

# Application of Wheat Meal Solvent Retention Capacity Tests Within Soft Wheat Breeding Populations

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## ABSTRACT

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The solvent retention capacity (SRC) test is a relatively new AACC Approved Method (56-11) for evaluating soft wheat flour quality. The test measures the ability of flour to retain a set of four solvents (water, 50% sucrose, 5% sodium carbonate, and 5% lactic acid) after centrifugation. The objective of this study was to evaluate the utility of wheat meal sodium carbonate and lactic acid SRC tests and SDS sedimentation volume within three populations of soft spring wheat inbred lines as tools for selecting for improved flour SRC profiles, flour extraction, and cookie and pastry quality. The populations were derived from the crosses Vanna/Penawawa, Kanto 107/IDO488, and M2/IDO470 and were grown in replicated, irrigated trials in 2000 and 2001 near Aberdeen, Idaho. Within each of the three populations, wheat meal sodium carbonate SRC effectively predicted straight-grade flour sodium carbonate ( $r = 0.69$ – $0.81$ ) and

sucrose SRC ( $r = 0.74$ – $0.84$ ). Wheat meal sodium carbonate SRC also was negatively correlated with flour extraction and sugar snap cookie diameter. Wheat meal lactic acid SRC predicted straight-grade flour lactic acid SRC in only one population. In contrast, SDS sedimentation volume predicted straight-grade flour lactic acid SRC in all three populations ( $r = 0.74$ – $0.93$ ). Moreover, SDS sedimentation volume and wheat meal sodium carbonate SRC were independent in two of the three populations. This suggests that the SDS sedimentation and sodium carbonate SRC may measure different intrinsic characteristics. Therefore, a combination of sodium carbonate SRC and SDS sedimentation volume analyses of wheat meal may be an efficient approach to selecting toward target SRC profiles, increased flour extraction, and larger sugar snap cookie diameter in soft wheats.

The solvent retention capacity (SRC) test is a relatively new method (Approved Method 56-11, AACC 2000) that quantifies soft wheat flour quality (Slade and Levine 1994; Gaines 2000). The test measures the ability of flour to retain a set of four solvents (water, 50% sucrose, 5% sodium carbonate, and 5% lactic acid) after centrifugation. Retention of these solvents produces a practical flour quality functionality profile for predicting commercial bakery performance better than a traditional sugar-snap cookie test (Approved Method 10-52) (Slade and Levine 1994; AACC 2000). Desirable cookie and cracker flours have low water-holding capacity (Faridi et al 1994), thus more water is available to dissolve the sugar to form syrup. Dough viscosity thereby decreases during baking, the dough spreads farther, and produces larger diameter cookies (Slade and Levine 1994). Flours with high water retention require increased baking times during cookie and cracker manufacturing, which produces a less tender product and increases energy costs.

Breeding soft wheat cultivars that produce flours with low water retention is an important goal of our breeding program. At the same time, manufacturers have indicated interest in soft wheat flours with moderate gluten strength to reduce the requirement for hard wheat flour in formulations for traditional soft wheat products. The sugar snap cookie test provides one indicator of the potential utility of a flour for cookie manufacturing, but it does not partition the underlying components of soft wheat quality. For example, weak gluten, moderate pentosan content flours may produce sugar snap cookies similar to those from moderate gluten, low pentosan flours. In contrast, the SRC characterizes the water-holding capacity due to damaged starch, pentosans, and gluten strength. It is thereby possible to select among wheat genotypes for those that produce flours with lower damaged starch and pentosan content, while retaining moderate gluten strength. Specifically, within our soft wheat breeding program, we select toward lower sodium carbonate and sucrose SRC and greater lactic acid SRC. In principle, an upper bound exists on desirable lactic acid SRC. However, our soft wheat breeding populations do not have excessive gluten strength.

SRC evaluation of flours is a useful tool for identifying high-quality genotypes. Within irrigated production environments in Idaho, SRC effectively differentiated 26 soft white spring wheat genotypes into groups of similar end use quality with very limited genotype  $\times$  environment interaction (Guttieri et al 2001). Specific fertility and irrigation treatments applied to two soft white spring wheat cultivars, Centennial and Pomerelle, did not significantly affect SRC (Guttieri et al 2002). Rain-fed trials characteristically produced flours with higher water, sodium carbonate, and sucrose SRC. However, genotype  $\times$  environment interaction was nonsignificant (Guttieri et al 2002). Therefore, selection among genotypes within a given environment would be expected to produce a gain-from-selection observable in multiple and diverse environments.

The utility of flour SRC as a selection tool was evaluated in inbred lines derived from three spring wheat populations (Vanna/Penawawa, Kanto 107/IDO488, and M2/IDO470). The standardized variances among genotypes in these three populations was 67–97% of the total variance (Guttieri and Souza 2003). These standardized variances were similar in magnitude to the standardized variances for plant height and grain hardness, two traits easily influenced by selection in conventional wheat breeding programs. Therefore, SRC can readily be manipulated in breeding populations through direct selection among lines.

