

Adaptation of AACC Method 56-11, Solvent Retention Capacity, for Use as an Early Generation Selection Tool for Cultivar Development

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ABSTRACT

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The solvent retention capacity (SRC) profile is useful for studying flour components contributing to end-use functionality. The method tests four different solvents with 5 g of flour each. Because of the amount of grain (30–40 g) typically needed to produce 20 g of flour for the SRC test, the method is not well-suited for assessing end-use quality of early generation breeding material, where grain quantities are limited. The method was therefore modified to require only 0.2 g of ground wheat instead of 5 g of flour per SRC solvent. The small-scale SRC results using whole meal had correlations of $r = 0.86$ for lactic acid, $r = 0.85$ for sodium carbonate, $r = 0.78$ for sucrose, $r = 0.74$ for sodium bicarbonate (the alkaline water retention capacity method) and $r = 0.69$ for water when compared with SRC values from full-scale tests using 5 g of flour.

Overall, cultivars with SRC values at the extremes of the distribution were in the same ranked order for the small- and large-scale SRC test results. However, variation in ranked order of cultivars between test methods was detected among samples that were not at the extremes of the distribution. Traditionally, successful wheat breeding strategies involve eliminating or advancing lines from the extremes of the distribution to increase the proportion of desirable genotypes within breeding programs. Results indicated that advancing promising germplasm or eliminating germplasm with inferior end-use quality potential is possible using the small-scale SRC technique to evaluate early generation wheat breeding material, as a sort of breeding triage.

Cereal chemists have often sought rapid, predictive tests to assess the end-use quality of wheat and flour. The cost of milling and baking each sample of interest is often prohibitive in personnel time and money, especially for cultivar-development programs where thousands of experimental lines are evaluated annually. To maximize efficiency, wheat breeders aim to eliminate lines with inferior quality and carry forward the remaining, more promising lines for more extensive testing. Rapid tests that are well-suited to estimate end-use quality of small samples of wheat or wheat meal are particularly valuable in that they are time and cost effective and require small quantities of grain. These tests can be used as a means of breeding “trriage” in which experimental lines with poor end-use potential are eliminated from the program before extensive field testing. A more complete assessment of end-use quality can be deferred until later in the breeding program when larger amounts of grain are available for full-scale milling and baking.

Many small-scale, predictive tests for wheat quality have been adapted from larger scale tests. Those methods share some of the same attributes: they require relatively small amounts of grain, wheat meal, or flour; are rapid; and provide information that can be used to improve the end-use quality potential of breeding material. SDS-sedimentation volume began as a 5-g flour test, which was reduced to a 1-g wheat meal test to facilitate its use as a selection tool for wheat cultivar enhancement (Greenway et al 1966). The 35-g, 10-g, and later 2-g mixograph tests to predict dough absorption and mixing characteristics, were derived from the original Swanson and Working 400-g mixograph instruments (Bloksma and Bushuk 1988). Methods that were developed specifically for small-scale testing include the flour swelling volume (FSV) for assessment of starch characteristics and the single kernel characterization system (SKCS) for determination of grain texture, diameter, moisture, and weight. The FSV test uses only 0.45 g of flour and the SKCS uses 300 kernels (≈ 10 g) of wheat.

These tests characterize physical and chemical attributes of the sample, and results are directly related to milling performance and dough rheology. However, physical and chemical test results are often only loosely associated with baking performance due to the interactions of many flour constituents and physical properties in a complex, dynamic medium. Other tests have been developed to assist in rapidly estimating baking performance, such as the alkaline water retention capacity (AWRC).

The AWRC test, Approved Method 56-10 (AACC 2000) originated as a 5-g test in which flour was hydrated with weakly alkaline buffered water (to minimize pH differences in laboratory water), centrifuged, decanted of excess solvent, and then the remaining pellet was weighed. The amount of solution retained was expressed as a percentage. That test worked well on a broad scale as a predictive test for cookie baking performance, especially when distinguishing between hard and soft wheat classes. However, the predictive power was reduced substantially within each hardness class, reducing the value of this procedure as a selection tool (Kitterman and Rubenthaler 1971).

