IMPROVEMENT OF SPONGE CAKE BAKING TEST PROCEDURE

AND CHARACTERISTICS OF SOFT WHEAT FLOUR

DESIRABLE FOR MAKING SPONGE CAKE

By

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ABSTRACT

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While the sponge cake (SC) baking test involves a lengthy, complicated procedure and requires experienced personnel to properly conduct the test, it provides the most informative and reliable estimation of overall end-use quality of soft white and club wheat especially for their uses in many Asian countries. Understanding of soft white wheat quality traits affecting SC baking is lacking and in great need of improvement. The objectives of this research were to develop a simple, fast and reliable baking test for predicting flour quality for use on sponge cakes and to identify functional properties of soft white wheat flour important for making acceptable sponge cakes.

A simpler and comparably reliable SC baking test procedure was developed by making considerable modifications to the conventional test procedure at the egg foam whipping and batter mixing stages. Foam density, SC volume and crumb grain comparable to that of the
conventional procedure were obtained with modifications, including extension of whipping time without heat input using a 5-liter KitchenAid® mixer, one time water addition at 3 min before the completion of egg whipping instead of twice, and flour incorporation into the egg foam using a KitchenAid® wire whisk or a Beater Blade®. The modified method of using Beater Blade® or wire whisk for batter mixing exhibited significant correlations in SC volume with the conventional procedure (r=0.931, P<0.001, r=0.925, P<0.001, respectively).

Significance of flour particle size on SC baking performance was determined using flours of different particle size prepared by re-grinding and sieving. Particle size reduction of flour by re-grinding improved SC volume (0.8-15.0%) and crumb grain, with little change in density and viscosity of the flour-water batter despite increases in flour starch damage (0.1-0.2%) and sodium carbonate retention capacity (4.8-13.9%). Flour fractions of small (< 55 µm) particles produced the largest SC volume, ranging from 1353-1450 mL. Even with comparable or higher protein content, flour fraction of intermediate particle size produced larger volume (1040-1195 mL) of SC than did flour fractions of large particle size (955-1130 mL).

The qualitative and quantitative roles of starch on SC baking potential of wheat flour were investigated using flours of various amylose content as well as different quantities and proportions of starch in the baking formula. Normal and single-null partial waxy flours produced SCs ranging from 1093 to 1335 mL in volume, while double-null partial waxy and waxy wheat
flours produced SC of 828 to 895 mL. Both amylose content and pasting properties (final viscosity and setback) of wheat flour exhibited significant positive relationships with SC volume.

Amylose content of normal and waxy starch blends was significantly related with their SC volume ($r=0.975$, $P<0.05$). Pure wheat starch of over 80 g or more than 75% starch in 100 g starch-gluten blends in replacement of 100 g wheat flour in the SC baking formula were needed to produce SC having the maximum volume potential.
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Dedication

This dissertation is dedicated to my family
CHAPTER 1.

INTRODUCTION
1.1. BACKGROUND

Wheat is grown in most parts of the world. In 2009, more than 682 million tons were produced worldwide, and was the second most-produced cereal after maize (817 million tons) (FAO 2009). The amount of wheat traded internationally exceeds that of all other grains. The United States, which is the second largest wheat producing country, has traditionally been one of the most important wheat exporters in the world. Many importing nations specify desired quantities, qualities and origins of the wheat they would like to import (FAO 2009). The U.S. produces about 13% of the world’s wheat and supplies about 25% of the world’s wheat export market (EPA 2009).

Wheat is widely cultivated as a cash crop because it produces a good yield per unit area, grows well in a temperate climate even with a moderately short growing season, and yields a versatile flour. In the United States, wheat is classified based on kernel hardness such as hard or soft, growing season such as spring or winter, and grain color such as white or red. The characteristics of each class of wheat affect milling and baking when used in food products. Most wheat is mainly consumed in the form of baked goods; therefore, wheat grains must be milled to produce flour prior to consumption. Wheat is also used as an ingredient in compound feedstuffs, starch production and as a feed stock in ethanol production. Flour milling has two objectives. First, it is a process that separates the endosperm from bran
and germ. Second, it involves grinding the grain to fine flour. Wheat kernels have three main parts, the endosperm, the germ, and the bran. Wheat flour is milled from the endosperm (Gooding 2009; Wrigley 2009).

In general, quality evaluation of wheat grain is tested by determining the weight per unit volume (test weight), kernel hardness and milling yield. Wheat flour is typically tested for chemical characteristics including moisture content, ash content, protein content, α-amylase activity, damaged starch and solvent retention capacity, and dough-forming properties evaluated using the alveograph, mixograph, and farinograph. Dough rheological instruments were originally designed for use with materials such as bread doughs, where strength and elasticity are valued. The rheological properties of soft and hard wheat flours are not simply opposites (Hoseney et al 1988). Baking tests are used to evaluate end-use quality of flour (Edwards and Carson 2009).

Soft white wheat grown in the Pacific Northwest states of the U.S.A. is largely exported to Asian countries, where it is used for making cookies, cakes, noodles, snacks and pastries. The applications of soft wheat are different from those of hard and durum wheats; therefore, the testing criteria are also significantly different. Typically, quality tests of soft wheat flours include tests for moisture, ash, protein, sprout damage, polyphenol oxidase, alkaline water retention capacity, solvent retention capacity, mixograph and alveograph, and baking tests for sugar-snap
cookie and sponge cake (Sumnu and Sahin 2008; Hoseney et al 1988). Compared to hard wheat flour, soft wheat flours are relatively whiter in color, lower in protein content, weaker in gluten protein quality, finer in milled particles and lower in starch damage. Soft wheat flour of superior quality is expected to produce sugar-snap cookies of large diameter and sponge cakes of large volume and fine, even crumb structure. Sponge cake is a popular product of soft white wheat flour in East Asia. The sponge cake baking test provides a reliable estimation of overall end-use quality of soft white wheat for Asian markets, and is widely accepted as a standard quality test (Kaldy et al 1991; Nagao et al 1976; Nagao et al 1977; Nishio et al 2009; Yamamoto et al 1996). The sponge cake baking test is, however, lengthy and laborious, requiring substantially experienced personnel who can conduct the test with accuracy and reliability making it unsuitable for routine evaluation of a large number of wheat breeding lines. The functional properties of hard wheat for baking bread have been intensively investigated and are relatively well established. On the other hand, limited information is available about the functional properties and characteristics of soft white wheat for sponge cake quality.

Therefore, the goals of this research are to enhance the ability to determine the end-use quality of soft white wheat by exploring simple, fast and reliable screening test and to identify functional properties of soft white wheat flour important for making sponge cake. The objectives of the research reported herein were to:
1. Improve the sponge cake baking test procedure

2. Clarify the effect of particle size on sponge cake quality

3. Elucidate the effect of starch property and quantity on sponge cake quality.

These objectives are presented in chapters two, three, and four of this dissertation.

1.2. LITERATURE REVIEW

Classification of wheat in the U.S.

In the United States, wheat is categorized according hard red winter (HRW), hard red spring (HRS), hard white (HDWH), durum, soft red winter (SRW), and soft white (SWH) wheat classes. HRW, composed of medium to hard endosperm, red seed coated, and fall sown wheat varieties, represents about 40% of the total U.S. wheat crop. HRS, composed of hard endosperm, red seed coated, and spring sown wheat varieties, constitutes about 25% of the total U.S. wheat crop. HDWH is the newest U.S. wheat class. It is used for steamed breads and noodles in Asian production. Durum, composed of hard endosperm with high protein content, accounts for about 5% of the total wheat crop in the U.S., and is used predominantly for milling into semolina for the production of pasta and couscous. SRW, composed of soft endosperm, red seed coated, and winter sown wheat varieties, represents about 18% of the total U.S. production. Lower protein wheat from this class is suited for cake, pastries, crackers, and cookies, while
higher protein wheat from this class is marketed for flat breads. SWH spring and winter wheat varieties, including white club wheat, are composed of soft endosperm and white seed coated wheat varieties. Soft white wheat is divided into three subclasses: soft white, white club, and western white. Soft white wheat contains no more than 10% white club wheat; white club contains no more than 10% of other soft white wheat; and western white contains more than 10% white club wheat and more than 10% other soft white wheat. White club wheat typically has weaker protein than other soft white wheat. The total production of soft white wheat represents about 10-15% of total wheat production in the U.S. It is used for end products such as cake, pastries, crackers, and cookies (U.S. Wheat Associates 2006).

Structure, characteristics and uses of soft wheat

The structure of the wheat grain is important for all aspects of utilization. The term hardness is defined as the physical resistance of wheat kernels to a crushing or shearing force as they are ground into smaller particles or flour (Turnbull and Rahman 2002). Kernel hardness is used to describe whether the kernel is physically hard or soft based on the texture of the endosperm. On the basis of kernel hardness, an important grading standard in wheat, the cultivated wheat varieties (Triticum aestivum L. and Triticum durum Desf.) are categorized into three distinct classes: hexaploid soft, hexaploid hard and durum. In general, wheat kernel
hardness has been attributed to the degree of adhesion between starch granules and the protein matrix. Starch granules can be easily separated from the protein matrix in soft wheat, whereas in hard wheat the tight adhesion between starch and protein matrix makes for difficult separation (Barlow et al 1973; Darlington et al 2000; Giroux and Morris 1997; Stenvert and Kingswood 1977; Symes 1965). Endosperm texture affects tempering requirements, flour particle size, flour density, starch damage, water absorption, and milling yield (Delwiche 1993). Wheat with a softer kernel texture fractures more easily and produces more flour in the break system than does wheat with a harder texture (Finney 1989). Compared to flours milled from hard wheat kernels, flours milled from soft wheat kernels are relatively whiter in color, lower in protein content, weaker in gluten protein quality, finer in particles and also show less starch damage, because the soft hardness of the kernel makes them easy to mill (Rogers et al 1993; Turnbull and Rahman 2002). Soft wheat flours are used in products where weaker protein is desired, including products such as cakes and cookies. However, soft wheat flours are also used for a wide range of goods such as a thickener for soups, in the manufacture of crumb for coating fish and meat products, and as the basis for some breakfast cereals. All of these products have a better appearance and better eating quality when made from soft rather than hard wheat flour (Hoseney et al 1988).

Wheat flour constituents (protein and starch) of soft wheat
Goeasaert et al (2005) reported that wheat flour is a major ingredient in many products and consists mainly of starch (ca.70-75%), water (ca.14%) and proteins (ca.10-12%). The constituents of wheat flour vary due to the genotype and the growing environment.

Protein content of wheat grain can vary from 6% to 20%. Wheat proteins are classified in albumins (extractable in water), globulins (extractable in dilute salt solution), gliadins (extractable in aqueous alcohol) and glutenins (extractable in dilute acid or alkali) according to their extractability and solubility in various solvents (Osborne 1924). Albumins and globulins in cereals are concentrated in the seed coats, the aleurone cells and the germ, with a somewhat lower concentration in the mealy endosperm. The albumin and globulin fraction, which are non-gluten proteins, compose about 25% of the total grain proteins (Belderok et al 2000). The gliadins and glutenins are mainly located in the mealy endosperm and are not found in the seed coat layers nor in the germ. The gliadins and glutenins, which involve into gluten proteins, are storage proteins and are about 75% of the total protein content. Storage proteins in wheat have a function in the formation of dough as they retain gas, producing spongy baked products (Belderok et al 2000). Strong protein of wheat tends to be more elastic and requires a longer mixing time and greater work input to develop, while weak protein of wheat exhibits much less elasticity and overall strength and has lower mixing requirements (Carson and Edwards 2009; Maghirang et al 2006). Both the quantity and quality (composition) of protein are important in
soft wheat products (Finney and Bains 1999; Hou et al 1996a, 1996b; Huebner et al 1999; Souza et al 1994). Soft wheat flours are typically low in protein content (8 to 10%) and the proteins are weak in strength, with characteristics better suited to making more tender products such as cakes and cookies, producing greater cookie spread and superior crumb texture in cakes (Finney and Barmore 1948; Goeasaert et al 2005; Kaldy et al 1991; Nagao et al 1976).

The starch content of American varieties of wheat has been reported to be in the range of 63-72% (Cerning and Guilbot 1974). Starch occurs in seeds in the form of granules. Wheat has two types of starch granules, large lenticular (25-40 µm) and small spherical (5-10 µm) ones (Alexander 1995). Chemically, starch consists of two major polymers, amylose and amylopectin. Amylose is a mostly linear α-D-1,4-linked glucose polymer with a degree of polymerization (DP) of 1,000-5,000 glucose units. Amylopectin is a highly branched polymer of glucose units with α-D-1,4 and 1,6-linkages from 1 X 10^7 to 5 X 10^8 molecular weights. Amylopectin is a much larger glucose polymer (DP 10^5-10^6) in which α-(1,4)-linked glucose polymers are connected by 5-6% α-(1,6)-linkages. Normal wheat starch typically contains 20-30% amylose and 70-80% amylopectin (Colonna and Buleon 1992; Konik-Rose et al 2007; Sramkova et al 2009; Zobel 1988). Starch granules are made up of amylose and/or amylopectin molecules arranged radially, and are semicrystalline, composed of alternating crystalline and amorphous regions. The semi-crystalline structures of amylose and amylopectin in the starch granules make them relatively
insoluble in cold water and retards their digestion. However, when starch is heated in water, starch granules undergo a process called gelatinization. Gelatinization is the disruption of granular and molecular order within granules that causes swelling, thickening and loss of crystallinity in starch granules. As starch pastes are cooled and stored, the gelatinized starch begins to recrystallize itself; this process is called retrogradation. Retrogradation is very rapid for amylose but takes a longer time for amylopectin. Many quality defects in food products are influenced by starch retrogradation such as bread staling, and loss of viscosity and precipitation in soups and sauces (Bemiller and Whistler 1996; Geera et al 2006). Starch is the primary contributor to wheat flour pasting behavior and is ultimately responsible for variability in flour pasting properties (Geera et al 2006). Processing, cooking and texture of wheat based food products are significantly related to gelatinization, pasting and retrogradation properties of wheat starch (Baik and Lee 2003). In general, wheat flour contains over 70% starch (Sollars and Rubenthaler 1971). Starch constitutes the major component of wheat flour and performs many roles in the production and quality of end-use. It contributes to crust color and crumb structure in bread and baked goods and to cooked texture in noodles. The starch content of wheat is negatively related to the protein content of wheat (Hopkins and Graham 1935). Thus, soft wheat varieties generally have a higher starch content than do hard wheat varieties (Miller 1974). Starch granules can be physically damaged during flour milling, increasing their water-holding
ability and susceptibility to attack from the enzyme α-amylase (Greer and Steward 1959). Soft wheat flour is lower in damaged starch content than hard wheat flour, due to the softer kernel texture and higher break flour yield. In bread flour, a controlled amount of damaged starch is needed because the enzymatic breakdown of starch provides some food for the yeast (Kulp 1973). However, in soft wheat products, the increased water absorption associated with increased levels of damaged starch can be detrimental to product quality.