A wheat meal version of the SRC test has great potential utility in a breeding program, provided it measures useful genetic variation. For example, in the first generation of inbred line evaluation (head-rows), breeding programs may evaluate thousands of samples. At this stage of testing, sample size generally is not sufficient for milling, and the labor required to temper and mill thousands of samples is prohibitive. Wheat meal determinations of NIR hardness, protein, and SDS sedimentation are conducted routinely (Souza et al 2002).

A small-scale version of the SRC test using wheat meal was developed by Bettge et al (2002). Among samples of the eight cultivars tested, the correlations between 1 g of wheat meal SRC and the standard 5 g of flour SRC were high for lactic acid ( $r = 0.90$ ), sodium carbonate ( $r = 0.97$ ), and sucrose ( $r = 0.80$ ). The authors also tested a method with 0.2 g of wheat meal in a microcentrifuge tube. Although correlations with tests using 5 g of flour were significant, they were lower than with 1 g of meal.

Laboratory throughput in early stages of testing could be increased by using fewer than the four standard SRC solvents. Results of

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previous studies suggest that selection for sodium carbonate SRC may result in indirect selection for sucrose SRC (Guttieri et al 2001; Guttieri and Souza 2003). In our initial survey of flours from 26 soft white spring wheat genotypes, sodium carbonate SRC and sucrose SRC were correlated ( $r = 0.78$ ) (Guttieri et al 2001). Sodium carbonate SRC and sucrose SRC were correlated in 46 flour samples of Centennial ( $r = 0.64$ ) and 45 flour samples of Pomerelle ( $r = 0.56$ ) grown in a wide range of production environments. Sodium carbonate and sucrose SRC also were highly correlated in the each of the three populations of inbred soft spring wheat lines, Vanna/Penawawa ( $r = 0.92$ ), Kanto 107/IDO488 ( $r = 0.89$ ), and M2/IDO470 ( $r = 0.81$ ) (Guttieri and Souza 2003). Sodium carbonate SRC testing has advantages over sucrose SRC testing: 5% (w/w) sodium carbonate is much less expensive than 50% (w/w) sucrose, and 5% sodium carbonate is easier to prepare.

Sodium carbonate SRC may either be correlated with or independent of lactic acid SRC, depending on the genetic background (Guttieri and Souza 2003). This suggests that sodium carbonate SRC may be used as a first approximation for estimating water absorption due to carbohydrate factors such as damaged starch and pentosan content, but not as a predictor of gluten strength as measured by the lactic acid SRC. Flour lactic acid SRC was correlated with 1 g of wheat meal lactic acid SRC in eight cultivars (Bettge et al 2002). Therefore, wheat meal lactic acid SRC is a possible alternative to the established SDS sedimentation volume test for gluten strength. Flour lactic acid SRC was correlated with wheat meal SDS sedimentation volume ( $r = 0.85$ ) in our survey of 26 soft white spring wheat genotypes (Guttieri et al 2001). While SDS sedimentation volume is a tool primarily used in selecting among bread wheats, it has demonstrated potential utility in pastry wheats (Carter et al 1999): SDS sedimentation volume of wheat meal, adjusted for protein content, differentiated among soft white winter and club wheats with limited genotype  $\times$  environment interaction.

The objective of this study was to evaluate the utility of wheat meal sodium carbonate and lactic acid SRC tests and SDS sedimentation volume within populations of inbred lines as a tool for selecting toward desired flour SRC profiles, flour extraction, and sugar snap cookie diameter.

## MATERIALS AND METHODS

Inbred lines of three crosses were evaluated. The crosses included Vanna/Penawawa (25  $F_{4,6}$  families), Kanto 107/IDO488 (18  $F_{5,8}$  families), and M2/IDO470 (26  $F_{5,8}$  families). Vanna, Penawawa, and IDO488 are soft white spring wheat genotypes adapted to irrigated production in the Pacific Northwest. Kanto 107 is a soft red wheat from Japan with a facultative growth habit. M2 is a synthetic wheat derived from crossing durum (*Triticum turgidum*, var. durum) and *Aegilops squarrosa* (Coss). IDO470 is a hard white spring wheat reselection of the cultivar Idaho 377s adapted to irrigated production in the Pacific Northwest. Inbred lines of the M2/IDO470 populations were selected for kernel softness based on single kernel hardness testing (SKCS 4100, Perten Instruments, Springfield, IL) before inclusion in this study. These populations and parents are described in detail in Guttieri and Souza (2003). Inbred lines were grown in irrigated field trials of two replicates at Aberdeen, ID, in 2000 and 2001. Grain production conditions were described previously (Guttieri and Souza 2003).