Recently, the AACC adopted the solvent retention capacity (SRC) test as method 56-11. The SRC test is essentially the same as the AWRC test, however, different aqueous solutions are utilized: lactic acid, sodium carbonate, sucrose, and water. Each solvent provides information on a different chemical or physical aspect of the sample (Slade and Levine 1994a,b; Gaines 2000). Lactic acid is an indicator of gluten quality; sodium carbonate an indicator of starch damage and, indirectly, hardness; sucrose is an indicator of pentosans and, to an extent, gliadins; and water is a general indicator of base absorption, or absorption of all compounds combined, to which the other solutions that are more specific in activity may be compared (Slade and Levine 1994a,b). SRC tests provide additional, complementary information to the AWRC and highlight aspects of the chemical make-up of flour that assist in rapidly estimating processing and baking parameters. For example, viscosity of pancake batters is important, but knowledge of the specific sources of the viscosity is helpful in predicting the texture. SRC tests provide some assistance in defining the origin of viscosity, such as identifying whether viscosity arises from protein characteristics (lactic acid SRC) or from pentosan content (sucrose SRC). Decisions in obtaining flour with the proper processing and baking characteristics can be assisted by profiling using the SRC tests (Slade and Levine, *personal communication*; Guttieri et al 2001).

Full-scale SRC testing requires 5 g of flour per solvent. Due to limited grain supplies for early generation testing (F_4 generation),

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it is often difficult to obtain four 5-g samples of flour (20 g total). Frequently, the amount of grain provided to the testing laboratory is not sufficient for milling quantities of flour sufficient for production of 20 g of flour, or more. Furthermore, there is generally insufficient time available to mill thousands of samples before planting the next generation of experimental lines in the field. This research examines the utility of extending the SRC method to smaller samples of flour (1 g) and small samples of wheat meal (0.2 g), as well as examining the influence of minor variations in solvent-to-flour ratio on SRC results.

MATERIALS AND METHODS

The study was conducted in four parts. First, the ability of five solvents (the four SRC solvents, plus AWRC, which is a bicarbonate solution) to differentiate cultivars with different quality characteristics and the influence of agitation method on SRC values was examined. Second, the differences between large, standard-method tubes and smaller tubes, both in terms of absolute SRC response and alterations in sample rank, were studied, as well as the performance of flour versus wheat meal. Third, the variation induced by sample weight differences on SRC values was studied by determining the linearity of SRC response across weights and identifying the degree of precision necessary in weighing. Fourth, the results of a small-scale sample method were to determine whether a 2-mL microcentrifuge tube affords the same resolution, precision and accuracy as the larger, 50-mL tube method, and whether the small-scale method using wheat meal is adequate for breeder screening work.

Wheat meal and flour milled from the same set of eight wheat cultivars were used throughout the study. Cultivars were selected to represent a range of end-use quality characteristics among and within U.S. market classes. The cultivars used were ‘Hiller’ and ‘Hyak’ (soft white club), ‘Madsen’, ‘Daws’ and ‘Eltan’ (soft white winter, SWW), ‘Penawawa’ and ‘Vanna’ (soft white spring, SWS) and ‘Klasic’ (hard white spring, HWS). Ground wheat was prepared with a cyclone grinder (UDY Corp., Boulder, CO) equipped with a 0.5-mm aperture screen. Flour of $\approx 70\%$ extraction was produced with a modified Brabender Quadrumat mill (Jeffers and Rubenthaler 1979), (Table I). Hiller is a soft cultivar with very high end-use quality for cookie and sponge cake production. Klasic is a hard cultivar with good breadbaking quality. The other cultivars have good overall quality potential for milling and for baking cookies and sponge cakes, but vary somewhat within the general limits of acceptable quality. Penawawa is generally not an especially good milling wheat and Daws generally has reduced cookie and sponge

cake quality. The other cultivars are typical of their U.S. market classes.

Moisture and protein contents were determined by Approved Methods 44-16 and 46-30, respectively (AACC 2000), on both wheat and flour. Flour ash was measured using Approved Method 08-01. Wheat grain hardness was determined using the Perten 4100 single kernel characterization system (SKCS) (Perten NA, Springfield, IL).

The SRC solvents (water, sodium carbonate, lactic acid, sucrose, and sodium bicarbonate) were formulated using Approved Method 56-11 (solvent retention capacity). AWRC was conducted according to Approved Method 56-10.

