05) correlated between the sodium carbonate SRC values (Table 34). The refined flour sodium carbonate SRC had a significant (P<0.0001) correlation with the whole wheat flour sucrose SRC (Table 34). However, the refined flour sucrose SRC was significantly (P<0.0001) correlated with the whole wheat flour sucrose SRC (Table 34). The different whole wheat flour composition may be causing the correlation between sodium carbonate and sucrose SRC solvents. Ram et al (2005), Guttieri and Souza (2003), and Bettge et al (2002) found significant correlations between sodium carbonate and sucrose SRC solvents for whole wheat and refined flours. Whole wheat flour typically has a higher arabinoxylan content due to the bran present in the flour. Therefore, the increase in arabinoxylan content may be producing a water holding capacity similar to the water holding capacity generated by damaged and pregelatinized starches found in refined flour.

The refined flour sucrose SRC value was significantly (P<0.05) correlated with whole wheat flour water SRC, sodium carbonate SRC, sucrose SRC and GPI values (Table 34). The refined flour sucrose SRC and the whole wheat flour sodium carbonate SRC had the greatest correlation coefficient (r=0.803) (Table 34). The different arabinoxylan contents of refined and whole wheat flours did have an effect on sucrose SRC and sodium carbonate SRC correlations, like the refined flour sodium carbonate SRC correlation with whole wheat flour sucrose SRC. The sucrose and sodium carbonate solvents may produce similar results for whole wheat flour based on the correlations with refined flour. The changes in arabinoxylan and damaged starch contents are mostly likely the cause of these correlations. The sodium carbonate and sucrose SRC solvents may not be appropriate for whole wheat flour based on these results.

The lactic acid SRC values for refined and whole wheat flours were significantly (P<0.001) correlated (Table 34). The gluten network and strength does not dramatically change between refined and whole what flours, so this correlation is expected. The GPI values between refined and whole wheat flours were not significantly (P>0.05) correlated (Table 34). The flour composition does change between refined and whole wheat flours, which results in a total protein content, damaged starch, and arabinoxylan content that may be interfering with the flour's gluten performance.

The ethanol solvent for refined flour and whole wheat flour were not significantly (P>0.05) correlated with any of the solvent (Table 34). The lack of correlations between the refined flour ethanol SRC and the whole wheat flour ethanol SRC indicates that the ethanol solvent is not best suited for measuring the end-product quality of whole wheat flour. The refined flour and whole wheat flour GPI values were not significantly (P>0.05) correlated (Table 34). The whole wheat flour GPI value was significantly (P<0.05) correlated with refined flour water SRC, sodium carbonate SRC, and sucrose SRC (Table 34). The GPI value for refined flour was significantly (P<0.05 and P<0.001) correlated with whole wheat sodium carbonate SRC and lactic acid SRC (Table 34). The GPI value is determined by the lactic acid, sodium carbonate and sucrose SRC values, which explains why these correlations were found.

Table 34: Correlations for Genotype between Refined and Whole Wheat Flours for Solvent Retention Capacity

		Refined Flour					
		Water	Sodium Carbonate	Lactic Acid	Sucrose	Ethanol	GPI
Whole Wheat Flour	Water	0.812*	0.840**	0.360^{NS}	0.788*	-0.215^{NS}	-0.642^{NS}
	Sodium Carbonate	0.716*	0.592^{NS}	0.073^{NS}	0.803*	-0.118^{NS}	-0.773*
	Lactic Acid	0.453*	0.398^{NS}	-0.392^{NS}	0.510^{NS}	-0.003^{NS}	-0.844**
	Sucrose	0.777*	0.928***	0.405^{NS}	0.743*	0.029^{NS}	-0.652^{NS}
	Ethanol	0.340^{NS}	0.581^{NS}	0.334^{NS}	0.279^{NS}	0.305^{NS}	-0.262^{NS}
	GPI	-0.739*	-0.740*	-0.476^{NS}	-0.759*	0.081^{NS}	0.511^{NS}

***P<0.0001, ***P<0.001, *P<0.05, NS: Non Significant, GPI: Gluten Performance Index

Table 35: Correlations for Environment between Refined and Whole Wheat Flours for Solvent Retention Capacity

		Refined Flour					
		Water	Sodium Carbonate	Lactic Acid	Sucrose	Ethanol	GPI
Whole Wheat Flour	Water	0.991***	0.965***	0.641^{NS}	0.925**	0.737*	-0.543^{NS}
	Sodium Carbonate	0.983***	0.908**	0.621^{NS}	0.944***	0.745*	-0.561^{NS}
	Lactic Acid	0.751*	0.867**	0.872**	0.706^{NS}	0.660^{NS}	-0.020^{NS}
	Sucrose	0.963***	0.901**	0.678^{NS}	0.991***	0.726*	-0.514^{NS}
	Ethanol	0.569^{NS}	0.602^{NS}	0.712*	0.497^{NS}	0.735*	0.122^{NS}
	GPI	-0.197^{NS}	0.041^{NS}	0.377^{NS}	-0.235^{NS}	-0.040^{NS}	0.641^{NS}

***P<0.0001, ***P<0.001, *P<0.05, NS: Non Significant, GPI: Gluten Performance Index

Relationship between Solvent Retention Capacity and Flour Quality

Correlations for Phenotype

The refined flour correlations for phenotype effects with SRC, flour composition, dough quality and baking quality results were observed (Table 36). The correlation coefficients between the SRC and other flour quality parameter results were fairly low, and some of the results were unexpected (Table 36). The water solvent was significantly (P<0.05 and P<0.001) correlated

with total protein, total starch, and arabinoxylan contents for refined flour composition (Table 36). Protein, starch, and arabinoxylans absorb and retain water during dough mixing. However, ash, gluten, and damaged starch absorb or retain water as well, but these flour parameters were not significantly (P>0.05) correlated with water SRC for refined flour (Table 36).

The Farinograph and baking absorptions were not significantly (P>0.05) correlated with the water SRC solvent for refined flour (Table 36). The water SRC is related to the baking absorption, since this value measures the water holding capacity of flour. Hammed et al (2015) found significant correlations between the water SRC and water absorption for Farinograph and baking with refined HRS wheat flour. The different phenotypes of HRS wheat do not strongly affect water SRC correlations with other refined flour quality parameters based on the observed data (Table 36).

The sodium carbonate SRC solvent is associated with damaged starch. Total starch composition of refined flour was significantly (P<0.05) correlated to sodium carbonate SRC (Table 36). However, the RVA pasting viscosity, breakdown, and final viscosity were significantly (P<0.0001 and P<0.05) correlated with sodium carbonate SRC (Table 36). Positive correlations between RVA parameters and sodium carbonate SRC were expected since both measures are determined by starch content and quality. The sucrose SRC solvent was significantly (P<0.0001) correlated with RVA parameters as well (Table 36). The sucrose SRC solvent is associated with soluble arabinoxylans in flour, not total starch. The arabinoxylan content of refined flour was significantly (P<0.05) correlated with sucrose SRC (Table 36). Arabinoxylans are located in the cell wall of cereal grains, and they have been found to affect starch gelatinization and pasting profiles (Arif et al, 2014). Arabinoxylans typically increase

peak viscosity for HRS wheat flour (Arif et al, 2014). This may explain the correlations between sucrose SRC and RVA parameters.

The lactic acid SRC is associated with gluten proteins, specifically glutenin. The lactic acid SRC for refined flour was not significantly (P>0.05) correlated with total protein, wet gluten, or gluten index for phenotype effects (Table 36). For baking quality, the lactic acid SRC was not significantly (P>0.05) correlated with loaf volume or specific volume (Table 36). The lactic acid SRC has been used to indicate loaf volume quality during baking (Kweon et al, 2011). The phenotype effects of refined flour did not have an effect on lactic acid SRC and flour quality parameters.

The Farinograph peak time and stability both were significantly (P<0.001 and P<0.05, respectively) correlated with lactic acid SRC (Table 36). The Farinograph peak time and stability parameters are indications of gluten strength and development. Therefore, correlations between Farinograph parameters and lactic acid SRC is a result of gluten proteins. Gliadin proteins are found in the gluten network and are associated with the ethanol SRC solvent. The ethanol solvent was significantly (P<0.0001 and P<0.001) correlated with total protein and wet gluten content, respectively (Table 36). The ethanol solvent was significantly (P<0.05) correlated with Farinograph peak time and specific loaf volume (Table 36). Since gliadin proteins are important components of the gluten network, the ethanol solvent should have a correlation with gluten development and bread loaf quality parameters. One would also expect the GPI to be correlated with total protein, wet gluten/gluten index, Farinograph parameters, or loaf volume. However, those correlations were not found for refined flour. The refined flour phenotypes did not have a strong impact on flour composition and end product quality based on the correlation results.

