Solvent Retention Capacity Values in Relation to Hard Winter Wheat and Flour Properties and Straight-Dough Breadmaking Quality[1]

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ABSTRACT

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Solvent retention capacity (SRC) was investigated in assessing the end use quality of hard winter wheat (HWW). The four SRC values of 116 HWW flours were determined using 5% lactic acid, 50% sucrose, 5% sodium carbonate, and distilled water. The SRC values were greatly affected by wheat and flour protein contents, and showed significant linear correlations with 1,000-kernel weight and single kernel weight, size, and hardness. The 5% lactic acid SRC value showed the highest correlation ($r = 0.83$, $P < 0.0001$) with straight-dough bread volume, followed by 50% sucrose, and least by distilled water. We found that the 5% lactic acid SRC value differentiated the quality of protein relating to loaf volume. When we selected a set of flours that had a narrow range of protein content of 12–13% ($n = 37$) from the 116 flours, flour protein content was not significantly correlated with loaf volume. The 5% lactic acid SRC value, however, showed a significant correlation ($r = 0.84$, $P < 0.0001$) with loaf volume. The 5% lactic acid SRC value was significantly correlated with SDS-sedimentation volume ($r = 0.83$, $P < 0.0001$). The SDS-sedimentation test showed a similar capability to 5% lactic acid SRC, correlating significantly with loaf volume for flours with similar protein content ($r = 0.72$, $P < 0.0001$). Prediction models for loaf volume were derived from a series of wheat and flour quality parameters. The inclusion of 5% lactic acid SRC values in the prediction model improved $R^2 = 0.778$ and root mean square error (RMSE) of 57.2 from $R^2 = 0.609$ and RMSE = 75.6, respectively, from the prediction model developed with the single kernel characterization system (SKCS) and near-infrared reflectance (NIR) spectroscopy data. The prediction models were tested with three validation sets with different protein ranges and confirmed that the 5% lactic acid SRC test is valuable in predicting the loaf volume of bread from a HWW flour, especially for flours with similar protein contents.

The quality of a hard winter wheat (HWW) is dependent on specific functional properties of biochemical components and their interactions which determine suitability for milling and baking production. Flour quality cannot be expressed just by one property, but rather depends on several aspects of quality attributes of end use products. All individual properties are important for production of bread. Therefore, there are many different test methods to evaluate various categories of wheat quality, and each method has different requirements for sample size, equipment, and resources. Still, the demand for rapid and reliable tests is increasing in the wheat industry, especially at the marketing channels. In addition, the demand of breeding programs for early generation screen, which requires test methods that need only a small amount of sample, has been increased to save time and expense.

The solvent retention capacity (SRC) test using four solvents on flours including 5% lactic acid, 50% sucrose, 5% sodium carbonate, and distilled water is relatively new (Approved Method 56-11, AACC International 2000), modified from the alkaline water retention capacity test (Approved Method 56-10, AACC International 2000). The use of four solvents was extended further to clarify functional components of a flour by Slade and Levine (1994). Distilled water reflects the ability of flour to hold water; sucrose solution differentiates flours with differing water-soluble pentosans; sodium carbonate solution is sensitive to swelling of damaged starch and pentosans in flour; and lactic acid acts to swell the glutenin subunits that reflect the strength of a dough (Gaines 2000; Guttieri et al 2001; Ram and Singh 2003; Roccia et al 2006). The SRC test has predicted the functional quality of soft wheat flour products like cookies and crackers (Gaines 2000; Gaines et al 2000; Guttieri et al 2001, 2002, 2004; Guttieri and Souza 2003; Ram and Singh 2004). Recently, quality of triticale flour for cookie making was assessed using SRC and small-scale SRC test profiles (Roccia et al 2006). After knowing how flour performs, breeders, millers, or bakers could modify a specific functional component of the flour, resulting in improvement of flour performance in dough handling and finished baked products.

To date, research on SRC test has been mainly focused on cookies, crackers, and some low-moisture sweet goods that are primarily made from soft wheat flour (Slade and Levine 1994; Gaines et al 2000; Guttieri et al 2001, 2002, 2004; Ram and Singh 2004). Assessing the quality of HWW flour by SRC test remains to be explored. Because only 5 g of flour is required for each SRC test, utilizing these tests as diagnostic tools to predict flour functionality is useful in a wheat breeding system where only small quantities of kernels are available for early generations. Even smaller scale (0.2 g of wheat meal) SRC test values were highly correlated with the standard SRC test (5 g of flour) (Bettge et al 2002).