Hand vs. Mechanical Agitation

The basic AACC SRC method 56-11 was used to provide a basis of comparison for all other tests. Method 56-11 uses 5 g of flour in a 50-mL conical-bottom tube (Falcon #2070, BD Biosciences, Bedford, MA) with 25 g of solution. Samples are agitated by hand. Alternatively, the tubes were placed on an SDS-sedimentation volume rocker (Approved Method 56-61A) and mechanically agitated throughout the hydration period. Other than modification of the method for constant rocking, the procedures were identical.

Flour and Wheat Meal SRC (1 g) vs. Flour SRC (5 g)

Flour (1 g) was used in a 15-mL, conical-bottom tube (Falcon #2096) with 5 g of solvent and agitated with the SDS-sedimentation volume rocker. In addition to flour, cyclone-ground wheat was evaluated using the same procedure. Both flour and wheat meal were weighed to 1 ± 0.01 g.

Sensitivity of SRC to Variation in Sample Weight

The 15-mL conical-bottom tubes were used, but the sample weight was varied by increments of 0.1 g (± 0.01 g) from 0.8 to 1.2 g to determine the linearity of SRC weight response. Cyclone-ground wheat was weighed accurately and precisely to determine the influence of variable sample dry weight with constant solvent weight (5 g solvent). The SDS-sedimentation volume rocker was used for sample agitation.

Micro Wheat Meal SRC vs. Standard Flour SRC

Ground wheat ($0.2 \text{ g} \pm 0.001 \text{ g}$) was weighed into 2-mL conical-bottom microfuge tubes (#T-9865; Sigma Chemical Co., St. Louis, MO). Instead of measuring solutions by weight, 1 mL of each solution was used instead to simplify dispensing and to provide information on the potential of a miniaturized SRC method for use in breeding programs where throughput is crucial due to large sample numbers.

TABLE I
Hardness, Milling, and Protein Values

Cultivar	SKCS Hardness	Flour Yield (%)	Break Flour Yield (%)	Wheat Protein (%)	Flour Protein (%)
Daws	20	67.1	48.7	9.9	8.0
Eltan	14	66.1	50.2	10.0	8.2
Hiller	14	70.6	50.5	9.9	7.9
Hyak	21	66.8	49.4	11.1	9.0
Klasic	62	67.4	41.9	13.1	11.4
Madsen	24	68.3	48.5	10.6	8.7
Penawawa	21	67.0	49.4	10.9	8.8
Vanna	12	66.6	49.4	11.9	9.6

TABLE II
Analysis of Variance for Solvent Retention Capacity (SRC) Tests^a

Source	Lactic Acid	Sodium Carbonate	Sodium Bicarbonate	Sucrose	Water
Genotype (G)	4,557	556	195	859	250
Treatment (T)	10,166	5,242	2,778	4,053	4,038
G \times T	376	21	74	53	10
Mean square error	15	6	3	9	4
R ²	0.98	0.97	0.98	0.96	0.97

^a $P \leq 0.001$ for all mean square values.

Each sample was vortexed before being continually agitated on a Labquake shaker (Fisher Scientific, Seattle, WA). The shaker rotates the tubes at ≈ 60 rpm, which is sufficient to keep the samples in suspension.

Statistical Analyses

SRC determinations were made with four replicates on different days. Full general linear models (GLM), incorporating genotype, treatment, and interaction effects were constructed to provide analysis of variance parameters (ANOVA), and Duncan's multiple range tests or least significant difference (LSD) analyses were used, as appropriate, to differentiate among or between the treatments. Ranked order of sample means also was used to differentiate treatments. All analyses were conducted using PC-SAS v. 8.0 (SAS Institute, Cary, NC).