Table 36: Correlations for Phenotype between Solvent Retention Capacity and Flour Quality Parameters for Refined Flour

		Solvent Retention Capacity Solvents											
		Water		Sodium Carbonate		Lactic Acid		Sucrose		Ethanol		GPI	
Flour Composition	Ash	-0.084	NS	-0.023	NS	-0.068	NS	-0.038	NS	-0.172	NS	-0.030	NS
	Total Protein	0.274	*	0.084	NS	0.178	NS	0.310	*	0.428	***	-0.075	NS
	Gluten Index	0.074	NS	0.140	NS	0.174	NS	-0.053	NS	-0.176	NS	0.142	NS
	Wet Gluten	0.119	NS	-0.055	NS	0.112	NS	0.164	NS	0.378	**	0.036	NS
	Total Starch	0.262	*	0.266	*	0.178	NS	0.294	*	-0.051	NS	-0.113	NS
	Starch Damage	0.029	NS	-0.062	NS	-0.120	NS	-0.099	NS	-0.168	NS	-0.010	NS
	Arabinoxylans	-0.345	**	-0.414	***	-0.342	**	-0.285	*	-0.246	*	0.077	NS
	Arabinose/Xylose Ratio	0.105	NS	0.103	NS	0.114	NS	0.119	NS	0.173	NS	-0.004	NS
Pasting Profile	Peak Viscosity	0.478	***	0.450	***	0.345	**	0.524	***	0.479	***	-0.267	*
	Breakdown	0.582	***	0.485	***	0.332	**	0.574	***	0.335	**	-0.320	**
	Final Viscosity	0.277	*	0.315	*	0.219	NS	0.386	**	0.511	***	-0.236	NS
	Setback	0.253	*	0.318	*	0.165	NS	0.376	**	0.380	**	-0.281	*
	Peak Time	-0.045	NS	0.004	NS	0.155	NS	-0.028	NS	0.181	NS	0.160	NS
Farinograph	Absorption	-0.132	NS	-0.160	NS	-0.166	NS	-0.111	NS	0.103	NS	-0.005	NS
	Peak Time	0.262	*	0.286	*	0.347	**	0.325	**	0.316	*	-0.018	NS
	Stability	0.107	NS	0.089	NS	0.247	*	0.134	NS	0.180	NS	0.134	NS
Bread Quality	Absorption	-0.025	NS	-0.128	NS	0.111	NS	-0.132	NS	0.095	NS	0.261	*
	Loaf Volume	0.064	NS	-0.102	NS	0.183	NS	0.140	NS	-0.198	NS	0.181	NS
	Specific Volume	0.019	NS	-0.121	NS	0.110	NS	0.116	NS	-0.305	*	0.136	NS
	Symmetry	-0.243	NS	-0.138	NS	0.033	NS	-0.162	NS	-0.166	NS	0.251	*
	Crust Color	-0.151	NS	-0.004	NS	-0.048	NS	-0.063	NS	-0.102	NS	0.011	NS
	Crumb Grain	-0.244	NS	-0.163	NS	-0.036	NS	-0.142	NS	-0.093	NS	0.175	NS
	Crumb Color	0.319	*	0.103	NS	0.257	*	0.326	**	0.339	**	-0.008	NS
	Firmness	0.118	NS	0.196	NS	-0.205	NS	0.138	NS	0.231	NS	-0.440	***

***P<0.0001, ***P<0.001, *P<0.05, NS= Non Significant, GPI= Gluten Performance Index

There were some correlations between SRC and flour quality parameters for whole wheat flour phenotype effects, but the correlations are weak based on correlation coefficient values. The water SRC was significantly ($P<0.001$ and $P<0.05$) correlated with ash content, total protein content, and damaged starch content of whole wheat flour (Table 37). These correlations with water SRC are expected since protein and damaged starch contribute to the water SRC value. The baking absorption was significantly ($P<0.0001$ and $P<0.05$) correlated with water, sodium carbonate, lactic acid, sucrose, ethanol and the GPI SRC values for whole wheat flour (Table 37). These correlations were expected since water SRC is directly related to baking absorption, and sodium carbonate, lactic acid, ethanol, and sucrose SRC solvents are associated with water retaining compounds.

The sodium carbonate SRC solvent was significantly ($P<0.05$) correlated with the Farinograph water absorption for whole wheat flour (Table 37). Damaged starch contains water holding properties that contribute to water absorption during dough mixing. Therefore, sodium carbonate SRC should have a strong relationship with Farinograph water absorption. Sodium carbonate SRC was significantly ($P<0.001$) correlated with the RVA peak viscosity and breakdown parameters (Table 37). Since sodium carbonate solvent is related to starch quality, correlations between sodium carbonate SRC and RVA parameters is a results of flour starch content.

The sucrose SRC was significantly ($P<0.0001$) correlated with the RVA peak viscosity and breakdown parameters, which are a result of arabinoxylans interfering with starch gelatinization (Table 37). The correlation between sucrose SRC and arabinoxylans was not significant ($P>0.05$) (Table 37). This result may be due to differences in arabinoxylan contents for the different whole wheat samples. The method for determining arabinoxylan content is

related to insoluble arabinoxylans, which could affect the correlation between sucrose SRC and arabinoxlyans as well. The ethanol solvent was significantly (P<0.001) correlated with total protein and wet gluten flour contents (Table 37). The Farinograph peak time and stability was also significantly (P<0.001) correlated with the ethanol solvent (Table 37). These results were expected for ethanol SRC solvent and flour quality, since ethanol is associated with gluten proteins, which impact end-product quality. Overall the correlations between whole wheat flour SRC and flour quality parameters were not strongly affected by phenotypes.

Table 37: Correlations for Phenotype between Solvent Retention Capacity and Flour Quality Parameters for Whole Wheat Flour

		Solvent Retention Capacity Solvents											
		Water		Sodium Carbonate		Lactic Acid		Sucrose		Ethanol		GPI	
Flour Composition	Ash	-0.350	**	-0.336	**	-0.206	NS	-0.367	**	-0.213	NS	0.148	NS
	Total Protein	0.292	*	0.304	*	0.146	NS	0.355	**	0.384	**	-0.200	NS
	Gluten Index	0.328	**	0.242	NS	0.127	NS	0.331	**	0.243	NS	-0.186	NS
	Wet Gluten	0.156	NS	0.201	NS	0.155	NS	0.185	NS	0.345	**	-0.019	NS
	Total Starch	0.146	NS	0.198	NS	0.256	*	0.135	NS	0.054	NS	0.079	NS
	Starch Damage	0.277	*	0.246	NS	0.299	*	0.294	*	0.202	NS	0.050	NS
	Arabinoxylans	-0.218	NS	-0.156	NS	-0.453	***	-0.124	NS	-0.340	**	-0.407	***
	Arabinose/Xylose Ratio	0.161	NS	0.174	NS	0.038	NS	0.114	NS	0.075	NS	-0.113	NS
Pasting Profile	Peak Viscosity	0.423	***	0.327	**	0.419	***	0.468	***	0.400	**	0.057	NS
	Breakdown	0.453	***	0.344	**	0.348	**	0.460	***	0.328	**	-0.039	NS
	Final Viscosity	0.204	NS	0.138	NS	0.303	*	0.293	*	0.292	*	0.126	NS
	Setback	0.031	NS	-0.024	NS	0.153	NS	0.139	NS	0.148	NS	0.122	NS
	Peak Time	0.115	NS	0.043	NS	0.220	NS	0.182	NS	0.224	NS	0.149	NS
Farinograph	Absorption	0.108	NS	0.252	*	0.040	NS	0.158	NS	0.201	NS	-0.183	NS
	Peak Time	0.231	NS	0.246	NS	0.022	NS	0.292	*	0.350	**	-0.287	*
	Stability	0.074	NS	0.013	NS	-0.056	NS	0.127	NS	0.345	**	-0.154	NS
Bread Quality	Absorption	-0.564	***	-0.583	***	-0.304	*	-0.563	***	-0.281	*	0.312	*
	Loaf Volume	0.217	NS	0.254	*	0.185	NS	0.261	*	0.058	NS	-0.050	NS
	Specific Volume	0.195	NS	0.212	NS	0.120	NS	0.234	NS	-0.038	NS	-0.091	NS
	Symmetry	0.045	NS	0.024	NS	0.209	NS	0.070	NS	0.289	*	0.216	NS
	Crust Color	0.036	NS	-0.029	NS	0.085	NS	0.040	NS	0.113	NS	0.093	NS
	Crumb Grain	0.187	NS	0.129	NS	0.144	NS	0.209	NS	0.174	NS	-0.024	NS
	Crumb Color	0.202	NS	0.204	NS	0.088	NS	0.191	NS	0.063	NS	-0.135	NS
	Firmness	-0.191	NS	-0.206	NS	-0.067	NS	-0.148	NS	-0.047	NS	0.108	NS