As described previously (Guttieri and Souza 2003), grain from each inbred line in each replication was tempered (Approved Method 26-10, AACC 2000) and milled with a Brabender Quadramat Senior Mill (Approved Method 26-21A). Sugar snap cookies were prepared and measured (Approved Method 10-52), and SRC of flours were measured using four water-based solvents (water, 5% sodium carbonate, 50% sucrose, 5% lactic acid) according to Approved Method 56-11, with minor modifications (Guttieri et al 2001).

For this study, SRC of wheat meal were measured as for flours using 5 g of meal ground on a Udy cyclone sample mill equipped with a 1.0-mm stainless steel sieve. The meal was handled in the same manner as flour samples. Meal was suspended in 25 mL of 5% sodium carbonate or 25 mL of 5% lactic acid using manual shaking, depending on the wheat meal test. Samples were placed horizontally on an orbital shaker and shaken for 20 min at  $\approx 100$  rpm, then centrifuged, drained, and weighed according to Approved Method 56-11. Wheat meal protein and hardness were measured using an NIR instrument (Inframatic 8611, Perten Instruments) as described in Approved Methods 39-10 and 39-70 (AACC 2000).

SDS sedimentation volume was measured by a modification of the method described by Dick and Quick (1983), as optimized within the University of Idaho Wheat Quality Laboratory. Samples of wheat meal (1 g) were placed in 25-mL glass graduated cylinders, and 10 mL of distilled water was added to each. Cylinders were shaken vigorously 15 sec, then placed on a rocker to rest for 2 min. The cylinders were inverted four times. The cycle of rest and inversions was repeated, after which 10 mL of 2.5% sodium lauryl sulfate was added to each cylinder. The cylinders were inverted four times and allowed to rest 2 min. This cycle of inversion and resting was repeated three additional times. A 1.1% (w/v) lactic acid solution (5 mL) was added, and cylinders were mixed by inversion on the rocker four times. The inversions were repeated 2, 4, and 6 min after addition of lactic acid solution. Cylinders then were removed from the rocker and allowed to settle for 20 min, at which time sedimentation volumes were recorded.

Statistical analyses were conducted as previously described (Guttieri and Souza 2003). The effect of trial year was considered a random environment effect, and inbred lines were assumed to be random representatives of a population of soft-kernel inbred lines. Least square means of inbred lines were calculated using a mixed effects analysis of variance (MIXED) procedure in SAS software (v. 8.1, SAS Institute, Cary, NC). Sums of squares due to the random effects models were calculated using a general linear models (GLM) procedure in SAS software. Each population was analyzed independently. Variances for breeding populations are typically valid only within the context of a uniform reference population and will vary depending on the genetic composition of the populations and the ability of the test environment to elicit the phenotype (Hallauer and Miranda 1981). The three populations were independently derived and intentionally selected for their nonoverlapping parent sets that differed in levels of parental genetic divergence. Therefore, we assumed they were different populations and could be analyzed independently to derive independent variance components as a method of validating the robustness of our conclusions.

Year  $\times$  genotype interactions were not significant, therefore, data were combined over years for analysis. The among-inbred line variance component ( $\sigma_g^2$ ) was calculated as

$$\sigma_g^2 = (\text{Mean squares}_{\text{genotypes}} - \text{mean squares}_{\text{genotypes} \times \text{environment}}) / RY \quad (1)$$

where R is the number of replicates within a year and Y is the number of years the experiment was repeated. Similarly, the variance for the genotype  $\times$  environment interaction ( $\sigma_{g \times e}^2$ ) was calculated as

$$\sigma_{g \times e}^2 = (\text{Mean squares}_{\text{genotypes} \times \text{environment}} - \text{mean squares}_{\text{error}}) / R \quad (2)$$

and error variance ( $\sigma_{\text{error}}^2$ ) as the pooled mean squares for the genotype  $\times$  environment  $\times$  replicate interaction.

The size of the variance component for each trait is dependent on the units of measure for the trait. Therefore, it is necessary to standardize the variance components as a fraction of the total variation before comparison among traits using the formula

$$\sigma_g^2 / (\sigma_g^2 + (\sigma_{g \times e}^2 / Y) + (\sigma_{\text{error}}^2 / RY)) \quad (3)$$

Analyses of covariance to test for uniform response across the three populations were conducted using the SAS GLM procedure.

Correlation analyses of the least squares means of each inbred line were conducted using SAS PROC CORR, and regression analyses were conducted using SAS PROC REG.