Our research objectives were to investigate the relationships between SRC values of four solvents and other quality parameters of HWW and flour, and to identify the suitability of SRC tests for use in prediction of loaf volume and crumb grain score.

MATERIALS AND METHODS

Materials

Two sets of HWW and flour samples were used; one set was for calibration and the other was for validation. The calibration set consisted of 116 HWW of 1999 and 2000 crops and was provided by the U.S. Department of Agriculture, Agricultural Research Service, Grain Marketing and Production Research Center, Hard Winter Wheat Quality Laboratory, Manhattan, KS. For the calibration set, the 116 wheats, including 20 white wheat, were selected from 966 samples, based on the following criteria applied in succession: 1) protein content, 2) bread loaf volume, 3) mixograph mix time, and 4) mixograph mixing tolerance to obtain a wide representation of the spectrum of HWW properties. In addition,

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37 flours containing similar protein content (12–13%) were selected out of 116 flours to determine whether the SRC tests can differentiate the quality of HWW flour for breadmaking in flours with a narrow range of protein content.

For the validation of the prediction models developed from the calibration set, we used 98 hard red winter samples (protein content 8.1–14.5%) of the 2003 crop from the U.S. Department of Agriculture, Grain Inspection, Packers and Stockyard Administration. This validation set comprised two subsets of flours with flour protein contents of 11–13% ($n = 36$) and 12–13% ($n = 14$).

For breadmaking, malt (50–60 dextrinizing units), shortening, and instant dry yeast were used from Cargill Flour Milling Co. (Wichita, KS), Bunge Foods (Bradley, IL), and Fleischmann's Foods (Portland, OR), respectively. All chemicals were reagent-grade or the highest quality available unless otherwise stated.

Methods

Wheat protein, ash, and hardness score were determined by near-infrared reflectance (NIR) spectroscopy (Approved Methods 39-10, 08-21, and 39-70A, respectively, AACC International 2000). Flour protein (N × 5.7) content was determined with a nitrogen determinator (Leco Corp., St. Joseph, MI) (Approved Method 46-40), and flour ash and moisture contents were determined according to Approved Methods 08-01 and 44-15A, respectively. Analytical data were reported on a 14% moisture basis. Test weight (lb/bu) was measured based on Approved Method 55-10. Single kernel characterization system (SKCS 4100, Perten Instrument, Reno, NV) was used to determine the mean values of kernel weight (mg), size (diameter, mm), moisture content (%), and hardness index (Approved Method 55-31) (Martin et al 1993). Wheat samples were milled on Quadrumat Sr. experimental mill (Brabender, Duisburg, Germany).

Optimum water absorption, mix time, and mixing tolerance were determined on a mixograph (National Mfg. Co., Lincoln, NE) using 10.0 g of flour (14% mb) (Finney and Shogren 1972) (Approved Method 54-40A). Mixing tolerance was rated on a scale of 0–6: 0 for unsatisfactory; 2 for questionable; 4 for satisfactory; and 6 outstanding (Finney 1965).

Solvent Retention Capacity (SRC) Tests

The SRC tests were conducted according to the Approved Method 56-11 (AACC International 2000) using 5% lactic acid, 5% sodium carbonate, 50% sucrose, and distilled water. Flour (5 g) was added into a 50-mL centrifuge tube with a screw cap. Then 25.0 mL of an appropriate solvent was added and the mixture was vortexed vigorously to suspend the flour for 5 sec. The mixture was allowed to set and swell for 20 min and was vortexed for 5 sec each at 5, 10, 15, and 20 min. After centrifugation at 1,000 × *g* for 15 min (not including time to achieve speed), the supernatant was decanted and the tube was drained at a 90° angle for 10 min on a paper towel. Finally, SRC value (14% mb) was calculated for each solvent as:

$$\text{SRC value (\%)} = [(\text{gel weight} - \text{flour weight})/\text{flour weight}] \times 100$$

SDS-Sedimentation Test

Modified Approved Method 56-70 (AACC International 2000) was used to conduct the SDS sedimentation test. First, 2.00 g of wheat flour was suspended in 20.0 mL of colored water by rapid shaking for 15 sec in a 100-mL stoppered measuring cylinder, followed by 4 min of shaking on a wrist-action (table-top) shaker. Next, 20.0 mL of 2.5% SDS solution was added and the contents of the cylinders were mixed by shaking for another 6.0 min. After that, 10.0 mL of 4.25% lactic acid solution was added and the contents of cylinders were mixed by shaking for another 6.0 min. The contents were allowed to settle and volumes of sediment were recorded at 20 min.

