

Solvent Retention Capacities of Indian Wheats and Their Relationship with Cookie-Making Quality

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ABSTRACT

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Ninety-two wheat genotypes including 50 cultivars released in India and 42 germplasm lines were subjected to solvent retention capacity (SRC) tests using 1 g of flour and 1 g of whole meal to see the relationship with cookie-making quality and the utility in breeding programs. Very high negative correlations ($P < 0.001$) were observed between cookie diameter and spread factor and alkaline water retention capacity (AWRC), and solvent retention capacities of both flour and whole meal samples. Multiple regression analysis showed that AWRC explained 43.8%, sodium carbonate SRC 27.3%, lactic acid SRC 15.1%, and protein content 13.8% of the total variability (multiple $r = 0.87$) in cookie diameter. Total variability (multiple $r = 0.85$) in spread factor was explained 40.3% by AWRC, 27.4% by SODSRC, 14.5% by LASRC, and 17.8% by protein content. When the technique was further used to reduce the number of parameters contributing to cookie diameter, AWRC explained 67.2% of the total variability (multiple $r = 0.85$) and the rest by lactic acid SRC

and protein content. Surprisingly, multiple regression analysis of whole meal samples exhibited that lactic acid SRC and sodium carbonate SRC explained 88 and 12%, respectively, of the total variability (multiple $r = 0.76$) in cookie diameter and 78 and 22%, respectively, of the total variability (multiple $r = 0.71$) in spread factor. Among the soft wheat flour samples selected based on $W > 7.70$ cm, pentosan content as revealed by sucrose SRC explained 87.7% of the total variability (multiple $r = 0.54$) of cookie diameter and 83.8% of total variability (multiple $r = 0.52$) in spread factor. Clustering of genotypes based on SRC profiles using both flour and whole meal produced clusters with similar average cookie diameter and spread factor. The data clearly demonstrate that whole meal tests can be used in screening the recombinant lines as well as in selecting desirable genotypes for making crosses to enhance cookie-making quality.

Wheat is the most important cereal crop to humankind. India is the second largest producer of wheat as well as biscuits (cookie is used here as synonym for biscuit in India) in the world and the biscuit industry is the largest constituent of food processing industry in the country. Biscuit quality is evaluated by measuring the diameter and spread factor of cookies baked according to the AACC sugar snap cookie test. Larger cookie diameter and higher spread factor are used as the main quality attributes (Nemeth et al 1994; Yamamoto et al 1996). During baking process, the dough expands and flows because of leavening gases and gravitational force. The final size of the cookie depends on the rate of the flow and the set time when the expansion stops. Doughs of good cookie-making quality flow much faster than those made from poor quality flour (Hoseney et al 1988). The set time is determined by the amount of the water in the dough that is free to act as solvent and the strength of the dough. Therefore, ultimate cookie quality depends on the chemical constituents in the flour responsible for water holding and the quality and quantity of the gluten proteins determining dough strength. Generally, soft wheats with weak gluten and low protein content are preferred for biscuit making (Gaines 1991; Souza et al 1994).

Based on the quality characteristics required for cookie-making, Slade et al (1994) developed solvent retention capacity (SRC) tests that for Approved Method 56-11 (AACC 2000). SRC is the weight of solvent held by flour after centrifugation and expressed as the percentage of flour weight (14% mb). In this test, four different solutions of lactic acid, sucrose, water, and sodium carbonate are utilized for providing information on chemical and physical aspects of wheat samples. A combined pattern is useful for predicting commercial baking performance. Generally, lactic acid SRC is associated with glutenin characteristics, sodium carbonate SRC is associated with starch damage, sucrose SRC is associated with pentosan content and gliadin characteristics, and water SRC is associated with all of those four constituents (Guttieri et al 2001). Thus, SRC

profiling provides additional, complementary information to the alkaline water retention capacity (AWRC) and assists in identifying the proper baking and processing characteristics of flours. Earlier, information on AWRC, along with SDS-sedimentation volume, 2-g mixogram tests, flour swelling volume for starch characteristics, and single kernel characterization system for testing grain texture was used for improving cookie-baking quality (Kitterman and Rubenthaler 1971; Bettge et al 2002).