***P<0.0001, ***P<0.001, *P<0.05, NS= Non Significant, GPI= Gluten Performance Index

Correlations for Genotype

Genotype had little effect on correlations between refined flour SRC and flour quality parameters (Table 38). The correlation coefficients for refined flour SRC and flour quality parameters were greater than the correlation coefficients for phenotype. Therefore, genotype has a greater effect on refined flour quality and SRC than phenotype. The water SRC was significantly (P<0.001) correlated with damaged starch (Table 38). Damaged starch contains water retention properties, which contribute to the water SRC value. The water SRC was significantly (P<0.05) correlated with the Farinograph absorption (Table 38). The water SRC should have a strong correlation with Farinograph and baking absorptions, since these values are all affected by the water holding capacity of flour components. Along with damaged starch, arabinoxylans are another flour component that retains water during dough mixing. Therefore, the significant (P<0.05) correlation between sucrose SRC and Farinograph absorption is expected (Table 38).

The lactic acid SRC was significantly (P<0.05) correlated with the gluten index value (Table 38). The lactic acid SRC value and the gluten index value are both indications of gluten strength in a given flour sample. The lactic acid SRC value was not significantly (P>0.05) correlated with bread loaf volume with genotype effects (Table 38). A strong correlation between the lactic acid SRC and bread loaf volume for refined HRS wheat flour is expected, since this correlation has been observed in other research (Hammed et al, 2015). However, these other research studies did not look at correlations for genotypes of HRS wheat flour. The GPI value did not correlate with any flour quality parameters (Table 38). Overall, genotype did not have a strong effect on HRS wheat refined flour SRC and flour quality parameters.

Table 38: Correlations for Genotype between Solvent Retention Capacity and Flour Quality Parameters for Refined Flour

		Solvent Retention Capacity Solvents											
		Water		Sodium Carbonate		Lactic Acid		Sucrose		Ethanol		GPI	
Flour Composition	Ash	0.111	NS	0.131	NS	-0.411	NS	0.281	NS	0.079	NS	-0.607	NS
	Total Protein	-0.338	NS	-0.501	NS	0.079	NS	-0.323	NS	-0.267	NS	0.481	NS
	Gluten Index	0.695	NS	0.752	*	0.763	*	0.608	NS	-0.184	NS	-0.092	NS
	Wet Gluten	-0.419	NS	-0.644	NS	-0.178	NS	-0.362	NS	-0.214	NS	0.374	NS
	Total Starch	0.615	NS	0.411	NS	0.316	NS	0.646	NS	0.054	NS	-0.275	NS
	Starch Damage	0.872	**	0.579	NS	0.561	NS	0.909	**	-0.363	NS	-0.317	NS
	Arabinoxylans	-0.550	NS	-0.243	NS	-0.500	NS	-0.438	NS	0.401	NS	-0.127	NS
	Arabinose/Xylose Ratio	-0.143	NS	0.252	NS	-0.099	NS	-0.107	NS	0.844	**	-0.187	NS
Pasting Profile	Peak Viscosity	0.370	NS	0.682	NS	0.383	NS	0.337	NS	0.427	NS	-0.246	NS
	Breakdown	0.719	*	0.713	*	0.686	NS	0.699	NS	-0.013	NS	-0.191	NS
	Final Viscosity	-0.284	NS	0.290	NS	-0.309	NS	-0.293	NS	0.851	**	-0.276	NS
	Setback	-0.402	NS	0.188	NS	-0.578	NS	-0.371	NS	0.741	*	-0.418	NS
	Peak Time	-0.155	NS	0.425	NS	0.072	NS	-0.230	NS	0.671	NS	-0.077	NS
Farinograph	Absorption	0.816	*	0.530	NS	0.614	NS	0.804	*	-0.600	NS	-0.262	NS
	Peak Time	-0.252	NS	-0.242	NS	0.410	NS	-0.322	NS	-0.270	NS	0.624	NS
	Stability	0.028	NS	0.333	NS	0.577	NS	-0.023	NS	0.270	NS	0.276	NS
Bread Quality	Absorption	0.597	NS	0.462	NS	0.475	NS	0.529	NS	-0.408	NS	-0.221	NS
	Loaf Volume	0.449	NS	0.155	NS	0.594	NS	0.508	NS	-0.593	NS	0.113	NS
	Specific Volume	0.406	NS	0.032	NS	0.554	NS	0.491	NS	-0.629	NS	0.176	NS
	Symmetry	-0.730	*	-0.485	NS	-0.584	NS	-0.737	*	0.629	NS	0.213	NS
	Crust Color	-0.688	NS	-0.318	NS	-0.510	NS	-0.775	*	0.460	NS	0.209	NS
	Crumb Grain	-0.634	NS	-0.385	NS	-0.374	NS	-0.598	NS	0.750	*	0.238	NS
	Crumb Color	0.444	NS	0.062	NS	0.312	NS	0.519	NS	-0.365	NS	0.027	NS
	Firmness	-0.548	NS	-0.210	NS	-0.636	NS	-0.415	NS	0.761	*	-0.182	NS

***P<0.0001, ***P<0.001, *P<0.05, NS= Non Significant, GPI= Gluten Performance Index

The results for genotype effects on whole wheat flour correlations between SRC and flour quality are similar to the results for refined flour (Table 39). The water and sodium carbonate SRC values were significantly (P<0.05) correlated with damaged starch and Farinograph absorption, respectively (Table 39). The water SRC was significantly (P<0.001) correlated with bread loaf volume and specific volume (Table 39). Proteins in flour contribute to water absorption during baking along with damaged starch and arabinoxylans. Gluten proteins need water and force to develop a network in flour and cause changes in dough during fermentation and baking. The correlation between water and loaf/specific volume is most likely caused by the gluten proteins in the flour samples, which absorbs water during dough development.

The lactic acid SRC was significantly (P<0.05) correlated with the Farinograph stability (Table 39). A correlation between lactic acid SRC and Farinograph stability results from the association between these two parameters and gluten proteins. The lactic acid SRC is associated with gluten proteins and is used to predict the gluten quality in a flour sample. The Farinograph stability is used to predict the strength and quality of gluten in a flour sample as well. The lactic acid SRC was significantly (P<0.001) correlated with the baking absorption (Table 39). As previously mentioned, gluten proteins contribute to baking absorption during dough development; therefore, the correlation between lactic acid SRC and baking absorption was caused by gluten proteins. The lactic acid SRC was not significantly (P>0.05) correlated with baked loaf volume (Table 39). The lactic acid SRC solvent, many not be an appropriate parameter for determining whole wheat bread loaf volume based on these results. The flour composition of whole wheat flour may be interfering with the interaction between lactic acid solvent and glutenin producing these results.

The GPI value was significantly (P<0.001) correlated with the Farinograph absorption (Table 39). The GPI value is determined by the lactic acid, sucrose, and sodium carbonate SRC values. Lactic acid, sucrose, and sodium carbonate SRC solvents are all associated with flour components that contribute to water absorption, which may explain the correlation between GPI and Farinograph absorption. Overall, genotype of whole wheat flour had little effect on correlations between SRC and flour quality parameters.

