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Relationship between physicochemical characteristics of flour and sugar-snap cookie quality in Korean wheat cultivar

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Abstract

The relationship of physicochemical properties of flour, including particle size of flour, damaged starch, SDS-sedimentation volume, gluten content and four solvent retention capacity (SRC) values with cookie baking quality, including cookie diameter and thickness was evaluated using 30 Korean wheat cultivars grown in the 2011-2012 seasons. Cookie quality and flour physicochemical properties were significantly influenced by year, cultivar and their interactions. Dahong, Dajoong, Goso, Joa, Namhae, Ol, Olgeuru and Uri produced larger cookie than other Korean wheat cultivars. Significant positive correlations were found among physicochemical properties of Korean wheat cultivars. Cookie diameter negatively correlated with cookie thickness ($r = -0.986$, $P < 0.001$) and negatively correlated with particle size, damaged starch, protein characteristics and all four SRC values ($P < 0.001$). A prediction equation developed using sodium carbonate SRC, SDS sedimentation volume and sucrose SRC provides a reliable estimation of cookie diameter. This equation could be explained 84% of the variability in cookie diameter. Therefore, a combination of SRC values, especially sodium carbonate and sucrose, and SDS-sedimentation volume could be used to select wheat lines with suitable for cookie baking in Korean wheat breeding populations.

Introduction

Cookie diameter is an excellent indictor of general soft wheat baking quality (Finney *et al.*, 1987; Hoseney *et al.*, 1988). Cookie diameter is strongly affected by the composition and especially characteristics of damaged starch, protein, and nonstarch polysaccharides of flour and known to significantly relate with water-holding properties of flour (Slade *et al.*, 1994; Kweon *et al.*, 2011).

Soft wheats generally produce less damaged starch than hard wheats due to the weak interactions between the starch granule and the protein matrix in the endosperm of kernel (Hoseney *et al.*, 1988). Protein content of flour also plays an important role in cookie baking quality (Finney *et al.*, 1987). Soft wheat products do not require an extensive gluten development, and thus, high protein content is undesirable in most soft wheat products, while hard wheat generally need to be high in protein content, which produce a well-developed gluten network during dough mixing and subsequently a large loaf volume of bread with fine crumb structure (Gaines, 2004). Cookie quality was more affected by protein content than protein compositions, which is fundamentally genetically controlled, but protein content is largely influenced by environmental conditions (Hoseney *et al.*, 1988; Slade *et al.*, 1994; Souza *et al.*, 1994).

The solvent retention capacity (SRC) method is developed by Slade and Levine (Slade *et al.*, 1994) and implemented as an AACC Approved Method (Gaines, 2000). Four different solutions (5% lactic acid, 5% sodium carbonate, 50% sucrose, and water) are employed in SRC methods (Gaines, 2000). SRC values are known to be reliable predictors of cookie baking performance of flour and influenced by both genotype and environmental conditions (Guttieri *et al.*, 2003; Walker *et al.*, 2008). The quality of cookie baking was also influenced by genotypes, environments, and their interactions in soft wheats (Mikhaylenko *et al.*, 2000; Souza *et al.*, 2004).

The Korean wheat breeding program has focused on improving grain yield and early maturation developed 30 cultivars since the 1970s. Improvement of wheat quality for flour milling and end-uses is receiving more attention by wheat breeders than ever in Korea (Kang *et al.*, 2010a; 2010b). However, screening methods for small scale samples of early generation breeding lines for cookie baking quality potential have not been identified nor practiced in Korean wheat breeding programs. Therefore, rapid and easy screening methods for evaluation of cookie baking quality should be introduced for selection of

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early generation wheat breeding lines. This study was conducted to evaluate the relationship between cookie diameter and physicochemical properties of flour, including protein characteristics and SRC values, in Korean wheat cultivars in order to provide useful information for improving cookie quality in Korean wheat breeding programs.