RESULTS AND DISCUSSION

Full Model

Solvent retention capacities were run on the eight flour samples using the four SRC solvents, plus AWRC. Genotype, treatment, and the interaction between the two significantly contributed to the ANOVA model (Table II). In the full model, which incorporated all methods used for SRC (agitation methods and wheat or flour material), treatment effects had an influence one order of magnitude greater than did genotype across all solutions as judged by parameter mean squares (Table II). Based on variation accounted for, the interaction between genotype and treatment was relatively less influential, though still significant. The influence of treatment (and to a large extent, material) was not surprising in that wheat and flour gave different mean SRC values due to their differing biochemical constituents; whole wheat contains more nonstarch carbohydrate and structural, as opposed to functional, protein. The impact of the differing compounds between wheat meal and flour was particularly noticeable for lactic acid and sucrose solvents (Table III) where bran effects are expressed particularly well. Lactic acid-SRC values are lower, and sucrose-, water- and bicarbonate-SRC values are greater in wheat than in flour (Slade and Levine 1994a,b).

Hand vs. Mechanical Agitation

The standard AACC Approved Method 56-11 that employs hand agitation at fixed time intervals was compared with a method that uses an SDS-sedimentation shaker and constant agitation to keep the flour samples in suspension after an initial hand-shaking to disperse the flour. Otherwise, the procedures were the same.

The use of mechanical agitation was considered as a potential means to enhance sample throughput and to decrease operator fatigue and variability. The technician can process more samples in the same time period if sample agitation is automatic, as opposed to requiring operator attention at fixed intervals. Also, large numbers of samples generated by breeding programs require methods that provide useful results with minimal physical input by the operator.

When hand and mechanically agitated samples are compared for the 5-g flour sample size only, mean SRC values were greater for hand-agitated samples. Significant ($\alpha = 0.05$) differences were observed between hand-agitated and mechanically agitated samples for the lactic acid solvent only; mean SRC differences between hand and mechanical agitation were greatest for lactic acid (5.1%). The other solvents showed no significant difference between hand and mechanical agitation (Table III). The mechanical method of agitation may linearize proteins in the lactic acid solvent, thus reducing SRC value (Slade, *personal communication*). The action of the SDS-sedimentation rocker produces a back-and-forth motion in a cylindrical tube that could contribute to this effect. Even though the mean values for lactic acid were not greatly different between hand and mechanical agitation, they were significantly different. However, the ordered results of the individual genotypes under both agitation conditions were almost identical (data not shown). Mean SRC values for lactic acid showed that two cultivars, Penawawa and Hyak, in the middle of the ranked order, had changed in their ranked order. For sucrose SRC, Penawawa and Klasic, which were in the middle of the ordered distribution changed their respective places. But beyond that, the ordered results for the other solvents were identical.

Sucrose SRC values were influenced considerably by genotype. Some cultivars had significant differences between hand and mechanical agitation; others did not. Daws, with sucrose SRC means of

TABLE III
Analysis of Variance and Duncan's Multiple Range Separation for Solvent Retention Capacity (SRC) Tests by Treatment

Treatment	Lactic Acid (%)	Sodium Carbonate (%)	Sodium Bicarbonate (%)	Sucrose (%)	Water (%)
5 g of flour hand-shaken	119.5a ^a	69.9d	56.6d	94.1c	52.7d
5 g of flour on rocker table	114.4b	68.8d	56.2d	91.1c	52.4d
1 g of flour on rocker table	114.9b	72.5c	61.6c	99.1b	59.1c
1 g of wheat on rocker table	80.2d	89.9b	71.7b	113.8a	71.2b
0.2 g of wheat on rotator	88.6c	96.6a	76.9a	115.4a	77.3a
LSD _{0.01}	2.49	1.64	1.12	1.92	1.36

^a Values followed by the same letter in the same column are not significantly different ($\alpha = 0.01$).

TABLE IV
Analysis of Variance and Duncan's Multiple Range Separation for Solvent Retention Capacity (SRC) Tests by Genotype^a