In the present investigation, the work was conducted to understand relationship between cookie-making quality and AWRC, SRC tests, protein content, and sedimentation rate using wheat cultivars released in India and selected germplasm lines available at DWR, Karnal. Available genotypes in the germplasm identified for better cookie-making were selected for the study. Earlier reports indicated low cookie diameter and spread factor of advanced lines including released cultivars of wheat in India (Sewa Ram et al 2001). Because baking tests are time consuming, labor intensive, expensive, and require large quantities of sample, small-scale tests are necessary to predict the end-use quality of grain from early generation breeding material. The limited quantity of grain available from early generation of segregating materials and the longer time required to mill thousands of samples are the constraints for analyzing breeding materials with ease. Therefore the SRC tests were conducted using 1 g of flour and 1 g of wheat meal to study interrelationships and utility in breeding programs.

MATERIALS AND METHODS

Fifty wheat cultivars representing a wide range of cultivars grown in different parts in India as well as 42 germplasm lines (both exotic and indigenous) grown in Karnal were evaluated for baking and chemical tests. Most of the germplasm lines selected showed higher cookie diameter and spread factor compared with released cultivars in India. The list of cultivars and the area of adaptation or origin are mentioned in Table I. All the lines are maintained at genetic resource unit of DWR, Karnal, India. All the genotypes were grown in replicate trials. Two replicates of each sample were tempered (AACC Approved Method 26-10) and milled using a Brabender Sr. quadrat mill (AACC Approved Method 26-21A) with $\approx 70\%$ extraction rate. Whole meal was extracted using a Cyclotec 1093 sample mill from Tecator, Sweden with a 0.5-mm sieve. Protein and moisture content were determined using NIR

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according to Approved Methods 44-16 and 46-30, respectively (AACC 2000) in wheat grains at 14% mb. Cookie-making quality was evaluated according to AACC Approved Method 10-52, measuring the spread of two sugar-snap cookies baked from 40 g of flour. The SRC solvents were formulated using Approved Method 56-11. AWRC test was conducted according to Approved Method 56-10. The tests were conducted using 1 g of wheat meal and 1 g of flour in 15-mL tubes with conical bottom. Material (1 g) was dispersed in 5 mL of solvent and kept for 20 min with intermittent vortexing at 5, 10, 15, and 20 min, followed by 15 min of centrifugation at 1,000 × g at room temperature. The SRC was calculated. SDS sedimentation tests were measured according to the modified method of Carter et al (1999) using 1 g of whole meal. Samples were placed in calibrated glass tubes (150 mm long × 14 mm i.d.). Distilled water (4 mL) was added to each sample and vortexed for 10 sec and allowed to hydrate for 5 min, vortexed again for 10 sec, and then allowed to hydrate for 5 min. LA/SDS solution (12 mL) was added to each sample and inverted 12× and kept upright for 10 min and the height of the sediment was recorded.

Statistical Analysis

Pearson's linear correlation coefficients among quality parameters were calculated by genotype means using SPAR1 (IASRI, New Delhi). The multiple regression was conducted with least square technique (LSQ) using cookie diameter and spread factor as dependent variables (Kendall 1985). Independent variables were selected to optimize the R^2 value of the model. Cluster analysis was done on the basis of Euclidean distances using nearest centroid sorting (Rao 1952) (SPAR1, IASRI, New Delhi), where the samples were allowed to segregate themselves arbitrarily into three clusters. The clusters were made using five independent variables: alkaline water retention capacity (AWRC), sodium carbonate SRC (SODSRC), sucrose SRC (SUCSR), lactic acid SRC (LASRC), and water SRC (WSRC) of both flour and whole meal.

RESULTS AND DISCUSSION

Cookie-Making Quality

In the present investigation, the cookie diameter varied from 6.65 to 8.57 cm with mean value of 7.56 cm. The spread factor

TABLE I
Wheat Genotypes Including Released Cultivars Representing Different Zones in India and Germplasm Collected from Different Countries^a