Materials and Methods

Materials

Thirty Korean wheat cultivars, which representing those developed in the 1970s, were grown in randomized complete blocks with 3 replicates in the Upland Crop Experimental Farm of National Institute of Crop Science, Rural Development Administration (Korea) in 2010/2011 and 2011/2012. The seeds were planted in late October and each plot consisted of three 4-m rows spaced 25 cm apart and plots were combine-harvested in mid June in both years. Fertilizer was applied at 5:7:5kg/10a (N: P: K) before sowing and weeds, insects and disease were stringently controlled. No supplemental irrigation was applied. Mean temperature of these two years (10.3ºC) was higher than that of an average year by 0.2ºC, and average precipitation (608 mm) was lower than that of an average year (576 mm). Harvested grain was dried using a forced air drier and grain from the replicate trials was bulked to obtain grain enough for quality analysis.

Physicochemical analysis of Flour

Wheat was milled to about 60% extraction using a Bühler experimental mill according to AACCI Approved Method 26-31.01 (AACCI, 2010). Distribution of flour particle size was measured using amulti-wavelength laser particle size analyzer LS13320 (Beckman Coulter, Inc., USA). Moisture and protein contents of wheat flour were determined according to AACCI Approved Methods 46-30.01 and 39-11.01, respectively (AACCI, 2010). The determination of starch damage content was carried out following the procedure described by Gibson *et al.* (1992) using an enzymatic assay kits (MegaZyme Pty., Ltd., Australia). A SDS sedimentation test was performed according to the procedure of Axford *et al.* (1979) with a modification in flour weight to 3 g. Wet and dry gluten content were determind using a Glutomatic 2200 (Perten Instruments AB, Sweden) with constant volume of Glutomatic wash solution of 4.8 mL according to AACCI Approved Method 38-12.02 (AACCI, 2010).

The SRC tests were conducted according to the AACCI Approved Method 56-11.01 (AACCI, 2010) using 5% lactic acid, 5% sodium carbonate and 50% sucrose solutions, and distilled water. Flour (5 g) was added into a 50-mL centrifuge tube with a screw cap. The appropriate solvent (25.0 mL) was added and the mixture was vortexed vigorously to suspend the flour for 5 sec. The mixture was allowed to set and swell for 20 min and vortexed for 5 sec each at 5, 10, 15, and 20 min. After centrifugation at 1,000 × g for 15 min (not including time to achieve speed), the supernatant was decanted and the tube was drained at a 90° angle for 10 min on a paper towel. Each pellet was weighed and the SRC (%) for each sample was calculated according to AACCI Approved Method 56-11.01 (2010). The SRC assay was performed in triplicates.

Cookie Baking

Sugar-snap cookie baking test were conducted following the AACCI Approved Method 10-52.01 (AACCI, 2010). The ingredients included flour (40.0 g, 14.0% moisture basis), sugar (24.0 g), shortening (12.0 g), nonfat dry milk solid (1.2 g), Sodium bicarbonate (0.4 g), Solution of sodium bicarbonate (0.32 g), Solution of ammonium chloride (0.2 g), sodium chloride (0.18 g) and deionized water (2.0 g). Sugar, nonfat dry milk, and sodium bicarbonate were sifted together, combined with the shortening, and creamed using Kitchen Aid Professional KPM5 mixer (Kitchen Aid, MI, USA) equipped with a flat beater mixing arm (type K45AB) for 4 min. Creamed mass (37.6 g) was weighed out and combined with water, sodium bicarbonate solution ammonium chloride solution and salt. Flour was added and mixed using a National cookie dough micromixer (National Mfg. Co., Lincoln, NE) at 172 rpm for 3 min. Cookie dough was scraped from bowl, formed into a single dough mass and cut using spatula into two equal pieces. The cookie dough was sheeted to a thickness of 7 mm and cut using a cookie dough cutter (60 mm inside diameter). The cut cookie dough was baked at 205 ± 2ºC for 10 min. After cookies were cooled to room temperature for 30 min, diameter and thickness were measured. The spread ratio was calculated by dividing the diameter by the thickness. Four cookies were baked for each flour.

Statistical analysis

At least two independent measurements per sample were collected for each quality parameter tested and analysized statistically using the SAS computer software package (SAS Institute, Cary, NC). Analysis of variance was conducted using the general linear model procedure, and genotype × year component was used as the error term. Sources of variation in the model were considered to be fixed effects. Pearson's correlation analysis was also conducted with significance level of $P < 0.05$ unless otherwise specified. Multiple regression analysis was conducted with cookie diameter as dependent variable. Independent variables were selected with partial least square method. The significance level was set at P value of 0.05 for entering a variable into the stepwise regression model and at P value of 0.15 to retain the variable.

