Influence of physicochemical characteristics of flour on pancake quality attributes

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Revised: 11 January 2019 / Accepted: 29 January 2019 / Published online: 13 February 2019
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Abstract This study was conducted to identify the influence of flour characteristics of 13 Korean wheat cultivars on quality attributes of pancake. Pancake diameter showed negative correlation with SRC with distilled water and pancake height and positive correlation with springiness of cooked pancake. Springiness of baked pancake was under negative correlation with protein content, SDSS, dry gluten content, and positive correlation with final viscosity and setback in pasting properties of flour. Springiness and cohesiveness of baked pancake were under negative correlation with mixing time of Mixograph. Hardness of baked pancake was correlated with amylose content and breakdown of flour. Regression and principal component analysis indicated that pancake diameter, and springiness and cohesiveness of baked pancake can be explained by protein quantity and quality parameters, protein content, SDSS, mixing time of Mixograph, and SRCs related to protein content. Hardness of baked pancake can be predicted from amylose content and breakdown of flour. Batter viscosity as well as texture of cooked pancake could be influenced by protein quality and quantity according to grain hardness.

Keywords Korean wheat · Flour characteristic · Pancake making · Quality · Texture

Introduction

Pancake is consumed as breakfast or dessert in the North America and widely cooked with modified recipes such as Crepe in France and Dorayaki in Japan, also called hotcake in Korea (Morris and Rose 1996). The pancake generally uses unique fluid batters with lots of water, which it minimizes the viscosity of batter and the formation of gluten, shape of pancake is round and flat after baking (Morris and Rose 1996). The light and fluffy texture of baked pancakes are common in North America, although there are no clear criteria for pancake making process and quality evaluation of baked pancake due to differences in consumer preferences (Finnie et al. 2006).

Pancake with appropriate diameter and thickness could be made by homogenous and low viscosity of batter flow (Morris and Rose 1996). For good pancake, soft wheat flour is usually used because of low protein content and gluten strength (Fajardo and Ross 2015). Pancake made from hard wheat is smaller and thicker than that of soft wheat because high protein content decreases the viscosity of batter flow (Fajardo and Ross 2015). Other flour properties, including damaged starch content, arabinoxylan content, solvent retention capacity and pasting temperature, also could affect the batter flow and diameter of pancake (Fajardo and Ross 2015; Kiszona et al. 2015; Bettge 2014). Dry heat of starch and tailings fractions of wheat flour cause an increase in the level of springiness for baked pancakes (Ozawa and Seguchi 2008). Chlorine-treated commercial soft wheat flour was commonly used for

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improving pancake quality in North America (Finnie et al. 2006).

However, only a few studies have been focused in improving pancake quality using soft wheat flours. There was no research on pancake quality using Korean wheat flours, although pancake premix products are recently sold in Korean market. Herein, it was to evaluate the making performances and texture for baked pancake of 13 Korean wheat cultivars, to elucidate the relationships between pancake quality attributes and physicochemical properties of flour and to verify the main quality parameters that could be used to improve quality of pancake in the breeding program for Korean wheat.

Materials and methods

Materials

Thirteen Korean wheat cultivars were sown for randomized complete block design with 3 replications at the Upland Crop Experimental Farm in the National Institute of Crop Science of Rural Development Administration (Republic of Korea) in late October of 2014/2015, and 2015/2016 on 50% clay loam soil. Each block consisted of three 4-m rows spaced 25 cm apart. Before sowing, fertilizer was applied (5 Nitrogen: 7 Phosphorus: 5 Potassium, kg/10a). There was no supplemental irrigation, and not only weeds but also disease and insect pest control were rigorously performed. Grains were harvested with a combine in mid-June for the 2 years and dried by forced-air drying and then milled. The wheat flours of two soft red winter (SRW) wheat cultivars, Tv8535 and Usg3612, provided from the Soft Wheat Quality Laboratory of United States Department of Agriculture Agricultural Research Service (Wooster, OH) and were used to compare pancake quality.