Baking Test

A modified straight-dough baking method (Finney 1984) (Approved Method 10-10B, AACC International 2000) was used for an experimental breadmaking test. The bread formula contained 100.0 g of flour, 11.0 mL of sucrose and sodium chloride solution (6.0 g of sucrose and 1.5 g of sodium chloride), 5.0 mL of aqueous malt mixture (0.25 g of dried malt), dry active yeast (1.0 g), shortening (3.0 g), and ascorbic acid (5 mg). Bake water absorption and mix time were estimated based on mixograph data and adjusted to the optimal point subjectively based upon the appearance and feel of the dough.

Doughs were fermented for 90 min at 86% rh and 30°C. Loaves were baked at 218.3°C (425°F) for 18 min and were weighed immediately after removal from the oven. The bread volumes were then measured by rapeseed displacement.

Day-old bread was machine-sliced, and crumb grain was graded by a skilled baker. Crumb grain scores were graded and recorded on a scale of 0–6: 0 for unsatisfactory, 2 for questionable, 4 for satisfactory, and 6 for outstanding. Each grade was well described by Park et al (2004).

Statistical Analysis

Statistical analysis of data was performed using the Statistical Analysis System (v. 8.0, SAS Institute, Cary, NC). The prediction models were developed by stepwise multiple regression analysis. Statistical abbreviations were simple correlation coefficient (r), coefficient of determinant (R^2), root mean square error (RMSE), $P < 0.05$ (*), $P < 0.01$ (**), $P < 0.001$ (***), and $P < 0.0001$ (****) with least significant difference (LSD).

RESULTS AND DISCUSSION

Characteristics of HWW and Flour Samples

The 116 samples of wheat, milling and flour, mixograph, SDS-sedimentation, SRC data, and bread characteristics are summarized in Table I. The data suggests that this sample set contained a large range of quality in HWW. Regarding wheat parameters, the sample set showed a large variation in protein content (8.7–16.2%), kernel weight and size (21.5–41.0 mg and 1.88–3.03 mm, respectively), SKCS hardness index (38.7–90.9), and test weight (53.1–63.8 lb/bu). Flour yield and ash content were 50.2–71.1% and 0.29–0.57%, respectively. Samples also showed variability in mixograph characteristics including water absorption (55.4–67.1%), mix time (1.75–7.75 min), and tolerance (0–6). The SDS sedimentation volume (8.4–42.8 mL) and SRC tests with 5% lactic acid (78.3–166.8%), 5% sodium carbonate (64.9–94.0%), 50% sucrose (88.1–142.1%), and distilled water (54.4–72.1%) all showed wide variation. Bread baking results, as expected, showed wide ranges in loaf volume (618–1,130 cm^3), and crumb grain score (1–5). Therefore, these samples appear to represent a wide spectrum of quality in HWW.

Wheat, Milling, and Flour Characteristics Correlated with SRC Tests

Many wheat characteristics were highly correlated with the four SRC tests (Table II). The 5% lactic acid SRC values showed a high positive correlation with wheat protein content (r = 0.66****), whereas negative correlations were shown with kernel weight and diameter and 1,000 kernel weight (r = –0.51****, r = –0.51****, and r = –0.52****, respectively). This is probably due to the inverse relationships between flour protein content and kernel weight and diameter and 1,000 kernel weight (r = –0.59****, r = –0.60****, and r = –0.63****, respectively) (data not shown), indicating that the higher the kernel weight or diameter, the lower the proportion of protein. The 5% sodium carbonate SRC values showed a similar relationship trend with a lesser degree, but this test showed a much higher correlation with SKCS hardness index (r = 0.49****). This is because, as described above, sodium carbonate reacts with damaged starch, and flour from harder wheat generally has more starch damage because of the milling process. The 50% sucrose SRC test, which increases with pentosan (Ram and Singh 2003; Roccia et al 2006), had a high inverse relationship (*r* = –0.63****) with kernel diameter probably because flour milled from large kernels contained a smaller proportion of cell wall materials such as pentosans compared with flour milled from many small kernels. Pentosan exists mainly in the cell walls of plant material and wheat flour contains ≈1.5–2.0% (db) pentosan, of which ≈20–30% (db) is water-soluble (Michniewicz et al 1990). The distilled water SRC showed a high positive correlation (*r* = 0.68****) with hardness index, probably due to the higher proportion of damaged starch in flour that absorbs and holds more water. Test weight showed weak but significant reverse correlations with 5% lactic acid, 50% sucrose, and distilled water SRC tests (Table II). Guttieri et al (2002) also observed negative correlations between test weight of soft white spring wheat and 5% Na_2CO_3 and 50% sucrose SRC tests. Ash content had no significant effects on the three SRC tests except the 5% lactic acid test.