Quality evaluation tests of soft wheat grain and flour

Quality tests on soft wheat grain include determining test weight, break flour yield, and kernel texture. Test weight is a measure of the weight of grain per unit volume (AACC 2000). Higher test weights are generally correlated with greater milling flour yield (Gaines et al. 1997). Break flour yield is the weight of the flour produced by the break rolls relative to the weight of all products obtained from the combined break and reduction rolls. Softer wheat grain produces more break flour. Higher break flour yields are particularly important for soft wheat products, because of the desire for flour with finer particle size and lower starch damage (Ng et al. 2007). Particle size index and single kernel characterization system (SKCS, Perten Instruments, Huddinge, Sweden) (AACC 2000) is a widely used measure of hardness. A softer wheat passes more of the meal through the sieve. Additionally, the SKCS measures the force required to crush
kernels and reports the average value for 300 kernels.

Quality of soft wheat flours are typically tested for proximate composition along with various chemical measurements (moisture, ash, protein, sprout damage, polyphenol oxidase, alkaline water retention capacity and solvent retention capacity), rheological properties (mixograph and alveograph), and baking tests (sugar-snap cookie and sponge cake).

The moisture content of flour is determined from the difference in weight of a sample before and after drying in an air oven (AACC 2000). Flour ash contents can be determined by incinerating a flour sample in a muffle furnace, leaving only the ash (AACC 2000), and are typically below 0.5%. Protein content is typically determined indirectly through measuring nitrogen content by methods such as Kjeldahl and combustion (AACC 2000). Sprout damage is caused by increased amounts of α-amylase activity. High levels of α-amylase are found in grain that has begun to germinate because of exposure to moisture before harvest. This enzyme reduces soft wheat flour quality by hydrolyzing the α-1,4-linked glucose molecules of starch. The α-amylase activity in flour can be measured by colorimetric method (AACC 2000), the falling number system (Perten Instruments, Huddinge, Sweden), amylograph (C.W. Brabender Instruments, Inc., South Hackensack, NJ) and rapid visco analyzer (RVA, Newport Scientific Pty. Ltd., Warriewood, Australia) (AACC 2000). Wheat with a falling number value below 300 and low peak viscosity of amylograph and RVA are suspected to have some sprout damage (Kaldy
and Rubenthaler 1987). The level of damaged starch can be measured by incubating a flour sample with $\alpha$-amylase, followed by measurement of the reducing sugars or glucose that are produced (AACC 2000). Damaged starch of soft wheat flour is typically below 3%. Polyphenol oxidase (PPO) is widely recognized as being responsible for browning of wheat food products. PPO activity is measured by incubating flour with a substrate (L-DOPA) and monitoring the color change spectrophotometrically (AACC 2000). PPO levels differ due to both genotype and growth environment (Baik et al 1994; Park et al 1997). Alkaline water retention capacity (AWRC) is defined as the amount of alkaline water held by the flour against a centrifugal force (AACC 2000). Lower AWRC of soft wheat is considered to be of good quality in cookie diameter (Yamazaki 1953). However, the relationship is not clear for distinguishing among soft and hard flours (Kitterman and Rubenthaler 1971). The solvent retention capacity (SRC) of wheat flour is defined as the amount of water, 50% sucrose, 5% sodium carbonate, or 5% lactic acid solvent held by the flour against a centrifugal force (AACC 2000) as determined by four solvents independently established to predict commercial flour properties (AACC 2000). In general, water SRC is affected by all flour constituents, sucrose SRC is associated with pentosan characteristics, sodium carbonate SRC is associated with the level of damaged starch, and lactic acid SRC is associated with glutenin characteristics (Gaines 2000).

Rheology with regard to wheat flour is the measure of the flow and deformation of
doughs. Dough-forming properties of flours are commonly evaluated using the alveograph (Chopin Technologies, Villeneuve-la-Garenne Cedex, France), the mixograph (National Manufacturing, Lincoln, NE), and the farinograph (C.W. Brabender Instruments, Inc., South Hackensack, NJ). Dough rheological instruments were originally designed for use with materials such as bread doughs, where strength and elasticity are valued. Soft wheat flour products, however, generally require doughs that are weaker (Hoseney et al 1988). The alveograph measures air pressure inside of a dough bubble as it is inflated until it bursts (AACC 2000), allowing for the measurement of the maximum overpressure (P), which relates to the resistance of dough to deformation, and the average length of the curve baseline at rupture (L), which is a measure of dough extensibility. The deformation energy (W) is a measure of the energy needed to inflate the dough and is derived from the area under the curve. W is related to flour strength (Faridi and Rasper 1987). In soft wheat products, Nemeth et al (1994) found that P and P/L were significantly correlated with sugar-snap cookie spread and score, and Yamamoto et al (1996) found that alveograph P was negatively correlated and L positively correlated with Japanese sponge cake volume. Both mixograph and farinograph give information regarding optimum dough water absorption, strength, mixing time, and tolerance to overmixing (AACC 2000). Yamamoto et al (1996) reported a negative correlation between cookie diameter and mixograph peak height, a positive correlation between cookie diameter and mixograph peak time, and
negative correlation between cookie diameter and farinograph water absorption.

The sugar-snap cookie baking test (AACC 2000) and the sponge cake baking test (Nagao et al 1976) are usually used to evaluate soft wheat baking quality in the United States (Gaines 2004; Choi et al 2012). Soft wheat flours that produce cookies with larger spread and softer texture, and sponge cakes with large volume and fine crumb structure are favored.

Researchers use these methods to better understand how flour affects end-use quality, and potential buyers need to know wheat flour quality for their needs.

Quality requirements of soft wheat for cookie and cake

Sugar-snap cookies made from hard wheat flour are usually thicker, harder in texture, and have a smaller diameter (Miller and Hoseney 1997). Yamamoto et al (1996) reported that sugar-snap cookie diameter was negatively correlated with protein content. However, some studies have found a poor correlation between cookie quality and protein content (Abboud et al 1985; Yamazaki 1954). However, the differences in protein content alone were not enough to fully explain the differences in cookie quality between the hard and soft wheat flour groups. Glutenin strength score was negatively correlated with cookie diameter (Souza et al 1994). A faster spread rate allows the cookie to spread to a larger diameter before setting occurs. Lower levels of soluble starch and damaged starch of soft wheat flours than for those of hard wheat flours were
attributed to being part of the large spread rate (Miller and Hoseney 1997). Pentosans also affect cookie quality with their ability to absorb large amounts of water. The amount of total pentosans had a negative correlation with sugar-snap cookie spread (Bettge and Morris 2000; Yamazaki 1955).

Cake batters are aerated emulsions that expand during baking and set into a soft, porous gel (Shelke et al 1990). The particle sizes of various soft wheat flours have been negatively correlated to cake volume (Yamamoto et al 1996; Yamazaki and Donelson 1972). Soft wheat flour high in protein or with strong gluten results in cakes with lower volume and coarser texture (Kaldy and Rubenthaler 1987; Yamamoto et al 1996). According to Takeda (1994), extraction of free flour lipids from flour reduced the volume of sponge cake. The polar lipids (monogalactosyl and digalactosyl diglycerides) had major effects on the cake volume, while the nonpolar fractions had only minor effects. The batter viscosity of sponge cake was inversely correlated with sponge cake volume (Nakamura et al 2010). Nishio et al (2009, 2011) reported that high amylose content of flour produced a sponge cake of large volume. Soft wheat flour of low protein, fine particle size and high amylose content is therefore believed to be suitable for making sponge cake, while those traits do not fully explain variation in soft flour end-use quality, nor is a quality profile of wheat flour for sponge cake available.
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CHAPTER 2.

IMPROVEMENT OF SPONGE CAKE BAKING TEST PROCEDURE

FOR SIMPLE AND RELIABLE ESTIMATION OF

SOFT WHITE WHEAT QUALITY
2.1. ABSTRACT

The sponge cake (SC) baking test is accepted and routinely used as a standard quality evaluation tool of soft white wheat for Asian markets, but its lengthy and laborious procedure makes it unsuitable for the routine evaluation of a large number of wheat breeding lines. We simplified the SC baking procedure in the egg whipping step and improved its consistency by replacement of the hand mixing of cake batter with mechanical mixing, using a wire whisk or a Beater Blade®. Egg whipping and mechanical batter mixing conditions were optimized by comparing foam density, and sponge cake volume and crumb grain to those obtained by the conventional procedure. Foam density, and sponge cake volume and crumb grain comparable to the conventional 100 g flour procedure were obtained with modifications, including extension of whipping time without heat input using a 5-liter KitchenAid® mixer, one time water addition at 3 min before the completion of egg whipping instead of twice, as in the conventional procedure, and cake batter mixing using a KitchenAid® wire whisk or a Beater Blade®. For baking a 50 g flour cake, egg foam of appropriate density was obtained with increased whipping speed and shortened egg whipping time to 8 min. The modified SC baking procedure yielded egg foam density, and cake volume and crumb grain similar to the conventional procedure and effectively differentiated soft wheat flours of different quality. Sponge cake volume of fourteen soft white wheat flours ranged from 1134 to 1426 mL with the conventional procedure, from 1113 to 1333
mL with the modified procedure of batter mixing using a wire whisk, from 1108 to 1360 mL with the modified procedure of batter mixing using a Beater Blade®, and from 577 to 719 mL with the modified method of 50 g flour and batter mixing using a wire whisk. The modified methods of Beater Blade® and wire whisk exhibited significant correlation to cake volume with a conventional procedure (r = 0.931, P < 0.001, r = 0.925, P < 0.001, respectively).
2.2. INTRODUCTION

Soft white wheat grown in the Pacific Northwest states of the U.S.A. is largely exported to Asian countries, where it is used for making cookies, cakes, noodles, snacks and pastries. In general, evaluation of soft wheat quality is conducted by considering wheat kernel hardness, flour yield and break flour yield, protein content, ash content, solvent retention capacity, sugar snap cookie bake test, and sponge cake bake test (Hoseney et al 1988; Summu and Shin 2008). Compared to hard wheat flour, soft wheat flour is characterized by relatively low protein content, weak protein strength, fine flour particle size, and low damaged starch content (Rosers et al 1993). Soft wheat grain of low protein content and low kernel hardness yields a high proportion of break flour during milling and flour of fine particle size and is desired for producing a variety of soft wheat products. Soft wheat flour of superior quality is expected to produce sugar-snap cookies of large diameter and sponge cake of large volume and fine, even crumb structure.

Sponge cake (SC) is a popular soft white wheat product in Japan and Korea. Generally, flour of fine particle size and low protein content is desirable for production of sponge cakes of high quality (Nagao et al 1976; Nagao et al 1977; Kaldy et al 1991; Yamamoto et al 1996; Nishio et al 2009). However, those traits do not fully explain the variation in soft flour end-use quality, nor is the quality profile of wheat flour for sponge cake available. The SC baking test provides a reliable estimation of overall end-use quality of soft white wheat for Asian markets, and it is
widely accepted as a standard quality test (Nagao et al 1976). The SC baking test is, however, lengthy and laborious, requiring experienced personnel who can conduct the test with accuracy and reliability, which makes it unsuitable for the routine evaluation of a large number of wheat breeding lines.

The objective of this study was to improve the simplicity and reliability of the SC baking test. We attempted to simplify the SC baking procedure by adopting a continuous mechanical process of egg foam whipping and batter mixing for a single cake, rather than a large batch preparation of egg foam sponge, division of sponge for each cake, and batter mixing by hand, as in the conventional procedure. The modified procedure would also eliminate concerns associated with foam volume decrease for each successive cake in a batch and the inconsistency of hand-batter mixing in the conventional procedure. Egg foam whipping, mechanical batter mixing and 50 g flour cake baking conditions were optimized by comparing egg foam density and sponge cake volume to those of the conventional procedure.

2.3. MATERIALS AND METHODS

2.3.1. Materials

Wheat flour of thirteen soft wheat cultivars (Diva, Louise, BZ604-002, BZ6M06-1001, IDO599, IDO644, Alturas, OR2040726, OR2060395, Stephens, 98-19010A, Brundage96, and
KWP006) milled from grain harvested in 2009 using a Miag mill to a straight grade was provided by the U.S. Department of Agriculture, Agricultural Research Service Western Wheat Quality Laboratory (WWQL, Pullman, WA). A sponge cake standard flour, consisting of about 60% extraction flour milled from a blend of elite soft white and club varieties, was also provided by the WWQL.

The protein content (N × 5.7) of flour was determined using a Leco FP-528 nitrogen analyzer (Leco Co., St. Joseph, MI) equipped with a thermoconductivity detector (AACC Methods 46-30). Ash content of flour was measured according to the approved AACC Methods 08-01 (AACC International 2000). Protein and ash contents of all flours ranged from 6.5 to 10.4% and 0.38 to 0.53%, respectively. Fresh eggs were purchased from a local grocery and cracked to obtain whole eggs. Pure cane baker’s special sugar (C&H sugar company, Crockett, CA) was used for the sponge cake baking test.