## RESULTS AND DISCUSSION

The means of the wheat meal sodium carbonate SRC, lactic acid SRC, and SDS sedimentation volume were similar among the three populations. The greatest ranges in wheat meal sodium carbonate SRC, lactic acid SRC, and SDS sedimentation volume were observed in the M2/IDO470 population (Table I). The wheat meal sodium carbonate SRC, lactic acid SRC, and SDS sedimentation volume effectively differentiated among inbred lines (significant genotypic *F*-value) within each of the three populations. Mean grain protein concentration was greatest in the M2/IDO470 population. The M2/IDO470 population also had the greatest mean NIR hardness value. Grain protein concentration effectively differentiated inbred lines within each of the three populations. NIR hardness differentiated inbred lines within the M2/IDO470 population and the Kanto 107/IDO488 population, but not within the Vanna/Penawawa population.

The wheat meal sodium carbonate SRC test had significant variance among inbred lines in all three populations, with standardized variances among inbred lines of 0.63–0.80 (Table II). Standardized variance among inbred lines for the wheat meal lactic acid SRC was lowest (0.47) in the Vanna/Penawawa population and greatest (0.87) in the M2/IDO470 population. These results are consistent with the results from straight-grade flour SRC tests (Guttieri and Souza 2003). Standardized variances among inbred lines tended to be greater for straight-grade flour tests than for the corresponding wheat meal tests. The standardized variance among inbred lines for SDS sedimentation volume in the M2/IDO470 population was particularly high (0.92), indicating large genetic

effects in this population. Standardized variance among inbred lines for grain protein concentration also was highest (0.80) in the M2/IDO470 population. The data suggest that selection among inbred lines using wheat meal SRC tests, SDS sedimentation volume, grain protein content, and NIR hardness would be effective.

Wheat meal sodium carbonate SRC was independent of flour protein concentration in all three populations (Table III). However, a positive correlation was observed with grain protein in one population (Vanna/Penawawa). Similar results were observed using straight-grade flour (Guttieri and Souza 2003). Wheat meal sodium carbonate SRC was negatively correlated with flour extraction in all three populations (Table III). This suggests that selection among inbred lines within a family for low wheat meal sodium carbonate SRC could result in greater flour extraction among selected progeny.

Wheat meal sodium carbonate SRC values were much greater than flour sodium carbonate SRC values: mean wheat meal sodium carbonate SRC values were 97.1–99.1% in the three populations (Table I); corresponding mean flour sodium carbonate SRC values were 62.0–63.6% in the three populations (Guttieri and Souza 2003). However, wheat meal sodium carbonate SRC was correlated with straight-grade flour sodium carbonate SRC and sucrose SRC in all three populations (Table III). Bettge et al (2002) also found that wheat meal sodium carbonate SRC values were much greater than flour SRC values, but that the two SRC values were highly (*r* = 0.97) correlated.

The potential application of the wheat meal sodium carbonate SRC as a preliminary selection tool toward reduced straight-grade flour sucrose SRC is of particular interest to our breeding program. Regression analysis was used to assess the relationship between straight-grade flour sucrose SRC and wheat meal sodium carbonate SRC.

The regression equation (Fig. 1) for flour sucrose SRC as a function of wheat meal sodium carbonate SRC was flour sucrose

**TABLE I**  
Genotypic Mean, Minimum, and Maximum Values, and Genotypic *F* Values for Wheat Meal Sodium Carbonate Solvent Retention Capacity (SRC), Lactic Acid (SRC), SDS Sedimentation Volume, Grain Protein, and NIR Hardness of Inbred Lines from Three Populations Grown at Aberdeen, ID, in 2000 and 2001

	Sodium Carbonate SRC (%)	Lactic Acid SRC (%)	SDS Sedimentation Volume (mL)	Grain Protein <sup>a</sup> (%)	NIR Hardness
Vanna/Penawawa ( <i>n</i> = 25)					
Mean	97.1	72.8	7.1	13.0	2.5
Minimum	91.7	69.5	5.4	12.4	-3.5
Maximum	103.1	77.2	10.4	14.1	7.8
<i>F</i> value of genotypes	2.4**b	2.2**	3.6***	3.1**	1.5ns
Kanto 107/IDO488 ( <i>n</i> = 18)					
Mean	97.9	73.3	6.2	12.9	0.2
Minimum	90.7	70.5	4.6	12.0	-4.8
Maximum	103.5	77.4	7.2	13.9	4.0
<i>F</i> value of genotypes	3.6***	6.3***	2.7**	3.5***	2.5**
M2/IDO470 ( <i>n</i> = 26)					
Mean	99.1	73.5	6.9	15.3	9.8
Minimum	91.7	67.2	3.2	13.0	5.0
Maximum	110.8	80.6	10.3	17.7	16.0
<i>F</i> value of genotypes	10.72***	4.71***	12.3***	7.1***	2.2**

<sup>a</sup> On a 12% moisture basis.

<sup>b</sup> \*, \*\*, \*\*\* = significant at *P* < 0.05, *P* < 0.01, *P* < 0.001, respectively; ns = not significant.