No.	Genotype	Origin/Area of Adaptation	No.	Genotype	Origin /Area of Adaptation
1	VHC6048	NHZ, India	47	NP4	NWPZ India
2	VHC6105	NHZ, India	48	HD2865	NWPZ, India
3	VHC6173	NHZ, India	49	WH542	NWPZ, India
4	VHC6152	NHZ, India	50	K68	NWPZ & NEPZ, India
5	VHC6185	NHZ, India	51	HD2687	NWPZ, India
6	VHC6197	NHZ, India	52	HYB65	CZ, India
7	DW776	India	53	HS207	NHZ, India
8	E147	Kenya	54	HD2380	PZ, India
9	E670	Argentina	55	PISSI	CZ, India
10	E671	Argentina	56	ERADU	Australia
11	E839	Australia	57	HPW42	NHZ, India
12	E2407	USA	58	UP2338	NWPZ, India
13	E4530	USA	59	HP1633	NEPZ, India
14	E4542	France	60	HP1658	NEPZ, India
15	E4812	Kenya	61	CS	
16	EC378758	Information not available	62	TIMCURIN	Australia
17	EC378772	Information not available	63	VL830	NHZ, India
18	EC378773	Information not available	64	SONALIKA	NHZ, India
19	EC378774	Information not available	65	HB208	NHZ, India
20	EC378775	Information not available	66	HUW468	NEPZ, India
21	EC378788	Information not available	67	C306	CZ, India
22	EC378790	Information not available	68	HUW541	NEPZ, India
23	EC378793	Information not available	69	UP2554	NWPZ, India
24	EC378799	Information not available	70	UP2556	NWPZ, India
25	VW115	Information not available	71	PBW502	NWPZ, India
26	CITR2190	Information not available	72	HD2329	NWPZ, India
27	HP1102	NEPZ, India	73	DBW14	NEPZ, India
28	HP1657	NEPZ, India	74	HUW234	NEPZ, India
29	HPW74	NHZ, India	75	NW1014	NEPZ, India
30	HPW89	NHZ, India	76	HW2045	NEPZ, India
31	HPW114	NHZ, India	77	HD2285	NEPZ, India
32	HPW143	NHZ, India	78	NW2036	NEPZ, India
33	HPW12	NHZ, India	79	LOK1	CZ, India
34	HUW311	NEPZ, India	80	DL788-2	CZ, India
35	HUW336	NEPZ, India	81	GW273	CZ, India
36	HY173	Pak	82	HI977	PZ, India
37	HY631	Pak	83	NIAW34	PZ, India
38	HPT147	India	84	HD2501	PZ, India
39	HB629	NHZ, India	85	MP4012	CZ, India
40	HD2668	CZ, india	86	K2008	NEPZ, India
41	NI9406	CZ, India	87	LOK45	PZ, India
42	NEPAL6	Nepal	88	GW337	CZ, India
43	DL3776	CZ, India	89	HD2868	PZ, India
44	NP828	CZ, India	90	UP2596	PZ, India
45	NI5439	CZ, India	91	HD2781	PZ, India
46	PBW343	NWPZ, India	92	GW173	CZ, India

^a All genotypes are maintained at Genetic Resource Unit of DWR, Karnal. North Hill Zone (NHZ), North Western Plains Zone (NWPZ), North Eastern Plains Zone (NEPZ), Central Zone (CZ), Peninsular Zone (PZ).

range was 5.30–9.84 with a mean value of 7.29. Most of the released cultivars showed lower spread factor value (<6.5). *Chapati*, the unleavened bread, is preferred and consumed in every household in India. Because chapati has been the staple diet, emphasis has been for the development of wheat cultivars suitable for this purpose. Harder grains and medium strong gluten are required for good chapati-making quality, while softer grains and weak gluten are required for good cookie-making quality (Hoseney et al 1988; Souza et al 1994). Earlier evaluations of released cultivars of wheat in India indicated the prevalence of harder grains with null mutation in puroindoline A (Sewa Ram et al 2002). Null mutation in puroindoline A has been associated with grain hardness (Giroux and Morris 1998). In this study, 25 germplasm lines had higher spread factor (>8.50). The identified lines can be used as a source of genes for good cookie-making quality traits in India.

Wide ranges of values were observed within each quality parameter using both whole meal and flour samples. AWRC of flour samples was 57–80% with the mean value of 65.2%. Sodium carbonate SRC was 65–114% with the average value of 79.2%. Sucrose SRC was 77–109% with the average value of 87.8%. Lactic acid SRC was 69–120% with the average value of 92.6%. Water SRC was 55–77% with the average value of 64.5%. The grain protein content was 8.0–14.2% (14% mb) with the average value of 11.4%. Sedimentation value was 4.2–13.0 cm³ with the average value of 8.8 cm³. SRC of whole meal samples were higher than those of flour samples except lactic acid SRC. Data clearly indicate the average higher values of AWRC, sodium carbonate SRC, and medium lactic acid SRC showing higher water absorption and medium gluten strength meet the requirements of good chapati quality.