Table 39: Correlations for Genotype between Solvent Retention Capacity and Flour Quality Parameters for Whole Wheat Flour

		Solvent Retention Capacity Solvents											
		Water		Sodium Carbonate		Lactic Acid		Sucrose		Ethanol		GPI	
Flour Composition	Ash	-0.382	NS	0.276	NS	-0.024	NS	0.071	NS	0.408	NS	-0.294	NS
	Total Protein	-0.367	NS	-0.104	NS	-0.546	NS	-0.334	NS	-0.072	NS	-0.055	NS
	Gluten Index	0.277	NS	-0.102	NS	-0.296	NS	0.573	NS	0.652	NS	-0.363	NS
	Wet Gluten	-0.376	NS	-0.014	NS	-0.355	NS	-0.478	NS	-0.298	NS	0.049	NS
	Total Starch	0.102	NS	0.101	NS	0.466	NS	-0.112	NS	-0.436	NS	0.258	NS
	Starch Damage	0.769	*	0.477	NS	0.361	NS	0.557	NS	0.141	NS	-0.480	NS
	Arabinoxylans	-0.475	NS	-0.137	NS	-0.435	NS	0.077	NS	0.539	NS	-0.178	NS
	Arabinose/Xylose Ratio	0.679	NS	0.735	*	0.716	*	0.716	*	0.347	NS	-0.588	NS
Pasting Profile	Peak Viscosity	0.318	NS	-0.122	NS	-0.082	NS	0.227	NS	0.140	NS	-0.043	NS
	Breakdown	0.536	NS	0.066	NS	-0.136	NS	0.467	NS	0.319	NS	-0.356	NS
	Final Viscosity	-0.104	NS	-0.314	NS	-0.024	NS	-0.177	NS	-0.130	NS	0.354	NS
	Setback	-0.255	NS	-0.348	NS	-0.044	NS	-0.305	NS	-0.194	NS	0.434	NS
	Peak Time	0.272	NS	-0.107	NS	-0.148	NS	0.370	NS	0.395	NS	-0.167	NS
Farinograph	Absorption	0.577	NS	0.743	*	0.190	NS	0.649	NS	0.362	NS	-0.846	**
	Peak Time	0.247	NS	0.049	NS	-0.554	NS	0.387	NS	0.455	NS	-0.548	NS
	Stability	-0.415	NS	-0.494	NS	-0.807	*	-0.270	NS	0.135	NS	0.095	NS
Bread Quality	Absorption	-0.351	NS	-0.533	NS	-0.910	**	-0.364	NS	-0.049	NS	0.125	NS
	Loaf Volume	0.891	**	0.522	NS	0.272	NS	0.493	NS	-0.108	NS	-0.522	NS
	Specific Volume	0.895	**	0.439	NS	0.289	NS	0.448	NS	-0.154	NS	-0.422	NS
	Symmetry	0.725	*	0.255	NS	-0.081	NS	0.497	NS	0.169	NS	-0.512	NS
	Crust Color	-0.620	NS	-0.423	NS	-0.275	NS	-0.296	NS	-0.063	NS	0.374	NS
	Crumb Grain	0.419	NS	0.276	NS	0.167	NS	0.366	NS	0.202	NS	-0.312	NS
	Crumb Color	0.302	NS	-0.074	NS	-0.129	NS	0.149	NS	-0.095	NS	-0.068	NS
	Firmness	-0.906	**	-0.680	NS	-0.334	NS	-0.727	*	-0.195	NS	0.740	*

***P<0.0001, ***P<0.001, *P<0.05, NS= Non Significant, GPI= Gluten Performance Index

Correlations for Environment

Environmental factors had little effect on correlations between SRC and flour quality parameters for refined flour. The correlation coefficients, however, are similar to those from the correlations for genotype refined flour (Tables 38 and 40). The water SRC was significantly (P<0.05) correlated with the RVA breakdown parameter (Table 40). The RVA breakdown parameter represents swollen starch granules collapsing during gelatinization. Gelatinized starch does absorb water, which may have caused the correlation between water SRC and RVA. The water, sodium carbonate, sucrose, lactic acid, and ethanol SRC solvents were not significantly (P>0.05) correlated with flour composition (Table 40). The environmental conditions had no effect on refined flour composition correlations with any of the SRC solvents (Table 40).

Sodium carbonate SRC and lactic acid SRC were not significantly (P>0.05) correlated with any flour quality parameters for refined flour when considering the environment (Table 40). The sucrose SRC solvent was significantly (P<0.05) correlated with the RVA peak viscosity, breakdown, and setback parameters (Table 40). Arabinoxylans have an effect on starch gelatinization, which may explain the correlation between sucrose and RVA values. Ethanol SRC and GPI values were significantly (P<0.05) correlated with the crumb color and firmness of bread, respectively (Table 40). These correlations seem unrelated since gluten proteins do not have a strong effect on crumb color and firmness, like loaf volume. The environmental conditions of the refined HRS wheat flour did not strongly affect correlations between SRC and flour quality parameters.

Table 40: Correlations for Environment between Solvent Retention Capacity and Flour Quality Parameters for Refined Flour

		Solvent Retention Capacity Solvents											
		Water		Sodium Carbonate		Lactic Acid		Sucrose		Ethanol		GPI	
Flour Composition	Ash	-0.209	NS	-0.006	NS	-0.088	NS	-0.091	NS	-0.381	NS	-0.010	NS
	Total Protein	0.472	NS	0.304	NS	0.163	NS	0.477	NS	0.572	NS	-0.362	NS
	Gluten Index	-0.399	NS	-0.281	NS	0.137	NS	-0.394	NS	-0.373	NS	0.688	NS
	Wet Gluten	0.305	NS	0.167	NS	0.134	NS	0.307	NS	0.556	NS	-0.203	NS
	Total Starch	0.423	NS	0.352	NS	0.484	NS	0.443	NS	0.319	NS	0.002	NS
	Starch Damage	-0.440	NS	-0.310	NS	-0.387	NS	-0.481	NS	-0.253	NS	0.139	NS
	Arabinoxylans	-0.515	NS	-0.616	NS	-0.548	NS	-0.445	NS	-0.611	NS	0.061	NS
	Arabinose/Xylose Ratio	0.400	NS	0.298	NS	0.405	NS	0.361	NS	0.552	NS	0.075	NS
Pasting Profile	Peak Viscosity	0.608	NS	0.570	NS	0.429	NS	0.718	*	0.683	NS	-0.392	NS
	Breakdown	0.721	*	0.672	NS	0.377	NS	0.806	*	0.613	NS	-0.560	NS
	Final Viscosity	0.500	NS	0.451	NS	0.354	NS	0.609	NS	0.652	NS	-0.337	NS
	Setback	0.662	NS	0.627	NS	0.392	NS	0.788	*	0.650	NS	-0.534	NS
	Peak Time	-0.095	NS	-0.096	NS	0.244	NS	0.025	NS	0.260	NS	0.308	NS
Farinograph	Absorption	0.222	NS	0.116	NS	0.227	NS	0.162	NS	0.651	NS	0.043	NS
	Peak Time	0.533	NS	0.479	NS	0.435	NS	0.552	NS	0.554	NS	-0.191	NS
	Stability	0.307	NS	0.123	NS	0.328	NS	0.366	NS	0.338	NS	0.060	NS
Bread Quality	Absorption	-0.332	NS	-0.335	NS	0.043	NS	-0.338	NS	0.112	NS	0.486	NS
	Loaf Volume	-0.122	NS	-0.189	NS	0.038	NS	0.174	NS	-0.409	NS	0.054	NS
	Specific Volume	-0.150	NS	-0.186	NS	-0.078	NS	0.126	NS	-0.514	NS	-0.048	NS
	Symmetry	-0.395	NS	-0.274	NS	0.200	NS	-0.282	NS	-0.424	NS	0.664	NS
	Crust Color	0.155	NS	0.152	NS	0.151	NS	0.150	NS	-0.242	NS	-0.007	NS
	Crumb Grain	-0.367	NS	-0.411	NS	0.071	NS	-0.145	NS	-0.460	NS	0.488	NS
	Crumb Color	0.597	NS	0.406	NS	0.513	NS	0.589	NS	0.826	*	-0.112	NS
	Firmness	0.554	NS	0.473	NS	-0.169	NS	0.333	NS	0.647	NS	-0.772	*

***P<0.0001, ***P<0.001, *P<0.05, NS= Non Significant, GPI= Gluten Performance Index

Like the refined flour results, there are only a few correlations between SRC and flour quality for whole wheat flour. Sodium carbonate SRC and baking absorption were significantly (P<0.05) correlated for whole wheat flour (Table 41). Sodium carbonate SRC solvent is associated with damaged starch, which contributes to water absorption during baking. The lactic acid SRC was significantly (P<0.05) correlated with total starch (Table 41). Lactic acid and ethanol SRCs were significantly (P<0.001) correlated with arabinoxylan content (Table 41). Lactic acid SRC is associated with gluten proteins, so a correlation between lactic acid SRC and total protein, wet gluten, or gluten index would be expected. The correlations between lactic acid SRC and ethanol SRC with arabinoxylan content may have resulted from arabinoxylans interfering with gluten development and performance.