Flour yield showed a high inverse correlation (*r* = –0.64****) with 50% sucrose SRC. This is due to the fact that flour yield has high positive correlations with kernel weight and diameter and

TABLE I
Wheat, Milling, Flour, Mixograph, Solvent Retention Capacity Data, and Bread Characteristics (*n* = 116)[a]

Quality Parameter	Median	Mean	SD	Range
Wheat characteristics				
NIR protein content (%)	13.6	13.2	1.8	8.7–16.2
NIR ash content (%)	1.43	1.42	0.10	1.23–1.70
NIR hardness score	60.2	59.6	12.0	18.5–82.3
SKCS kernel weight (mg)	28.2	28.9	4.0	21.5–41.0
SKCS kernel diameter (mm)	2.26	2.31	0.26	1.88–3.03
SKCS hardness index	72.2	71.2	10.8	38.7–90.9
Test weight (lb/bu)	59.2	59.3	2.1	53.1–63.8
1,000 kernel weight (g)	26.5	27.4	4.6	19.7–42.1
Milling and flour characteristics				
Flour yield (%)	66.3	66.0	3.4	50.2–71.1
Protein content (%)	12.0	11.5	1.8	7.4–14.6
Ash content (%)	0.35	0.36	0.04	0.29–0.57
Mixograph characteristics				
Water absorption (%)	63.2	62.5	2.6	55.4–67.1
Mix time (min)	3.57	3.77	1.17	1.75–7.75
Mixing tolerance	4.0	3.2	1.7	0–6
SDS-sedimentation (mL)	35.6	33.8	6.7	8.4–42.8
Solvent retention capacity (%)				
5% Lactic acid	121.2	121.8	15.9	78.3–166.8
5% Sodium carbonate	76.5	76.7	5.4	64.9–94.0
50% Sucrose	105.2	105.9	9.2	88.1–142.1
Distilled water	61.5	61.9	3.0	54.4–72.1
Bread characteristics				
Loaf volume (cm^3)	847	854	120	618–1,130
Crumb grain score	3.2	3.2	1.1	1–5

[a] Values are on a 14% moisture basis. NIR = near-infrared reflectance; SKCS = single kernel characterization system; SD = standard deviation.

TABLE II
Correlation Coefficient (*r*) Values Between Solvent Retention Capacity Data and Wheat, Milling, Flour, Mixograph, SDS-Sedimentation, and Bread Characteristics (*n* = 116)[a]

	Solvent Retention Capacity (%)			
Quality Parameter	5% Lactic Acid	5% Sodium Carbonate	50% Sucrose	50% Distilled Water
Wheat characteristics				
NIR protein content (%)	0.66****	0.32***	0.50****	0.45****
NIR ash content (%)	0.27**	ns	ns	ns
NIR hardness score	ns	0.19*	–0.24**	0.51****
SKCS kernel weight (mg)	–0.51****	–0.38****	–0.51****	–0.31***
SKCS kernel diameter (mm)	–0.51****	–0.48****	–0.63****	–0.37****
SKCS hardness index	0.28**	0.49****	ns	0.68****
Test weight (lb/bu)	–0.19*	ns	–0.25**	–0.25**
1,000 kernel weight (g)	–0.52****	–0.40****	–0.54****	–0.32***
Milling and flour characteristics				
Flour yield (%)	–0.29**	–0.47****	–0.64***	–0.22*
Protein content (%)	0.60****	0.30***	0.46****	0.45****
Ash content (%)	ns	0.22*	ns	0.32***
Mixograph characteristics				
Water absorption (%)	0.62****	0.26**	0.37****	0.46****
Mix time (min)	ns	–0.25**	–0.20*	–0.23*
Mix tolerance	0.36****	ns	ns	ns
SDS-sedimentation (mL)	0.83****	0.23*	0.47****	0.25**
Bread characteristics				
Loaf volume (cm^3)	0.83****	0.33***	0.58****	0.38****
Crumb grain score	0.46****	ns	ns	ns

[a] Significant at $P = 0.05$ (*), $P = 0.01$ (**), $P = 0.001$ (***), and $P = 0.0001$ (****); ns = *r* value is not significant at $P = 0.05$. NIR = near-infrared reflectance; SKCS = single kernel characterization system.