Correlation Analysis Using Flour Samples

A correlation matrix was developed using cookie diameter, spread factor, AWRC, SRC, protein content, and sedimentation value (Table II). There were significant positive correlations ($P < 0.001$) among different SRC but unrelated with grain protein content and sedimentation values except lactic acid SRC. The previous studies also indicated no correlation between protein content and SRC values (Gaines 2000; Guttieri et al 2001). However, lactic acid SRC showed positive correlation with grain protein content ($r = 0.35$,

$P < 0.001$) and sedimentation value ($r = 0.44$, $P < 0.001$). Lactic acid SRC is associated with gluten strength and was therefore expected to be associated with protein content and sedimentation value. Guttieri et al (2002) also reported positive significant correlation between increased protein content and lactic acid SRC within a cultivar.

Correlation analysis indicated strong negative correlations between cookie diameter and AWRC ($r = -0.79$, $P < 0.001$), sucrose SRC ($r = -0.78$, $P < 0.001$), sodium carbonate SRC ($r = -0.76$, $P < 0.001$), lactic acid SRC ($r = -0.62$, $P < 0.001$), water SRC ($r = -0.63$, $P < 0.001$), less highly significant with protein content ($r = -0.39$, $P < 0.001$) and no correlation with sedimentation value (Table II). The spread factor also showed similar correlations with SRC, protein content, and sedimentation value. Thus SRC clearly explains a large part of the potential cookie-making quality. There are conflicting reports on the role of protein content and sedimentation value in determining cookie-making quality. Faridi et al (1994) reported the negative relationship between protein content and cookie diameter while Yamamoto et al (1996) found the lack of relationship between protein content and sugar-snap cookie diameter. Reports also indicate that higher protein content is related more to the density of cookies rather than the spread factor (Hoseney et al 1988). The sedimentation value depends on the swelling of glutenin strands and high values have been associated with stronger gluten and superior bread-making quality (Axford et al 1979; Ayoub et al 1983; Lorenzo and Kronstad 1987). In this investigation, the nonsignificant correlation between sedimentation value and cookie quality may be due to the overriding effect of flour characteristics related to SRC and diverse genotypes used in this study. For example, Carter et al (1999) reported a negative relationship of SDS sedimentation, taking into account the protein content with soft white wheat end product quality.

Multiple regression analysis was conducted using LSQ technique to find out the contribution of various parameters toward cookie diameter and spread factor. AWRC explained 43.8%, sodium carbonate SRC 27.3%, lactic acid SRC 15.1%, and protein content 13.8% of the total variability (multiple $r = 0.87$) toward cookie-diameter. Total variability (multiple $r = 0.85$) in spread factor was explained 40.3% by AWRC, 27.4% by SODSRC, 14.5% by LASRC, and 17.8% by protein content. When the technique was further used to reduce the number of parameters contributing toward

TABLE II
Correlation Coefficients for Flour Characteristics Related to Solvent Retention Capacities and Genotypes^{a,b}

	W/T	AWRC	SODSRC	SUCSRC	LASRC	WSRC	GPC	SED
W	0.95***	-0.79***	-0.76***	-0.78***	-0.62***	-0.63***	-0.39***	-0.13ns
W/T		-0.75***	-0.73***	-0.74***	-0.61***	-0.60***	-0.42***	-0.15ns
AWRC			0.93***	0.91***	0.51***	0.78***	0.08ns	0.08ns
SODSRC				0.88***	0.47***	0.70***	0.06ns	-0.11ns
SUCSRC					0.59***	0.69***	0.17ns	0.01ns
LASRC						0.39***	0.35***	0.45***
WSRC							0.07ns	-0.09ns
GPC								0.36***

^a Cookie diameter (W), spread factor (W/T), alkaline water retention capacity (AWRC), sodium carbonate SRC (SODSRC), sucrose SRC (SUCSRC), lactic acid SRC (LASRC) and water SRC (WSRC) of flour samples, grain protein content (GPC) and sedimentation value (SED).

^b ***, Significant at $P < 0.001$; ns, not significant.

