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Single-Kernel Characteristics of Soft Wheat in Relation to Milling and End-Use Properties

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Abstract To investigate the relationship of wheat single kernel characteristics with end-use properties, 183 soft wheat cultivars and lines were evaluated for milling quality characteristics (kernel hardness, kernel and flour protein, flour ash), and end-use properties (i.e., as ingredients in sugar-snap cookies, sponge cake). Significant positive correlations occurred among wheat hardness parameters including near-infrared reflectance (NIR) score and single kernel characterization system (SKCS). The SKCS characteristics were also significantly correlated with conventional wheat quality parameters such as kernel size, wheat protein content, and straight-grade flour yield. The cookie diameter and cake volume were negatively correlated with NIR and SKCS hardness, and there was an inverse relationship between flour protein contents and kernel weights or sizes. Sugar-snap cookie diameter was positively correlated with sponge cake volume.

Keywords: soft wheat, single-kernel, milling, cookie, cake

Introduction

Soft wheat flour has been used for a wide range of commercial baked products. Soft white and club wheats typically have high flour extraction rates, weak gluten, and low protein concentration. These characteristics make them the preferred market subclasses for use in baking pastries, cookies, cakes, flat breads, and similar products (1-3).

A recent survey of U.S. soft wheat quality indicated that the protein content of U.S. soft white wheat and club wheat had increased over the last 13 years, being higher than that of soft red winter wheat since 1988, while the protein content of soft red winter wheat has remained almost constant during the same period (1).

Soft wheats have quality factors and end-uses very different from those of hard wheats. Soft wheats typically have been bred to have low protein content. This has contributed to the general belief that, in soft wheat, protein composition is of little importance. There is much quality variation among soft wheats, however, some soft wheat cultivars can be used to produce breads as well as typical cookie and cake production. This suggests that proteins may, in fact, also be major contributors to soft wheat functionality and product quality (4, 5).

In quality testing of soft wheat breeding lines, it has been customary to obtain data relevant to the chemical and physical characteristics of the grain such as test weight, protein, ash and moisture contents, kernel texture, and sometimes kernel weight, size, and shape (6, 7). The wheat is milled to produce flour which is then subjected to another set of analytical, physicochemical, and baking tests. On the basis of these test results, the breeding line is evaluated for quality potential, usually in relation to a standard of control cultivar grown under the same conditions as the test line (8).

While there has been general awareness that soft wheat breeding lines often differ in millability, sufficient usable information has not been documented to provide a firm basis for evaluating lines for this attribute. One notable difficulty in establishing laboratory parameters associated with milling quality was the question of applicability of small scale evaluations to performance in a commercial mill where quality would be expressed in terms of cost and profitability (9, 10).

Several studies have demonstrated that wheat kernel size is related to the milling potential. The relationship was complex and appeared to vary among wheats of different classes and origin (11). Marshall *et al.* (12, 13) attempted to relate wheat flour yield to kernel size and shape with limited success. As kernel size decreased, flour yield and flour refinement (ash and color) were adversely affected (14).

Wheat hardness is an important index for differentiation of wheat classes and is related to the end-use properties of wheat. Wheat hardness was estimated through the near-infrared reflection (NIR) of ground wheat (15). Chang *et al.* (16) reported significant linear relationships of wheat hardness to break flour yield, but no significant correlations were observed between single kernel and baking parameters.

Recently, measurements of wheat single kernel characteristics have become possible using the single kernel characterization system (SKCS) developed by Martin *et al.* (17). The SKCS can be used to measure the mean values of single kernel hardness, single kernel weight and to calculate the standard deviation of each parameter using data obtained from 300 kernels.

The objective of this study was to investigate the relationships among single kernel characteristics, milling, and baking parameters in soft white spring and club wheats.

Materials and Methods

Wheat samples The wheat cultivars (or lines) harvested

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in 2000 from the Washington State were selected for this study. These cultivars cover 90 of soft white spring (SWS) and 93 club wheats.

Sample preparation and analysis Wheat samples were cleaned with an air aspirator (Kice Metal Products Co., Wichita, KS, USA) before analysis. Nitrogen content was determined on 0.25 g aliquots of ground wheat sample using the Dumas combustion method (model FP-428; Leco Corp., St. Joseph, MI, USA; AACC Approved Method 46-30) (18), and converted into % protein by multiplying with 5.7. The moisture and ash contents of flours were determined according to AACC Methods 44-16 and 08-01, respectively.