The lactic acid SRC was not significantly (P>0.05) correlated with the bread loaf volume (Table 41). The flour composition and specifically the fiber content of whole wheat flour may be effecting the correlations between lactic acid SRC and bread loaf volume. The lactic acid SRC solvent may not be best suited for predicting bread loaf volume of whole wheat flour based on these results. The GPI value was significantly (P<0.05) correlated with total starch and arabinoxylan contents (Table 41). GPI is calculated from the lactic acid, sodium carbonate and sucrose SRC values. Sodium carbonate and sucrose SRC solvents are associated with starch and arbinoxylans, which may cause a correlation between these two flour components and GPI. Environmental conditions of whole wheat HRS wheat flour had little effect on correlations between SRC and flour quality parameters.

Table 41: Correlations for Environment between Solvent Retention Capacity and Flour Quality Parameters for Whole Wheat Flour

		Solvent Retention Capacity Solvents											
		Water		Sodium Carbonate		Lactic Acid		Sucrose		Ethanol		GPI	
Flour Composition	Ash	-0.441	NS	-0.518	NS	-0.247	NS	-0.514	NS	-0.349	NS	0.284	NS
	Total Protein	0.487	NS	0.498	NS	0.216	NS	0.565	NS	0.550	NS	-0.343	NS
	Gluten Index	0.461	NS	0.457	NS	0.291	NS	0.498	NS	0.367	NS	-0.199	NS
	Wet Gluten	0.295	NS	0.292	NS	0.194	NS	0.346	NS	0.570	NS	-0.109	NS
	Total Starch	0.362	NS	0.217	NS	0.807	*	0.260	NS	0.705	NS	0.786	*
	Starch Damage	0.323	NS	0.313	NS	0.607	NS	0.372	NS	0.444	NS	0.369	NS
	Arabinoxylans	-0.386	NS	-0.257	NS	-0.846	**	-0.296	NS	-0.840	**	-0.781	*
	Arabinose/Xylose Ratio	0.291	NS	0.166	NS	0.135	NS	0.169	NS	0.130	NS	-0.008	NS
Pasting Profile	Peak Viscosity	0.532	NS	0.491	NS	0.579	NS	0.619	NS	0.504	NS	0.096	NS
	Breakdown	0.602	NS	0.530	NS	0.587	NS	0.672	NS	0.433	NS	0.048	NS
	Final Viscosity	0.311	NS	0.297	NS	0.420	NS	0.433	NS	0.388	NS	0.117	NS
	Setback	0.106	NS	0.097	NS	0.237	NS	0.255	NS	0.189	NS	0.103	NS
	Peak Time	0.160	NS	0.160	NS	0.452	NS	0.268	NS	0.400	NS	0.358	NS
Farinograph	Absorption	-0.015	NS	0.111	NS	0.012	NS	0.135	NS	0.345	NS	-0.129	NS
	Peak Time	0.361	NS	0.400	NS	0.119	NS	0.450	NS	0.398	NS	-0.331	NS
	Stability	0.217	NS	0.225	NS	0.031	NS	0.275	NS	0.444	NS	-0.241	NS
Bread Quality	Absorption	-0.673	NS	-0.727	*	-0.307	NS	-0.681	NS	-0.348	NS	0.461	NS
	Loaf Volume	0.423	NS	0.470	NS	0.409	NS	0.617	NS	0.301	NS	-0.082	NS
	Specific Volume	0.325	NS	0.371	NS	0.208	NS	0.513	NS	-0.012	NS	-0.224	NS
	Symmetry	-0.011	NS	-0.036	NS	0.389	NS	0.032	NS	0.532	NS	0.530	NS
	Crust Color	0.180	NS	0.096	NS	0.269	NS	0.145	NS	0.282	NS	0.186	NS
	Crumb Grain	0.499	NS	0.490	NS	0.394	NS	0.407	NS	0.506	NS	-0.029	NS
	Crumb Color	0.347	NS	0.394	NS	0.206	NS	0.308	NS	0.196	NS	-0.175	NS
	Firmness	-0.100	NS	0.040	NS	-0.074	NS	-0.119	NS	-0.167	NS	-0.063	NS

***P<0.0001, ***P<0.001, *P<0.05, NS= Non Significant, GPI= Gluten Performance Index

CONCLUSIONS

Phenotype, genotype, and environmental factors had an effect on refined and whole wheat flour quality. Wheat cultivar, location, and year impacted flour quality for refined and whole wheat flours. The relationship between SRC profiles for refined and whole wheat flours with flour quality parameters were not strongly affected by phenotype, genotype, and environment.

The flour composition of refined flour was affected the most by cultivar and year. The whole wheat flour composition was affected by cultivar more than refined flour, but cultivar and year together had the greatest impact on whole wheat flour composition. Breeding programs are used to develop wheat cultivars with the most desirable traits by the flour industry. Different cultivars of HRS wheat have different genetic profiles that cause differences in flour composition and flour quality. Year affects flour composition and quality, because environmental conditions change every year. These environmental factors include soil conditions, weather conditions, such as temperature and rain fall, insects/pest damage, and crop disease.

The pasting profiles, or starch quality, of refined and whole wheat flours were impacted the most by cultivar and year. The dough quality (Farinograph) of refined and whole wheat flours was affected by cultivar and year the most. For the cultivar by year interaction, cultivar impacted dough quality more than year for both flour types. The results for bread baking were different for refined and whole wheat flours. The refined bread quality was impacted the most by year and cultivar. The whole wheat bread quality was affected more by year and location. Location appeared to affect whole wheat bread quality more than year. Whole wheat flour contains the outer bran layer of the kernel, which is more exposed to the environment. The bran

layer protects the endosperm, which is used to mill refined flour. Therefore, environmental conditions have a greater effect on whole wheat flour as compared to refined flour.

For refined flour SRC profiles, the results were affected by both location x year and cultivar x year interactions the most. Location and cultivar seem to affect refined flour SRC profiles more than year. The year x cultivar interaction had the greatest impact on whole wheat flour as well. Differences between cultivars were more prominent than year. The correlations between refined flour and whole wheat flour SRC profiles were affected by phenotype, genotype and environment. The correlation coefficients between refined and whole wheat flour SRC values were the greatest for genotype and environment. The higher correlations between refined and whole wheat flour SRC profiles indicates that the SRC method may be an adequate quality method for whole wheat flour end-product functionality.

Phenotype, genotype, and environment had little effect on correlations between SRC and flour quality parameters for both refined and whole wheat flours. The refined flour had stronger correlations between SRC and flour quality parameters. Thus, the SRC method may be more suited for refined HRS wheat flour. The lack of correlations between whole wheat SRC and quality parameters means the SRC method is not an appropriate measure for whole wheat flour quality.

The main purpose of this research was to determine if the SRC method could be used in the future by the milling and baking industries as a means for determining whole wheat flour end-product quality and functionality. The strong correlations between refined and whole wheat flour SRC profiles does indicate that the SRC method potentially could be used for whole wheat flour. However, the SRC method did not correlate strongly with other flour quality parameters

for phenotype, genotype, and environmental effects. Therefore, further research should be conducted on the relationship between the SRC method and other flour quality parameters for whole wheat HRS wheat flours. A strong correlation between lactic acid SRC solvent and loaf volume of whole wheat bread would be desirable in future research. This correlation has been found in some research studies using hard wheat flours, and is a key component for determining the usage of the SRC method for predicting end-product quality of bread flour. In future research involving the SRC method with whole wheat HRS wheat flour, the cultivars used and the sample replications can be changed. The replications could be conducted by plots within each location from more than two years. Using a wide variety of HRS wheat cultivars with known desirable and undesirable quality traits may result in stronger correlations between SRC and flour quality.