TABLE III
Correlation Coefficients for Cookie Diameter and Solvent Retention Capacity (SRC) Tests of Whole Meal^{a,b}

	W/T	AWRC	SODSRC	SUCSRC	LASRC	WSRC
W	0.94***	-0.51***	-0.66***	-0.62***	-0.76***	-0.54***
W/T		-0.49***	-0.63***	-0.58***	-0.70***	-0.52***
AWRC			0.79***	0.65***	0.66***	0.78***
SODSRC				0.76***	0.83***	0.84***
SUCSRC					0.81***	0.68***
LASRC						0.74***

^a Cookie diameter (W), spread factor (W/T), alkaline water retention capacity (AWRC), sodium carbonate SRC (SODSRC), sucrose SRC (SUCSRC), lactic acid SRC (LASRC), and water SRC (WSRC) (whole meal SRC).

^b ***, Significant at $P < 0.001$.

cookie diameter, AWRC explained 67.2% of the total variability (multiple $r = 0.85$) and the rest by lactic acid SRC and protein content. When AWRC was not introduced as the explainable variable in the multiple regression analysis, sodium carbonate SRC explained 63.9% of the variability (multiple $r = 0.84$) toward spread factor. Sodium carbonate SRC also showed high positive correlation with sucrose SRC ($r = 0.88$) and thus concealed the effect attributable to sucrose SRC in multiple regression analysis. The variability to the tune of 36% was explained equally by lactic acid SRC and grain protein content.

Because AWRC explained a larger part of variability in cookie diameter, multiple regression was used to find the components explaining the variability in AWRC. Sodium carbonate SRC explained 60% and sucrose SRC explained 40% of the total variability (multiple $r = 0.95$) in AWRC. This demonstrates that major component of AWRC is explained by starch damage as exhibited by sodium carbonate SRC and pentosan content as exhibited by sucrose SRC. This further establishes that the major components determining the cookie spread factor are grain hardness and pentosan content and, to a lesser extent, gluten strength and protein content. Recently, Igrejas et al (2002) also reported the major effect of grain hardness and viscosity of water-extractable arabinoxylans on cookie quality. Harder grain texture causes higher starch damage and consequently higher water absorption that is detrimental to the cookie quality (Nemeth et al 1994; Yamamoto et al 1996). Kaldy et al (1991) showed a correlation between pentosan content and smaller cookie diameter and cake volume across the environments. Recently, Bettge and Morris (2000) demonstrated that pentosans together with protein content accounted for 87% of variation in cookie diameter in soft wheat cultivars. Pentosans may affect cookie quality by modifying grain texture as well as contributing to water absorption. Because diverse genotypes representing both hard and soft wheats were used in this investigation, a larger amount of genetic variability in cookie quality was explained by SRC, which can be used in improving cookie-making quality with interclass hybridizations. Campbell et al (2001) also reported the utility of interclass hybridizations in wheat breeding for the improvement of agronomic and milling and baking quality traits.

Whole Meal (1 g) vs. Flour (1 g)

Whole meal flours were evaluated for SRC and sedimentation tests and compared with flours using 1 g of material. Whole meal SRC had greater values than the flour SRC, except for lactic acid

SRC which had lower values in flour samples. The decreased whole meal lactic acid SRC versus flour is partly due to the diluent effect of bran (Bettge et al 2002). Moreover, fewer functional gluten-forming proteins (glutenins and gliadins) are present on a weight basis in ground wheat, resulting in lower lactic acid SRC values. The correlation coefficients between wheat meal and flour were very high for sodium carbonate SRC ($r = 0.85$, $P < 0.001$), alkaline water retention capacity ($r = 0.75$, $P < 0.001$), sucrose SRC ($r = 0.71$, $P < 0.001$), and water SRC ($r = 0.74$, $P < 0.001$) and less for lactic acid SRC ($r = 0.50$, $P < 0.001$). Using a set of eight cultivars, Bettge et al (2002) reported a significant correlation between whole meal SRC and flour SRC at the 2 and 5% level of significance. In the present investigation, the correlation was significant at the 0.1% level for all SRC.