Measurement of grain hardness Wheat kernels were ground in a cyclone sample mill (Udy Co., Fort Collins, CO, USA) fitted with a 0.5-mm sieve, and kernel hardness was estimated by NIR (Technicon InfraAlyzer 400; Technicon, Terrytown, NY, USA) using the two-wavelength (1,680 and 2,230 nm) as described in AACC Method 39-70A (18). Hardness was estimated by the single kernel characterization system (SKCS). A 300-kernel sample was analyzed for hardness with a commercial prototype of the SKCS (model 4100; Perten Instruments, Springfield, IL, USA) as described by Martin *et al.* (17). In addition to individual grain hardness, the instrument also measured individual kernel weight.

Milling properties Mature wheats were tempered to 14.5% moisture content and experimentally milled in duplicate, into straight-grade flours on a Buhler mill (Buhler Bros., Inc., Uzwill, Switzerland). Break flour yields were determined in percentage based on the weight of total products recovered as flours of break rolls. Milling scores were calculated as follows (19):

$$\text{Milling score}=100-[(80-A)+50(B-0.30)+0.48(C-12.5)+0.5(D)+0.5(16-E)]$$

where A, flour yield; B, flour ash; C, milling time; D, 65% long patent; E, 1st tempering moisture.

Rheological properties of flour A 10-g mixograph (National Mfg. Co., Lincoln, NE, USA) was used to evaluate the rheological properties of the flours. Mixograph water absorption was determined according to AACC Method 54-40 (18) and was reported as percent by weight, corrected to a 14% (m.b.). Mixograph type was estimated by the instruction chart of the Western Wheat Quality Lab. (19). The flour swelling volume (FSV) was expressed in mL/g. Twelve and a half mL of water was added to 0.45 g flour on a dry weight basis and the mixture was well dispersed. Samples were placed in a hot water bath at 92.5°C and were continuously inverted for 30 min. Then the samples were cooled in an ice water bath followed by incubating at 25°C for 5 min. Tap water was used to bring the samples to room temperature. Samples were centrifuged at 1,000×g for 15 min. The height of the flour was read in mm and expressed in mL/g using the following conversion formula [FSV=(mm×1.52)-0.30 mL/0.45 g] (19).

Hot-pasting viscosity was measured with a rapid visco-analyzer (RVA, Newport Scientific, Narrabeen, NSW, Austrailia) using 3.5 g of flour on a 14% (m.b.) in 25 mL water. The viscosity reported was the peak viscosity in RVA units (cp×12). The temperature profile used to obtain the peak viscosity consisted of 2 min at 60°C, then constant rate heating to 93°C in 6 min with a final hold of 2 min at 93°C for a total of 10 min (18, 19).

Sugar-snap cookie test A micro method was employed for the sugar-snap cookie test with the following composition; 40 g flour at 25°C absorption, 60% sugar, 30% emulsified shortening, 3% dry skim milk, 2.06% $NaHCO_3$, 0.68% NH_4Cl, 0.26% NaCl, and 0.24% emulsifier (distilled mono- and di-glycerides). Cookie batter was mixed using a National cookie dough micromixer (National Mfg. Co.) by AACC Method 10-52 with modification (18, 19). Cookie diameters were sum of diameters of 2 cookies; top grain scores indicated the extent of surface breakup, a desired attribute. Score range was 0 to 10, with 10 being the best.

Sponge cake test Sponge cakes were baked by the recipe and procedure described by AACC Method 10-52 with modification (18, 19). Cake batter was mixed using a KitchenAid mixer (K5SS; KitchenAid Inc., Detroit, MI, USA) with a wire whip attachment. Each batter contained 100 g of flour, 100 g of baker's special-fine sifted sugar, 100 g of fresh whole eggs, and 40 g of water. Batter samples (330 g) were measured into a cake pan and baked in a preheated 180°C oven for 30 min. Loaf volume was determined by rapeseed displacement method. Crumb grain for internal structure and for external factor was visually evaluated. A grade of 80°C was assigned for superior quality and equaled the standard flour.

Statistical analysis All grain and flour analyses as well as milling and baking were conducted in triplicate. Data were analyzed using the statistical analysis system as described by the SAS Institute (20).