Results and Discussion

Analysis of variance

Year, cultivar and their interaction effects were significant on physicochemical properties, including solvent retention capacity, and cookie quality of 30 Korean wheat cultivars (Table 1). Significant influences of genotypes, environments, and their interactions on flour characteristics and cookie baking quality were also previously reported (Mikhaylenko *et al*., 2000; Souza *et al*., 2004). Flour characteristics of Korean wheat cultivars were significantly changed by different cultural environments in our previous reports (Souza *et al.*, 2004; Shin *et al*., 2012). Cookie diameter was mainly influenced by cultivars, but thickness of cookie was influenced by genotypes and environmental conditions in Korean wheat cultivars and experimental lines (Park *et al*., 2001; Kang *et al.*, 2010b).

Particle size of flour and damaged starch content are directly affected by grain hardness, which is influenced by both genotype and environmental factors, including growing locations and seasons (Hoseney *et al*., 1988). Cultivar accounted for the largest proportion of variation in average particle size and damaged starch content of flour (98 and 92%, respectively) in this study. These results indicate that average particle size and damaged starch content of flour were mainly influenced by genotype rather than year and cultivar × year interactions. SDS-sedimentation volume is mainly controlled by quantity and quality of protein (Baik *et al*., 1994). SDS-sedimentation volume was significantly influenced by cultivars and cultivar × year interactions but not by years (Shin *et al*., 2012). However, SDS-sedimentation volume was significantly influenced by year, cultivar and their interactions in this study, probably due to significant differences in protein content between crop years in this study. In analysis of variance for protein content and quality parameters, the largest proportion of variation was contributed by cultivar (> 73%), followed by year (4 – 18%) and cultivar × year interactions (7 – 12%). Crop year was accounted for higher proportion of the variation in protein content (18%) than cultivar × year interactions.

Cultivar mainly accounted for the variation in SRC values of water, lactic acid and sodium carbonate solvents (> 81%). SRC values showed much larger variation among genotypes than crop years. Sucrose SRC were affected by year and cultivar × year interactions (17 and 22%, respectively), cultivars still accounted for variance over 60%. Diameter and thickness of cookie were mainly influenced by the cultivar (85 and 80%, respectively) and the contribution of year and cultivar × year interactions was less than 8 and 9% of the overall variation, respectively. Walker et al. (2008) reported that the interactions of genotype × environment and genotype × field replication within environment were significant ($P < 0.05$) for most solvent and sample weight combinations.

Variations in Korean wheat cultivars

Means of average particle size of flour, damaged starch content and protein characteristics of 30 Korean wheat cultivars over two crop years were summarized in Table 2. Cultivars grown in 2011 showed significantly higher average particle size of flour, damaged starch content and protein characteristics, including protein content, SDS-sedimentation volume and gluten content than those grown in 2012 crop year. Means of average particle size of flour and damaged starch content were 70.29 µm and 4.59%, respectively. Average particle size of flour and damaged starch content of cultivars over two crop years ranged from 49.75 to 87.01 µm and from 2.41 to 7.90%, respectively. Mean protein content, SDS-sedimentation volume, wet gluten and dry gluten of cultivars grown in two crop years were 10.23%, 28.65ml, 19.94% and 6.69%, respectively. Protein content and SDS-sedimentation volume ranged from 7.56 to 13.45% and from 11.00 to 45.75 ml, respectively. Gluten content ranged from 14.48 to 28.97% at wet gluten and from 4.48 to 10.24% at dry gluten.

Hanbaek showed higher average particle size of flour and damaged starch (87.01 µm and 7.90%, respectively) than other cultivars. Average particle size of flour of Namhae was lower (49.75 µm) than that of other flours. Dahong, Olgeuru and Saeol showed lower damaged starch content (< 2.50%) than others. Joeun had higher protein content, wet gluten and dry gluten (13.45, 28.97 and 10.24%, respectively) than others, while Dahong was relatively lower in protein content and dry gluten (7.86 and 4.48%, respectively) than others. Baekjoong (14.48%) was lowest in wet gluten content. Dahong exhibited lower SDS-

Table 1. Analysis of variance for physicochemical properties and parameters of sugar-snap cookie baked from 30 Korean wheat cultivars grown in two years