2.3.2. Conventional Sponge Cake Baking Test

The conventional procedure of sponge cake baking test (Nagao et al. 1976) is shown in Figure 2.1. To prepare egg foam in the conventional procedure, whole fresh eggs (700 g) and sugar (700 g) were hand-mixed using a whisk in a 12-L stainless steel bowl of the Hobart mixer (Hobart, Co., Troy, OH) to obtain a homogenous blend and then the mixture was warmed to 41°C
in a 50°C water bath to completely dissolve the sugar in the whole eggs. The egg-sugar mixture was continuously whipped for 0.5 min on low speed, for 5.75 min on high speed, and for 0.5 min on low speed using the Hobart mixer equipped with a wire whisk, with the application of heat to the mixing bowl using heat guns to maintain warmth throughout the entire whipping process. During egg-sugar whipping, 50°C water (140 mL) was added twice, at 3.75 min and 4.75 min. After whipping for a total of 6.75 min, egg foam density was checked for the desired egg foam density of 24.5-25.5 g/100 mL. Egg foam density was measured with a 100 g specific gravity cup (Magnuson Engineers, Inc., San Jose, CA). If egg foam density fell out of the target range, whipping time on high speed in a new batch of egg and sugar was adjusted to achieve the desired density. This step was necessary to prepare a consistent property of egg foam from fresh eggs of varying quality. The whipped egg foam was divided into 4-5 portions of 240 g. Sifted flour (100 g) was incorporated into each portion of egg foam by gently folding the batter 40 times, and then quickly mixing 40 times manually using a wooden rice scoop. The batter was poured into a round cake pan of 15.2 cm diameter and 5.7 cm height, and then baked at 190°C for 35 min. The cake was removed immediately from the pan after baking and cooled at room temperature (25.6°C) for 24 hr. The volume of the sponge cake was determined by rapeseed displacement. Sponge cake was cut in half vertically using a knife for visual examination of crumb fineness and uniformity. The formula for making a sponge cake includes flour (100 g, as-is moisture), sugar
(100 g), fresh whole egg (100 g, without shell), and water (40 mL). Sponge cake was baked for all 14 wheat flours using the conventional test procedure described above, volume was determined and visually examined for internal crumb structure.

2.3.3. Modifications of Sponge Cake Baking Procedure

To improve the efficiency and reliability of the SC baking test, possibilities of omitting heat input during egg whipping, practicing one time water addition instead of twice, adopting a 5-L KitchenAid mixer (KitchenAid, Troy, OH) instead of 12-L Hobart mixer, mechanical batter mixing instead of hand mixing, and reducing the formula for baking 50 g flour cake instead of 100 g cake were considered. A procedure of continuous egg foam whipping and batter mixing in the same bowl was tested with the adoption of a 5-L KitchenAid mixer and single cake formula. This procedure will eliminate the step of transferring and dividing egg foam, and also minimize the egg foam breakdown that commonly occurs in the conventional procedure. The egg-sugar mixture whipping and batter mixing conditions in the modified procedure were optimized based on egg foam density and sponge cake volume in comparison to the conventional procedure using the standard sponge cake flour. Egg whipping, batter mixing and baking were all conducted at constant room temperature of 25.6°C. At least two replicates were performed for egg foam density and sponge cake volume determinations. To determine the validity of the intended
modifications in egg whipping and batter mixing, and to identify the optimum conditions, the following five independent experiments were performed. Egg foam density was determined. Cake volume was determined and examined for internal crumb grain characteristics, as described previously. Both egg foam density and cake volume were used to determine the validity of the modifications and to identify the optimum egg whipping and batter mixing conditions.

1) To simply the egg foam whipping step, we examined the possibility of omitting heat input during egg whipping. Whole egg (700 g) and sugar (700 g) were placed in a 12-L stainless steel bowl of a Hobart mixer and then hand-blended using a wire whisk to obtain a homogenous blend while warming to 41°C in a 50°C water bath. The egg-sugar mixture was whipped for 0.5 min on low speed initially, for 5.75, 6.75, or 7.75 min on high speed, and then for 0.5 min on low speed in a Hobart mixer at 25.6°C without application of heat to achieve the desired foam density. During the egg-sugar whipping, water (50°C, 140 mL) was added twice at 2.5 min and 1.5 min before the completion of whipping on high speed. Egg foam was determined for density and baked into sponge cake following the conventional procedure. Egg foam density and cake volume were compared to those of the conventional procedure.

2) The possibility of adding water once instead of twice during egg whipping was tested. Whole egg (700 g) and sugar (700 g) were placed in a 12-L stainless steel bowl of a Hobart mixer and then hand-blended using a wire whisk to obtain a homogenous blend while warming
to 41°C in a 50°C water bath. The egg-sugar mixture was whipped for 0.5 min on low speed initially, for 6.75 min on high speed, and then for 0.5 min on low speed in a Hobart mixer without application of heat to achieve the desired foam density. During the egg-sugar whipping, 50°C water (280 mL) was added at 0 min, 4.75 min, 5.75 min, or 7.75 min. Egg foam density and cake volume were determined and compared to those of the conventional procedure.

3) To achieve a sponge cake baking procedure of continuous egg-sugar mixture whipping and batter mixing in the same bowl with no need for transferring and partitioning the batter, a 5-L KitchenAid mixer was adopted to prepare egg foam and then batter for a single cake. Whole egg (100 g) and sugar (100 g) in a 5-L stainless steel bowl were hand-blended using a whisk to obtain a homogenous blend while warming to 41°C in a 50°C water bath. The egg-sugar mixture was continuously whipped for 5.5, 6.5, 7.5, 8.5, 9.5, 10.5, or 11.5 min on speed level 6, and for 0.5 min on speed level 1 without heat input, in order to identify the optimum whipping time. During the egg-sugar whipping, water (50°C, 40 mL) was added at 3 min before completion of the procedure. Egg foam density was determined and mixed with wheat flour (100 g) by hand to prepare the batter, baked and evaluated for volume and internal crumb characteristics following the conventional procedure.

4) To replace the hand batter mixing in the conventional procedure by using mechanical means, a wire whisk or Beater Blade® attached to a 5-L KitchenAid mixer were tested for their
performance. The Beater Blade® resembles a regular paddle, but it is covered with silicon and features flexible rubber wings on the edge, which allows thorough mixing of batter by scraping the sides and bottom of the mixing bowl. Whipped egg mixture in a 5-L bowl of a KitchenAid mixer was determined for density, and gently sprinkled with flour and mixed using a wire whisk at a speed level of 4 for 10, 15, 20, or 25 sec, or a Beater Blade® at speed level 1 and 4 each for 10 sec. The batter was then baked following the conventional procedure. Cake volume was determined and examined for internal crumb grain characteristics.

5) To develop a 50-g flour sponge cake baking procedure, whole egg (50 g) and sugar (50 g) in a 5-L stainless steel bowl of a KitchenAid mixer were hand-mixed using a whisk to obtain a homogenous blend while warming to 41°C in a 50°C water bath. The egg-sugar blend was whipped for 7, 7.5, 8, or 9 min on speed level 8, and for 0.5 min on speed level 1 without heat input to identify the optimum whipping time. When 3 min remained for total egg whipping, 50°C distilled water (20 mL) was added. Upon completion of whipping, egg foam density was determined and was sprinkled with flour (50 g) and mixed on speed level 4 for 15 sec with a wire whisk. The batter was baked following the conventional procedure using a round cake pan of 10.2 cm diameter and 6.4 cm height. Cake was evaluated for volume and internal crumb characteristics.
2.3.4. Sponge Cake Baking Using the Modified Procedures

All 14 wheat flours were tested for their cake baking quality using the modified procedures. The whole eggs (100 g) and sugar (100 g) blend was warmed to 41°C and whipped for 9.5 min on speed level 6 and for 0.5 min on speed level 1 without additional heat input. Water (50°C, 40 mL) was added to the egg foam at 7 min during the egg-sugar whipping. The egg foam was mixed with wheat flour (100 g) using a wire whisk for 15 sec on speed level 4 or a Beater Blade® for each 10 sec on speed level 1 and 4 to prepare the batter, and then baked following the conventional procedure. Cake volume and internal crumb grain characteristics were determined as described previously. Sponge cakes were also baked from all 14 flours using the 50 g flour baking procedure, with egg whipping time of 8 min and cake volume and crumb grain characteristics determined.

2.3.5. Statistical Analysis

Egg foam density and cake volume data were expressed as the mean of at least two replicates. Data were subjected to analysis of variance, Fisher’s least significant difference test at a significance level of 0.05, and Pearson correlation analysis using the Statistical Analysis System (SAS Institute, Cary, NC).
2.4. RESULTS AND DISCUSSION

2.4.1. Whipping Egg Foam Without Heat Input

The possibility of whipping the egg-sugar blend without warming the bowl using a heat gun during egg whipping was explored. To compensate for the loss of heat input, the approach of extending whipping time was taken in order to identify whipping time that provides comparable egg foam density and sponge cake volume in the conventional procedure. Nagao et al. (1976) reported the desired egg foam density of 25.0 g/100 mL at 30°C. The egg foam density and sponge cake volume for 6.75 min whipping time with heat input (conventional method) and those for 6.75 min, 7.75 min, and 8.75 min whipping time without heat input are summarized in Table 2.1.

When the same whipping time was applied, egg foam density was greater without heat input than with heat input. Egg foam density decreased to an acceptable 25.4 g/100 mL when whipping time was extended to 7.75 min without heat input, a value comparable to that achieved with the conventional procedure. Further extending whipping time to 8.75 min resulted in increased foam density of 26.5 g/100 mL. The temperature of egg was 41.0°C just before whipping, and the egg foam temperature decreased to 32.0°C during whipping for 6.75 min with heat input. On the other hand, without heat input, the egg foam temperature decreased to 28.0 and 27.0°C with 7.75 and 8.75 min whipping, respectively. The increase in whipping time from
6.75 to 7.75 min lowered egg foam density, probably by creation of more foam, despite the decrease in foam temperature. The increase in egg foam density with whipping time of 8.75 min could have resulted from further decrease in foam temperature without creation of more foam and partial breakage of egg foam. Even with different egg foam densities and temperatures, the volumes of cakes baked from egg foam whipped without heat input for 6.75, 7.75, and 8.75 min were not significantly different from each other and were also similar to the volumes of cakes baked with the conventional procedure. The sponge cake volume was 1373 mL with the conventional procedure and ranged from 1375 to 1420 mL using egg foam whipping without heat input. Sponge cakes produced with or without heat input and varying whipping time exhibited very similar crumb grain uniformity and fineness. It appears that the mechanical force of whipping was able to be substituted for heat input during egg foam whipping. Omission of heat input using a heat gun would make the egg foam whipping process more convenient than the conventional procedure of egg whipping because it would not be necessary for an experimenter to operate the heat gun.

2.4.2. Timing of water incorporation during egg foam whipping

In order to identify the appropriate time of one-time water incorporation, water (280 mL) was added to the egg foam at 0, 4.75, 5.75, or 7.75 min during whipping (Table 2.2). Whipping
the egg-sugar mixture for 7.75 min without heat input and with 140 mL water additions at 4.75 min and 5.75 min resulted in egg foam density of 25.4 g/100ml and SC volume of 1389 mL, which served as target values for the modified water incorporation procedure. The density of egg foam prepared with one-time water addition was lowest when water was incorporated before whipping and increased consistently as the time of addition was delayed to 7.75 min during whipping. The target density of egg foam (25.4 g/100 mL) was achieved with the water addition time of 4.75 min (Table 2.2). With the exception of adding water at 0 min, which produced a significantly smaller volume of cake than in other cases, there were no differences in cake volume and crumb grain characteristics among different water addition times, including the control (Table 2.2). One-time water addition at 4.75 min during whipping resulted in comparable egg foam density, cake volume, and crumb grain to results obtained with two-time water addition.

2.4.3. Egg whipping with a 5-L KitchenAid mixer

In the conventional procedure, two people are needed to divide the egg foam and incorporate the flour in preparation of the batter; while one individual divides the whipped egg foam into 4-5 portions of 240 g, the other person incorporates sifted flour (100 g) into each portion of egg foam. The cake volume for each successive cake prepared from the same batch of egg foam, however, tends to decrease over time due to the partial breakage of egg foam over
time. This situation often necessitates an adjustment of the measured volume of cakes prepared from the same batch of egg foam, especially when cakes are prepared at high altitude, in which case the egg foam appears to be less stable.

When whipping egg-sugar mixture for just a single cake using a 5-L mixer, there is no need to divide the egg foam as in the conventional procedure of batch preparation of egg foam, and less need for concern about egg foam stability. Whipping of the egg-sugar mixture for 7.75 min without heat input using a Hobart mixer with a 12-L stainless steel bowl and with one-time water addition of 280 mL at 4.75 min produced egg foam of 25.0 g/100 mL density and cake of 1390 mL in volume, which served as the target values for the modified whipping procedure with use of a KitchenAid 5-L mixer. As whipping time increased from 6 to 12 min, egg foam density consistently increased from 23.7 to 26.1 g/100 mL with decrease in egg foam temperature from 27.0 to 24.0°C, respectively (Table 2.3). As expected, much lower foam temperature was observed with 100 g eggs whipped in a 5-L bowl than for 700 g eggs whipped in a 12-L bowl for comparable whipping time. This increase in egg foam density could be caused by the decrease in foam temperature and/or breakage of large bubbles. Sponge cake volume increased from 1103 mL at 6 min whipping to 1333 mL at 10 min, and then leveled off with further whipping (Table 2.3). A 10 min whipping of egg in a KitchenAid mixer yielded the egg foam of 24.7 g/100 mL density and produced sponge cake of 1333 mL, which is comparable to both results obtained
The sponge cakes baked with 6 to 8 min egg foam whipping exhibited more open and uneven crumb structure than others, whereas those baked with egg whipping for 9 to 12 min were similar in crumb grain characteristics and comparable to those of conventional procedures. This finding indicates that the 5-L mixer could be used as a replacement for the 12-L mixer with production of comparable density of egg foam, and volume and crumb grain of sponge cake.