The correlation analysis exhibited significant ($P < 0.001$) negative correlation between cookie diameter and SRC tests of whole meal (Table III). Correlation coefficients were ($r = -0.76$) for lactic acid SRC, ($r = -0.66$) for sodium carbonate SRC, ($r = -0.62$) for sucrose SRC, ($r = -0.54$) for water SRC, and ($r = -0.51$) for AWRC. Similarly significant negative correlations were between spread factor and SRC of whole meal samples. The multiple regression analysis was also conducted to find the contribution of different SRC of whole meal flours toward cookie diameter and spread factor. Surprisingly, lactic acid SRC and sodium carbonate SRC explained 88 and 12%, respectively, of the total variability (multiple $r = 0.76$) toward cookie diameter and 78 and 22%, respectively, of the total variability (multiple $r = 0.71$) toward spread factor. Whole meal flour lactic SRC was highly correlated with sodium carbonate SRC ($r = 0.83$), sucrose SRC ($r = 0.81$), and water SRC ($r = 0.74$). Though less sensitive than flour SRC, whole meal flour SRC explained a large amount of variation in cookie diameter and spread factor. Data clearly indicate that a change of methodology from flour to wheat meal is feasible. This will help in selecting early generation lines where the amount of grain available is low. In more advanced generations where the sufficient material is available for milling, the flour SRC and baking tests can supplant wheat meal SRC tests.

Correlations in Genotypes with Higher Cookie Diameter

The data in this investigation clearly demonstrated the strong correlations between cookie-making quality and SRC when diverse genotypes were used. However, with a view to observe the relationship of SRC with cookie-making quality within soft wheats in

TABLE IV
Correlation Coefficients for Flour Samples of 50 Genotypes Selected by Cookie Diameter (>7.70 cm)^{a,b}

	W/T	AWRC	SODSRC	SUCSRC	LASRC	WSRC
W	0.81***	-0.41**	-0.37**	-0.53***	-0.27*	-0.42**
W/T		-0.33*	-0.32*	-0.46***	-0.25ns	-0.38**
AWRC			0.81***	0.77***	0.25ns	0.71***
SODSRC				0.76***	0.28*	0.69***
SUCSRC					0.27*	0.72***
LASRC						0.31*

^a Cookie diameter (W), spread factor (W/T), alkaline water retention capacity (AWRC), sodium carbonate SRC (SODSRC), sucrose SRC (SUCSRC), lactic acid SRC (LASRC) and water SRC (WSRC).

^b *, **, ***, Significant at $P < 0.05$, 0.01, and 0.001; ns, not significant.

TABLE V
Correlation Coefficients for Whole Meal Samples of 50 Genotypes Selected by Cookie Diameter (>7.70 cm)^{a,b}

	W/T	AWRC	SODSRC	SUCSRC	LASRC	WSRC
W	0.81***	-0.40**	-0.51***	-0.33*	-0.51***	-0.59***
W/T		-0.36**	-0.48***	-0.34*	-0.44***	-0.54***
AWRC			0.55***	0.45***	0.59***	0.58***
SODSRC				0.56***	0.75***	0.70***
SUCSRC					0.66***	0.60***
LASRC						0.74***

^a Cookie diameter (W), spread factor (W/T), alkaline water retention capacity (AWRC), sodium carbonate SRC (SODSRC), sucrose SRC (SUCSRC), lactic acid SRC (LASRC) and water SRC (WSRC).

^b *, **, ***, Significant at $P < 0.05$, 0.01, and 0.001; ns, not significant.

the present investigation, a population of 50 genotypes was identified with higher cookie diameter. The distribution of cookie diameter of all the genotypes studied was plotted and genotypes with larger cookie diameter (>7.70 cm) were selected. The population represented all the genotypes (31) in cluster I and 19 genotypes of cluster II. The correlation matrix was developed using all SRC, cookie diameter, and spread factor. Significant negative correlations (though less significant than correlations obtained using both hard and soft wheats) were observed between cookie diameter and AWRC, SODSRC, SUCSRC, LASRC, and WSRC using both flour and whole meals (Tables IV and V). This was expected because quality differences between hard and soft populations are quite distinct as compared to within each population separately. Thus, limited variation in the SRC and cookie diameters may cause lower correlations and other factors may become important (Bergman et al 1988). In flour samples, sucrose SRC showed high correlation ($P < 0.001$) with both cookie diameter and spread factor, while in whole meal samples, sodium carbonate SRC, lactic acid SRC, and water SRC exhibited high correlation ($P < 0.001$) with cookie diameter and spread factor. In multiple regression analysis using flour samples, 87.7% of the total variability (multiple $r = 0.54$) of cookie diameter and 83.8% of total variability (multiple $r = 0.52$) in spread factor was explained by sucrose SRC, respectively. The data clearly indicate that pentosan content in flour as revealed by sucrose SRC is responsible for variation in cookie diameter among soft wheats. Earlier studies also indicated the role of pentosans in cookie-making quality in soft wheats (Kaldy et al 1991; Bettge and Morris 2000). While multiple regression using whole meal samples of soft wheats indicated that 76.9% of the total variability (multiple $r = 0.62$) of cookie diameter and 70.2% of total variability (multiple $r = 0.61$) in spread factor was explained by water SRC and the remaining by lactic acid SRC and sodium carbonate

SRC. The data clearly demonstrate that some other factors become important in whole meal flours in cookie-making quality. Overall, the study showed that SRC can be used both as selection criteria for the improvement of cookie-making quality using both hard and soft wheat cultivars in the breeding program.