Analytical methods

Wheat grains were milled using a Bühler experimental mill, based on the American Association of Cereal Chemists International (AACCI) Approved Method: 26-31.01 (AACCI 2010). Wheat grains (12 kg) were tempered to 15% moisture for 12 h and then milled. Milling conditions were in accordance with 100 g/min feed rate and roll settings of 8 and 5 in break rolls and 4 and 2 in reduction rolls. Moisture, ash content, protein content and sodium dodecyl sulfate (SDS) sedimentation values of wheat flours were measured in accordance with AACCI Approved Methods: 44-15.02, 08-01.01, 46-30.01 and 56-70.01, respectively (AACCI 2010). Amylose and damaged starch contents were determined by using enzymatic assay kits (Megazyme, Bray, Ireland), in accordance with the methods

explained by Gibson et al. (1992, 1997). Dough mixing properties were analyzed with a 10 g Mixograph (National Mfg. Co., USA) following AACCI Approved Method: 54-40.02 (Gibson et al. 1992). Content of dry gluten was quantified with a Glutomatic 2200 (Perten Instruments AB, Sweden) with 4.8 mL Glutomatic wash solution (AACCI Approved Method: 38-12.02, 2010).

A test for solvent retention capacity (SRC) was performed using 5% lactic acid, 5% sodium carbonate, 50% sucrose solutions, and distilled water (AACCI Approved Method 56-11.01, 2010). Pasting properties of wheat flours were determined using RVA-Super4, a Rapid Visco Analyser (Newport Scientific Pty, Ltd., Australia) (AACCI Approved method 76-21.01). Wheat flour (4.0 g, 14% moisture basis) was suspended in 25 mL DW and the mixture was held at 50 °C for 1 min, heated from 50 to 95 °C at a rate of 12 °C/min, kept at 95 °C for 2.5 min, chilled to 50 °C at a rate of 12 °C/min, and then kept at 50 °C for 2 min under 160 rpm, constant stirring. Viscosity was expressed in RVA unit. Peak and final viscosities and holding strength of wheat flour were detected. Breakdown was calculated by subtracting the holding strength from the peak and final viscosities.

Pancake baking test

A test for pancake baking was conducted based on Approved methods: 10-80.01 (AACCI 2010; Bettge 2014). Dry pancake mixture powder consisted of flour (175 g, 14%, mb), sucrose (17 g), dextrose (5.5 g), sodium bicarbonate (3.16 g), monocalcium phosphate (0.79 g), sodium acid pyrophosphate (3.51 g), and sodium chloride (2.6 g). Those ingredients were mixed together under speed 1 of a Hobart N5 mixer (Hobart Corporation, Troy, OH, USA) for 1 min. The insides of the bowl were scraped down and then the mixture was blended for 1 min. Canola oil (11 g) was poured over the mixture and then mixed for 1 min at the speed 1. The insides of the bowl were scraped down and the mixture was blended for another 1 min. The mixture with 210 g of dry pancake mixture and 242 mL water was mixed for 10 s at the speed 1. The side of the mixing bowl was scraped down, and the batter was blended for an additional 10 s at the speed 1. The batter was rested for 2 min, and then the specific volume (mL/g), temperature and viscosity of the batter were measured. The batter viscosity was measured with the Bostwick consistometer (CSC Scientific, USA) for 40 s. Food scoop (#20, 44 mL) was used to pour batter onto the griddle with a surface temperature of 190 °C. Four pancakes were baked for 90 s on each side and then cooled 20 min at 25 °C on a cooling rack. Diameter and height of each pancake and weight of four pancakes were measured after cooling.

Texture profile analysis of pancakes

Texture profile analysis (TPA) of baked pancakes was measured using TA-XT2i, a texture analyzer (Stable Micro System, USA). The texture analyzer was fitted out with a load cell (50-kg) and a round compression platen probe (75-mm diameter). The pancake was compressed to 50% of its original height and the compression speed was 1 mm/s (Finnie et al. 2006). Height of the peak as hardness and negative area between the first and second peak as adhesiveness were measured. Springiness was measured based on the ratio between the height of the first compression and the recovered height after the first compression. Cohesiveness was determined based on the ratio between the area under the second peak and the area under the first peak.