2.4.4. Cake batter mixing using a wire whisk and a Beater Blade®

Table 2.4 summarizes the volume of sponge cakes prepared using baking procedures in which cake batter mixing was performed either manually using a wooden rice scoop or mechanically using a wire whisk or a Beater Blade®. Manual batter mixing requires skillful personnel in order to achieve reproducibility in cake volume. To reduce inconsistency in cake volume caused by human error, an objective mechanical way to prepare cake batter was explored, using a wire whisk or a Beater Blade®. The egg-sugar mixture was whipped for 7.75 min without heat input using a Hobart mixer in a 12-L stainless steel bowl and with the addition of water (280 mL water) at 4.75 min. The prepared egg foam was incorporated with wheat flour by hand mixing to prepare cake batter, which produced SC of 1363 mL in volume and served as the target value for the modified batter mixing.
Batter mixing using a wire whisk for 15 sec at speed level 4 produced the highest volume (1362 mL) of cake, although there were no significant differences in cake volume among batter mixing times of 10, 15 and 20 sec. Cake volume decreased to 1290 mL as mixing time increased to 25 sec. Batter mixing using a Beater Blade® for 10 sec at speed level 1 and for 10 sec at speed level 4 produced sponge cake of 1380 mL in volume. Mechanical batter mixing using a wire whisk for 15 sec or a Beater Blade® produced a comparable volume and crumb grain of sponge cake to the conventional hand batter mixing.

2.4.5. Sponge cake baking test procedure of 50 g flour

The amount of flour is limited in the end-use quality evaluation of wheat breeding lines, especially in the early generation. Cake baking test procedures requiring only 50 g flour, instead of 100 g flour as in the conventional procedure, would make it possible to apply the test of the earlier generation breeding lines.

The whipping of the egg (100 g) and sugar (100 g) blend for 10 min without heat input using a KitchenAid mixer in a 5-L stainless steel bowl and with addition of water (40 mL) at 7 min produced egg foam of 24.7 g/100 mL in density, served as the target value for the 50 g flour modified procedure. The egg (50 g)-sugar (50 g) blend, whipped for 9 min on speed level 6, and for 0.5 min on speed level 1 with 50°C water (20 mL) addition at 6.5 min, did not produce egg
foam. As whipping time increased from 7 to 9 min on speed level 8 (7.5-9.5 min total whipping time), egg foam density consistently increased from 24.2 to 27.8 g/100 mL (Table 2.5). An 8 min whipping of egg in a KitchenAid mixer yielded an egg foam of 25.0 g/100 mL density, which is comparable to those obtained with the control procedure (Table 2.5). SC volume of 14 flours based on the 50 g procedure ranged from 577 to 719 mL (Figure 2.2C.). Although cakes baked using the 50 g procedure exhibited similar trends in volume among 14 flours to those baked using the 100 g procedures; volume differences between flours became smaller, diminishing the differentiating power of the test.

2.4.6. Comparison Between Modified and Conventional Procedures

Figure 2.2. shows the relationship between conventional and modified procedures in sponge cake volume. Correlation coefficient between the conventional procedure and the modified procedure was 0.925 ($P < 0.001$) for batter mixing with a wire whisk, 0.931 ($P < 0.001$) for batter mixing with a Beater Blade®, and 0.769 ($P < 0.01$) for the 50 g flour procedure. The modified procedures for batter mixing using a wire whisk or a Beater Blade® were identified to produce sponge cakes of similar volume to the conventional procedure and to effectively differentiate wheat flours possessing different sponge cake baking potentials.
2.5. CONCLUSION

Egg foam for making sponge cake can be whipped to a comparable density with extension of whipping time, without heat input. Incorporation of water during egg whipping can be reduced to one time instead two times without negatively affecting egg foam density, and sponge cake volume and crumb grain. Use of a 5-L KitchenAid mixer instead of a 12-L Hobart mixer, used in the conventional test, can be adopted for preparing egg foam of comparable density and, eventually, comparable SC volume and crumb grain. Sponge cake batter mixing can be achieved using a Beater Blade or a wire whisk instead of manual hand mixing without significantly decreasing cake volume. The modified procedure with adoption of a 5-L mixer for egg whipping and flour incorporation, no heat input and one time water addition during egg foam whipping, and flour batter mixing using a wire whisk or a Beater Blade®, yielded comparable volume and crumb grain of SC compared to the conventional procedure.

2.6. ACKNOWLEDGEMENT

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2.7. BIBLIOGRAPHY


Method 8-1. The Association: St.Paul, MN.


<table>
<thead>
<tr>
<th>Heat Input</th>
<th>Whipping Time&lt;sup&gt;b&lt;/sup&gt; (min)</th>
<th>Egg Foam Density (g/100 mL)</th>
<th>Cake Volume (mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>With&lt;sup&gt;c&lt;/sup&gt;</td>
<td>6.75</td>
<td>25.0d</td>
<td>1373a</td>
</tr>
<tr>
<td>Without</td>
<td>6.75</td>
<td>26.7a</td>
<td>1375a</td>
</tr>
<tr>
<td></td>
<td>7.75</td>
<td>25.4c</td>
<td>1389a</td>
</tr>
<tr>
<td></td>
<td>8.75</td>
<td>26.5b</td>
<td>1420a</td>
</tr>
</tbody>
</table>

<sup>a</sup>Values are means (n=2) and different letters in the same column are significantly different (<i>P</i> < 0.05).

<sup>b</sup>Egg was whipped using a Hobart mixer with a 12 L bowl. Whipping time includes an initial 0.5 min on low and a final 0.5 min on low; the remainder was on high.

<sup>c</sup>Conventional procedure.
Table 2.2 Effects of water addition time during egg whipping on foam density and sponge cake volume\(^a\)

<table>
<thead>
<tr>
<th>Water Addition</th>
<th>Time of Water Addition (min)</th>
<th>Egg Foam Density (g/100 mL)</th>
<th>Cake Volume (mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Twice(^b)</td>
<td>4.75 &amp; 5.75</td>
<td>25.4c</td>
<td>1389a</td>
</tr>
<tr>
<td>Once</td>
<td>0</td>
<td>22.1d</td>
<td>1268b</td>
</tr>
<tr>
<td></td>
<td>4.75</td>
<td>25.0c</td>
<td>1390a</td>
</tr>
<tr>
<td></td>
<td>5.75</td>
<td>28.7b</td>
<td>1370a</td>
</tr>
<tr>
<td></td>
<td>7.75</td>
<td>30.6a</td>
<td>1330a</td>
</tr>
</tbody>
</table>

\(^{a}\)Values are means (n=4) and different letters in the same column are significantly different (\(P < 0.05\)). Egg was whipped using a Hobart mixer with a 12 L bowl without heat input.

\(^{b}\)Egg was whipped for 7.75 min (0.5 min on low, 6.75 min on high, and 0.5 min on low) with two water additions, 140 mL each time, and without heat input.
Table 2.3 Effects of egg whipping time on foam density and sponge cake volume prepared using mixers of different capacity.

<table>
<thead>
<tr>
<th>Mixer Type</th>
<th>Whipping Time (min)</th>
<th>Egg Foam Density (g/100 mL)</th>
<th>Cake Volume (mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12-L mixer</td>
<td>7.75</td>
<td>25.0b</td>
<td>1390a</td>
</tr>
<tr>
<td>5-L mixer (speed: L6 + L1)</td>
<td>6</td>
<td>23.7d</td>
<td>1103d</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>23.7d</td>
<td>1185c</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>23.7d</td>
<td>1253bc</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>24.2cd</td>
<td>1313ab</td>
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<td>10</td>
<td>24.7bc</td>
<td>1333ab</td>
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<td></td>
<td>11</td>
<td>25.7a</td>
<td>1330ab</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>26.1a</td>
<td>1315ab</td>
</tr>
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</table>

aValues are means (n=4) and different letters in the same column are significantly different (P < 0.05).

bProvided target values. Egg-sugar mixture was whipped for 7.75 min (0.5 min on low, 6.75 min on high, and 0.5 min on low) without heat input with a Hobart mixer with a 12-L stainless steel bowl and with an one-time water addition of 280 mL at 4.75 min; 700 g of egg and 700 g of sugar were used.

cKitchenAid stand mixer; 100 g of egg and 100 g of sugar were used. Whipping time includes a final 0.5 min on level 1.
Table 2.4 Volume of sponge cake prepared by hand batter mixing or mechanical batter mixing using KitchenAid stand mixer with a wire whisk or Beater Blade® attached\(^a\)

<table>
<thead>
<tr>
<th>Batter Mixing Method</th>
<th>Speed</th>
<th>Mixing Time (sec)</th>
<th>Cake Volume (mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hand(^b)</td>
<td>40 slow + 40 fast</td>
<td>-</td>
<td>1363(^a)</td>
</tr>
<tr>
<td>Wire Whisk</td>
<td>Level 4</td>
<td>10</td>
<td>1325(^ab)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>15</td>
<td>1362(^a)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20</td>
<td>1310(^ab)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>25</td>
<td>1290(^b)</td>
</tr>
<tr>
<td>Beater Blade®(^c)</td>
<td>Level 1 &amp; 4</td>
<td>10 each</td>
<td>1380(^a)</td>
</tr>
</tbody>
</table>

\(^a\)Values are means (n=2) and different letters in the same column are significantly different (\(P < 0.05\)).

\(^b\)Conventional procedure.

\(^c\)Paddle covered with silicon and with attached flexible rubber wings along the edge, which allows through mixing of batter by scraping the sides and bottom of the mixing bowl.
Table 2.5 Effects of egg whipping time on foam density prepared using the 5-L mixers with 50 g egg, 50 g sugar, and 20 mL water.

<table>
<thead>
<tr>
<th>Mixer Type (speed)</th>
<th>Whipping Time (min)</th>
<th>Egg Foam Density (g/100 mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5-L mixer (speed: L6 + L1)</td>
<td>10</td>
<td>24.7bc</td>
</tr>
<tr>
<td>5-L mixer (speed: L8 + L1)</td>
<td>7.5</td>
<td>24.2c</td>
</tr>
<tr>
<td></td>
<td>8.0</td>
<td>25.0bc</td>
</tr>
<tr>
<td></td>
<td>8.5</td>
<td>26.5ab</td>
</tr>
<tr>
<td></td>
<td>9.5</td>
<td>27.8a</td>
</tr>
</tbody>
</table>

Values are means (n=2) and different letters in the same column are significantly different (P < 0.05).

Provided target values. Egg-sugar mixture was whipped for 10 min (9.5 min on level 6, and 0.5 min on level 1) without heat input with an one-time water addition of 40 mL at 7 min; 100 g of egg and 100 g of sugar were used. KitchenAid stand mixer.

KitchenAid stand mixer; 50 g of egg and 50 g of sugar were used. Whipping time includes a final 0.5 min on level 1.
### Figure 2.1. Diagrams for sponge cake baking test with 100 g of flour following the conventional procedure (A) and modified procedure (B).
Figure 2. Correlations between conventional and modified sponge cake baking procedures in volume of cake. Cake batter from the modified procedures was mixed using a wire whisk (A), or a Beater Blade® (B) with 100 g flour. Sponge cake made with 50 g of flour (C) was prepared with batter mixing using a wire whisk. ** and *** indicate significance at P < 0.01 and 0.001, respectively.
CHAPTER 3.

SIGNIFICANCE OF PARTICLE SIZE ON SPONGE CAKE BAKING QUALITY OF WHEAT FLOUR
3.1. ABSTRACT

We evaluated the effect and magnitude of flour particle size on sponge cake baking quality. Two different sets of wheat flours, including flours of reduced particle size obtained by re-grinding and flour fractions of different particle size separated by sieving, were tested for batter properties and sponge cake baking quality. The proportion of small particles (<55 µm) of flour was increased by 11.6-26.9% by re-grinding. Despite the increased sodium carbonate retention capacity, which was probably a result of the increased starch damage and particle size reduction, re-ground flour exhibited little change in density and viscosity of flour-water batter, and produced sponge cake of improved volume by 0.8-15.0%. The volume of sponge cake baked from flour fractions of small (< 55 µm), intermediate (55-88 µm) and large (> 88 µm) particles of soft and club wheat ranged from 1353 to 1450, 1040 to 1195, and 955 to 1130 mL, respectively. Even with comparable or higher protein content, flour fraction of intermediate particle size produced larger volume of sponge cake than flour fractions of large particle size. The flour fractions of small particle size in soft white and club wheat exhibited lower flour-water batter density (102.6-105.9 g/100 mL) than did those of large and intermediate particle fractions (105.2-108.2 g/100 mL). The viscosity of flour-water batter was lowest in flour fractions of small particle size, higher in intermediate particles and highest in large particles.
3.2. INTRODUCTION

Endosperm hardness is an important quality characteristic of wheat. Kernel hardness of soft wheat grain determined using a single kernel characterization system (SKCS) is expected to be lower than 50, but lower than 30 in most of the elite soft white wheat varieties. With soft endosperm texture, soft wheat grain commonly produces flour of finer particles and lower damaged starch content during milling, and also contains less and weaker protein than hard wheat grain. Consequently, soft wheat flour is better suited for making cake, cookies, and pastry, whereas hard wheat flour is mainly used for making bread-type products (Rogers et al 1993).

In many Asian countries, sponge cake (SC) is a popularly consumed soft wheat product and its quality depends heavily on the characteristics of wheat flour. It is widely believed that soft wheat flour of excellent SC baking quality is also desirable for making a variety of soft wheat products. Therefore, SC making potential of wheat flour serves as a standard quality evaluation tool of soft wheat quality for Asian markets (Nagao et al 1976; Nagao et al 1977).

Generally, sponge cakes are prepared according to the procedure of Nagao et al (1976). The sponge cake formula includes flour (100 g), sugar (100 g), shelled whole eggs (100 g) and distilled water (40 mL). Eggs and sugar are blended, whipped to prepare egg foam of about 25 g/100 mL in density, mixed with flour into a batter and then baked to sponge cake. Sponge cake is evaluated for volume and crumb structure. A good quality cake is expected to have large
volume, fine and uniform crumb structure, and tender and moist crumb.