1,000 kernel weight (*r* = 0.64****, *r* = 0.65****, and *r* = 0.66****, respectively) (data not shown). As mentioned, the larger the kernel size, the less cell wall material there is to interact with 50% sucrose. Even though the precise measurement of the quantitative binding between the solvent and vast numbers of types of molecular components in the flour is very difficult, if not impossible, the four SRC values still show differences in chemical and physical properties of HWW and flours.

Relationships of Mixograph and SDS-Sedimentation to SRC Tests

A mixograph provides a set of variables (quality parameters) that correlate with different aspects of the breadmaking process. The mixograph water absorption provides a quantitative guide for the level of water required to make the best dough. Water absorption was most highly correlated with 5% lactic acid SRC (*r* = 0.62****) and was correlated with distilled water SRC (*r* = 0.46****) to a lesser degree (Table II). The 5% lactic acid SRC, however, showed no significant correlation with mix time and the other three SRC tests also showed no or very low significant correlations. Mix time was inversely correlated with flour protein content (*r* = –0.31***) (data not shown). In a related study (Park et al 2006), we found that one of the protein fractions, 50% 1-propanol insoluble polymeric protein (IPP), was highly positively correlated with mix time; the 50% 1-propanol soluble polymeric protein (SPP) fraction was inversely correlated. So, it is suggested that as a result of the opposite effects of those protein fractions on mix time, the mix time and protein content do not show significant correlation or show an inverse relationship because relative content of SPP tends to be higher than IPP as the total flour protein content increases. Due to the complicated relationship between individual protein fractions and mix time, it seems that the SRC tests can not provide significant information about the optimal mix time for dough.

The mixograph tolerance indicates how rapidly a dough loses consistency (breakdown) upon overmixing. Of four sets of SRC tests, only 5% lactic acid SRC showed a significant correlation (*r* = 0.36****) with mixing tolerance.