**TABLE II**  
Standardized Variance<sup>a</sup> Among Inbreds for Wheat Meal Sodium Carbonate Solvent Retention Capacity (SRC), Lactic Acid SRC, SDS Sedimentation Volume, Grain Protein, and NIR Hardness in Three Families of Soft Spring Wheat Inbred Lines Grown at Aberdeen, ID, in 2000 and 2001

	Sodium Carbonate SRC (%)	Lactic Acid SRC (%)	SDS Sedimentation Volume (mL)	Grain Protein (%)	NIR Hardness
Vanna/Penawawa	0.63 ± 0.35	0.47 ± 0.37	0.63 ± 0.35	0.50 ± 0.36	0.48 ± 0.37
Kanto 107/IDO488	0.80 ± 0.33	0.67 ± 0.34	0.62 ± 0.35	0.46 ± 0.37	0.59 ± 0.35
M2/IDO470	0.74 ± 0.34	0.87 ± 0.33	0.92 ± 0.33	0.80 ± 0.33	0.59 ± 0.35

<sup>a</sup> Standardized variance:  $\sigma_g^2 / [\sigma_g^2 + (\sigma_{gxe}^2 / Y) + (\sigma_{error}^2 / RY)]$ .

SRC = 8.1 + (0.91 × wheat meal sodium carbonate SRC) ( $F = 22.4^{***}$ ;  $r^2 = 0.63$ ).

The relationship between flour sucrose SRC and wheat meal sodium carbonate SRC was not different among the three populations, based on analysis of covariance ( $F = 0.53$ ,  $P < 0.59$ ).

Wheat meal sodium carbonate SRC also was negatively correlated with sugar snap cookie diameter in all three populations (Table III). Therefore, the wheat meal sodium carbonate SRC test may be an effective tool for selection toward genotypes with greater flour extraction, larger sugar snap cookie diameter, and lower straight-grade flour sodium carbonate and sucrose SRC.

Wheat meal lactic acid SRC was independent of flour protein concentration in all three populations (Table III). SDS sedimentation volume was correlated with flour protein concentration in the Vanna/Penawawa population ( $r = 0.54$ ), but was independent of flour protein concentration in the other two, more divergent, populations.

Wheat meal lactic acid SRC was negatively correlated with flour extraction in all three populations (Table III). SDS sedimentation volume was negatively correlated with flour extraction in the Vanna/Penawawa population ( $r = -0.53$ ) but was independent of flour extraction in the Kanto 107/IDO488 and M2/IDO470 populations. Therefore, selection among genotypes within a family for wheat meal lactic acid SRC could result in a corresponding response in flour extraction, but selection among genotypes within a family for SDS sedimentation may or may not affect flour extraction.

Wheat meal lactic acid SRC values were much lower than the corresponding flour lactic acid values. For example, the mean wheat meal lactic acid SRC values of the three populations was 72.8–73.5% (Table I), while the mean flour lactic of the three populations was 88.9–94.8% (Guttieri and Souza 2003). Bettge et al (2002) similarly observed that wheat meal lactic acid SRC values were lower relative to flour lactic acid SRC values. They noted that the concentration of gluten-forming proteins (gliadins and glutenins) is lower in wheat meal relative to flour.

Wheat meal lactic acid SRC was correlated with straight-grade flour lactic acid SRC only in the Vanna/Penawawa population (Table III). In the Kanto 107/IDO488 and M2/IDO470 populations, wheat meal lactic acid SRC and straight-grade flour lactic acid SRC were independent. In these two populations, wheat meal lactic acid SRC was correlated with both straight-grade flour sodium carbonate SRC and sucrose SRC (Table III). In the study by Bettge et al (2002), wheat meal lactic acid SRC was correlated with straight-grade flour lactic acid SRC. This inconsistency with our

findings may be due to differences in the range of genotypes evaluated in the present study relative to previous work. Klasic, a strong gluten bread wheat, and Hiller, a very weak gluten club wheat cultivar, were included in the set of eight genotypes in the previous study (Bettge et al 2002). When these two genotypes, which represent extremes, are excluded, the rankings of the remaining six genotypes are not consistent among the wheat meal and flour lactic acid SRC tests. Although the wheat meal lactic acid SRC test may effectively predict differences in flour lactic acid SRC among very weak gluten and very strong gluten genotypes, the wheat meal lactic acid SRC test may be less effective in predicting differences in flour lactic acid SRC among genotypes with a narrower range of gluten strength.