The importance of cake batter density and viscosity for final cake quality was studied by Shelke et al (1990), Wilderjans et al (2008), Wilderjans et al (2010) and Nakamura et al (2010). Shelke et al (1990) reported that increasing cake batter viscosity with emulsifiers or hydrocolloids produced increased volume of white layer cake, and Wilderjans et al (2008) reported that cake batter of relatively low density and high batter viscosity produced pound cakes of relatively low cake density, a uniform cell distribution and better volume. On the other hand, Nakamura et al (2010) reported that batter viscosity was negatively correlated with sponge cake volume. Batter properties of cake are a significant predictor of SC baking quality of wheat flour; however, the viscosity of cake batter has not been used to evaluate SC baking quality of wheat flour alone.

Proteins and particle size of flour affect cake quality as well. According to Kaldy and Rubenthaler (1987), flour of high protein content and strong gluten results in lower volume and coarser texture of sponge cake, due to disruption of the foam structure by the gluten matrix formed during cake batter mixing. Soft wheat flour has a much higher proportion of flour particles < 41 µm than hard wheat flour (Hareland 1994). The particle sizes of soft wheat flours negatively correlated to cake volume (Yamazaki and Donelson 1972; Yamamoto et al 1996). Soft wheat flour of low protein and fine particle size is therefore believed to be suitable for making
sponge cake, while the significance of flour particle size and its independent role on sponge cake quality has not been well established.

In this study, we investigated the influence of flour particle size on sponge cake baking quality with minimum interference from other flour characteristics. Two different sets of flours, including flours of reduced particle size obtained by an additional grinding and flour fractions of different particle size obtained by screening, were tested for protein content, batter properties and sponge cake baking quality.

3.3. MATERIALS AND METHODS

3.3.1. Materials

Wheat flours were milled using a Miag mill from grains of two soft white wheat (Eltan, ORCF102), one club wheat (Cara), and two hard white wheat (Darwin, Silver) cultivars harvested in 2009, and were provided by the USDA-ARS, Western Wheat Quality Laboratory (Pullman, WA). A sponge cake standard flour, which was about 60% extraction flour milled from a blend of elite soft white and club varieties, was also provided by the WWQL. Two hard wheat flours milled using a Miag mill to a straight grade were also included for comparison.

The protein content (N X 5.7) of flour was determined using a Leco FP-528 nitrogen analyzer (Leco Co., St. Joseph, MI) equipped with a thermoconductivity detector (AACC
Method 46-30). Fresh eggs were purchased from a local grocery store and cracked to obtain whole eggs. Pure cane baker’s special sugar (C&H Sugar Company, Inc., Crockett, CA) was used for the sponge cake baking test.

3.3.2. Reduction of Flour Particle Size

To reduce particle size, flour was ground using a pin mill, (Kitchen mill™ Blendtec Co., West Orem, UT), at a mill setting of 5. Before and after regrinding, wheat flour starch damage was determined using an enzymatic starch damage assay kit from Megazyme Pty., Ltd. (Wicklow, Ireland) according to approved method 76-31 and sodium carbonate solvent retention capacity according to approved method 56-11 (AACC 2000).

3.3.3. Fractionation of Flours Based on Particle Size

Flour (240 g) milled from three soft white, one club and two hard white wheat cultivars was sieved on a screen with openings of 88 µm for 20 min and the flour passed through the screen with openings of 88 µm was then sieved on a screen with openings of 55 µm for 20 min using a shifter (Stand Shaker Co., Minneapolis, MN). Flour fractions of coarse (>88 µm), intermediate (55-88 µm), and fine (< 55 µm) particle size were obtained by collecting the flour remaining on each screen and that passing through the screen of 55 µm openings.
3.3.4. Particle Size Distribution of Wheat Flour

An ATM sonic sifter (model L3P, ATM Co., Milwaukee, WI) was used to determine the flour particle size distribution. Flour (2 g) was weighed and sifted on the two stacked screens of 88 µm and 55 µm openings for 12 min at an amplitude setting of 10 in sift/pulse mode. Proportions of particles >88 µm, 55-88 µm and < 55 µm were determined by weighing the flour remaining on the screens of 88 and 55 µm openings, and that passing through both screens. Particle size distribution of wheat flour was expressed as percentages of flour in each particle size range.

3.3.5. Density, Flow Distance, and Viscosity of Flour-Water Batter

Flour (100 g) was blended in water (140 mL) to prepare a flour-water batter in a 5-L bowl of a KitchenAid® mixer using a Beater Blade® at speed levels 1 and 4 for 10 sec each. The density of flour-water batter was determined using a 100 mL specific gravity cup (Magnuson Engineers, Inc., San Jose, CA). After preparing a flour-water batter, the batter was poured into the specific gravity cup, and then the specific gravity cup was weighed (g/100 mL).

Flow distance of flour-water batter (100 mL) as an estimation of viscosity was determined using a Bostwick consistometer (CSC Scientific Company, Inc., Fairfax, VA) at room
temperature (22°C). Flour-water batter (100 mL) immediately after preparation was filled into the reserve tank of the Bostwick consistometer and flow distance of flour-water batter was recorded at 30 sec after lifting the gate of the reserve tank. Viscosity of flour-water batter was also determined using a Brookfield viscometer (model RVDV-II + Pro, Brookfield Engineering Laboratories, Stoughton, MA). Flour–water batter (140 g) immediately after preparation was filled into a 250-mL beaker and viscosity was recorded at 30 sec using a spindle no. 4 rotating at 5 rpm at room temperature (22°C).

3.3.6. SC Baking Test

Wheat flour before and after re-grinding, and flour fractions of different particle size were baked to SC using the modified procedure of Choi et al (2012). Whole eggs (100 g) and sugar (100 g) were hand-blended in a 5-L stainless steel bowl using a whisk to obtain a homogenous blend while warming to 41°C in a 50°C water bath, and then whipped using a KitchenAid® stand mixer attached with a wire whisk for 9.5 min on speed level 6 and for 0.5 min on speed level 1. Warm water (50°C, 40 mL) was added to egg foam at 7 min during whipping. The whipped egg foam was added with wheat flour (100 g) and gently mixed using a Beater Blade® for 10 sec each on speed levels 1 and 4 to prepare cake batter. The Beater Blade® resembles a regular paddle, but it is covered with silicon and features flexible rubber wings on
the edge, which allows thorough mixing of batter by scraping the sides and bottom of the mixing bowl. The batter was poured into a round baking pan (15.2 cm diameter and 5.7 cm height) covered with baking paper and then baked at 190°C for 35 min. Cake was removed immediately from the pan after baking and cooled at 25.6°C for 24 hr. Volume of sponge cake was determined using a rapeseed displacement method and visually examined for internal crumb structure.

3.3.7. Statistical Analysis

Protein content, starch damage, and sodium carbonate solvent retention capacity of flour, density, Bostwick flow distance, and Brookfield viscosity of flour-water batter, proportion of flour particles and sponge cake volume data were expressed as the mean of at least two replicates. Data were subjected to the analysis of variance, Fisher’s least significant difference test at a significance level of $P < 0.05$, and Pearson correlation analysis using the Statistical Analysis System (SAS Institute, Cary, NC).

3.4. RESULTS AND DISCUSSION

3.4.1. Effects of Re-Grinding Flour

The protein content of SC standard flour was 6.5% and that of soft white and club wheat flour (Eltan, ORCF102 and Cara) ranged from 8.6 to 8.8%. Protein content of hard wheat flour
(Darwin and Silver) was 12.5-12.6% (Table 3.1).

The proportion of fine particles increased with re-grinding in all six flours (Figure 3.1A.). The proportion of flour particles smaller than 55 µm increased from 55.9-67.9% to 78.3-82.9% in soft and club wheat flours, and from 45.5-47.1% to 81.4-83.2% in hard wheat flours by re-grinding flour using a pin mill. Hard wheat flour exhibited much greater increases in the proportion of flour particles smaller than 55 µm than soft wheat flour by re-grinding, having similar proportion of particles smaller than 55 µm to soft and club wheat flour after re-grinding.

Figure 3.1B. shows the volume of SC baked from six flours before and after re-grinding. Before re-grinding, SC standard flour produced bigger volume of SC than Eltan, even though their proportions of flour particles smaller than 55 µm were similar. Larger SC volume of SC standard flour than that of Eltan probably resulted from much lower protein content of the former than latter (Table 3.1). ORCF102 and Cara were similar in the proportion of particles smaller than 55 µm and significantly lower than SC standard flour and Eltan, but higher than the two hard wheat flours (Figure 3.1A). These trends in flour particle size distribution were also observed in SC volumes of flours. SC volumes of ORCF102 and Cara were similar and smaller than those of SC standard flour and Eltan, but greater than those of two hard wheat flours. The two hard wheat flours (Darwin and Silver) produced the smallest SC volume, probably due to their much higher protein content and higher proportion of coarse flour particles than soft white
and club wheat flours.

In all six wheat flours, the volume of SC was increased by re-grinding. The magnitudes of increases in SC volume by re-grinding were 28 mL in the SC standard, 10 mL in Eltan, 98 mL in ORCF102, 165 mL in Cara, 83 mL in Darwin, and 63 mL in Silver. ORCF102 and Cara showed greater increases in SC volume than SC standard and Eltan with re-grinding, which corresponded to the results that the proportion of flour particles smaller than 55 µm in ORCF102 and Cara exhibited much greater increases than those of SC standard and Eltan by re-grinding. In addition, SC standard and Eltan were similar in crumb grain characteristics between before and after re-grinding, whereas ORCF102 and Cara exhibited finer crumb structure after re-grinding than those of before re-grinding (Figure 3.2.). Darwin and Silver also showed greater increase in SC volume than SC standard and Eltan, but a lesser increase than ORCF102 and Cara; even Darwin and Silver exhibited much greater increases in the proportion of flour particles smaller than 55µm than other flours by re-grinding. Darwin and Silver after re-grinding produced SC with finer crumb grain compared to those before re-grinding, but they were still coarser than those of soft and club wheat flour (Figure 3.2.). These results signified the importance both flour particle size, and protein content on SC volume.

Starch damage and sodium carbonate solvent retention capacity (sodium carbonate-SRC) before and after re-grinding flour are presented in Table 3.1. Starch damage content increased by
0.1 to 0.2% by additional pin milling, but the increases were not significant. Sodium carbonate-SRC, on the other hand, significantly increased with re-grinding by 4.8-13.9%. Soft wheat flour generally has lower damaged starch content than hard wheat flour. While endosperm of soft wheat grain is easily disintegrated into fine particles during milling, that of hard wheat grain needs additional passing rolls, increasing damaged starch content (Hoseney et al. 1988). Damaged starch granules tend to absorb more water than intact starch granules. Sodium carbonate-SRC is known to be mainly determined by the damaged starch content (Gaines 2000).

Nishio et al (2009) reported that sodium carbonate-SRC was negatively correlated with sponge cake volume. While the six wheat flours regardless of re-grinding showed little differences in starch damage, they varied considerably in sodium carbonate-SRC. The two hard wheat flours were much higher in sodium carbonate-SRC than soft white and club wheat flour, probably due to their higher content of protein and pentosan.

Nakamura et al (2010) reported that flour-sugar-water batter viscosity was negatively correlated with sponge cake volume. To improve the simplicity and reliability of the test for cake batter rheological properties, cake batters were prepared with flour-water batter in our experiments. We observed that flour-water batter viscosity and density were closely related to those of sponge cake batter. Density of flour-water batter after re-grinding was lower or comparable to that before re-grinding (Table 3.2). Viscosity of flour-water batter determined
using Bostwick flow distance and Brookfield viscometer failed to show any significant trends of re-grinding. Re-grinding not only reduces particle size of flour particles, but also increased sodium carbonate-SRC of flour (Table 3.1), which could subsequently increase the viscosity of flour-water batter. The lack of significant changes in viscosity of flour-water batter before and after re-grinding with increasing sodium carbonate-SRC may be at least partially caused by the reduced particle size of flour, which counter-actively lowered the viscosity of flour-water batter. Despite the increase in sodium carbonate-SRC, which could negatively affect the SC volume, flour of reduced particle size by re-grinding produced SC of increased volume and improved crumb structure in all six wheat flours, signifying the importance of flour particle size on SC volume and crumb grain.

3.4.2. Flour Fractions of Different Particle Size

Flour fractions of fine particles were lowest in protein content in all six flours (Figure 3.3A.). Compared to the coarse particle fractions, intermediate particle fractions were higher in protein content with the exception of Cara, a club wheat. The fine particle fractions contained 2.6-3.1% less protein than coarse particle fractions in soft white and club wheat, while the differences in protein content between coarse and intermediate particle fractions were less than 1.2%. In two hard wheat flours, on the other hand, intermediate particle fractions contained 1.5-
2.4% more protein than coarse particle fractions and differences in protein content between coarse and fine particle fractions were less than 0.7%.

Figure 3.3B. shows the volumes of SCs baked from the flour fractions of different particle sizes obtained from six flours. The fine particle fractions, having the finest flour particles and lowest protein content (Figure 3.3A.), produced bigger volumes and finer crumb grain of SCs than coarse and intermediate particles fractions in all six wheat flours (Figure 3.4.). SC crumb grain was appeared finest in the flour fractions < 55 µm, less in the fraction 55-88 µm, and coarsest in the fraction > 88 µm (Figure 3.4.). SC volumes of the fine particle fractions in the four soft white and club wheat flours were higher by 255 to 353 mL than those of the intermediate particle fractions, while the differences in SC volumes between intermediate and coarse particle fractions were less than 170 mL. Intermediate particle fractions produced similar or bigger volumes and finer crumb grain of cakes despite the higher protein content than those of coarse particles. The biggest volume and finest crumb grain of SC baked from fine particle fractions signifies the importance of both protein content and flour particle size on SC volume and crumb grain. The bigger volume and finer crumb grain of SC of intermediate particle fractions than coarse particle fractions may, however, suggest the dominant influence of flour particle size over protein content on SC volume and crumb grain.