Statistical analysis

Statistic analysis of all values of measured parameters in this study was performed by R, a statistical free software (The R Project for Statistical Computing, R version 3.4.4 from <https://www.r-project.org>) with Fisher's least significant difference procedure (LSD), analysis of variance (ANOVA), and Pearson's correlation coefficient. A principal component analysis (PCA) was carried out with the Proc Princomp procedure in SAS software (SAS Institute, NC, USA) to load the measured traits under visualization. Regression equation was formulated with the optimum model excluding non-significant variations based on the highest *R*-square value. All measured values were in triplicate and averaged.

Results and discussion

Flour characteristics

Ash content of Korean wheat flours ranged from 0.39 to 0.55%, and damaged starch content ranged from 1.67 to 6.11% (Table 1). Two U.S. SRW wheat cultivars, Tv8535 and Usg3612, ranged from 0.38 to 0.39% in ash content and lower than 2.34% in damaged starch content. Four different solvents, distilled water, 50% sucrose solutions, 5% lactic acid, and 5% sodium carbonate, were used in SRC tests and these tests are referred as WSRC, SucSRC, LASRC and SCSRC. Korean wheat cultivars ranged from 54.0 to 71.4% in WSRC, 66.6 to 90.8% in SucSRC, 89.8 to 156.3% in LASRC and 96.3 to 115.7% in SCSRC, respectively. SRC values of Usg3612 showed lower than Korean wheats, Tv8535 also showed lower SRC values than Korean wheat flours except in LASRC. Among SRCs of Korean wheat cultivars, WSRC, SucSRC, and SCSRC

were lower than Indian wheats, whereas Korean wheat cultivars showed wide range and higher value of LASRC than Indian wheats (Kaur et al. 2014; Katyal et al. 2016). Protein content of Korean wheat cultivars ranged from 7.48 to 15.84% (Table 1). Two U.S. SRW wheat cultivars showed lower flour protein content than Korean wheat cultivars, with exception of cv. Uri. The SDS sedimentation volume and dry gluten content of Korean wheat cultivars ranged from 21.0 to 68.10 mL and 5.45 to 15.58%, respectively, while SDS sedimentations of Tv8535 and Usg3612 were 25.00 mL and 15.75 mL, and their dry gluten contents were 7.03% and 5.23%, respectively.

Protein content showed positive correlations with SDS sedimentation volume and dry gluten content ($r = 0.925$, $P < 0.001$ and $r = 0.972$, $P < 0.001$, respectively). These relationships coincided with the report by Kang et al. (2014) for Korean wheat cultivars. There were significantly positive correlations between SRC values in Korean wheat cultivars, which coincide with the report by Gaines (2000). WSRC and SCSRC were positively correlated with damaged starch content of Korean wheats ($r = 0.731$, $P < 0.01$ and $r = 0.649$, $P < 0.05$, respectively). Damaged starch content was positively correlated with WSRC as well as with SCSRC in commercial European wheat flours (Duyvejonck et al. 2011). Damaged starch content has shown correlations with WSRC, LASRC, and SCSRC, except in SucSRC in hard red spring wheats and Argentinean wheats (Colombo et al. 2008; Hamed et al. 2015). Protein content, SDS sedimentation volume and dry gluten contents were also under positive correlation with LASRC values, while these protein properties positively correlated with the four SRC values in our previous results (Kang et al. 2014). Protein content and SDS sedimentation volume were highly correlated with the four SRC tests in hard winter wheats (Xia et al. 2006). Gluten content was under positive relationship with LASRC value in Argentinean wheat (Colombo et al. 2008).