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APPENDIX

Table A1: Analysis of Variance for Refined Flour Composition

	Source	DF	Mean Square	F Value	Pr>F
Ash	Year	1	0.03	19.17	0.00*
	Location	3	0.009	5.72	0.005*
	Cultivar	7	0.002	1.46	0.235 NS
	Year*Location	3	0.004	2.81	0.064 NS
	Year*Cultivar	7	0.003	1.8	0.141 NS
	Location*Cultivar	21	0.002	1.07	0.44 NS
	Error	21	0.002	-	-
Total Starch	Year	1	0.01	0.01	0.94 ^{NS}
	Location	3	5.88	2.7	0.07 ^{NS}
	Cultivar	7	2.71	1.25	0.32 ^{NS}
	Year*Location	3	8.97	4.11	0.02*
	Year*Cultivar	7	1.38	0.63	0.72 ^{NS}
	Location*Cultivar	21	1.17	0.54	0.92 ^{NS}
	Error	21	2.18	-	-
Damaged Starch	Year	1	12.36	20.05	0.00*
	Location	3	3.71	6.02	0.00*
	Cultivar	7	7.70	12.48	<.0001*
	Year*Location	3	3.47	5.63	0.01*
	Year*Cultivar	7	0.39	0.64	0.72 ^{NS}
	Location*Cultivar	21	0.47	0.77	0.72 ^{NS}
	Error	21	0.62	-	-
Arabinoxlyan	Year	1	2.26	7.26	0.01*
	Location	3	1.21	3.9	0.02*
	Cultivar	7	0.81	2.61	0.04*
	Year*Location	3	0.83	2.68	0.07 ^{NS}
	Year*Cultivar	7	0.38	1.21	0.34 ^{NS}
	Location*Cultivar	21	0.40	1.29	0.28 ^{NS}
	Error	21	0.31	-	-
Arabinose/Xylose Ratio	Year	1	0.01	1.67	0.21 ^{NS}
	Location	3	0.00	0.46	0.72 ^{NS}
	Cultivar	7	0.00	0.74	0.64 ^{NS}
	Year*Location	3	0.01	1.16	0.35 ^{NS}
	Year*Cultivar	7	0.01	0.98	0.47 ^{NS}
	Location*Cultivar	21	0.01	1.16	0.37 ^{NS}
	Error	21	0.01	-	-

Table A2: Analysis of Variance for Refined Flour Protein Quality

	Source	DF	Mean Square	F Value	Pr>F
Total Protein	Year	1	31.08	80.44	<.0001*
	Location	3	1.13	2.92	0.06 NS
	Cultivar	7	2.06	5.34	0.00*
	Year*Location	3	1.46	3.77	0.03*
	Year*Cultivar	7	0.18	0.45	0.86 NS
	Location*Cultivar	21	0.24	0.63	0.86 NS
	Error	21	0.39	-	-
Wet Gluten	Year	1	211.45	40.46	<.0001*
	Location	3	30.36	5.81	0.00*
	Cultivar	7	32.38	6.19	0.00*
	Year*Location	3	35.15	6.73	0.00*
	Year*Cultivar	7	4.22	0.81	0.59 NS
	Location*Cultivar	21	4.33	0.83	0.67 NS
	Error	21	5.23	-	-
Gluten Index	Year	1	126.36	10.94	0.00*
	Location	3	10.86	0.94	0.44 NS
	Cultivar	7	130.47	11.29	<.0001*
	Year*Location	3	45.94	3.98	0.02*
	Year*Cultivar	7	22.31	1.93	0.12 NS
	Location*Cultivar	21	18.14	1.57	0.15 NS
	Error	21	11.55	-	-

Table A3: Analysis of Variance for Whole Wheat Flour Protein Quality

	Source	DF	Mean Square	F Value	Pr>F
Total Protein	Year	1	23.16	64.68	<.0001*
	Location	3	1.11	3.1	0.05*
	Cultivar	7	2.12	5.93	0.00*
	Year*Location	3	1.05	2.92	0.06 NS
	Year*Cultivar	7	0.16	0.46	0.85 NS
	Location*Cultivar	21	0.25	0.69	0.80 NS
	Error	21	0.36	-	-
Wet Gluten	Year	1	212.37	29.67	<.0001*
	Location	3	12.58	1.76	0.19 NS
	Cultivar	7	28.31	3.95	0.01*
	Year*Location	3	42.64	5.96	0.00*
	Year*Cultivar	7	2.55	0.36	0.92 NS
	Location*Cultivar	21	3.88	0.54	0.92 NS
	Error	21	7.16	-	-
Gluten Index	Year	1	892.47	13.38	0.00*
	Location	3	618.78	9.28	0.00*
	Cultivar	7	557.13	8.35	<.0001*
	Year*Location	3	651.31	9.77	0.00*
	Year*Cultivar	7	250.89	3.76	0.01*
	Location*Cultivar	21	108.00	1.62	0.14 NS
	Error	21	66.69	-	-

Table A4: Analysis of Variance for Whole Wheat Flour Composition

	Source	DF	Mean Square	F Value	Pr>F
Ash	Year	1	0.162	29.67	<.0001*
	Location	3	0.125	22.76	<.0001*
	Cultivar	7	0.022	3.97	0.01*
	Year*Location	3	0.016	2.84	0.06 NS
	Year*Cultivar	7	0.015	2.82	0.03*
	Location*Cultivar	21	0.003	0.48	0.95 NS
	Error	21	0.005	-	-
Total Starch	Year	1	1.19	0.31	0.58 NS
	Location	3	6.14	1.61	0.22 NS
	Cultivar	7	14.84	3.89	0.01*
	Year*Location	3	12.40	3.26	0.04*
	Year*Cultivar	7	5.12	1.34	0.28 NS
	Location*Cultivar	21	4.47	1.17	0.36 NS
	Error	21	3.81	-	-
Damaged Starch	Year	1	0.00	0	0.96 NS
	Location	3	2.00	2.2	0.12 NS
	Cultivar	7	4.13	4.54	0.00*
	Year*Location	3	6.82	7.51	0.00*
	Year*Cultivar	7	0.52	0.57	0.77 NS
	Location*Cultivar	21	0.92	1.01	0.49 NS
	Error	21	0.91	-	-
Arabinoxylans	Year	1	2.21	1.58	0.22 NS
	Location	3	4.05	2.9	0.06 NS
	Cultivar	7	3.85	2.76	0.03*
	Year*Location	3	7.56	5.42	0.01*
	Year*Cultivar	7	1.54	1.11	0.40 NS
	Location*Cultivar	21	1.13	0.81	0.68 NS
	Error	21	1.39	-	-
Arabinose/Xylose Ratio	Year	1	0.001	0.63	0.44 NS
	Location	3	0.001	0.87	0.47 NS
	Cultivar	7	0.004	3.96	0.01*
	Year*Location	3	0.001	0.77	0.52 NS
	Year*Cultivar	7	0.002	1.65	0.18 NS
	Location*Cultivar	21	0.001	1.04	0.46 NS
	Error	21	0.001	-	-

Table A5: Analysis of Variance for Refined Flour Farinograph

	Source	DF	Mean Square	F Value	Pr>F
Absorption	Year	1	36.30	42.73	<.0001*
	Location	3	24.62	28.97	<.0001*
	Cultivar	7	11.17	13.14	<.0001*
	Year*Location	3	13.25	15.59	<.0001*
	Year*Cultivar	7	0.67	0.79	0.61 NS
	Location*Cultivar	21	1.03	1.22	0.33 NS
	Error	21	0.85	-	-
Peak Time	Year	1	26.65	43.77	<.0001*
	Location	3	2.51	4.11	0.02*
	Cultivar	7	2.06	3.38	0.01*
	Year*Location	3	1.23	2.02	0.14 NS
	Year*Cultivar	7	0.43	0.7	0.67 MS
	Location*Cultivar	21	0.63	1.03	0.47 NS
	Error	21	0.61	-	-
Stability	Year	1	25.38	18.76	0.00*
	Location	3	9.14	6.75	0.00*
	Cultivar	7	4.58	3.38	0.01*
	Year*Location	3	2.24	1.66	0.21 NS
	Year*Cultivar	7	2.20	1.62	0.18 NS
	Location*Cultivar	21	3.12	2.3	0.03*
	Error	21	1.35	-	-
MTI	Year	1	400.00	14.03	0.00*
	Location	3	339.60	11.91	<.0001*
	Cultivar	7	113.67	3.99	0.01*
	Year*Location	3	72.38	2.54	0.08 NS
	Year*Cultivar	7	48.75	1.71	0.16 NS
	Location*Cultivar	21	75.02	2.63	0.02*
	Error	21	28.51	-	-

Table A6: Analysis of Variance for Whole Wheat Flour Farinograph

	Source	DF	Mean Square	F Value	Pr>F
Absorption	Year	1	6.70	6.81	0.02*
	Location	3	12.11	12.31	<.0001*
	Cultivar	7	10.75	10.93	<.0001*
	Year*Location	3	3.98	4.05	0.02*
	Year*Cultivar	7	0.89	0.91	0.52 NS
	Location*Cultivar	21	1.19	1.21	0.34 NS
	Error	21	0.98	-	-
Peak Time	Year	1	10.32	40.73	<.0001*
	Location	3	3.38	13.32	<.0001*
	Cultivar	7	0.35	1.4	0.26 NS
	Year*Location	3	0.64	2.53	0.09 NS
	Year*Cultivar	7	0.32	1.28	0.31 NS
	Location*Cultivar	21	0.35	1.39	0.23 NS
	Error	21	0.25	-	-
Stability	Year	1	46.07	28.13	<.0001*
	Location	3	14.94	9.12	0.00*
	Cultivar	7	4.17	2.55	0.05*
	Year*Location	3	7.18	4.38	0.02*
	Year*Cultivar	7	3.18	1.94	0.11 NS
	Location*Cultivar	21	1.11	0.68	0.81 NS
	Error	21	1.64	-	-
MTI	Year	1	1105.56	41.38	<.0001*
	Location	3	176.73	6.61	0.00*
	Cultivar	7	164.96	6.17	0.00*
	Year*Location	3	127.73	4.78	0.01*
	Year*Cultivar	7	24.17	0.9	0.52 NS
	Location*Cultivar	21	13.05	0.49	0.95 NS
	Error	21	26.72	-	-