Genotype	Lactic Acid		Sodium Carbonate		Sodium Bicarbonate		Sucrose		Water	
	Flour	Wheat	Flour	Wheat	Flour	Wheat	Flour	Wheat	Flour	Wheat
Klasic	134.9a ^b	99.1a	72.5b	109.6a	73.2a	79.9ab	91.6b	120.6a	60.8a	79.6ab
Eltan	126.8b	87.3b	67.6c	92.7cd	55.3bc	74.7d	90.4b	116.8ab	50.7de	77.3ab
Penawawa	124.0b	88.7b	66.7c	93.0cd	52.2d	78.0bc	91.7b	116.4ab	49.0fg	77.4ab
Daws	122.6b	88.9b	80.8a	103.8b	57.1b	81.6a	115.3a	120.8a	56.1b	81.4a
Vanna	122.1b	89.6b	71.0b	96.8c	53.8cd	74.8d	85.6c	115.0ab	49.6ef	77.1ab
Hyak	115.0c	90.9b	66.3cd	95.7c	55.2bc	80.7a	88.4bc	115.8ab	53.8c	80.6ab
Madsen	98.2d	86.9b	64.5d	92.5cd	53.6cd	76.6cd	85.1c	113.5b	51.1d	75.9b
Hiller	71.6e	77.5c	60.9e	88.6d	49.2e	69.0e	80.4d	104.1c	57.8g	69.2c
LSD _{0.05}	5.6	5.1	2.0	5.5	2.3	2.4	3.3	6.1	1.3	4.5
R ²	0.97	0.77	0.96	0.79	0.96	0.88	0.96	0.64	0.96	0.64
F-value	110.2	11.4	76.7	13.3	84.2	25.6	88.1	6.1	90.7	6.1

^a For 5 g of flour mechanically agitated or 0.2 g of wheat rotated.

^b Values followed by the same letter in the same column are not significantly different ($\alpha = 0.05$).

112.6% for hand and 106.0% for mechanical agitation, and Vanna, with sucrose SRC means of 90.5 and 85.6%, for hand and mechanical agitation, respectively, were significantly affected by agitation method. Other cultivars showed no significant differences between the two methods. It should be noted that Daws had the highest sucrose SRC values of any of the cultivars used in this study, probably because it has the greatest pentosan content of the cultivars studied (Bettge and Morris 2000).

Overall, significant differences between hand and mechanical agitation were minimal, and genotype rank was essentially the same within each SRC solvent. With the goal of obtaining a method that was useful for maximizing throughput in early generation breeding work, it was decided that mechanical agitation would be used for the remainder of the study.

Flour and Wheat Meal (1 g) SRC vs. Flour (5 g) SRC

Flour quantities are often limited in the early generations of wheat breeding programs. Milling 100 g of wheat, obtainable in about the F_5 generation, which produces ≈ 65 –70 g of flour is common. As such, there is little surplus flour for physical and chemical testing, especially if baking tests are to be performed. Reduction from 5 g to 1 g of flour for use in SRC testing would be beneficial, especially because four solvents are used to provide a complete SRC profile. That reduces flour consumption from 20 g to 4 g total. In this experiment, 1 g flour in a 15-mL conical bottom tube with 5 g of solvent was used to determine whether the results were comparable to those using 5 g of flour in a 50-mL conical bottom tube with 25 g of solvent. Additionally, the use of 1 g of wheat meal was tested in similar fashion to determine whether milling wheat into flour was necessary to obtain adequately predictive results.

Compared to mechanical agitation of 5 g of flour SRC results, the 1 g of flour SRC values were significantly greater for all solvents except lactic acid (Table III). The 15-mL tube had a greater length-to-diameter ratio than the 50-mL tube. However, ranked results were essentially the same for all SRC means, including lactic acid, for 1-g and 5-g flour sample sizes, as reflected by correlation coefficients of $r = 0.78$ and 0.99 ($P < 0.05$ for all). There was some variation in rank in the middle of the ranked cultivar distribution. However, at the extreme values, genotype ranking remained constant. Generally, the highest and lowest two or three ranked samples remained the same, and only the three or four samples in between the extremes were somewhat variable in rank. In breeding work where either advancing only the best cultivars or removing only the poorest cultivars is the goal, depending on the philosophy of the program, resolution of the extreme values is more important than discerning differences among cultivars in the middle of the data range. The results indicate that scaling down the amount of flour required for the test is appropriate for breeding work, where only the more promising germplasm is advanced to the next generation.