Source of Variance	df	Sum of Squre[a]					
		Physicochemical Properties					
		Average Particle Size	Damaged Starch	Protein Characteristics			
				Protein	SDS- Sedimentation	Wet Gluten	Dry Gluten
Year (Y)	1	141.76***	24.09***	78.80**	766.73***	225.46***	29.50***
Cultivar (C)	29	26165.48***	368.43***	319.48***	18747.31***	2216.95***	337.21***
Rep	2	0.01ns	0.07ns	0.01ns	0.49ns	0.29ns	0.06ns
Y × C	29	493.31***	4.11***	34.51***	1570.31***	340.89***	41.48***
Error	118	23.66	4.06	0.54	14.01	14.79	3.83
Total	179	26824.51	400.76	433.34	21098.85	2798.38	412.09

Source of Variance	df	Sum of Square					
		Solvent Retention Capacity				Sugar-Snap Cookie	
		Water	Sucrose	Lactic acid	Sodium Carbonate	Diameter	Thickness
Year (Y)	1	1139.89***	3384.77***	4339.16***	565.91***	691.70***	122.98***
Cultivar (C)	29	8047.90***	11588.21***	66032.52***	18161.03***	23177.90***	1308.83***
Rep	2	0.05ns	0.61ns	0.02ns	0.02ns	16.25ns	1.83ns
Y × C	29	707.54***	4298.14***	212.09***	1752.97***	2348.67***	121.32***
Error	118	25.46	79.07	37.90	20.62	977.51	73.94
Total	179	9920.85	19350.80	76570.70	20500.55	27212.03	1628.91

a*** , significant at P < 0.001; ns, not significant.

Table 2. Means for average particle size of flour, damaged starch and protein characteristics of 30 Korean wheat cultivars grown in two crop years

	Average Particle Size (um)	Damaged starch (%)	Protein Characteristics			
			Protein (%)	SDSS[a] (ml)	Wet gluten (%)	Dry gluten (%)
Year						
2011	71.17±12.79	4.95±1.46	10.89±1.56	30.71±11.98	21.05±4.34	7.09±1.59
2012	69.40±11.68	4.22±1.44	9.57±1.24	26.58±9.22	18.82±3.18	6.28±1.33
LSD[b]	0.13	0.05	0.02	0.10	0.10	0.05
Cultivar						
Alchan	72.00±5.06	4.08±0.23	9.11±0.74	30.00±4.38	16.16±0.56	4.59±0.23
Anbaek	81.73±4.04	6.12±0.33	10.16±1.55	26.25±6.85	19.91±3.61	6.25±1.70
Baekjoong	80.91±0.95	5.12±0.44	9.46±1.18	25.33±3.33	14.48±1.15	5.25±0.90
Chunggye	55.74±1.19	2.88±0.41	9.28±0.05	21.00±1.70	19.65±0.49	6.62±0.14
Dahong	51.07±1.40	2.50±0.49	7.86±0.26	11.00±1.10	16.17±0.56	4.48±0.08
Dajoong	74.74±2.27	5.28±0.50	10.38±0.27	33.75±0.42	21.13±0.53	6.82±0.33
Eunpa	79.31±3.25	5.78±0.40	10.47±0.39	31.75±3.03	20.43±0.64	7.23±0.20
Geuru	77.51±4.12	5.95±0.26	9.78±0.91	17.50±1.18	21.50±2.13	7.53±0.70
Gobun	75.67±3.10	4.49±0.37	10.46±0.97	34.50±4.40	21.02±1.83	7.05±0.56
Goso	58.36±0.69	5.81±0.49	10.39±0.30	31.83±0.93	20.70±0.33	6.89±0.06
Hanbaek	87.01±1.91	7.90±0.49	11.59±0.48	41.50±3.83	20.84±0.59	8.57±0.20
Jeokjoong	82.30±0.68	4.93±0.25	9.24±1.07	31.50±4.93	14.78±1.68	5.20±1.05
Jinpoom	78.92±2.22	4.31±0.28	9.56±1.12	28.00±4.38	16.17±0.87	5.52±0.26
Joa	59.23±2.60	3.19±0.47	10.43±0.59	17.50±6.02	20.12±0.63	5.87±0.15
Joeun	86.42±2.90	5.96±0.56	13.45±1.59	40.75±7.40	28.97±6.77	10.24±2.00
Jokyung	75.72±0.84	5.78±0.38	11.39±2.09	40.75±9.59	23.10±4.93	6.58±0.97
Jonong	58.00±0.81	3.50±0.54	11.76±0.95	34.00±5.48	24.80±1.34	8.91±0.90
Jopoom	69.81±0.38	5.43±0.52	12.29±0.95	45.75±3.57	26.22±1.71	8.38±1.07
Keumkang	79.63±0.51	5.22±0.64	11.98±1.16	45.75±2.48	24.45±1.11	8.28±0.39
Milseong	56.76±0.28	2.80±0.29	8.95±0.54	12.50±2.74	14.90±1.54	4.85±0.50
Namhae	49.75±1.65	2.79±0.46	8.56±0.38	16.00±0.71	18.26±0.61	6.47±0.33
Ol	55.99±0.62	2.84±0.39	8.51±0.36	13.00±0.71	17.02±0.71	6.03±0.37
Olgeuru	55.50±0.90	2.49±0.54	9.63±0.12	17.75±1.41	20.33±0.73	6.97±0.29
Saeol	53.80±0.49	2.41±0.43	10.20±0.46	23.25±0.88	19.50±0.83	6.45±0.04
Seodun	80.76±2.36	4.96±0.31	10.46±0.95	33.25±4.67	21.10±1.11	6.93±0.30
Suan	77.85±0.57	5.22±0.29	11.25±0.05	38.75±0.88	20.12±0.08	6.56±0.19
Sukang	83.98±0.46	5.84±0.42	12.56±0.66	41.50±4.93	24.68±1.47	8.98±0.26
Tapdong	75.80±1.80	5.68±1.04	10.41±0.55	34.50±1.64	19.04±0.51	6.37±0.23
Uri	53.83±1.20	2.59±0.52	8.06±0.61	15.25±0.88	16.30±1.43	5.16±0.33
Younbaek	80.51±1.34	5.76±0.44	9.32±0.67	25.00±2.48	16.24±1.31	5.71±1.02
LSD	0.51	0.21	0.08	0.39	0.40	0.21