Table A7: Analysis of Variance for Refined Flour Solvent Retention Capacity

	Source	DF	Mean Square	F Value	Pr>F
Water	Year	1	1394.07	215.62	<.0001*
	Location	3	75.93	11.74	<.0001*
	Cultivar	7	77.65	12.01	<.0001*
	Year*Location	3	193.18	29.88	<.0001*
	Year*Cultivar	7	8.24	1.27	0.31 NS
	Location*Cultivar	21	7.03	1.09	0.42 NS
	Error	21	6.47	-	-
Sodium Carbonate	Year	1	5079.02	77.49	<.0001*
	Location	3	932.35	14.23	<.0001*
	Cultivar	7	188.82	2.88	0.03*
	Year*Location	3	1342.54	20.48	<.0001*
	Year*Cultivar	7	138.22	2.11	0.09 NS
	Location*Cultivar	21	45.68	0.7	0.79 NS
	Error	21	65.54	-	-
Lactic Acid	Year	1	2665.18	142.67	<.0001*
	Location	3	1750.48	93.71	<.0001*
	Cultivar	7	198.18	10.61	<.0001*
	Year*Location	3	3769.88	201.81	<.0001*
	Year*Cultivar	7	32.63	1.75	0.15 NS
	Location*Cultivar	21	34.83	1.86	0.08 NS
	Error	21	18.68	-	-
Sucrose	Year	1	8466.06	382.91	<.0001*
	Location	3	883.20	39.95	<.0001*
	Cultivar	7	158.95	7.19	0.00*
	Year*Location	3	1713.77	77.51	<.0001*
	Year*Cultivar	7	30.56	1.38	0.26 NS
	Location*Cultivar	21	17.74	0.8	0.69 NS
	Error	21	22.11	-	-
Ethanol	Year	1	6412.74	255.57	<.0001*
	Location	3	516.75	20.59	<.0001*
	Cultivar	7	13.44	0.54	0.80 NS
	Year*Location	3	1155.94	46.07	<.0001*
	Year*Cultivar	7	19.89	0.79	0.60 NS
	Location*Cultivar	21	13.98	0.56	0.91 NS
	Error	21	25.09	-	-
GPI	Year	1	0.08	66.12	<.0001*
	Location	3	0.04	35.67	<.0001*
	Cultivar	7	0.01	4.76	0.00*
	Year*Location	3	0.03	23.07	<.0001*
	Year*Cultivar	7	0.00	1.09	0.41 NS
	Location*Cultivar	21	0.00	1.73	0.11 NS
	Error	21	0.00	-	-

Table A8: Analysis of Variance for Whole Wheat Flour Solvent Retention Capacity

	Source	DF	Mean Square	F Value	Pr>F
Water	Year	1	2825.03	503.56	<.0001*
	Location	3	227.81	40.61	<.0001*
	Cultivar	7	24.96	4.45	0.00*
	Year*Location	3	364.69	65.01	<.0001*
	Year*Cultivar	7	8.31	1.48	0.23 NS
	Location*Cultivar	21	5.25	0.94	0.56 NS
	Error	21	5.61	-	-
Sodium Carbonate	Year	1	6435.68	207.44	<.0001*
	Location	3	448.01	14.44	<.0001*
	Cultivar	7	130.61	4.21	0.00*
	Year*Location	3	956.49	30.83	<.0001*
	Year*Cultivar	7	49.11	1.58	0.20 NS
	Location*Cultivar	21	20.04	0.65	0.84 NS
	Error	21	31.02	-	-
Lactic Acid	Year	1	2339.09	106.36	<.0001*
	Location	3	804.96	36.6	<.0001*
	Cultivar	7	9.60	0.44	0.87 NS
	Year*Location	3	2359.13	107.27	<.0001*
	Year*Cultivar	7	11.93	0.54	0.79 NS
	Location*Cultivar	21	14.60	0.66	0.82 NS
	Error	21	21.99	-	-
Sucrose	Year	1	8498.95	687.59	<.0001*
	Location	3	614.51	49.72	<.0001*
	Cultivar	7	50.56	4.09	0.01*
	Year*Location	3	1279.57	103.52	<.0001*
	Year*Cultivar	7	28.46	2.3	0.07 NS
	Location*Cultivar	21	17.61	1.43	0.21 NS
	Error	21	12.36	-	-
Ethanol	Year	1	3249.75	515.46	<.0001*
	Location	3	792.23	125.66	<.0001*
	Cultivar	7	7.65	1.21	0.34 NS
	Year*Location	3	864.66	137.15	<.0001*
	Year*Cultivar	7	8.59	1.36	0.27 NS
	Location*Cultivar	21	12.57	1.99	0.06 NS
	Error	21	6.30	-	-
GPI	Year	1	0.02	34.4	<.0001*
	Location	3	0.02	35.43	<.0001*
	Cultivar	7	0.00	1.58	0.20 NS
	Year*Location	3	0.02	44.71	<.0001*
	Year*Cultivar	7	0.00	0.59	0.76 NS
	Location*Cultivar	21	0.00	0.82	0.68 NS
	Error	21	0.00	-	-

Table A9: Analysis of Variance for Refined Flour Pasting Profile

	Source	DF	Mean Square	F Value	Pr>F
Peak Viscosity	Year	1	13770.00	80.73	<.0001*
	Location	3	3084.93	18.09	<.0001*
	Cultivar	7	2190.81	12.84	<.0001*
	Year*Location	3	2357.75	13.82	<.0001*
	Year*Cultivar	7	146.68	0.86	0.55 NS
	Location*Cultivar	21	310.82	1.82	0.09 NS
	Error	21	170.56	-	-
Breakdown	Year	1	2586.87	104.55	<.0001*
	Location	3	421.42	17.03	<.0001*
	Cultivar	7	708.29	28.63	<.0001*
	Year*Location	3	228.70	9.24	0.00*
	Year*Cultivar	7	48.41	1.96	0.11 NS
	Location*Cultivar	21	86.12	3.48	0.00*
	Error	21	24.74	-	-
Final Viscosity	Year	1	11587.00	65.63	<.0001*
	Location	3	3030.78	17.17	<.0001*
	Cultivar	7	1493.87	8.46	<.0001*
	Year*Location	3	3702.80	20.97	<.0001*
	Year*Cultivar	7	155.41	0.88	0.54 NS
	Location*Cultivar	21	281.21	1.59	0.15 NS
	Error	21	176.56	-	-
Setback	Year	1	1064.45	16.21	0.00*
	Location	3	210.27	3.2	0.04*
	Cultivar	7	275.61	4.2	0.00*
	Year*Location	3	421.45	6.42	0.00*
	Year*Cultivar	7	40.83	0.62	0.73 NS
	Location*Cultivar	21	81.94	1.25	0.31 NS
	Error	21	65.66	-	-

Table A10: Analysis of Variance for Whole Wheat Flour Pasting Profile

	Source	DF	Mean Square	F Value	Pr>F
Peak Viscosity	Year	1	3706.53	54.26	<.0001*
	Location	3	2773.77	40.61	<.0001*
	Cultivar	7	1300.77	19.04	<.0001*
	Year*Location	3	2166.37	31.71	<.0001*
	Year*Cultivar	7	48.19	0.71	0.67 NS
	Location*Cultivar	21	101.79	1.49	0.18 NS
	Error	21	68.31	-	-
Breakdown	Year	1	499.22	42.08	<.0001*
	Location	3	537.60	45.32	<.0001*
	Cultivar	7	429.42	36.2	<.0001*
	Year*Location	3	330.57	27.86	<.0001*
	Year*Cultivar	7	10.29	0.87	0.55 NS
	Location*Cultivar	21	36.36	3.06	0.01*
	Error	21	11.86	-	-
Final Viscosity	Year	1	1670.41	14.57	0.00*
	Location	3	3336.73	29.11	<.0001*
	Cultivar	7	1345.36	11.74	<.0001*
	Year*Location	3	3276.34	28.58	<.0001*
	Year*Cultivar	7	86.94	0.76	0.63 NS
	Location*Cultivar	21	150.03	1.31	0.27 NS
	Error	21	114.62	-	-
Setback	Year	1	5.98	0.18	0.67 NS
	Location	3	715.22	22.12	<.0001*
	Cultivar	7	274.89	8.5	<.0001*
	Year*Location	3	738.51	22.84	<.0001*
	Year*Cultivar	7	35.89	1.11	0.39 NS
	Location*Cultivar	21	35.84	1.11	0.41 NS
	Error	21	32.34	-	-