Results and Discussion

Wheat quality characteristics General grain quality characteristics of the 90 soft white wheat cultivars studied, including test weight, protein content, milling properties, ash content, and single kernel characteristics, are presented in Table 1. The test weight ranged from 58.1 to 65.4 lb/bu with a mean of 62.4 lb/bu and standard deviation (SD) of 1.3 lb/bu. The mean and SD for near-infrared hardness were 25.3 and 9.3, respectively. Wheat protein and ash content are important chemical characteristics for evaluating the quality of wheats. The wheat protein content varied greatly from 6.8 to 12.2% (12%, m.b.) with a mean of 9.7%, and protein and ash contents were similar in both the soft white spring (SWS) and club wheats.

Pomeranz and Mattern (21) pointed out that wheat kernel density should not be used as an indirect measure of wheat hardness because of the large environmental effects on protein content, genetic control on hardness, and strong influence of wheat composition (including protein content) on density. Variation in wheat hardness may be due to the interactions of proteins and starch granules (22, 23).

Table 1. Wheat and milling characteristics for 90 soft white spring (SWS) and 93 club wheat cultivars and lines

Quality parameter	Mean[1)]			Range	
	SWS	Club	SWS+Club	SWS	Club
Test weight (lb/bu)	62.5±1.3	62.4±1.3	62.4±1.3	59.4-65.4	58.1-65.0
NIR[2)] hardness	22.4±5.9	28.0±10.9	25.3±9.3	10.0-37.0	7.0-74.0
Wheat protein content (%)[3)]	9.7±1.3	9.8±1.2	9.7±1.3	6.8-12.2	7.3-11.9
Single kernel characteristics[4)]					
Hardness index	20.0±12.4	28.8±12.9	24.5±13.4	0.8-47.2	3.7-59.8
Kernel weight (mg)	40.1±6.7	38.7±4.4	39.4±5.7	26.7-53.5	30.3-56.4
Kernel size (mm)	2.5±0.3	2.4±0.2	2.5±0.3	1.6-3.1	2.0-3.3
Straight flour yield (%)	70.5±1.5	70.6±1.6	70.5±1.6	66.8-74.2	65.0-73.6
Break flour yield (%)	51.1±6.8	50.9±5.3	50.9±5.3	31.4-59.3	31.9-56.8
Flour ash content (%)	0.4±0.04	0.38±0.03	0.39±0.04	0.31-0.50	0.32-0.45
Milling score	85.1±3.0	85.5±2.5	85.9±0.04	78.1-90.5	77.1-91.1
Flour swelling volume (mL/g)	23.5±2.5	23.6±1.4	23.5±2.5	14.6-29.2	22.2-26.0
RVA peak viscosity (cp×12)	164.3±46.0	170.3±46.4	165.0±45.9	64-263	128-254

1)Means are average of triplicates for each cultivar and line.
2)Near-infrared reflectance.
3)12% moisture content basis.
4)Single kernel parameters estimated from 300 kernels.

The milling quality of wheat can be judged by the straight-grade flour yield, break flour yield, milling score, flour ash content, and other characteristics. The flour yield of wheat is one of the most important quality factors for millers. The primary objective of wheat milling is to increase the recovery of starchy endosperm and protein. The potential amount of flour from wheat endosperm is about 82 to 84% of grain weight. Normally, the extraction rate obtained commercially from wheat is in the range of 68 to 77%. In this study, the mean value of flour yield was 70.5%, where the yield ranged from 65.0 to 74.2%. Break flour yield ranged from 31.4 to 59.3% with a mean of 50.9%. The flour ash content ranged from 0.31 to 5.0% with a mean of 0.39%. The milling score ranged from 76.3 to 85.0% with a mean of 80.7%. The flour yield and milling scores were not significantly different between SWS and club wheats.

The SKCS can be used to measure the mean values of hardness index, moisture content, weight, and size of wheat using data obtained from 300 kernels. The SKCS hardness index ranged from 0.8 to 59.8 with a mean of 24.5 and SD of 13.4. The SKCS kernel weight ranged from 26.7 to 56.4 mg with a mean of 24.5 mg. The range of SKCS kernel size and SD were 1.6-3.3 and 0.3 mm, respectively. Single kernel characteristics showed similar variations between SWS and club wheats, whereas, for cultivars and lines, higher variations were observed.

Flour protein content varied greatly from 5.5 to 10.7% (Table 2). Mixograph absorption ranged from 44.8 to 57.1% with a mean of 52.3% and SD of 2.1%.