In the Kanto 107/IDO488 and M2/IDO470 populations, SDS sedimentation volume was independent of all flour parameters other than straight-grade flour lactic acid SRC, with which it correlated ( $r = 0.74$  and  $0.93$ , respectively). In the Vanna/Penawawa population, SDS sedimentation volume was correlated with all straight-grade flour SRC, and was particularly highly correlated ( $r = 0.80$ ) with straight-grade flour lactic acid SRC. Therefore, SDS sedimentation volume may be more useful than wheat meal lactic acid SRC in predicting straight-grade flour gluten strength, as measured by the flour lactic acid SRC test.

Regression analysis was used to assess the relationship between straight-grade flour lactic acid SRC and SDS sedimentation volume. The regression equation (Fig. 2) for flour lactic acid SRC as a function of SDS sedimentation volume was flour lactic acid SRC = 43.4 + (7.2 × SDS sedimentation volume) ( $F = 232^{***}$ ;  $r^2 = 0.78$ ).

The relationship between flour lactic acid SRC and SDS sedimentation volume was not different among the three populations based on analysis of covariance ( $F = 2.22$ ,  $P < 0.12$ ).

Wheat meal lactic acid SRC and sugar snap cookie diameter were negatively correlated in all three populations (Table III). Similarly, SDS sedimentation volume was strongly negatively correlated with sugar snap cookie diameter in the Vanna/Penawawa population ( $r = -0.72$ ) but was independent of cookie diameter in the Kanto 107/IDO488 and M2/IDO470 populations.

SDS sedimentation volume correlations with sugar snap cookie diameter were similar to results in our previous study (Guttieri and Souza 2003), where flour lactic acid SRC was negatively correlated with sugar snap cookie diameter in the Vanna/Penawawa population ( $r = -0.70$ ) but flour lactic acid SRC was independent of sugar snap cookie diameter in the Kanto 107/IDO488 and M2/IDO470 populations.

**TABLE III**  
Pearson Correlation Coefficients of Genotypic Means for Wheat Meal Tests with Genotypic Means of Straight-Grade Flour Tests Among Inbred Lines of Three Populations Grown at Aberdeen, ID, in 2000 and 2001

	Flour Protein Conc.	Total Flour Yield	Flour Water SRC <sup>a</sup>	Flour Sodium Carbonate SRC	Flour Sucrose SRC	Flour Lactic Acid SRC	Cookie Diameter
Wheat meal sodium carbonate SRC							
Kanto 107/IDO488	ns <sup>b</sup>	-0.72***	0.49*	0.81***	0.74***	ns	-0.57**
M2/IDO470	ns	-0.57**	0.44*	0.74***	0.80***	ns	-0.50**
Vanna/Penawawa	ns	-0.68***	0.74***	0.69***	0.84***	0.75***	-0.76***
Wheat meal lactic acid SRC							
Kanto 107/IDO488	ns	-0.76***	0.51*	0.64**	0.76***	ns	-0.72***
M2/IDO470	ns	-0.51**	0.51**	0.70***	0.71***	ns	-0.70***
Vanna/Penawawa	ns	-0.67***	0.65***	0.74***	0.76***	0.70***	-0.69***
SDS sedimentation volume							
Kanto 107/IDO488	ns	ns	ns	ns	ns	0.74***	ns
M2/IDO470	ns	ns	ns	ns	ns	0.93***	ns
Vanna/Penawawa	0.54**	-0.53**	0.74***	0.67***	0.74***	0.80***	-0.72***
Grain protein							
Kanto 107/IDO488	0.68**	-0.54*	ns	ns	ns	ns	-0.51*
M2/IDO470	0.87***	-0.62***	ns	ns	ns	ns	-0.66***
Vanna/Penawawa	0.81***	-0.57**	0.57**	ns	0.52**	0.51**	-0.54**

<sup>a</sup> Solvent retention capacity.

<sup>b</sup> \*, \*\*, \*\*\* = significant at  $P < 0.05$ ,  $P < 0.01$ ,  $P < 0.001$ , respectively; ns = not significant.

## CONCLUSIONS

Grain protein concentration was correlated, as expected, with flour protein concentration in each of the three populations (Table III). Grain protein concentration also was negatively correlated with flour extraction and sugar snap cookie diameter in each of the populations. Grain protein concentration was positively correlated with flour water, sucrose, and lactic acid SRC only in the Vanna/Penawawa population.

NIR hardness generally was independent of flour parameters. In the M2/IDO470 population, NIR hardness and flour protein concentration were positively correlated ( $r = 0.71$ ). And in the Vanna/Penawawa population, NIR hardness was weakly correlated with flour extraction ( $r = 0.49$ ) and sugar snap cookie diameter ( $r = 0.40$ ). NIR hardness was independent of all flour SRC parameters in all three populations.