[a]SDSS = SDS-sedomentation volume of wheat flour.
[b]east significant difference (P = 0.05).

sedimentation volume (11.00 ml) than others, while Jopoom and Keumkang showed higher sedimentation volume (45.75 and 47.75 ml).

Mean solvent retention capacity and quality parameters of sugar-snap cookie of 30 Korean wheat cultivars over two crop years were summarized in Table 3. Cultivars grown in 2011 showed significantly lower SRC values of water, sucrose and sodium

Table 3. Means for solvent retention capacity and sugar-snap cookie of 30 Korean wheat cultivars grown in two crop years

	Solvent Retention Capacity				Sugar-Snap Cookie	
	Water (%)	Sucrose (%)	Lactic acid (%)	Sodium carbonate (%)	Diameter (mm)	Thickness (mm)
Year						
2011	66.79±7.52	105.77±10.23	119.00±20.18	90.07±1.18	87.72±8.13	13.07±1.94
2012	71.83±6.48	114.44± 8.64	109.18±20.11	93.62± 9.95	90.12±6.69	12.05±1.59
LSD[a]	0.14	0.24	0.17	0.13	0.28	0.08
Cultivar						
Alchan	70.29±3.04	104.27± 2.66	137.58± 0.85	94.70±3.81	90.58±1.66	11.73±0.29
Anbaek	76.08±0.55	118.04± 1.16	95.63± 8.01	102.85±0.26	83.53±1.58	14.17±0.40
Baekjoong	69.37±0.97	105.55± 5.02	104.50± 9.45	93.90±2.86	91.36±5.26	11.81±0.88
Chunggye	64.41±3.41	106.39± 13.06	113.09± 1.49	82.38±5.20	96.24±2.00	10.93±0.97
Dahong	59.84±3.25	97.95± 9.64	84.42± 1.33	77.68±3.20	102.08±3.27	9.67±0.59
Dajoong	64.29±1.76	103.42± 1.91	117.32± 4.43	82.15±1.43	96.09±3.51	11.02±1.13
Eunpa	77.22±1.74	114.92± 0.62	130.11±13.56	104.13±5.17	81.39±0.94	14.24±0.38
Geuru	73.42±0.75	110.33± 2.91	81.21± 3.71	98.04±1.27	83.80±1.68	13.44±0.94
Gobun	70.79±1.20	107.04± 2.90	126.50± 8.03	92.99±0.29	85.50±2.15	13.15±0.38
Goso	66.81±6.83	110.35± 5.29	112.94± 0.79	86.14±4.30	96.10±1.70	11.55±0.43
Hanbaek	83.76±3.27	132.82± 5.91	142.78± 6.12	116.71±0.58	75.50±2.58	16.24±0.93
Jeokjoong	69.26±0.99	103.68± 5.96	103.43± 0.39	92.26±3.58	89.51±3.55	12.72±0.87
Jinpoom	74.74±1.42	111.09± 0.63	115.13± 9.59	97.55±2.15	83.81±2.53	13.58±0.77
Joa	61.12±4.51	104.61± 4.92	89.90± 3.34	78.61±0.62	99.32±1.79	10.20±0.46
Joeun	83.55±4.00	127.19± 8.17	136.17± 4.46	114.09±6.50	79.08±1.85	14.81±0.79
Jokyung	71.53±4.33	114.75± 0.85	138.63± 6.83	96.20±4.26	81.90±8.35	14.28±2.43