The fine particle fractions produced lower density flour-water batters than batters made
with intermediate and coarse particle fractions, an exception in one hard wheat flour, Silver, where no differences in the density of flour-water batter were observed between intermediate and coarse particle fractions (Table 3.4). It is possible that small flour particles with a bigger total surface area could trap more air bubbles during batter mixing than coarse particles, resulting in increased volume and reduced density of flour-water batter. The lowest flour-water batter density of fine particle fractions corresponds well with the biggest volume and finest crumb grain of SC. On the other hand, differences in density of flour-water batter between wheat varieties within each fraction of different particle size as well as between flour fractions were relatively small, indicating that density measurement may not be an effective predictor of SC baking quality of wheat flour.

Table 3.4 summarizes the viscosity of flour-water batter prepared from flour fractions of different particle size. Viscosity of the flour-water batter was determined using a Bostwick consistometer and Brookfield viscometer. The more viscous the batter, the shorter the flow distance of the Bostwick consistometer. Consistent differences in Bostwick flow distances and Brookfield viscosities of flour-water batters were observed between flour fractions of different particle size in soft and club wheat flours. The coarser the flour particles, the shorter the Bostwick flow distance and the higher the viscosity of flour-water batter. The fine particle fractions of four soft white and club wheat flours exhibited the longest flow distance and lowest
viscosity of flour-water batter, followed by intermediate particle fractions. In two hard wheat flours, on the other hand, differences in the flow distance and viscosity of flour-water batters between flour fractions of different particle size were few evident. The intermediate particle fractions of soft white and club wheat flours showed longer flow distance and lower viscosity of flour-water batter than coarse particle fractions, even though the protein content was higher in the former than in the latter. This result indicates that flour particle size may have a bigger influence on the flow distance and viscosity of flour-water batter than does protein content. Both Bostwick flow distance and viscosity values varied widely among wheat varieties within each flour fraction. The two hard wheat flours exhibited shorter flow distance and higher viscosity than soft and club wheat flours. The density, Bostwick flow distance and Brookfield viscosity of flour-water batter of the flour fractions of different particle size were significantly related to SC volume with correlation coefficients of -0.849 ($P < 0.001$), 0.934 ($P < 0.001$), and -0.688 ($P < 0.01$), respectively (Table 3.5).

3.5. CONCLUSION

Particle size reduction of flour produced by re-grinding result in increases in sodium carbonate solvent water retention capacity, but improves sponge cake volume and crumb grain. This result indicated that particle size is one of the most important factors determining SC
volume and crumb grain. Smaller flour particles in soft white and club wheat gave lower viscosity flour-water batter and greater SC volume. Particle size appears to have a greater influence on batter viscosity, and SC volume and crumb grain score than protein content. Flour fractions of different particle size made evident differences in flour-water batter viscosity and was significantly related to sponge cake volume and crumb grain score.

3.6. ACKNOWLEDGEMENT

This study was conducted with the financial support of the Washington Grain Commission (Spokane, WA).

3.7. BIBLIOGRAPHY


Table 3.1 Protein content, starch damage and sodium carbonate solvent retention capacity of wheat flour before and after re-grinding

<table>
<thead>
<tr>
<th>Flour/Variety</th>
<th>Protein (%)&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Starch Damage (%)&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Sodium Carbonate Solvent Retention Capacity (%)&lt;sup&gt;b&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before</td>
<td>After</td>
<td>Before</td>
</tr>
<tr>
<td>SC std&lt;sup&gt;c&lt;/sup&gt;</td>
<td>6.5c</td>
<td>5.8a</td>
<td>6.0a</td>
</tr>
<tr>
<td>Eltan</td>
<td>8.7b</td>
<td>5.8a</td>
<td>6.0a</td>
</tr>
<tr>
<td>ORCF102</td>
<td>8.8b</td>
<td>6.0a</td>
<td>6.2a</td>
</tr>
<tr>
<td>Cara</td>
<td>8.6b</td>
<td>5.8a</td>
<td>6.1a</td>
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<tr>
<td>Darwin</td>
<td>12.5a</td>
<td>6.2a</td>
<td>6.3a</td>
</tr>
<tr>
<td>Silver</td>
<td>12.6a</td>
<td>6.3a</td>
<td>6.3a</td>
</tr>
</tbody>
</table>

<sup>a</sup>Values are means (n=3) and different letters in the same column are significantly different (<i>P < 0.05</i>).

<sup>b</sup>Values are means (n=2) and different letters in the same row are significantly different (<i>P < 0.05</i>).

<sup>c</sup>Standard flour for making sponge cake, which was a blend of the patent flour of several soft white and club wheat varieties.
Table 3.2 Density, Bostwick flow distance and Brookfield viscosity of flour-water batter before and after flour re-grindinga

<table>
<thead>
<tr>
<th>Flour/Variety</th>
<th>Density (g/100 mL)</th>
<th>Bostwick Flow Distance (cm)b</th>
<th>Brookfield Viscosity (cP)c</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before</td>
<td>After</td>
<td>Before</td>
</tr>
<tr>
<td>SC stdd</td>
<td>104.3a</td>
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<td>10.5a</td>
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<td>103.2a</td>
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<tr>
<td>Darwin</td>
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<td>105.9b</td>
<td>6.8a</td>
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<tr>
<td>Silver</td>
<td>106.2a</td>
<td>106.2a</td>
<td>4.5a</td>
</tr>
</tbody>
</table>

aValues are means (n=2) and different letters in the same row are significantly different (P < 0.05).

bFlow distance of the flour (100 g)–water (140 mL) batter was recorded at 30 sec after lifting the gate at room temperature (22°C).

cViscosity of flour (100 g)-water (140 mL) batter was recorded at 30 sec using a spindle no. 4 rotating at 5 rpm at room temperature (22°C).

dStandard flour for making sponge cake, which was a blend of the patent flour of several soft white and club wheat varieties.
Table 3.3 Density of flour (100g)-water (140mL) batter prepared from flour fractions of different particle size\textsuperscript{a}

<table>
<thead>
<tr>
<th>Flour/Variety</th>
<th>Density of Flour-Water Batter (g/100 mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&gt;88 µm</td>
</tr>
<tr>
<td>SC std\textsuperscript{b}</td>
<td>106.8a</td>
</tr>
<tr>
<td>Eltan</td>
<td>105.9a</td>
</tr>
<tr>
<td>ORCF102</td>
<td>107.2a</td>
</tr>
<tr>
<td>Cara</td>
<td>108.2a</td>
</tr>
<tr>
<td>Darwin</td>
<td>107.6a</td>
</tr>
<tr>
<td>Silver</td>
<td>108.5a</td>
</tr>
</tbody>
</table>

\textsuperscript{a}Values are means (n=2) and different letters in the same row are significantly different ($P < 0.05$).

\textsuperscript{b}Standard flour for making sponge cake, which was a blend of the patent flour of several soft white and club wheat varieties.
Table 3.4 Bostwick flow distance and viscosity of flour (100g)-water (140mL) batter of flour fractions with different particle size

<table>
<thead>
<tr>
<th>Flour/ Variety</th>
<th>Bostwick Flow Distance&lt;sup&gt;b&lt;/sup&gt; (cm)</th>
<th>Brookfield Viscosity&lt;sup&gt;c&lt;/sup&gt; (cP)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&gt;88 µm</td>
<td>55-88 µm</td>
</tr>
<tr>
<td>SC std&lt;sup&gt;d&lt;/sup&gt;</td>
<td>9.1c</td>
<td>10.5b</td>
</tr>
<tr>
<td>Eltan</td>
<td>4.8c</td>
<td>7.3b</td>
</tr>
<tr>
<td>ORCF102</td>
<td>5.9c</td>
<td>7.0b</td>
</tr>
<tr>
<td>Cara</td>
<td>7.1c</td>
<td>9.8b</td>
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<tr>
<td>Darwin</td>
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<td>5.6ab</td>
</tr>
<tr>
<td>Silver</td>
<td>4.1a</td>
<td>3.9a</td>
</tr>
</tbody>
</table>

<sup>a</sup>Values are means (n=2) and different letters in the same row are significantly different (P < 0.05).

<sup>b</sup>Flow distance of the flour (100 g)–water (140 mL) batter was recorded at 30 sec after lifting the gate at room temperature (22°C).

<sup>c</sup>Viscosity of flour (100 g)-water (140 mL) batter was recorded at 30 sec using a spindle no. 4 rotating at 5 rpm at room temperature (22°C).

<sup>d</sup>Standard flour for making sponge cake, which was a blend of the patent flour of several soft white and club wheat varieties.
Table 3.5 Correlation of density, Bostwick flow distance and Brookfield viscosity of flour (100g)-water (140mL) batter of the flour fractions of different particle size with sponge cake volume (n=18)

<table>
<thead>
<tr>
<th>Density</th>
<th>Bostwick Flow Distance</th>
<th>Brookfield Viscosity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cake Volume</td>
<td>-0.849***</td>
<td>0.934***</td>
</tr>
</tbody>
</table>

**,*** significant at $P \leq 0.01$ and 0.001, respectively.
Figure 3.1. Particle size distribution (A) and sponge cake volume (B) of wheat flour before and after re-grinding. SC std flour, standard flour for making sponge cake, which was a blend of the patent flour of several soft white and club wheat varieties. Bars with different letters for each wheat flour variety are significantly different (ANOVA, $P < 0.05$).
Figure 3.2. Vertical sectional views of sponge cake baked from wheat flours before and after re-grinding. SC std flour, standard flour for making sponge cake, which was a blend of the patent flour of several soft white and club wheat varieties.
**Figure 3.3.** Protein content (A) and volume of sponge cake (B) made from flour fractions of different particle size separated by sieving. SC std flour, standard flour for making sponge cake, which was a blend of the patent flour of several soft white and club wheat varieties. Bars with different letters for each wheat flour variety are significantly different (ANOVA, $P < 0.05$).
Figure 3.4. Vertical sectional views of sponge cake baked from flour fractions of different particle size separated by sieving. SC std flour, standard flour for making sponge cake, which was a blend of the patent flour of several soft white and club wheat varieties.
CHAPTER 4.

SIGNIFICANCE OF STARCH PROPERTY AND QUANTITY

ON SPONGE CAKE QUALITY
4.1. ABSTRACT

We evaluated the qualitative and quantitative effects of wheat starch on sponge cake baking quality. Twenty wheat flours, including sponge cake standard, soft white and club wheat of normal, partial waxy and waxy endosperm, and hard wheat, were tested for amylose content, pasting properties, and sponge cake baking quality. Starches were fractionated from wheat flours of normal, single-null partial waxy, double-null partial waxy and waxy starch endosperm, pasting properties determined and baked to sponge cake (SC). Double-null partial waxy and waxy wheat flours produced SC of 828 to 895 mL in volume, while volume of SC baked from flours of normal and single-null partial waxy flours ranged from 1093 to 1335 mL. The amylose content of soft white and club wheat flour was positively related to the volume of sponge cake (r=0.790, P<0.001). Pasting temperature, peak viscosity, final viscosity, breakdown and setback also showed significant relationship with SC volume. Normal and waxy starch blends having amylose content of 25, 20, 15 and 10% produced SCs of 1570, 1435, 1385 and 1185 mL in volume, respectively. More than 80 g starch and more than 75% starch in 100 g starch-gluten blends in replacement of 100 g wheat flour in the SC baking formula were needed to produce SC having the maximum volume potential. Starch properties including amylose content and pasting properties as well as proportion of starch evidently play significant roles in SC baking quality of wheat flour.
4.2. INTRODUCTION

Starch is the major constituent of wheat flour and the primary contributor to pasting properties of wheat flour (Goesaert et al 2005). Processing, cooking and textural quality, and shelf life of many wheat-based food products are significantly related to pasting properties of starch (Baik and Lee 2003). Among the many physical and chemical characteristics of starch, amylose content has the biggest influence on pasting properties of wheat flour (Geera et al 2006). Wheat varieties are, therefore, classified as normal, partial waxy, and waxy types, based on amylose content of starch. Starches from partial waxy wheat flours generally exhibit lower pasting temperature, higher peak viscosity, higher breakdown, and lower setback than starches of regular type wheat flours (Baik et al 2003). Yoo and Jane (2002) reported that waxy wheat starch showed a higher peak viscosity than normal wheat starch and a very sharp increase in paste viscosity at lower temperature, but low stability of paste viscosity.

Soft wheat flour with finer particles and less and weaker protein than hard wheat flour is suitable for making cake, cookies and pastry, whereas hard wheat flour is better suited for making bread-type products (Nagao et al 1976; Nagao et al 1977; Nishio et al 2009; Rogers et al 1993; Yamamoto et al 1996). Sponge cake (SC) is a popular product of soft wheat flour in East Asia, and its quality depends considerably on wheat flour characteristics. Soft wheat flour of high quality is expected to produce sponge cake with larger volume, fine and uniform crumb
structure, and tender crumb. Kaldy and Rubenthaler (1987) reported that SC with flour of higher protein content and stronger gluten exhibited low volume and coarse texture sponge cake. Regarding starch, Nishio et al (2009) indicated that sponge cake volume was positively correlated to amylose content and sugar snap cookie diameter, but negatively correlated to protein content, sodium dodecyl sulfate sedimentation (SDSS) volume, water solvent retention capacity, sodium carbonate solvent retention capacity, sucrose solvent retention capacity and lactic acid solvent retention capacity, while sponge cake volume was significantly correlated to only amylose content and SDSS volume within the normal and partial waxy lines. Nisho et al (2011) reported that regardless of seeding season, growing conditions, or protein content, the volume of sponge cake was strongly correlated to amylose content. Even though starch seems to be an important factor for making sponge cake, with the exception of amylose content little is known about the quantitative and qualitative influences of starch on sponge cake quality.