Cluster Analysis

SRC profiles developed by both flour as well as whole meal were used to cluster the genotypes (Figs. 1 and 2). In this analysis, samples were allowed to segregate into clusters. The clusters were made using five variables: alkaline water retention capacity (AWRC), sodium carbonate SRC (SODSRC), sucrose SRC (SUCSRC), lactic acid SRC (LASRC), and water SRC (WSRC) of flour and whole meal of 92 genotypes. The three clusters of flour had 31, 41, and 20 genotypes while whole meal clusters had 37, 31, and 24 genotypes, respectively. The average distances of cluster members from cluster centroids of I, II, and III clusters of flour were 1.29, 1.29, and 1.07, respectively. The distances between cluster centroids were 2.66 (between I and II), 2.44 (between II and III), and 5.05 (between I and III). The average distances of cluster members from cluster centroids of I, II, and III clusters of whole meal flour were 1.10, 1.14, and 1.54, respectively. The distances between cluster centroids were 2.19 (between I and II), 2.43 (between II and III), and 4.60 (between I and III). Cluster I of flour typifies lower SRC for all the solvents and significantly higher ($P < 0.001$)

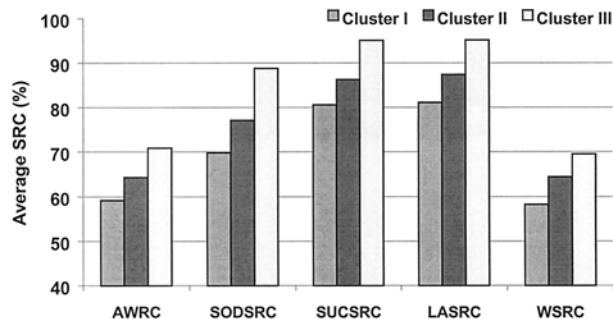


Fig. 1. Average solvent retention capacities (SRC) of three clusters made using five variables: alkaline water retention capacity (AWRC), sodium carbonate SRC (SODSRC), sucrose SRC (SUCSRC), lactic acid SRC (LASRC), and water SRC (WSRC) of flour of 92 lines. Cluster I, 31 lines; cluster II, 41 lines; cluster III, 20 lines.

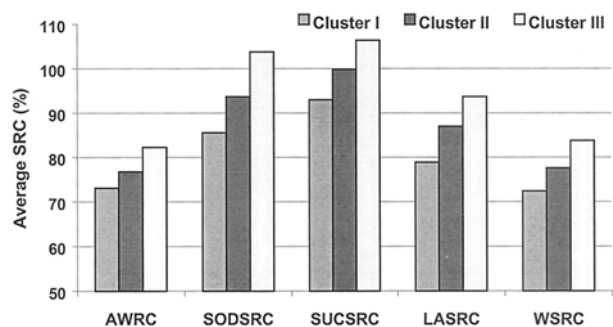


Fig. 2. Average solvent retention capacities (SRC) of three clusters made using five variables: alkaline water retention capacity (AWRC), sodium carbonate SRC (SODSRC), sucrose SRC (SUCSRC), lactic acid SRC (LASRC), and water SRC (WSRC) of whole meal flour of 92 lines. Cluster I, 37 lines; cluster II, 31 lines; cluster III, 24 lines.