Table 2. Rheological properties of flour from 90 soft white spring (SWS) and 93 club wheat cultivars and lines

Quality parameter	Mean[1)]			Range	
	SWS	Club	SWS+Club	SWS	Club
Flour protein content (%)[2)]	8.1±1.3	8.2±1.1	8.1±1.2	5.5-10.7	6.1-10.2
Mixograph absorption (%)[2)]	56.6±1.5	51.6±1.8	52.3±2.1	49.4-57.1	44.8-56.7
Flour swelling vol. (mL/g)	23.5±2.5	23.6±1.4	23.5±2.5	14.6-29.2	22.2-26.0
RVA peak visco. (cp×12)	164.3±46.0	170.3±46.4	165.0±45.9	64-263	128-254
Cookie properties					
Cookie diameter (cm)	9.3±0.3	9.4±0.2	9.3±0.2	8.7-10.3	8.7-9.9
Top grain score[3)]	7.0±1.3	6.7±1.4	6.8±1.4	2.0-9.0	4.0-9.0
Sponge cake properties					
Cake volume (cc)	1,260±52	1,262±56	1,261±54	1,131-1,400	1,125-1,405
Cake score[4)]	72.6±4.1	72.7±4.6	72.6±4.4	62-82	58-85

1)Means are average of triplicates for each cultivar and line.
2)14% moisture content basis.
3)A visual evaluation score describing the top grain of the sugar-snap cookie; Range 0-10, with 10 being the best.
4)The standard flour produces a cake with a score equal to 80.

The mixograph was designed to test wheat dough strength, a particularly important determinant of bread-making quality. Its usefulness for testing soft wheat flours for other baked products is less clear. For cookies or cakes, little or no mixing is required for dough development.

The cookie baking test is an important test in soft wheat flour evaluation. The principal criterion of quality is the diameter increase during the baking process, which is also referred to a spread factor. Flour that produces cookies of large diameter is considered superior for most soft wheat products. For comparative purposes, Table 2 showed rheological properties of the baked cookies. The cookie diameter ranged from 8.7 to 10.3 cm. The mean and SD for cookie diameter were 9.2 and 0.2 cm, respectively. The top grain score of cookie ranged from 2.0 to 9.0 with a mean of 6.8 according to cultivars and lines.

The cake baking test is also an important test in the evaluation of soft wheat flour. The main criteria for good cake quality are high cake volume and a fine uniform crumb structure that is tender and moist. The sponge cake volume of the soft wheat flour set tested was significantly high; it ranged from 1,131 to 1,405 mL with a mean of 1,261 mL. The cake score ranged from 58 to 85 with a mean of 72.6. Such results might be expected because low-protein soft wheats generally produce the best quality of cookies and cakes.

Relationships between wheat and milling parameters
Simple linear correlation coefficients among analytical data, single kernel characteristics obtained by using the SKCS and milling parameters for the wheat samples were presented in Table 3. The wheat protein content had a significantly positive correlation with test weight ($r = 0.367^{**}$) and NIR hardness ($r = -0.482^{**}$) whereas, there was an inverse correlation between wheat protein and SKCS characteristics. Straight-grade flour yield had a significant negative correlation to SKCS hardness index ($r = -0.522^{**}$).

Pomeranz and Afework (24) reported that smaller wheat kernels generally had lower NIR values. However, Peterson *et al.* (25) reported an insignificant phenotypic correlation and a negative genotypic correlation between kernel weight and hardness measured by the microscopic observation of crushed kernels. These inconsistent observations might have resulted from different growing conditions and wheat varieties.

Break flour yields were correlated negatively with hardness parameters such as NIR hardness and SKCS hardness. Break flour yields were negatively correlated with test weight and wheat protein content. These results confirm that the factors controlling break flour yield contribute to greater cookie spread and cake volume (26).

The ash content was an indicator of higher flour quality. There were significantly negative correlations between the ash content and SKCS characteristics. The milling score showed a significantly positive correlation with total flour yield, as well as with break flour yield, whereas there was an inverse correlation between milling score and ash content ($r = -0.706^{**}$).

The correlation coefficients between wheat hardness including NIR and SKCS hardness index and baking parameters such as cookie diameter and sponge cake volume indicated that baking parameters and SKCS characteristics were negatively correlated (Table 4). The cookie diameters had a significantly correlation of $r = -0.240^{**}$ with NIR hardness index, and $r = -0.425^{**}$ with SKCS hardness index. The sponge cake volume were negatively correlated with NIR hardness index ($r = -0.302^{**}$) and with SKCS hardness ($r = -0.305^{**}$). Also, there were a negative correlation among the NIR hardness, cookie top grain score and sponge cake scores. Therefore, NIR or SKCS hardness values may be potential parameters for estimating the baking capacity of soft wheats. In addition, baking parameters showed significant negative correlations with SKCS weight and size. Ohm *et al.* (27) reported that single kernel weight and size could be estimated using the significant negative correlations with dough proof height and loaf volume due to the inverse relationship of SKCS weight and SKCS size with wheat protein content (Table 3).