The objective of this study was to explore the significance of starch properties of wheat flour on SC quality. We investigated the influence of amylose content and pasting properties of wheat flour on SC quality. Quantitative and qualitative roles of starch on SC quality were also determined using the isolated starch of various amylose content, blends of normal and waxy starch and blends of starch and gluten for sponge cake baking with minimum interference from other flour constituents.
4.3. MATERIALS AND METHODS

4.3.1. Materials

Wheat flours were provided by the USDA-ARS, Western Wheat Quality Laboratory (Pullman, WA). The flours were milled from grains of ten regular soft white wheats (Eltan, ORCF102, Louise, IDO599, OR2040726, OR2060395, Stephens, ID9064901a, Brundage96, KWP006), four single-null (Alturas, BZ604-002, BZ6m06-1001, IDO644) and one double-null (Double null) partial waxy soft white wheats, one waxy soft white wheat (Waxy Pen), and one club wheat (Cara) cultivars harvested in 2009, and two hard white wheat (Darwin, Silver) cultivars were included for comparison purposes. A sponge cake standard (SC std) flour, which was about 60% extraction flour milled from a blend of elite soft white and club varieties, was also provided by the WWQL.

The prime starches were fractionated from nine wheat flours (SC std, Eltan, ORCF102, Cara, Alturas, Double null, Waxy Pen, Darwin, Silver) by the modified dough-dispersion and centrifugation method (Czuchajowska and Pomeranz 1993). Two commercial starches, corn starch (Argo, ACH Food Companies, Inc., Cordova, TN) and commercial potato starch (Swan Potato Starch Flour, Noon Hour Food Products, Inc., Chicago, IL), were also included for comparison purposes. A commercial wheat starch and a commercial vital wheat gluten were graciously provided by Archer Daniels Midland Co. (Decatur, IL) and MGP Ingredients, Inc.
(Atchison, KS), respectively, and used to determine the quantitative effect of starch and gluten on sponge cake quality.

The protein content (N X 5.7) of flour was determined using a Leco FP-528 nitrogen analyzer (Leco Co., St. Joseph, MI) equipped with a thermoconductivity detector (AACC Method 46-30). Amylose content of flours and starches were determined using the iodine colorimetric method (Williams et al 1970).

Fresh eggs were purchased from a local grocery store and cracked to obtain whole eggs. Pure cane baker’s special sugar (C&H Sugar Company, Inc., Crockett, CA) was used for the sponge cake baking test.

4.3.2. Pasting Properties of Wheat Flour and Starch

Pasting properties of flour and starch were determined in duplicate using a Brabender Micro-viscoamylograph (C.W. Brabender Instruments, Inc., South Hackensack, NJ). Wheat flour (11.5 g, dry weight basis) or starch (9.2 g, dry weight basis) was weighed into the container and distilled water was added to achieve a total weight of 115 g, which was equivalent to 10% flour suspension and 8% starch suspension, respectively. The suspension was heated at a rate of 4.5°C/min from 30°C to 95°C, held at 95°C for 5 min, cooled at a rate of 4.5°C/min to 50°C, and maintained for 3.5 min at 50°C with 250 rpm. Pasting temperature, peak viscosity, final viscosity,
breakdown, and setback were collected from the pasting curves.

4.3.3. SC Baking Test

Wheat flour and starch were baked to SC using the modified procedure of Choi et al (2012). Whole eggs (100 g) and sugar (100 g) were hand-blended in a 5-L stainless steel bowl using a whisk to obtain a homogenous blend while warming to 41°C in a 50°C water bath, then whipped using a KitchenAid® stand mixer attached with a wire whisk for 9.5 min on speed level 6, and for 0.5 min on speed level 1. Warm water (50°C, 40 mL) was added to egg foam at 7 min during whipping. To the whipped egg foam, wheat flour or starch (100 g) was added and gently mixed using a Beater Blade® for 10 sec each on speed levels 1 and 4 to prepare a cake batter. The Beater Blade® resembles a regular paddle, but it is covered with silicon and features flexible rubber wings on the edge, which allows thorough mixing of batter by scraping the sides and bottom of the mixing bowl. The batter was poured into a round baking pan (15.2 cm diameter and 5.7 cm height), covered with baking paper, and then baked at 190°C for 35 min. Cake was removed immediately from the pan after baking and cooled at 25.6°C for 24 hr. Volume of sponge cake was determined using a rapeseed displacement method and visually examined for internal crumb structure.
4.3.4. Effect of Starch Quality and Quantity on Sponge Cake Quality

To explore the effect of amylose content of starch with minimum interference from other flour constituents on sponge cake quality, starches with amylose content of 25, 20, 15 and 10% were prepared by blending the commercial wheat starch and waxy starch at the ratio of 10:0, 8:2, 6:4 and 4:6, respectively, and baked to sponge cake in replacement for wheat flour in the formula.

To investigate the effect of starch quantity on sponge cake quality, sponge cakes were also baked from the commercial wheat starch of various weight (100, 90, 80, 70, 60, 50, 40 and 30 g) in replacement for wheat flour in the formula.

To estimate the quantitative role of starch in the presence of protein, simulated flours were prepared by blending the commercial wheat starch with vital wheat gluten in ratios of 100:0, 96:4, 94:6, 92:8, 90:10, 88:12, 85:15, 80:20, 75:25, 70:30, 60:40, 50:50 and 0:100 %, and baked for sponge cake.

4.3.5. Statistical Analysis

Protein content, amylose content, sponge cake volume, and pasting properties were all expressed as the means of at least two replicates. Data were subjected to the analysis of variance, Fisher’s least significant difference test at a significance level of $P = 0.05$, and Pearson correlation coefficient using the Statistical Analysis System (SAS Institute, Cary, NC).
4.4. RESULTS AND DISCUSSION

4.4.1. Protein Content, Amylose Content and Sponge Cake Volume of Wheat Flour and Starch

The protein content of SC standard flour, soft white and club wheat flour (Eltan, ORCF102, Cara, Alturas, a double-null line, Waxy Pen, Louise, BZ604-002, BZ6M06-1001, IDO599, IDO644, OR2040726, OR2060395, Stephens, ID9064901a, Brundage96, KWP006) ranged from 6.5 to 10.3%. Protein content of two hard wheat flours (Darwin, Silver) was much higher than soft white and club wheat and ranged from 12.5 to 12.6% (Table 4.1).

The amylose content of SC standard flour and soft white and club wheat flour of normal starch endosperm (Eltan, ORCF102, Cara, Louise, IDO599, OR2040726, OR2060395, Stephens, ID9064901a, Brundage96, KWP006) ranged from 14.1 to 17.0%, while amylose content of single-null and double-null partial waxy wheat flour (Alturas, Double-null, BZ604-002, BZ6m06-1001, IDO644) ranged from 9.4 to 13.9%. Amylose content of hard wheat flour (Darwin, Silver) was 14.3-14.4% (Table 4.1), indicating normal starch endosperm.

SC standard flour produced the biggest SC of 1335 mL in volume. SC volumes of soft white and club wheat flour of normal starch endosperm exhibited a large variation and ranged from 1093 to 1268 mL. Compared to soft white and club wheat of normal starch endosperm, single-null partial waxy white flour produced comparable volume (1108-1183 mL) of SC, while
the double-null partial waxy wheat flour yielded smaller SC of 895 mL. The smallest volume (828 mL) of SC was produced from waxy white flour. The large variations in SC volume among wheat flours possessing normal, single-null partial waxy and double-null partial waxy starch endosperm signify the influence of starch amylose content on SC volume and quality. Two hard wheat flours produced smaller volume (890 and 910 mL) SC than soft white and club wheat flours of normal starch endosperm, probably due to their much higher protein content and higher proportion of coarse flour particles than soft white and club wheat flours.

The protein content of flours exhibited a significant relationship with SC volume (r= -0.651, P < 0.01), but the relationship was no longer significant when two hard wheat flours with much higher protein content than soft white and club wheat flours were omitted in the correlation analysis. This result indicates that for soft white and club wheat flours in which protein contents are in a relatively narrow range, protein content may not play a significant role in SC quality. The amylose content of soft and club wheat flours, on the other hand, showed a positive relationship with SC volume (r=0.790, P < 0.001).

Amylose content of starch isolated from wheat flour containing normal starch endosperm including SC standard flour, Eltan, ORCF102, Cara, Darwin, and Silver ranged from 24.1 to 25.6%, while starch amylose content of single and double-null partial waxy wheat flours was 23.5% and 19.4%, respectively. Much bigger volume of SC was produced from the isolated
wheat starch than wheat flour. Sponge cake volume of soft white, club and hard wheat starches of normal and partial waxy starch endosperm ranged from 1466 to 1513 mL, showing little variation, possibly due to the limitation of maximum SC volume in the current SC baking test. The amount of starch (100 g) used in replacement of wheat flour for baking SC was much greater than the starch in wheat flour, considering that starch constitutes about 80% of wheat flour. With about 20 g more starch in the formula, therefore, the volume of SC baked from starch regardless of its source and amylose content might be close to the maximum volume achievable in the current SC baking test. Still, waxy wheat starch produced much smaller SC than regular and partial waxy wheat starches (Table 4.1).

Vertical sectional views of SCs baked from wheat flours and starches isolated from their respective flour are shown in Figure 4.1. The isolated starch always produced SC of bigger volume and finer crumb structure than wheat flour. Differences in volume between starch and flour SCs were larger in hard, double-null partial waxy and waxy wheat flours than in soft white wheat flours of normal or single-null partial waxy starch endosperm. In contrast to others, SCs baked from waxy wheat starch or flour exhibited a sunken center, which resulted from the collapse of the crumb after baking during cooling. The collapse of SC was probably caused by the lack of starch retrogradation during cooling, which provides structural support to the SC crumb. Even corn and potato starches produced SC of comparable volume and fine crumb
structure to the isolated normal and single-null partial waxy wheat starches (Table 4.1 & Figure 4.1). Potato starch, which is well known to possess a much greater pasting viscosity and a slower degree of starch retrogradation than corn starch, produced a smaller SC than corn starch. These results again prove the significant contribution of starch and its properties on SC volume and crumb grain fineness.

4.4.2. Pasting Properties of Wheat Flour and Starch

Pasting temperature, peak viscosity, final viscosity, breakdown, and setback of 10% (dry basis) wheat flour suspensions measured using a micro-viscoamylograph are presented in Table 4.2. Wheat flours of normal starch endosperm produced lower peak viscosity, lower breakdown, and higher setback than those of partial waxy and waxy starch endosperms. It is well known that normal starch shows lower maximum starch swelling, lesser starch granule rupture on heating, and more amylose retrogradation on cooling than partial waxy and waxy wheat starches (Baik et al 2003; Yoo and Jane 2002). Variations in pasting properties of flour among soft wheat varieties could also be attributed to their differences in starch granule size distribution, crystallinity, branch chain length distribution of amylopectin, and network with other constituents. The pasting temperature, peak viscosity, final viscosity, breakdown and setback of flour were significantly related to SC volume with correlation coefficients of 0.487 (P < 0.05), -0.476 (P <
indicating the possible implications of starch properties for SC volume and quality. Low breakdown viscosity may be important for building a fine crumb structure during cake baking, while high final viscosity and setback occur with a high degree of starch retrogradation during cooling and thus are probably related to the structural supports to the SC crumb structure during cooling, preventing the sunken center of cake.

Pasting properties of 8% starch suspension determined using a micro-viscoamylograph are presented in Table 4.4. Normal wheat starches had lower peak viscosity and lower breakdown than those of partial waxy and waxy wheat starches. The peak viscosity and breakdown of starch were significantly related to SC volume of wheat flour with correlation coefficients of -0.832 \( (P < 0.05) \) and -0.772 \( (P < 0.05) \), respectively. High peak viscosity and breakdown are the result of increased degrees of starch swelling and starch granule rupture during heating, which may be related to the decreased structural support by retrograded starch, leading to the collapse of SC after oven spring and during cooling. Nakamura et al (2010) reported that peak viscosity and breakdown were not significantly correlated with sponge cake volume, but final viscosity and setback were significantly correlated with sponge cake volume in pasting properties of wheat flour. In this study, however, SC volume was significantly related to final viscosity, breakdown and setback of flour. No significant correlations between pasting
properties and SC volume of starch were observed, mainly because of the small variation in sponge cake volume of starches.

4.4.3. Effect of Starch Amylose Content on Sponge Cake Quality

SCs baked from starches of 25, 20, 15 and 10% amylose content, prepared by blending a commercial wheat starch of 25% amylose content and Waxy Pen starch of 0% amylose content, were consistently smaller as amylose content decreased (Figure 4.2A.). As starch amylose content decreased with the increased proportion of waxy starch in blends, central depression and coarse crumb grain of SC became more evident (Figure 4.2B.), probably due to the reduced degree of starch retrogradation to provide the structural support to the SC crumb. Amylose content of starch blends was significantly related with their SC volume ($r=0.975$, $P < 0.05$). A positive relationship between amylose content of flour and SC volume was also reported by Nishio et al (2009).

4.4.4. Effect of Starch Quantity on Sponge Cake Quality

The volumes of SC baked with various amounts of starch in the formula are summarized in Table 4.5; vertical sectional views of sponge cake are shown in Figure 4.3. There were no evident differences in the volumes of SCs baked with 100, 90, 80 and 70 g wheat starch. Central
depression of SC appeared in SC with less than 70 g starch in the formula. With less than 60 g starch, significant reduction in both volume and crumb grain fineness were observed (Figure 4.3.). These results indicate that wheat starch over 80g is required to obtain sponge cake of desirable volume and crumb structure.

4.4.5. Effect of Proportion of Wheat Starch and Vital Gluten on Sponge Cake Quality

The quantitative roles of starch and gluten protein on SC quality were estimated by preparing blends of starch and gluten of various ratios. The volumes of SCs are summarized in Table 4.6 and their vertical sectional views are shown in Figure 4.4. Sponge cakes baked from starch with up to 30% gluten showed no differences in volume and crumb structure. The SC volume started to decrease and crumb structure became impaired with more than 40% gluten in starch and gluten blends. With more than 40% gluten in starch and gluten blends, SC exhibited coarser crumb structure (Figure 4.4.). It appears that the decreased SC volume and impaired crumb structure are mainly caused by reduced starch content in the formula rather than increased proportion of gluten, again signifying the role of starch on SC volume and crumb grain structure.
4.5. CONCLUSION

SC volume varied widely among soft white and club wheat flours of normal, single-null partial waxy, double-null partial waxy and waxy starch endosperm. Amylose content of both flour and starch showed positive relationships with the volume of SC baked from soft white and club wheat flours. Starch of reduced amylose content isolated from double-null partial waxy and waxy wheat flour, in replacement of wheat flour in the formula, produced smaller SC than normal and single-null partial waxy starches. Starch blends of varying amylose content produced consistently smaller SC as amylose content decreased, verifying again the significant role of starch amylose content on SC volume. Considering the positive relationships of amylograph final viscosity and setback with SC volume, it is postulated that the released amylose molecules during SC baking rapidly retrograde during cooling and provide a structural support to SC crumb, producing a large volume of SC. SC volume and crumb grain were also influenced heavily by the quantity of starch, but little by gluten. More than 80 g starch or more than 75% starch in starch-gluten blend in replacement of 100 g flour in the formula was required to achieve a full volume potential of SC. Protein content may play a meager role in SC baking quality of wheat flour by changing the relative proportion of starch rather than its direct implication to and influence on SC baking.
4.6. ACKNOWLEDGEMENT

This study was conducted with the financial support of the Washington Grain Commission (Spokane, WA).