Wheat meal sodium carbonate SRC was correlated with wheat meal lactic acid SRC in each of the three populations (Table IV). Wheat meal SRC tests were most tightly correlated in the Vanna/Penawawa population ( $r = 0.82$ ). In our previous study, straight-grade flour sodium carbonate and lactic acid SRC tests also were correlated in the Vanna/Penawawa population ( $r = 0.85$ ) but were independent in the Kanto 107/IDO488 and M2/IDO470 populations (Guttieri and Souza 2003). Although SDS sedimentation volume was correlated with wheat meal lactic acid SRC in the Vanna/Penawawa and M2/IDO470 populations, it was independent of wheat meal SRC values in the Kanto 107/IDO488 population.

Among the whole grain tests, grain protein concentration was correlated with wheat meal sodium carbonate SRC only in the Vanna/Penawawa population. NIR hardness was independent of both wheat meal sodium carbonate SRC and wheat meal lactic acid SRC in each of the three populations.

The context of this study is an effort to expand the testing protocols in soft wheat cultivar development. Specifically, we are examining tests that rapidly characterize functionality as it relates to soft wheat products and tests that complement other end use tests that have dominated the breeding methodology of soft wheat programs (Gaines 2000; Guttieri et al 2001, 2002; Bettge et al 2002; Guttieri and Souza 2003). Although this study does not reach that objective by itself, it was designed as part of a larger set of experiments to understand the genetic and environmental contributions to variation in flour macromolecules and their impact on end use quality. Our soft wheat breeding program uses SRC profiles to complement a baking test (sugar snap cookie) in much the same manner that our program and other hard wheat programs use mixograph, farinograph, or alveograph evaluations to complement pup loaf bread evaluations (Souza and Graybosch 2002). No single quality test in hard wheat is a definitive predictor performance in a commercial-scale bread bake (Graybosch et al 1999). Hence, millers and bakers often specify hard wheat quality based not only on loaf volume but also on farinograph characteristics, among other specifications. Similarly, a broader set of soft wheat quality evaluations than flour ash and sugar snap cookie diameter could enhance the ability of breeders, millers, and bakers to predict a soft wheat cultivar's commercial bakery performance.

The wheat meal sodium carbonate SRC test effectively measured genotypic variation for straight-grade flour sodium carbonate and sucrose SRC among inbred lines within three populations. Therefore, this inexpensive and rapid test may be an efficient means of selecting for lower flour sodium carbonate SRC and flour sucrose SRC for inbred lines within sibling selections of breeding materials

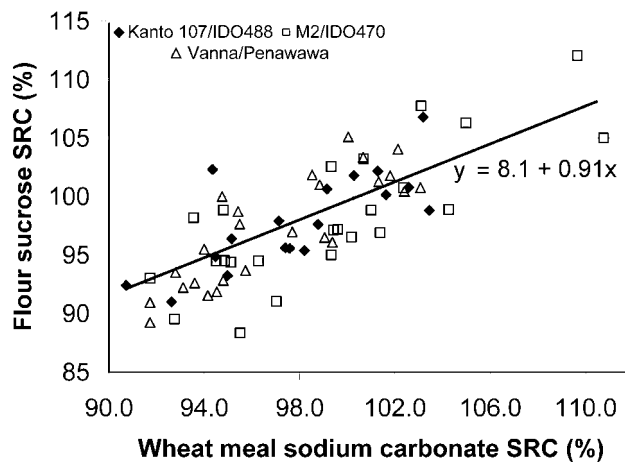


Fig. 1. Genotypic mean straight-grade flour sucrose solvent retention capacity (SRC) vs. wheat meal sodium carbonate SRC.

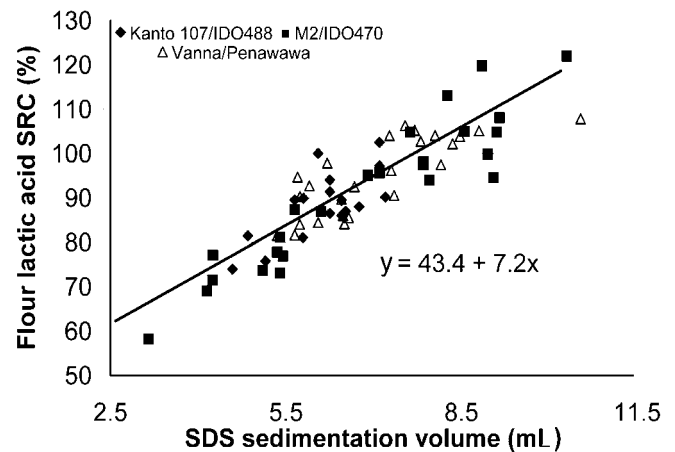


Fig. 2. Genotypic mean straight-grade flour lactic acid solvent retention capacity (SRC) vs. SDS sedimentation volume.