The SRC test is used to predict the functional contribution of each individual flour component, which LASRC is for glutenin characteristics, SCSRC is for damaged starch content, SucSRC is for arabinoxylan content and WSRC is related to water retention capacity (Gaines 2004; Kweon et al. 2011). Most of Korean wheats higher SRC values compared to SRW wheats and SRC values for standard reference flour, although Goso, Hojoong, Joa, and Joongmo2012 are similar values to standard reference flour for pancakes. Korean wheat flours showed much higher LASRC than standard reference flour. Korean wheats showed higher protein content and dry gluten content than SRW wheats, and then Korean wheats showed higher LASRC value than SRW wheats. Glutenin content is largely influenced by environmental conditions, such as fertilization and weather, although its genetic compositions

Table 1 Flour characteristics of 13 Korean wheat cultivars and two U.S. soft red winter wheats^a

Cultivar	Ash (%)	Damaged starch (%)	Solvent retention capacity		Sodium carbonate (%)	Sucrose (%)	Protein (%)	SDS sedimentation volume (mL)	Dry gluten (%)
			Water (%)	Lactic acid (%)					
Korean									
Baekjoong	0.46 ± 0.02	5.22 ± 0.07	62.57 ± 2.18	98.04 ± 5.50	77.06 ± 3.74	96.30 ± 2.70	9.10 ± 0.39	27.50 ± 1.18	7.76 ± 0.65
Goso	0.40 ± 0.04	4.69 ± 0.62	57.70 ± 4.31	99.69 ± 4.05	73.30 ± 8.91	113.17 ± 5.73	9.02 ± 0.83	26.00 ± 4.95	7.46 ± 0.65
Hojooong	0.41 ± 0.02	3.07 ± 0.37	53.97 ± 1.99	99.25 ± 2.06	67.36 ± 5.10	107.92 ± 2.99	9.31 ± 0.48	32.25 ± 0.42	8.80 ± 0.60
Joa	0.39 ± 0.02	1.67 ± 0.51	54.25 ± 2.02	89.79 ± 12.28	66.59 ± 4.90	107.97 ± 8.04	10.07 ± 0.05	24.75 ± 1.94	9.61 ± 0.42
Jojoong	0.45 ± 0.03	6.11 ± 0.78	71.35 ± 3.80	127.22 ± 7.70	90.83 ± 9.11	111.34 ± 5.76	10.88 ± 0.45	33.00 ± 0.71	10.00 ± 0.26
Jokyung	0.47 ± 0.02	5.47 ± 0.99	61.89 ± 5.81	112.12 ± 11.32	77.94 ± 6.60	102.80 ± 4.79	9.46 ± 1.16	33.75 ± 3.03	7.26 ± 1.14
Joongmo2008	0.42 ± 0.03	3.13 ± 1.28	64.98 ± 2.77	156.30 ± 4.92	80.53 ± 5.86	115.67 ± 1.73	15.84 ± 1.26	68.10 ± 10.49	15.58 ± 2.66
Joongmo2012	0.48 ± 0.08	1.78 ± 0.24	54.15 ± 1.65	116.16 ± 7.96	71.19 ± 3.45	114.18 ± 4.68	10.02 ± 0.17	40.75 ± 0.88	8.34 ± 0.34
Jopoom	0.48 ± 0.00	3.55 ± 1.57	60.62 ± 3.54	123.38 ± 3.18	75.66 ± 3.30	98.23 ± 3.08	9.60 ± 0.69	37.75 ± 4.12	8.91 ± 0.94
Keumkang	0.45 ± 0.04	4.80 ± 0.63	58.36 ± 2.94	123.40 ± 3.19	71.28 ± 3.90	97.55 ± 1.47	10.80 ± 0.58	41.25 ± 2.48	10.84 ± 0.84
Suan	0.55 ± 0.07	4.79 ± 0.61	60.91 ± 4.19	110.40 ± 7.18	76.97 ± 5.72	103.64 ± 0.51	9.41 ± 0.53	32.13 ± 0.77	8.32 ± 0.49
Uri	0.47 ± 0.02	3.42 ± 0.13	60.03 ± 1.40	109.80 ± 9.01	81.61 ± 3.74	113.33 ± 11.50	7.48 ± 0.08	21.00 ± 3.29	5.45 ± 0.44
Younbeak	0.46 ± 0.01	5.86 ± 0.72	65.43 ± 2.21	108.58 ± 1.81	82.74 ± 6.45	102.84 ± 1.97	9.41 ± 0.69	30.88 ± 4.52	8.20 ± 1.15
U.S.									
Tx8535	0.39 ± 0.07	2.07 ± 0.80	50.55 ± 4.75	97.13 ± 20.84	65.91 ± 8.80	93.57 ± 5.23	8.39 ± 0.98	25.00 ± 7.13	7.03 ± 1.51
Usg3612	0.39 ± 0.05	2.34 ± 0.34	53.83 ± 4.75	75.34 ± 14.04	66.23 ± 8.33	90.62 ± 5.34	7.17 ± 0.95	15.75 ± 4.66	5.23 ± 0.69
LSD ^b	0.04	0.90	3.72	8.05	5.92	6.64	0.77	4.58	1.17