The degree to which ground wheat can be used instead of flour also was studied. By using ground wheat meal in SRC testing, time can be saved that would otherwise be expended on milling the grain into flour. Also, less material is needed for ground grain analyses because ≈ 100 g is often the minimum amount required for milling, but 5 g can be ground easily on a cyclone mill. Wheat meal (1 g) SRC mean values were greater than those values obtained from 5 g of flour, with the exception of lactic acid SRC, which was lower (Table III). However, correlation coefficients between wheat meal (1 g) and flour (5 g) SRC means were high for lactic acid, sodium carbonate, and sucrose SRC ($r = 0.90$, 0.97 and 0.80 , respectively, $P < 0.02$ for all). Correlation coefficients were somewhat reduced for sodium bicarbonate and water SRC results ($r = -0.57$ and 0.75 , $P = 0.14$ and $P < 0.05$, respectively). Lack of high correlation for these two solvents may be due to varying amounts of bran in the wheat meal that leads to differences in absorption for the two most aqueous solvents that test only generally for functional components. Lactic acid provides information relating to functional proteins (glutenins),

sodium carbonate provides information reflective of starch damage, and sucrose provides information relating to pentosans (Slade and Levine 1994a,b). The three solvents that measure functional components measure not only absorption, but also the potential impact of the functional compounds, whereas water and sodium bicarbonate provide only a baseline water absorption value. Use of solvents that provide information about compounds contributing to end-use functionality of wheat can assist in making selection decisions in breeding programs.

When compared to the 1-g flour results, the 1-g wheat meal SRC values again were greater, excepting lactic acid SRC, which was lower. Decreased wheat meal lactic acid SRC versus flour is partly due to the diluent effect of bran. Relatively less functional gluten-forming proteins (glutenins and gliadins) are present, on a weight basis, in ground wheat; therefore, the lactic acid SRC value will be lower as well (Orth and Bushuk 1972). Also, the tube geometry may exert a role. In the other solvents, the presence of bran in the wheat meal samples accounted for additional solvent retention. That effect was especially present with sucrose which is an indicator of pentosans, major components of bran cells (MacMasters et al 1971). But again, the cultivar order showed the same general trend: the cultivars with extreme SRC values remained in the same ranked order, but the intermediate cultivars showed some changes in order (data not shown).

Overall, the data indicate that reducing the size of the flour sample required to run the SRC tests is feasible, especially for screening early generation wheat breeding samples. A change to wheat meal instead of flour also is feasible, as long as the confounding absorption effect of bran on background absorption, as revealed by water or sodium bicarbonate SRC, is considered, as well as the effect of bran on lactic acid and sucrose SRC values, as discussed above. Even reduced resolution due to the change in material from

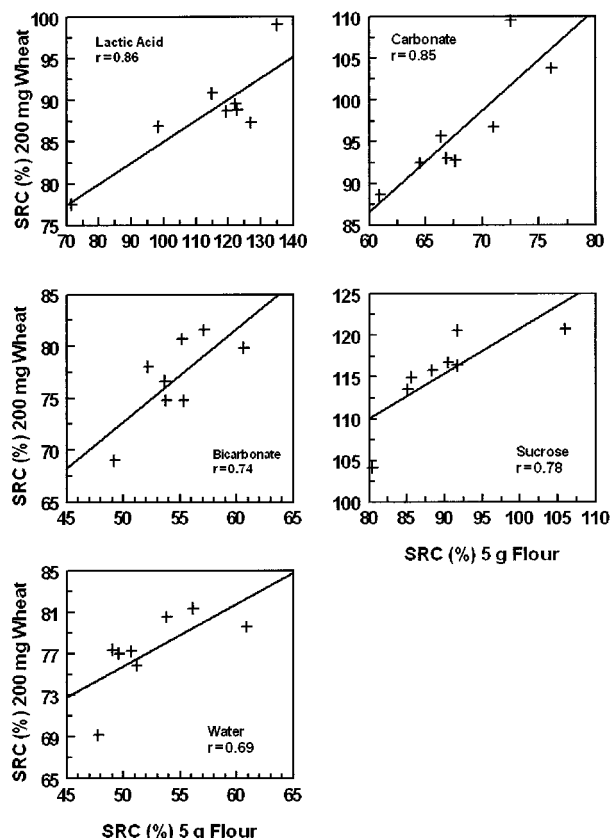


Fig. 1. Flour (5 g) vs. wheat (200 mg) solvent retention capacity (SRC) profiles for lactic acid, sodium carbonate, sodium bicarbonate, sucrose, and water solvents.