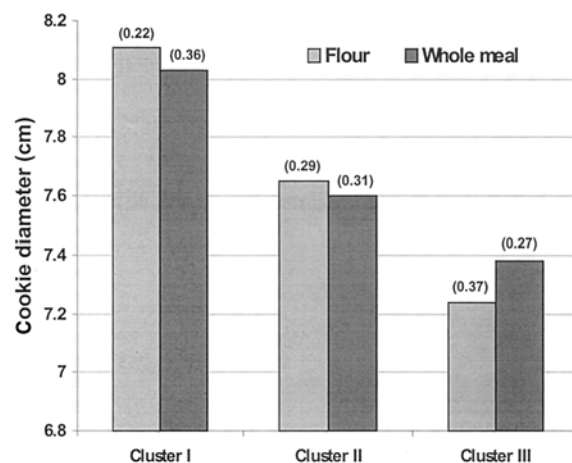


Fig. 3. Average cookie diameter of three clusters made using five variables: alkaline water retention capacity (AWRC), sodium carbonate SRC (SODSRC), sucrose SRC (SUCSRC), lactic acid SRC (LASRC), and water SRC (WSRC) of flour and whole meal flour of 92 lines. Standard deviations in parentheses above bars.

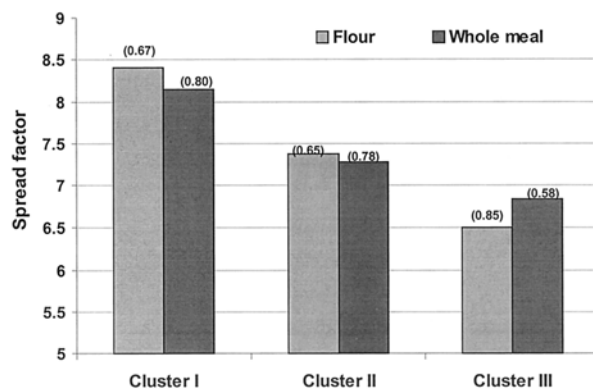


Fig. 4. Average spread factor of three clusters made using five variables: alkaline water retention capacity (AWRC), sodium carbonate SRC (SODSRC), sucrose SRC (SUCSRC), lactic acid SRC (LASRC), and water SRC (WSRC) of flour and whole meal flour of 92 lines. Standard deviations in parentheses above bars.

cookie diameter (average W 8.11 cm) and spread factor (average W/T 8.40) as compared to other clusters II and III (Figs. 3 and 4). Cluster II had intermediate values for SRC, cookie diameter (average W 7.62 cm), and spread factor (average W/T 7.60). Cluster III possessed higher SRC values of all the solvents and lowest cookie diameter (7.22 cm) and spread factor (6.50). Similarly, genotypes in cluster I of whole meal flour had lower value of all the SRC and significantly higher ($P < 0.001$) cookie diameter and spread factor as compared to other clusters II and III. There was no significant difference in the average value of cookie diameter and spread factor of the corresponding clusters of flour and whole meal. Average SRC values of each cluster made from whole meal flour were higher than the corresponding cluster made using whole meal flour except lactic acid SRC. Essentially, the lines representing the corresponding cluster of whole meal and flour were common, except a few lines in adjacent clusters I and II and II and III. However, there was not a single line of cluster I of flour representing cluster III of whole meal. Most of the lines in cluster I represented exotic collections with E and EC numbers and genotypes developed for Northern Hills Zone and had higher cookie diameter and spread factor. Cluster II had most of the genotypes developed for North Western Plains Zone and had intermediate SRC values. Cluster III had genotypes developed for Central Zone, North Eastern Plains Zone, and Peninsular Zone and had comparatively higher SRC values and lower cookie diameter. The list of genotypes is given in Table I. The cluster analysis further established the utility of whole meal flour SRC in selecting desirable genotypes of good cookie-making quality.

CONCLUSIONS

SRC profile explained a larger amount of genetic variability in cookie-making quality among all the genotypes representing both hard and soft wheats though comparatively less significant within soft wheat class. In stepwise multiple regression analysis of flour samples, AWRC explained 67.2% of the total variability (multiple $r = 0.85$) toward cookie diameter and the rest by lactic acid SRC and protein content. Multiple regression analysis of whole meal samples showed that lactic acid SRC explained 88% of the total variability (multiple $r = 0.76$) toward cookie diameter and 78% toward spread factor (multiple $r = 0.71$). Among the soft wheat flour samples, sucrose SRC explained 87.7% of the total variability (multiple $r = 0.54$) of cookie diameter and 83.8% of total variability (multiple $r = 0.52$) in spread factor. Clusters made using flour and whole meal SRC had similar average values for cookie diameter and spread factor. Thus, the data clearly demonstrate that whole meal tests can be used in screening the recombinant line in breeding programs for improving cookie-making quality of Indian wheats.

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