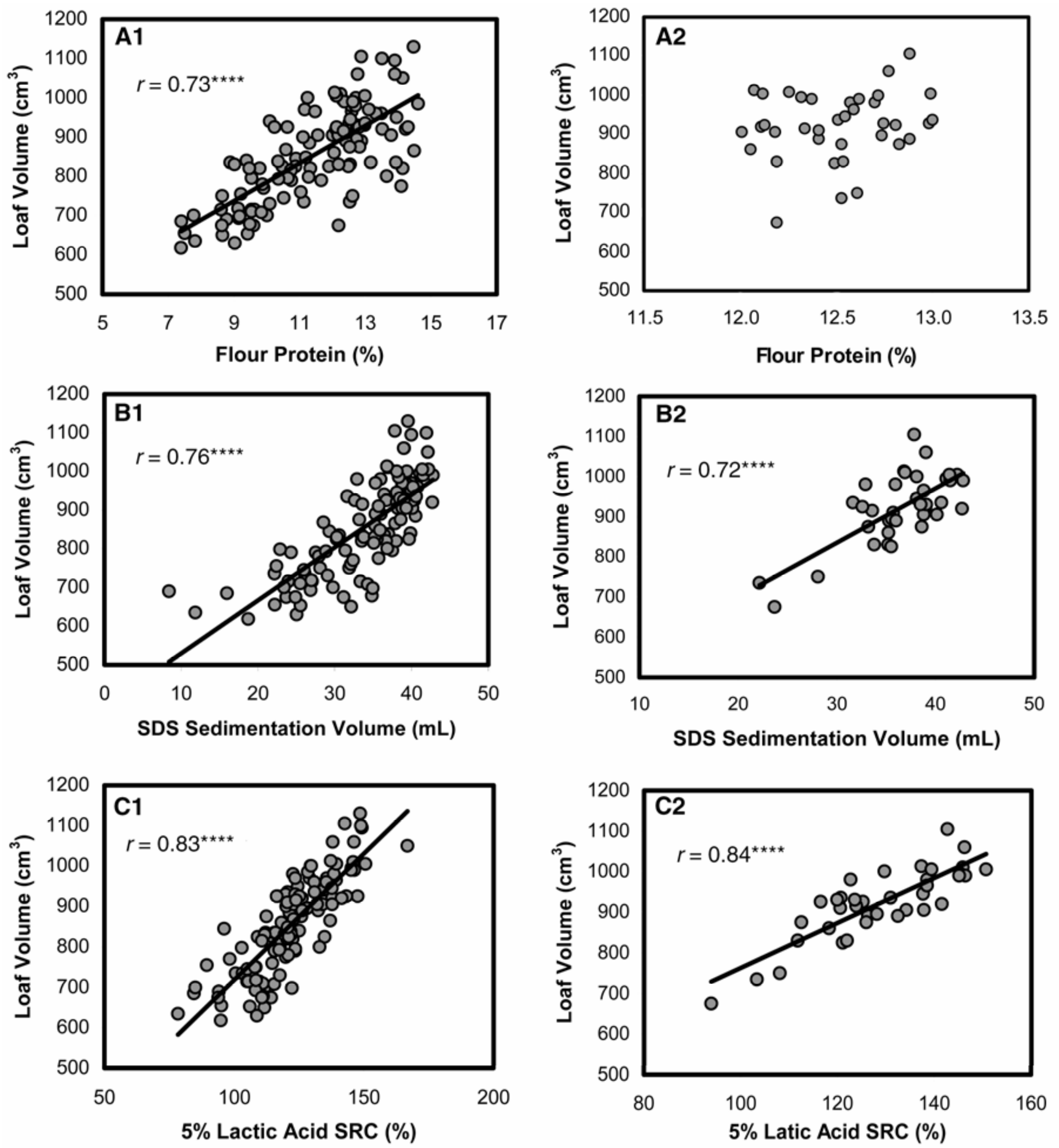

Fig. 1. Relationships between loaf volume vs. flour protein content, SDS sedimentation volume, and 5% lactic acid SRC values in 116 samples (**A1, B1, C1**) and in 37 samples of similar protein content (12–13%) (**A2, B2, C2**).

The SDS sedimentation volumes were significantly correlated with all four SRC tests values, but the most significant correlation was found with 5% lactic acid SRC (*r* = 0.83****) (Table II). This is probably due to the fact that 50 mL of solvent used in the SDS sedimentation test also contains 0.85% lactic acid. The SDS sedimentation volume was reported as a good indicator of bread quality (Kruger and Hatcher 1995; Wang and Kovacs 2001).

Relationships of Bread and Other Quality Parameters to SRC Tests

Loaf volume was most highly correlated with 5% lactic acid SRC (*r* = 0.83****) followed by 50% sucrose SRC (*r* = 0.58****), which were highly correlated with flour protein content (*r* = 0.60**** and *r* = 0.46****, respectively) (Table II). In comparison to the correlation coefficient between flour protein content and loaf volume (*r* = 0.73****) (Fig. 1. A1), the correlation between 5% lactic acid SRC and loaf volume was stronger. The SDS sedimentation volume, which was highly correlated with 5% lactic acid SRC, also showed a high correlation with loaf volume (*r* = 0.76****) (Fig. 1. B1).

Within the subset of flours with protein at 12–13% (*n* = 37), we found that loaf volume was significantly correlated with SDS sedimentation volume (*r* = 0.72****) (Fig. 1. B2) and 5% lactic acid SRC (*r* = 0.84****) (Fig. 1. C2), whereas flour protein content did not show significant correlation with loaf volume (Fig. 1. A2). This data indicates that flour protein content is generally highly correlated with bread loaf volume when the protein range is wide, but within a narrow protein content range, protein quality usually governs the final breadmaking result. So, it seems that the 5% lactic acid SRC has a robust ability to differentiate the protein quality of HWW flour for breadmaking, even when the flours have similar protein contents.

The bread crumb grain score is an important parameter for describing the appearance of sliced bread. Crumb grain score did not show as high a correlation with many quality parameters as loaf volume did. It was barely significantly correlated with flour protein content (*r* = 0.21*) (data not shown) and somewhat more significant with 5% lactic acid SRC (*r* = 0.46****, Table II). In addition, of the 37 flours with 12–13% protein, we found higher correlation between crumb grain score and 5% lactic acid SRC (*r* = 0.57****) (data not shown), whereas the relationship between protein content and crumb grain was not significant. Crumb grain score was also significantly correlated with SDS sedimentation volume (*r* = 0.59****, *n* = 37) (data not shown). These results suggest that quality of crumb grain is not determined by protein content, but rather by protein quality. Also, based on generally low correlations between protein content and quality (5% lactic acid SRC) and crumb grain score, protein may not be a dominant factor contributing to the quality of crumb grain. It has been reported that other flour characteristics such as starch granule size distribution (Hayman et al 1998; Park et al 2004, 2005) and overall rheological properties of dough (Van Vliet et al 1992) may affect the stabilization of gas cells in the dough and finally affect the quality of crumb grain structure.