Jonong	65.78±3.02	119.95± 6.70	129.98± 8.03	85.72±0.52	94.92±2.13	11.34±0.49
Jopoom	74.28±1.3	120.02± 1.89	145.06±4.44	99.62±1.18	82.02±1.45	14.40±0.82
Keumkang	71.44±5.37	105.91± 7.72	133.22±4.35	91.31±6.69	80.82±3.71	14.24±1.13
Milseong	57.42±4.71	97.10± 10.10	83.48±2.40	77.28±4.55	92.76±3.73	11.36±1.00
Namhae	62.45±2.66	105.01± 12.17	110.53±0.69	81.04±5.85	98.11±2.50	10.39±0.60
Ol	58.40±5.64	98.89± 10.99	87.16±1.39	77.53±2.75	94.40±1.76	10.96±0.62
Olgeuru	64.07±3.52	104.91± 14.34	89.72±1.40	82.98±3.63	93.47±1.85	11.68±0.69
Saeol	62.66±4.55	109.60± 10.73	99.50±0.86	87.70±4.36	94.95±1.81	10.82±0.48
Seodun	75.14±1.16	112.09± 0.77	121.35±6.56	98.90±1.72	84.39±3.87	13.63±1.08
Suan	73.49±7.71	117.90± 9.12	119.99±0.70	97.45±8.07	84.16±2.60	13.92±0.50
Sukang	75.67±3.34	113.97± 1.56	124.41±1.45	97.86±4.12	82.30±4.05	14.23±0.85
Tapdong	71.46±2.14	112.10± 6.36	138.74± 0.52	95.00±4.01	82.11±1.51	13.76±0.47
Uri	63.72±2.56	105.13± 10.76	104.23± 2.90	82.48±5.41	96.05±1.94	10.67±0.49
Younbaek	66.89±1.06	108.13± 1.44	105.98± 4.89	90.14±2.95	91.37±1.20	11.85±0.48
LSD	0.53	0.94	0.65	0.48	1.07	0.29

[a]Least significant difference (P = 0.05).

carbonate than those grown in 2012, but lactic acid SRC values of cultivars was lower in 2012 than 2011. Mean SRC values of cultivars over crop years were 69.31% for water, 110.10% for sucrose, 114.09% for lactic acid and 91.85% for sodium carbonate. SRC values ranged from 57.42 to 83.76% for water, from 97.10 to 132.82% for sucrose, from 81.21 to 145.06% for lactic acid and from 77.28 to 116.71% for sodium carbonate. Hanbaek and Joeun showed higher water SRC value (83.76 and 83.55%, respectively) and Milseong showed lower water SRC value (57.42%) than other cultivars. In sucrose and sodium carbonate SRC, Hanbaek exhibited higher values (132.82 and 116.71%, respectively), and Milseong and Dahong were lower value (97.10 and 97.95% for sucrose SRC and 77.28 and 77.68% for sodium carbonate SRC, respectively) than others. Ol showed similar sodium carbonate SRC value (77.50%) to Milseong and Dahong. In lactic acid SRC value, Jopoom showed higher value (145.06%) and Geuru showed lower value (81.21%) than other cultivars.