Table A11: Analysis of Variance for Refined Four Baking Quality

	Source	DF	Mean Square	F Value	Pr>F
Absorption	Year	1	4.60	1.84	0.19 ^{NS}
	Location	3	35.14	14.08	<.0001*
	Cultivar	7	8.47	3.4	0.01*
	Year*Location	3	37.54	15.05	<.0001*
	Year*Cultivar	7	4.17	1.67	0.17 ^{NS}
	Location*Cultivar	21	2.93	1.17	0.36 ^{NS}
	Error	21	2.50	-	-
Mixing Time	Year	1	0.43	4.29	0.05*
	Location	3	0.46	4.61	0.01*
	Cultivar	7	0.22	2.22	0.07 ^{NS}
	Year*Location	3	1.27	12.65	<.0001*
	Year*Cultivar	7	0.05	0.53	0.80 ^{NS}
	Location*Cultivar	21	0.09	0.9	0.59 ^{NS}
	Error	21	0.10	-	-
Loaf Volume	Year	1	1.56	0	0.98 ^{NS}
	Location	3	16245.00	6.9	0.00*
	Cultivar	7	7350.00	3.12	0.02*
	Year*Location	3	6248.44	2.65	0.08 ^{NS}
	Year*Cultivar	7	1555.13	0.66	0.70 ^{NS}
	Location*Cultivar	21	2212.65	0.94	0.56 ^{NS}
	Error	21	2355.58	-	-
Specific Volume	Year	1	0.07	0.61	0.44 ^{NS}
	Location	3	1.36	11.09	0.00*
	Cultivar	7	0.54	4.38	0.00*
	Year*Location	3	0.69	5.64	0.01*
	Year*Cultivar	7	0.08	0.67	0.69 ^{NS}
	Location*Cultivar	21	0.17	1.41	0.22 ^{NS}
	Error	21	0.12	-	-
Firmness	Year	1	1866.24	5.96	0.02*
	Location	3	1158.15	3.7	0.03*
	Cultivar	7	123.51	0.39	0.89 ^{NS}
	Year*Location	3	238.81	0.76	0.53 ^{NS}
	Year*Cultivar	7	284.76	0.91	0.52 ^{NS}
	Location*Cultivar	21	179.70	0.57	0.89 ^{NS}
	Error	21	312.96	-	-

Table A12: Analysis of Variance for Whole Wheat Baking Quality

	Source	DF	Mean Square	F Value	Pr>F
	Year	1	7516.35	189.91	<.0001*
	Location	3	747.09	18.88	<.0001*
	Cultivar	7	162.34	4.1	0.01*
	Year*Location	3	663.44	16.76	<.0001*
	Year*Cultivar	7	179.54	4.54	0.00*
	Location*Cultivar	21	44.55	1.13	0.39 NS
	Error	21	39.58	-	-
Mixing Time	Year	1	4.13	56.12	<.0001*
	Location	3	0.37	5.04	0.01*
	Cultivar	7	0.17	2.37	0.06 NS
	Year*Location	3	0.83	11.24	0.00*
	Year*Cultivar	7	0.08	1.11	0.40 NS
	Location*Cultivar	21	0.08	1.06	0.45 NS
	Error	21	0.07	-	-
Loaf Volume	Year	1	5347.27	1.01	0.33 NS
	Location	3	5464.97	1.03	0.40 NS
	Cultivar	7	10289.00	1.95	0.11 NS
	Year*Location	3	4767.06	0.9	0.46 NS
	Year*Cultivar	7	7155.30	1.35	0.28 NS
	Location*Cultivar	21	4792.06	0.91	0.59 NS
	Error	21	5285.81	-	-
Specific Volume	Year	1	0.09	0.34	0.57 NS
	Location	3	0.39	1.44	0.26 NS
	Cultivar	7	0.63	2.34	0.06 NS
	Year*Location	3	0.28	1.02	0.40 NS
	Year*Cultivar	7	0.31	1.12	0.39 NS
	Location*Cultivar	21	0.26	0.95	0.55 NS
	Error	21	0.27	-	-
Firmness	Year	1	150.0625	0.11	0.75 NS
	Location	3	1614.88	1.14	0.36 NS
	Cultivar	7	7895.79	5.55	0.00*
	Year*Location	3	733.69	0.52	0.68 NS
	Year*Cultivar	7	1825.11	1.28	0.31 NS
	Location*Cultivar	21	1338.49	0.94	0.55 NS
	Error	21	1421.68	-	-

Table A13: Analysis of Variance for Refined Flour Bread Loaf Quality

	Source	DF	Mean Square	F Value	Pr>F
Symmetry	Year	1	5.35	10.28	0.00*
	Location	3	0.69	1.33	0.29 NS
	Cultivar	7	0.71	1.36	0.27 NS
	Year*Location	3	0.87	1.67	0.20 NS
	Year*Cultivar	7	1.00	1.92	0.12 NS
	Location*Cultivar	21	0.53	1.03	0.48 NS
	Error	21	0.52	-	-
Crust Color	Year	1	0.77	2.54	0.13 NS
	Location	3	0.77	2.54	0.08 NS
	Cultivar	7	0.59	1.95	0.11 NS
	Year*Location	3	0.77	2.54	0.08 NS
	Year*Cultivar	7	0.59	1.95	0.11 NS
	Location*Cultivar	21	0.52	1.71	0.11 NS
	Error	21	0.30	-	-
Crumb Grain	Year	1	0.25	0.79	0.38 NS
	Location	3	0.39	1.22	0.33 NS
	Cultivar	7	1.15	3.63	0.01*
	Year*Location	3	0.07	0.23	0.87 NS
	Year*Cultivar	7	0.27	0.85	0.56 NS
	Location*Cultivar	21	0.37	1.16	0.37 NS
	Error	21	0.32	-	-
Crumb Color	Year	1	2.25	9.75	0.01*
	Location	3	0.39	1.67	0.20 NS
	Cultivar	7	1.16	5.03	0.00*
	Year*Location	3	0.18	0.77	0.52 NS
	Year*Cultivar	7	0.05	0.23	0.97 NS
	Location*Cultivar	21	0.17	0.72	0.77 NS
	Error	21	0.23	-	-

Table A14: Analysis of Variance for Whole Wheat Flour Bread Loaf Quality

	Source	DF	Mean Square	F Value	Pr>F
Symmetry	Year	1	0.25	0.27	0.61 ^{NS}
	Location	3	2.21	2.37	0.10 ^{NS}
	Cultivar	7	1.37	1.47	0.23 ^{NS}
	Year*Location	3	2.96	3.18	0.05*
	Year*Cultivar	7	0.26	0.28	0.96 ^{NS}
	Location*Cultivar	21	0.81	0.87	0.62 ^{NS}
	Error	21	0.93	-	-
Crust Color	Year	1	0.00	0.00	1.00 ^{NS}
	Location	3	0.29	1.58	0.22 ^{NS}
	Cultivar	7	0.96	5.23	0.00*
	Year*Location	3	1.13	6.1	0.00*
	Year*Cultivar	7	0.11	0.58	0.76 ^{NS}
	Location*Cultivar	21	0.21	1.13	0.39 ^{NS}
	Error	21	0.18	-	-
Crumb Grain	Year	1	1.13	2.4	0.14 ^{NS}
	Location	3	0.32	0.67	0.58 ^{NS}
	Cultivar	7	0.58	1.22	0.34 ^{NS}
	Year*Location	3	0.63	1.33	0.29 ^{NS}
	Year*Cultivar	7	0.14	0.29	0.95 ^{NS}
	Location*Cultivar	21	0.30	0.64	0.84 ^{NS}
	Error	21	0.47	-	-
Crumb Color	Year	1	0.77	4.04	0.06 ^{NS}
	Location	3	0.95	5	0.01*
	Cultivar	7	0.42	2.21	0.08 ^{NS}
	Year*Location	3	0.36	1.89	0.16 ^{NS}
	Year*Cultivar	7	0.20	1.07	0.42 ^{NS}
	Location*Cultivar	21	0.17	0.87	0.62 ^{NS}
	Error	21	0.19	-	-