4.7. BIBLIOGRAPHY


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starch characteristics. Cereal Chem. 83:558-564.


Table 4.1 Protein content, amylose content and sponge cake volume of wheat flours and fractionated starches

<table>
<thead>
<tr>
<th>Variety</th>
<th>Flour Protein content (%)</th>
<th>Flour Amylose content (%)</th>
<th>Flour Sponge cake volume (mL)</th>
<th>Starch Amylose content (%)</th>
<th>Starch Sponge cake volume (mL)</th>
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aValues are means (n=3 for protein content, n=2 for amylose content and sponge cake volume) and different letters in the same column are significantly different (P < 0.05).

bStandard flour for making sponge cake, which was a blend of the patent flour of several soft white and club wheat varieties.
Table 4.2 Pasting properties of wheat flour (10%, dry basis)\textsuperscript{a}

<table>
<thead>
<tr>
<th>Variety</th>
<th>Pasting Temp. ((^\circ)C)</th>
<th>Peak Viscosity (BU)</th>
<th>Final Viscosity (BU)</th>
<th>Breakdown (BU)</th>
<th>Setback (BU)</th>
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<td>602a</td>
<td>216h</td>
</tr>
<tr>
<td>Louise</td>
<td>64.7abc</td>
<td>828h</td>
<td>1487bcd</td>
<td>85hi</td>
<td>753cde</td>
</tr>
<tr>
<td>BZ604-002</td>
<td>63.1efg</td>
<td>986c</td>
<td>1077i</td>
<td>471b</td>
<td>556g</td>
</tr>
<tr>
<td>BZ6m06-1001</td>
<td>62.8fg</td>
<td>1190b</td>
<td>1380fgh</td>
<td>467b</td>
<td>650f</td>
</tr>
<tr>
<td>ID0599</td>
<td>64.9ab</td>
<td>904ef</td>
<td>1383fgh</td>
<td>212d</td>
<td>679ef</td>
</tr>
<tr>
<td>ID0644</td>
<td>63.9bcde</td>
<td>1204b</td>
<td>1547b</td>
<td>386c</td>
<td>722cde</td>
</tr>
<tr>
<td>OR2040726</td>
<td>63.5def</td>
<td>748i</td>
<td>1440def</td>
<td>39k</td>
<td>722cde</td>
</tr>
<tr>
<td>OR2060395</td>
<td>63.9abcde</td>
<td>746i</td>
<td>1397efgh</td>
<td>61jk</td>
<td>718cdef</td>
</tr>
<tr>
<td>Stephens</td>
<td>63.9bcde</td>
<td>737i</td>
<td>1408defg</td>
<td>44k</td>
<td>706cdef</td>
</tr>
<tr>
<td>ID9064901a</td>
<td>65.0a</td>
<td>955cd</td>
<td>1531bc</td>
<td>178ef</td>
<td>746bcd</td>
</tr>
<tr>
<td>Brundage96</td>
<td>64.1abcde</td>
<td>752i</td>
<td>1376fgh</td>
<td>69ij</td>
<td>684ef</td>
</tr>
<tr>
<td>KWP006</td>
<td>62.8fg</td>
<td>847gh</td>
<td>1408defg</td>
<td>165f</td>
<td>717cde</td>
</tr>
</tbody>
</table>

\textsuperscript{a}Values are means (n=2) and different letters in the same column are significantly different (\(P < 0.05\)).

\textsuperscript{b}Standard flour for making sponge cake, which was a blend of the patent flour of several soft white and club wheat varieties.
Table 4.3 Correlation between pasting properties of soft wheat flour, and flour amylose content and sponge cake volume (n=18)

<table>
<thead>
<tr>
<th></th>
<th>Pasting Temp. (°C)</th>
<th>Peak Viscosity (BU)</th>
<th>Final Viscosity (BU)</th>
<th>Breakdown (BU)</th>
<th>Setback (BU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cake volume of flour</td>
<td>0.487*</td>
<td>-0.476*</td>
<td>0.738***</td>
<td>-0.755***</td>
<td>0.818***</td>
</tr>
<tr>
<td>Amylose content of flour</td>
<td>0.315</td>
<td>-0.867***</td>
<td>0.435</td>
<td>-0.958***</td>
<td>0.650**</td>
</tr>
</tbody>
</table>

*,**,*** significant at P ≤ 0.05, 0.01 and 0.001, respectively.
Table 4.4 Pasting properties of wheat starch (8%, dry basis)\textsuperscript{a}

<table>
<thead>
<tr>
<th>Starches</th>
<th>Pasting Temp. (°C)</th>
<th>Peak Viscosity (BU)</th>
<th>Final Viscosity (BU)</th>
<th>Breakdown (BU)</th>
<th>Setback (BU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC std\textsuperscript{b}</td>
<td>71.0abc</td>
<td>417h</td>
<td>621f</td>
<td>0e</td>
<td>201d</td>
</tr>
<tr>
<td>Eltan</td>
<td>74.9a</td>
<td>493fg</td>
<td>767ef</td>
<td>2e</td>
<td>270d</td>
</tr>
<tr>
<td>ORCF102</td>
<td>70.3abcd</td>
<td>446gh</td>
<td>650f</td>
<td>1e</td>
<td>200d</td>
</tr>
<tr>
<td>Cara</td>
<td>66.9cdef</td>
<td>673e</td>
<td>1096c</td>
<td>41e</td>
<td>457c</td>
</tr>
<tr>
<td>Darwin</td>
<td>69.9bcd</td>
<td>629e</td>
<td>941d</td>
<td>10e</td>
<td>317d</td>
</tr>
<tr>
<td>Silver</td>
<td>73.6ab</td>
<td>534f</td>
<td>775ef</td>
<td>2e</td>
<td>238d</td>
</tr>
<tr>
<td>Alturas</td>
<td>65.5def</td>
<td>954d</td>
<td>1437b</td>
<td>239cd</td>
<td>711b</td>
</tr>
<tr>
<td>Double null</td>
<td>68.8bcde</td>
<td>1080c</td>
<td>1374b</td>
<td>272c</td>
<td>558c</td>
</tr>
<tr>
<td>Waxy Pen</td>
<td>62.9f</td>
<td>1473b</td>
<td>888de</td>
<td>917b</td>
<td>323d</td>
</tr>
<tr>
<td>Corn</td>
<td>71.6abc</td>
<td>939d</td>
<td>1223c</td>
<td>189d</td>
<td>468c</td>
</tr>
<tr>
<td>Potato</td>
<td>64.4ef</td>
<td>2758a</td>
<td>2061a</td>
<td>1676a</td>
<td>966a</td>
</tr>
</tbody>
</table>

\textsuperscript{a}Values are means (n=2) and different letters in the same column are significantly different \((P < 0.05)\).

\textsuperscript{b}Standard flour for making sponge cake, which was a blend of the patent flour of several soft white and club wheat varieties.
**Table 4.5** Volumes of sponge cake prepared with different amount of wheat starch in replacement of wheat flour in the formula

<table>
<thead>
<tr>
<th>Wheat Starch (g)</th>
<th>Cake Volume (mL)&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>1558&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>90</td>
<td>1525&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>80</td>
<td>1533&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td>70</td>
<td>1555&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>60</td>
<td>1470&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>50</td>
<td>1280&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>40</td>
<td>1008&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>30</td>
<td>collapse</td>
</tr>
</tbody>
</table>

<sup>a</sup>Values are means (n=2) and with different letters in the same column are significantly different (<i>P</i> < 0.05).
Table 4.6 Volumes of sponge cake prepared with blends of a commercial wheat starch and vital wheat gluten in replacement of wheat flour in the formula

<table>
<thead>
<tr>
<th>Starch (g):Vital Gluten (g)</th>
<th>Cake Volume (mL)(^a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100:0</td>
<td>1570a</td>
</tr>
<tr>
<td>96:4</td>
<td>1510ab</td>
</tr>
<tr>
<td>94:6</td>
<td>1523ab</td>
</tr>
<tr>
<td>92:8</td>
<td>1495ab</td>
</tr>
<tr>
<td>90:10</td>
<td>1525ab</td>
</tr>
<tr>
<td>88:12</td>
<td>1510ab</td>
</tr>
<tr>
<td>85:15</td>
<td>1535ab</td>
</tr>
<tr>
<td>80:20</td>
<td>1520ab</td>
</tr>
<tr>
<td>75:25</td>
<td>1490ab</td>
</tr>
<tr>
<td>70:30</td>
<td>1485b</td>
</tr>
<tr>
<td>60:40</td>
<td>1408c</td>
</tr>
<tr>
<td>50:50</td>
<td>1175d</td>
</tr>
<tr>
<td>0:100</td>
<td>568e</td>
</tr>
</tbody>
</table>

\(^a\)Values are means (n=2) and different letters in the same column are significantly different (\(P < 0.05\)).
Figure 4.1. Vertical sectional views of sponge cake baked from wheat flour and starch. SC std flour, standard flour for making sponge cake, which was a blend of the patent flour of several soft white and club wheat varieties.
Figure 4.2. Volumes (A) and vertical sectional views (B) of sponge cake baked with wheat starches of different amylose content in replacement of wheat flour in the formula. Bars with different letters for each wheat flour variety are significantly different (ANOVA, $P < 0.05$).

*significant at $P \leq 0.05$. 

$R^2 = 0.95$
Figure 4.3. Vertical sectional views of sponge cake baked with different amount of wheat starch in replacement of wheat flour in the formula.
**Figure 4.4.** Vertical sectional views of sponge cakes baked with blends of commercial wheat starch and vital gluten of different proportions in replacement of wheat flour in the formula. S, wheat starch, P, vital gluten.
CHAPTER 5.

SUMMARY AND CONCLUSIONS
In order to evaluate the soft white and club wheat flour, the sponge cake baking test is widely used for overall end-use quality of soft white and club wheat. However, to conduct the sponge cake baking test properly, skillful personnel is required due to complicated procedure of test. Moreover, there is limited information for the functional properties and quality of soft white wheat on the sponge cake. The objectives of the research reported herein were to improve the sponge cake baking test procedure, to clarify the effect of particle size on sponge cake quality and to elucidate the effect of starch quantity and quality on sponge cake quality. The results of the research can be summarized as follows:

For a simple and comparably reliable sponge cake baking test procedure, the conventional test was modified in egg foam whipping and batter mixing stages. Comparable foam density, sponge cake volume and crumb grain to the conventional procedure were obtained with modifications, including extension of whipping time without heat input using a 5-liter KitchenAid® mixer, one time water addition at 3 min before the completion of egg whipping instead of twice, and flour incorporation into the egg foam using a KitchenAid® wire whisk or a Beater Blade®. The modified methods of Beater Blade® and wire whisk exhibited significant correlations in cake volume with a conventional procedure (r=0.931, P<0.001, r=0.925, P<0.001, respectively).

Significance of flour particle size on sponge cake baking performance was determined
using flours of different particle size prepared by re-grinding or sieving. Particle size reduction of flour produced by re-grinding improves sponge cake volume and crumb grain despite it accompanies the increase in starch damage (0.1-0.2%) and sodium carbonate solvent retention capacity (4.8-13.9%) of flour. Flour fractions of small (< 55 µm) particles produced the largest sponge cake volume, ranging from 1353 to 1450 mL. Even with comparable or higher protein content, flour fraction of intermediate particle size produced larger volume (1040-1195 mL) of sponge cake than did flour fractions of large particle size (955-1130 mL). These results indicated that particle size is one of the most important factors on SC volume and crumb grain. Furthermore, flour-water batter viscosity made from flour fractions of different particle size exhibited evident differences and was significantly related to sponge cake volume and crumb grain score.

To investigate the qualitative and quantitative roles of starch on sponge cake baking potential of wheat flour, flours of various amylose content as well as different quantities and proportions of starch in the baking formula were used. SC volume varied widely among soft white and club wheat flours of normal (1093-1335 mL), single-null partial waxy (1108-1183 mL), double-null partial waxy (895 mL) and waxy (828 mL) starch endosperm. The amylose content of soft and club wheat flours showed a positive relationship with SC volume (r=0.790, P < 0.001). In the results of amylograph of 10% whea flour, pasting temperature, peak viscosity, final
viscosity, breakdown and setback were significantly related to SC volume with correlation coefficients of 0.487 ($P < 0.05$), -0.476 ($P < 0.05$), 0.738 ($P < 0.001$), -0.755 ($P < 0.001$), and 0.818 ($P < 0.001$), respectively. Both amylose content and pasting properties of wheat flour and starch exhibited significant relationships with sponge cake volume, it is postulated that the released amylose molecules during sponge cake baking rapidly retrograde during cooling and provide a structural support to sponge cake crumb, producing a large volume of sponge cake. Furthermore, amylose content of normal and waxy starch blends was significantly related with their sponge cake volume ($r=0.975$, $P < 0.05$). Pure wheat starch of over 80 g or more than 75% starch in 100 g starch-gluten blends in replacement of 100 g wheat flour in the SC baking formula were needed to produce sponge cakes having the maximum volume potential. Protein content may play a meager role in SC baking quality of wheat flour by changing the relative proportion of starch rather than its direct implication to and influence on sponge cake baking.