Cultivars of 2012 showed larger diameter and smaller thickness of cookie compared to those wheats harvested in 2011. Mean diameter and thickness of cookie were 88.92 and 12.56mm, respectively. Diameter and thickness of cookie ranged from 75.50 to 102.08 mm and from 9.67 to 16.24 mm, respectively. Hanbaek showed lower cookie diameter and higher thickness (75.50 and 16.24 mm, respectively) than other cultivars. Dahong showed larger cookie diameter and smaller thickness (102.08 and 9.67 mm, respectively) than other cultivars. Dahong also exhibited superior top gain than others (Figure 1). Larger cookie diameter and smaller thickness of Dahong were also reported in our previous report (Kang *et al.*, 2010b). Ol, Olgeuru and Uri showed comparable cookie diameter to commercial flour for cookie in our previous report (Kang *et al.*, 2010b) and also produced cookie of larger diameter (> 93.47 mm) and lower thickness (< 9.01 mm) than other cultivars in this study. Dajoong, Goso and Joa, which are developed after 2010, and Namhae also produced relatively larger diameter cookie (> 96.09 mm).

Correlation and regression analysis

Correlation coefficients of solvent retention capacity and sugar snap cookie with physicochemical properties of flour in Korean wheat cultivars are summarized in Table 4. Average particle size was positively correlated with damage starch content,

Table 4. Correlations between flour characteristics and solvent retention capacity (SRC) and sugar-snap cookie in 30 Korean wheat cultivars

Parameter[a]	PS	DS	PC	SDSS	WG	DG	WSRC	SSRC	LASRC	SCSRC	CD
DS	0.861***[b]										
PC	0.540**	0.601***									
SDSS	0.688***	0.721***	0.853***								
WG	0.261ns	0.388*	0.885***	0.658***							
DG	0.346 ns	0.470**	0.867***	0.644***	0.921***						
WSRC	0.841***	0.827***	0.674***	0.758***	0.669***	0.635***					
SSRC	0.535**	0.683***	0.736***	0.681***	0.868***	0.686***	0.829***				
LASRC	0.484**	0.541**	0.507**	0.645***	0.543**	0.444*	0.644***	0.635***			
SCSRC	0.823***	0.815***	0.588***	0.726***	0.531**	0.539**	0.979***	0.843***	0.606***		
CD	-0.827***	-0.784***	-0.665***	-0.735***	-0.473**	-0.545**	-0.898***	-0.706***	-0.615***	-0.893***	
CT	0.824***	0.826***	0.701***	0.770***	0.509**	0.580**	0.919***	0.763***	0.623***	0.907***	-0.986***

[a]Average of particle size (PS), damaged starch (DS), protein content (PC), SDS-sedimentation volume (SDSS), wet gluten (WG), dry gluten (DG), water SRC (WSRC), sucrose SRC (SSRC), lactic acid SRC (LASRC), sodium carbonate SRC (SCSRC), cookie diameter (CD) and cookie thickness (CT).
[b]*, **, ***, significant at P < 0.05, P < 0.01 and P < 0.001, respectively; ns, not significant.

Figure 1. Sugar-snap cookies baked from 30 Korean wheat flours.

protein content and SDS-sedimentation volume, which agreed with previous reports for Korean wheat cultivars (Park *et al*., 2001; Shin *et al*., 2012). Damaged starch content also positively correlated with protein content, SDS-sedimentation volume and gluten content. Protein content positively correlated with SDS sedimentation volume and gluten content, which agreed with previous report for Korean wheat cultivars (Kang *et al*., 2010a).