TABLE IV  
Pearson Correlation Coefficients Among Genotypic Means of Wheat Meal Tests of Inbred Lines from Three Populations Grown at Aberdeen, ID, in 2000 and 2001

	Wheat Meal Lactic Acid SRC <sup>a</sup>	SDS Sedimentation Volume	Grain Protein
Vanna/Penawawa			
Wheat meal sodium carbonate SRC	0.82*** <sup>b</sup>	0.76***	0.62***
Wheat meal lactic acid SRC	...	0.81***	ns
Kanto 107/IDO488			
Wheat meal sodium carbonate SRC	0.68**	ns	ns
Wheat meal lactic acid SRC	...	ns	ns
M2/IDO470			
Wheat meal sodium carbonate SRC	0.69***	ns	ns
Wheat meal lactic acid SRC	...	0.75***	ns

<sup>a</sup> Solvent retention capacity.

<sup>b</sup> \*, \*\*, \*\*\* = significant at  $P < 0.05$ ,  $P < 0.01$ ,  $P < 0.001$ , respectively; ns = not significant.

at early stages of testing, within populations targeted for traditional soft wheat uses. Higher flour extraction and larger sugar snap cookie diameter may be an additional benefit derived from selection for lower wheat meal sodium carbonate SRC. NIR hardness generally was not a useful predictor of finished flour quality within populations of soft-textured genotypes. Grain protein concentration was a useful predictor of flour protein concentration, which may explain the negative correlation of grain protein concentration with sugar snap cookie diameter. Grain protein concentration generally was not a useful predictor of flour SRC within these populations. The wheat meal lactic acid SRC predicted straight-grade flour lactic acid SRC in only one of the three populations (Vanna/Penawawa). In contrast, SDS sedimentation volume effectively predicted straight-grade flour lactic acid SRC in all three populations. Moreover, SDS sedimentation volume and wheat meal sodium carbonate SRC were independent in two of the three populations. This suggests that the SDS sedimentation and sodium carbonate SRC measure different intrinsic characteristics. Therefore a combination of sodium carbonate SRC and SDS sedimentation volume analyses of wheat meal may be an efficient approach to selecting toward desired SRC profiles in soft wheats.

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#### LITERATURE CITED

American Association of Cereal Chemists. 2000. Approved Methods of the AACC, 10th Ed. Methods 26-10, 26-21A, 10-52, and 56-11. The Association: St. Paul, MN.

- Bettge, A. D., Morris, C. F., DeMacon, V. L., and Kidwell, K. K. 2002. Adaptation of AACC method 56-11, solvent retention capacity, for use as an early generation selection tool for cultivar development. *Cereal Chem.* 79:670-674.
- Carter, B. P., Morris, C. F., and Anderson, J. A. 1999. Optimizing the SDS sedimentation test for end-use quality selection in a soft white and club wheat breeding program. *Cereal Chem.* 76:907-911.
- Dick, J. W., and Quick, J. S. 1983. A modified screening test for rapid estimation of gluten strength in early generation durum wheat breeding lines. *Cereal Chem.* 60:315-318.
- Faridi, H., Gaines, C., and Finney, P. 1994. Soft wheat quality in the production of cookies and crackers. Pages 154-168 in: *Wheat: Production, Properties, and Quality*. W. Bushuk and V. F. Rasper, eds. Chapman & Hall: Glasgow.
- Gaines, C. S. 2000. Report of the AACC committee on soft wheat flour. Approved Method 56-11, solvent retention capacity profile. *Cereal Foods World* 45:303-306.
- Graybosch, R. A., Peterson, C. J., Hareland, G. A., Shelton, D. R., Olewnik, M. C., He, H., and Stearns, M. M. 1999. Relationships between small-scale wheat quality assays and commercial test bakes. *Cereal Chem.* 76:428-433.
- Guttieri, M. J., and Souza, E. J. 2003. Sources of variation in the solvent retention capacity test of wheat flour. *Crop Sci.* 43:1628-1633.
- Guttieri, M. J., Bowen, D., Gannon, D., O'Brien, K., and Souza, E. 2001. Solvent retention capacities of irrigated soft white spring flours. *Crop Sci.* 41:1054-1061.
- Guttieri, M. J., McLean, R., Lanning, S. P., Talbert, L. E., and Souza, E. J. 2002. Assessing environmental influences on solvent retention capacities of two soft white spring wheat cultivars. *Cereal Chem.* 79:880-884.
- Hallauer, A. R., and Miranda, J. B. 1981. *Quantitative genetics in maize breeding*. Iowa State University Press: Ames, IA.
- Slade, L., and Levine, H. 1994. Structure-function relationships of cookie and cracker ingredients. Pages 23-141 in: *The Science of Cookie and Cracker Production*. H. Faridi, ed. Chapman & Hall/AVI: New York.
- Souza, E. J., Graybosch, R. A., and Guttieri, M. J. 2002. Breeding wheat for improved milling and baking quality. *J. Crop Prod.* 5:39-74.

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