flour to wheat meal may not be a major problem in early generations of breeding programs where high levels of phenotypic variation are present among experimental wheat lines that have not yet been subjected to selection pressure. As breeding selection narrows the range of quality variation among samples by removing poorly performing cultivars, more care should be taken in using SRC testing based on wheat meal. By advancing only the best performing cultivars to the next generation in the breeding process, the range of functional performance begins to narrow. As such, the changes in ranked order of cultivars become more apparent and the chance of mistakenly discarding a line with good end-use potential increases. However, sufficient wheat for milling probably exists in more advanced generations, and flour SRC or baking tests should supplant wheat meal SRC testing. Overall, in ranking samples for their potential end-use quality with wheat meal SRC, the best samples could be discriminated from the poor samples with any of the solvents used.

Sensitivity of SRC to Variation in Sample Weight

Although the amount of wheat meal used was varied $\pm 20\%$ from the base amount of 1 g, no significant or consistent differences in SRC for any solvent were observed when weight was taken into account in SRC calculations. Some cultivars showed a trend of decreasing SRC values with decreasing sample weight, but the difference between 1.2-g sample and 0.8-g sample was not significant ($\alpha = 0.05$). As those data showed no significant differences, they are not discussed in detail.

Weighing samples accurately, even to $\pm 20\%$ of the target value, appeared to provide results that can be used in screening samples for a breeding program. Precision in recording the weights of tubes, wheat meal, and tubes plus pellet is likely much more influential in obtaining meaningful results. Care also must be taken to assure that any residual solvent droplets are removed from the tubes before final weighing. When dealing with a 1-g sample, a residual solvent droplet weighing 20 mg causes a 2% error; several residual droplets would lead to more substantial error. However, for consistency, weighing each sample as close as feasible to the target weight should be encouraged as a proper scientific practice.

Wheat Meal (0.2 g) SRC vs. Flour (5 g) SRC

The amount of wheat meal was scaled to maintain the 1:5 weight ratio of meal to solvent and still fit into a 2-mL microcentrifuge tube with enough room to vortex the sample and maintain sufficient room for agitation throughout the hydration period. Using 0.2 g of wheat meal, the amount of wheat needed for a four-solvent SRC test is then < 1 g, an amount easily available in early generation wheat breeding programs.

The results were similar to those of the 1-g wheat meal vs 5-g flour SRC: SRC values were significantly higher for the 0.2-g wheat meal with the exception of the lactic acid SRC values where the 5 g of flour SRC gave higher values (Table IV). Once again, ordered mean values showed that the cultivars at the extremes remained essentially the same when wheat meal SRC and flour SRC results were compared, but some variation in order occurred for samples between the extreme values. The 0.2-g wheat meal ordered results are more similar to those of the 1-g wheat meal than the 5-g flour results. Even though 0.2-g wheat meal water SRC had the lowest correlation with the 5-g flour water SRC, significant differences ($\alpha = 0.05$) were present between the cultivars with highest and lowest water SRC values.

Correlation coefficients between the 0.2-g wheat meal SRC and 5-g flour SRC results were lower than the correlations between the 1-g wheat or flour and 5-g flour SRC results. The correlations for 0.2-g wheat versus 5-g flour SRC values were $r = 0.69$, $P = 0.06$ (water) to $r = 0.86$, $P < 0.01$ (lactic acid) (Fig. 1). The lower correlation may be due additively to differences in tube geometry, agitation method, and sample size. The small 0.2-g sample size is more prone to sampling error than the 1-g sample size, despite use of a 0.5 mm aperture screen in the cyclone grinder to produce a more homogeneous wheat meal.

CONCLUSIONS

The AACC SRC Approved Method 56-11 can be scaled down for use in breeding programs where the goal is to eliminate genotypes that have the least potential to perform adequately in end-use applications. Using 0.2-g samples of ground wheat in 2-mL microcentrifuge tubes with 1 mL of solution for SRC tests provides sufficient separation of the samples with the highest and lowest SRC values. Some variation in ranked order occurred for samples between the extremes, but the resolution was sufficient to be able to advance or remove experimental lines with the best or worst potential, respectively, from a breeding program. Changes in rank order are meaningless among genotypes that do not differ significantly. If better prediction of end-use potential is required, using the 5-g flour SRC test is more appropriate, though limited to occasions where adequate milled flour is available.

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