Significant positive correlations (P < 0.001) were found among flour SRC values in Korean wheat cultivars, which agreed with previous reports (7, 20). Positive correlations (P < 0.001) were found in among physicochemical properties of flour and different SRC values in this study. SRC values also positively correlated with average particle size, damaged starch and protein content. These results agree with previous report (Gaines, 2000). Xia *et al.* (2006) reported that hardness index, protein content and SDS sedimentation volume were highly correlated with the four SRC tests in hard winter wheats. But, Zhang *et al.* (2007) reported that particle size of flour was not significantly correlated with SRC values, although flour yield showed a negatively correlation with SRC values in Chinese wheats. Colombo *et al.* (2008) reported that damaged starch content was positively correlated with sucrose, sodium carbonate and water SRC values. Gluten content showed positive relationship with lactic acid SRC value in Argentinean wheats. Duyvejonck *et al.* (2011) observed strong linear relations between the flour damaged starch level and WRC values, as well as with sodium carbonate SRC values in commercial European wheat flours.

Cookie diameter negatively correlated with cookie thickness (r = -0.986, P < 0.001) and negatively correlated with particle size, damaged starch content, protein characteristics and different SRC values (P < 0.001), which agreed with previous reports in Korean wheat flours (Park *et al*., 2001; Kang *et al*., 2010a). Souza *et al.* (1994) reported that cookie diameter had negative correlation with protein content of flour, and cookie quality was more affected by protein content than quality. Mikhaylenko *et al.* (2000) also reported the relationship between protein content, SDS-sedimentation volume and cookie diameter. Gaines (2004) suggested that sucrose SRC results could be used reliably to predict sugar-snap cookie diameter; increase in sucrose SRC corresponds with decrease in cookie diameter. Negative relationships between cookie diameter and SRC values were found in Argentinean, Chinese, Indian, Pakistan wheats and European commercial flours (Colombo *et al.*, 2003; Ram and Singh, 2004; Zhang *et al.*, 2007; Moiraghi *et al.*, 2011; Duyvejonck *et al.*, 2012). Souza *et al.* (2012) postulated that a low sucrose SRC response, which was due to low pentosan content, may also indirectly aid in selection of varieties with high flour yield. Duyvejonck *et al.* (2011) proposed that WRC value was a better parameter to assess the cookie diameter than Farinograph or Mixograph water absorption capacities and Alveograph dough tenacity values.

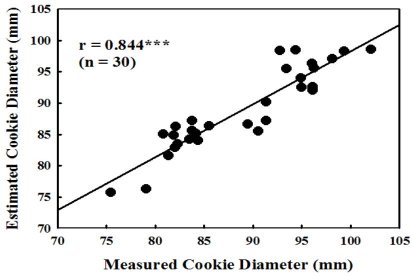

Figure 2. Relationships between measured and estimated cookie diameter using sodium carbonate SRC, SDS sedimentation volume and sucrose SRC.

The multiple regression analysis using partial least square method was conducted to develop an equation for cookie diameter prediction. Regression equation was: CD = 127.930 –0.637 SCSRC –0.192 SDSS + 0.227 SSRC, where CD is cookie diameter, SCSRC is sodium carbonate SRC, SDSS is SDS sedimentation volume, and SSRC is sucrose SRC. Estimated cookie diameter obtained using the regression eqation correlated with measured cookie diameter at $P < 0.001$ (Figure 2). These results indicate that the variability in cookie diameter could be explained 84% from damaged starch, pentosans and protein characteristics including protein content and quality. Sodium carbonate SRC is a measure of starch damage content and sucrose SRC is largely contributed by pentosans and gliadins (Gaines, 2004). SDS sedimentation volume based on constant flour weight is influenced by protein content and quality (Baik *et al*., 1994). Guttieri *et al.* (2004) proposed that a combination of sodium carbonate SRC and SDS sedimentation volume of wheat meal may be an efficient approach to selection wheat lines with larger cookie diameter in soft wheat breeding populations. Ram and Singh (2004) reported that cook diameter was explained by alkaline water retention capacity, like sodium carbonate SRC, and lactic acid SRC and protein content up to 87% in Indian wheats. Zhang *et al.* (2007) found that cookie diameter of Chinese wheats could be predicted by sucrose SRC and flour particle size of flour with up to 83%. Colombo *et al.* (2008) showed a simple regression model of cookie factor, which was determined by the ratio between diameter and thickness of cookies, using water SRC in Argentine flours including hard and soft wheats. Moiraghi *et al.* (2011) reported that cookie factor could be predicted by particle size of flour, water soluble pentosans, lactic acid SRC and sucrose SRC in Argentine soft wheat flours.

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