Prediction Models for Loaf Volume

To develop a better genotype of wheat, large numbers of samples must be analyzed with a variety of tests on each sample. In the early stages of wheat breeding, the amount of kernels for each sample is very limited. Therefore, a prediction model that requires only a limited number of parameters is very beneficial (Chung et al 2001). Furthermore, it would be highly advantageous to obtain those parameters from simple, rapid, precise, and routine tests.

The development of prediction models for loaf volume and crumb grain score was conducted using six different sets of wheat and flour quality parameters (Table III). The first set included the data generated on only two laboratory instruments, SKCS and NIR. Those two instruments are used routinely to analyze physical and chemical properties of wheat, and the data are attainable as soon as wheat samples are received. Test weight was excluded from the first set of parameters because the data may not be available in the early generation breeding lines. SKCS single kernel weight was used in place of 1,000 kernel weight. The second set of parameters included basic milling and flour characteristics such as flour yield, protein, and ash contents in addition to the first set of parameters. The third set included conventional mixograph data including mixing time, absorption, and tolerance, in addition to the second set of parameters. In the same way, the fourth and fifth set contained SDS sedimentation and 5% lactic acid SRC data, respectively, in addition to the second set of parameters. Lastly, the sixth set included all parameters from the first set to the fifth set.

As mentioned earlier, it is highly desirable to derive a prediction model using as few parameters as possible because of the limited sample available in early generation lines and because we can save the cost and time from unnecessary tests. From the first set of parameters, we obtained a prediction model for loaf volume with R^2 = 0.609 and root mean square of error (RMSE) = 75.6 with only two quality parameters, single kernel weight and NIR

TABLE III
Prediction Models for Loaf Volume[a]

Set	Prediction Model	Calibration R^2 (n = 116)	RMSE
1	Wheat characteristics (SKCS and NIR data) LV = 445.3 + 40.49 × NIR-protein – 5.33 × SKW	0.609	75.6
2	Set 1 + Milling and flour characteristics (flour yield, protein, and ash) LV = 445.3 + 40.49 × NIR-protein – 5.33 × SKW	0.609	75.6
3	Set 2 + Mixograph (mixing time, absorption, and tolerance) LV = 553.8 + 23.3 × NIR-protein + 37.19 × MTOL – 89.8 × SK-size – 27.75 × MT – 1.19 × SK-HD + 22.33 × FP	0.706	66.8
4	Set 2 + SDS-sedimentation LV = 55.5 + 26.67 × NIR-protein + 8.02 × SDS-sedimentation + 104.76 × NIR-ash	0.709	65.5
5	Set 2 + 5% Lactic acid SRC LV = 122.4 + 4.17 × 5% lactic acid SRC + 21.54 × NIR-protein – 2.63 × SKW	0.778	57.2
6	Set 2 + Mixograph + SDS-sedimentation + 5% lactic acid SRC LV = –105.9 + 4.85 × 5% lactic acid SRC +15.68 × NIR-protein – 14.12× MT + 135.92 × NIR-ash	0.790	56.7

[a] R^2 = coefficient of determinant; RMSE = root mean square error; SKCS = single kernel characterization system; NIR = near-infrared reflectance; LV = loaf volume; SKW = single kernel weight; MTOL = mix tolerance; SK-Size = single kernel size; MT = mix time; SK-HD = single kernel hardness; FP = flour protein; SRC = solvent retention capacity.

TABLE IV

Correlation Coefficients (*r*) Among Protein Content and Actual Loaf Volume of Validation Set, and Predicted Loaf Volumes Using Model Set 1 and 5[a]

	Whole Validation Set (n = 98) Protein Content (8.1-14.5%)		Sub-Validation Set (*n* = 36) Protein Content (11–13%)		Sub-Validation Set (*n* = 14) Protein Content (12–13%)	
	Flour Protein	Experimental LV	Flour Protein	Experimental LV	Flour Protein	Experimental LV
Experimental LV	0.91****	–	0.35*	–	0.17	–
Predicted LV by Set 1[b]	0.97****	0.91****	0.78****	0.46**	0.29	0.15
Predicted LV by Set 5[b]	0.94****	0.92****	0.71****	0.66****	0.38	0.73**

[a] Significant at $P = 0.05$ (*), $P = 0.01$ (**), and $P = 0.0001$ (****); LV = loaf volume.