The simple linear correlation coefficients among baking

Table 3. Simple linear correlation coefficients (n=183) between wheat quality characteristics and milling parameters

Wheat characteristics	Test weight	NIR hardness	Wheat protein	SKCS characteristics			Flour yield	Break flour	Flour ash
				Hardness	Weight	Size			
Test weight (lb/bu)	1								
NIR[1)] hardness	0.211**	1							
Wheat protein (%)	0.367**	0.482**	1						
SKCS[2)] characteristics									
Hardness index	0.024ns[3)]	0.239**	-0.149*	1					
Kernel weight (mg)	0.227**	-0.128ns	-0.246**	-0.073ns	1				
Kernel size (mm)	0.158**	-0.133ns	-0.340**	0.223**	0.903**	1			
Flour yield (%)	-0.053ns	0.148*	0.092ns	-0.522**	0.003ns	-0.145ns	1		
Break flour yield (%)	-0.374**	-0.250**	-0.451**	0.070ns	-0.169*	-0.072ns	0.013ns	1	
Flour ash (%)	-0.253**	0.041ns	-0.011ns	-0.179**	-0.159*	-0.234**	0.303**	-0.213**	1
Milling score	0.076ns	0.058ns	-0.068ns	0.010ns	0.092ns	0.110ns	0.359**	0.496**	-0.706*

[1)]Near-infrared reflectance.
[2)]Single kernel characterization system.
[3)]Not significant; $^{*}p<0.05$, $^{**}p<0.01$.

Table 4. Simple linear correlation coefficients among near-infrared reflectance (NIR) hardness, single kernel characterization system (SKCS) characteristics, and baking quality parameters for 183 soft wheat cultivars and lines

Baking parameter	NIR hardness index	SKCS characteristics		
		Hardness	Weight (mg)	Size (mm)
Cookie diameter (cm)	-0.240**	-0.425**	-0.232**	-0.303**
Cookie top grain score	-0.156*	-0.352**	-0.196**	-0.239**
Sponge cake vol. (cc)	-0.302**	-0.305**	-0.200**	-0.221**
Sponge cake score	-0.343**	-0.302**	-0.177*	-0.182*

*$p<0.05$, **$p<0.01$.

Table 5. Simple linear correlation coefficients (r) among flour protein content, mixograph characteristics, and baking parameters for 183 soft wheat cultivars and lines

Baking parameter	r-Value
Flour protein content (%) vs.	
Mixograph absorption (%)	0.251**
Cookie diameter (cm)	-0.180*
Cookie top grain score	0.065
Sponge cake volume (cc)	-0.367**
Sponge cake score	-0.409**
Mixograph absorption (%) vs.	
Cookie diameter (cm)	-0.235**
Cookie top grain score	-0.043
Sponge cake volume (cc)	-0.211**
Sponge cake score	-0.216**
Cookie diameter (cm) vs.	
Cookie top grain score	0.572**
Sponge cake volume (cc)	0.384**
Sponge cake score	0.427**
Cookie top grain score vs.	
Sponge cake volume (cc)	0.146
Sponge cake score	0.170*

*$p<0.05$, **$p<0.01$.

parameters were shown in Table 5. Flour protein content affected mixograph absorption (r = 0.251**), cookie diameter (r = -0.180*), sponge cake volume (r = -0.367**), and sponge cake score (r = -0.409**). The significant negative correlation of flour protein content with cookie diameter and sponge cake volume suggests that flour with higher protein content exert lower diameter and loaf volume potential on per unit protein content. In addition, mixograph absorption showed significant negative correlations with cookie diameter and sponge cake volume. The significant correlation of mixograph absorption with baking parameters might have resulted from the role of proteins affecting both water absorption baking parameters.

Significant correlations were also shown among cookie and sponge cake quality characteristics such as cookie diameter versus cookie top grain score (r = 0.572**) and sponge cake volume (r = 0.384**). The significant positive correlation of cookie top grain scores and sponge cake volume/cake scores suggested larger cookie and cake volume generally resulted from softer textured with lower protein content, which produced high break flour yield (28, 29).

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