[b] Model sets 1 and 5 as in Table III.

wheat protein. Considering the ease of obtaining data for single kernel weight and NIR wheat protein, this prediction equation is reasonably valuable for screening of early generation of breeding lines. Flour yield, protein content, and ash content did not improve the prediction model in the second set of parameters. However, mixograph data did improve the prediction model with $R^2 = 0.706$ and RMSE = 66.8 compared with first and second sets. The addition of SDS sedimentation data instead of mixograph data generated a slightly better prediction model with $R^2 = 0.709$ and RMSE = 65.5. The inclusion of 5% lactic acid SRC in the data set significantly improved prediction model with $R^2 = 0.778$ and RMSE = 57.2. The sixth set, however, which included all parameters showed only marginal improvement in the prediction model with $R^2 = 0.790$ and RMSE = 56.7 when compared with the fifth set. This is a disappointing result when one considers the cost and time spent to analyze the samples. So it is concluded that a prediction model developed from the fifth set could be the most desirable. The prediction model developed for crumb grain score, however, showed low R^2 and high RMSE that seemed inappropriate to use as a predicting tool. The highest values we obtained were $R^2 = 0.331$ with RMSE = 0.87 from the sixth set and $R^2 = 0.321$ and RMSE = 0.88 from the fifth set (prediction models not shown).

The prediction models were applied to a separate validation set (flour protein content 8.1–14.5%, *n* = 98) and two sub-validation sets that were selected from the 98 samples by flour protein contents of 11–13% (*n* = 36) and 12–13% (*n* = 14). We wanted to know how the prediction models would work with a sample set containing a wide range of protein content and also test the robustness of the prediction models for samples with a narrow protein range. We chose two prediction models, the first and fifth set, which showed efficient results when compared with other prediction models as to cost and accuracy. Table IV shows the correlation coefficients among protein content and loaf volume of the validation set and predicted loaf volume by first and fifth set. One notable item is this validation set (*n* = 98) was not a good choice to show the difference in predicting ability of the two prediction models due to the high correlation of flour protein and loaf volume ($r = 0.91$****). As a result, the correlations between actual loaf volume and predicted loaf volumes by two models that showed quite different R^2 and RMSE values in Table III were almost the same ($r = 0.91$**** and 0.92****, respectively). Other prediction models also showed almost the same correlation coefficients (data not shown).

We did find differences in correlation when we used sub-validation sets that had flours with a narrow range of protein contents. With the first sub-validation set samples (protein content 11–13%, *n* = 36), the correlations decreased sharply between experimental loaf volume and protein content ($r = 0.35$*) and predicted loaf volume by model from the first set ($r = 0.46$**), whereas the correlation between experimental loaf volume and predicted loaf volume by the fifth set model decreased moderately ($r = 0.66$****). This trend was more obvious with the second sub-validation set, which had flours with a narrower protein content (12–13%, *n* = 14). There were no significant correlations between experimental loaf volume and protein content and predicted loaf volume by the first set model, whereas predicted loaf volume by the fifth set model still showed significant correlation ($r = 0.73$**) with experimental loaf volume. This confirms our previous results in this study that 5% lactic acid SRC has the capability to differentiate the quality of protein in relation to loaf volume, even for flours with similar protein content.

CONCLUSIONS

The SRC four solvents (5% lactic acid, 5% sodium carbonate, 50% sucrose, and distilled water) were tested to find relationships with HWW quality parameters. SRC tests showed high correlations with many wheat and flour quality parameters but the degrees of correlation on specific quality parameters were different among others. The 5% lactic acid SRC showed the highest correlation with loaf volume, followed by protein content. Our results suggested that 5% lactic acid SRC has the capability to differentiate the quality of protein that is closely related to loaf volume. This observation was confirmed by the result that the prediction model developed for loaf volume with 5% lactic acid SRC value showed robustness in predicting loaf volume even in flours with a narrow range of protein content. The SDS sedimentation also showed the capability to differentiate the quality of protein, but to a lesser degree than 5% lactic acid SRC. The 5% lactic acid SRC was the best for assessing bread quality parameters in this study, therefore, the adaptation of this test for evaluation of HWW quality is recommended.

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