^aValues are averages of two crop years and mean ± SD from triplicate determinations per year^bLSD means least significant difference ($P = 0.05$), and difference between two means exceeding this value is significant

are mainly controlled by genetic factors. Cultivation and wheat lines to reduce LASRC value of Korean wheats should be considered in breeding programs for improving pancake quality. According to Katyal et al. (2016), protein content is significantly correlated with LASRC. Also, it was identified that fine flour particles, 0–55 μm size are correlated with LASRC and sedimentation value (Singh et al. 2016). Unextractable polymeric proteins is correlated to gluten index and LASRC (Katyal et al. 2016). Hence, it is important to study related to not only protein content but also proportion of size fraction of protein for improving pancake quality.

Dough and pasting properties

Water absorption, mixing time and tolerance in Mixograph ranged from 54.00 to 68.00%, from 1.00 to 4.47 min, and from 5.08 to 16.54 mm, respectively, in Korean wheat cultivars (Table 2). Water absorption and mixing time of Usg3612 (54.50% and 0.90 min, respectively) were similar to those of Uri (54.00% and 1.00 min, respectively). Uri had the lowest optimum water absorption and mixing time of Mixograph in Korean wheat cultivars, while Joongmo2008 showed the higher those values. Tv8535 showed longer mixing time (2.00 min) and higher mixing tolerance (12.42 mm) versus Usg3612 (mixing time: 0.90 min and mixing tolerance: 9.09 mm).

Water absorption of Mixograph was under positive correlation with protein content ($r = 0.972$, $P < 0.001$), SDS Sedimentation volume ($r = 0.912$, $P < 0.001$), dry gluten content ($r = 0.946$, $P < 0.001$), and LASRC ($r = 0.837$, $P < 0.001$). Water absorption is strongly correlated with SCSRC in Indian wheats (Singh et al. 2016). However, Korean wheat cultivars showed no correlation between water absorption and SCSRC. Mixing time was under positive correlation with SDS Sedimentation volume ($r = 0.621$, $P < 0.05$). These relationships were agreed with our previous results in Korean wheats (Kang et al. 2010a). Dough development time is strongly correlated with LASRC in Indian wheats (Singh et al. 2016). However, there was no correlation between them in Korean wheat cultivars. Water absorption of Mixograph was under positive correlation with protein content in U.S. hard winter wheat, while there is no such correlation in U.S. soft wheat (Dong et al. 1992; Morris et al. 2004). Korean wheat cultivars showed no correlation mixing tolerance and protein. According to Singh et al. (2016), dough stability shows positive correlation with extractable and unextractable polymeric protein but negative correlation with extractable and unextractable monomeric protein in Indian wheats. It is necessary to analyse dough properties according to proportion and content of protein fractions for Korean wheat breeding program.

Amylose content ranged from 20.7 to 29.2% in Korean wheats and ranged from 28.2 to 28.7% in SRW wheats (Table 2). Hojoong and Joongmo2012 exhibited less amylose contents (23.4% and 20.7%, respectively) than the other Korean wheat cultivars. Hojoong, carrying *Wx-A1b* and *Wx-B1b* alleles, and Joongmo2012, carrying *Wx-A1b* allele, are partial waxy wheat cultivars (Cho et al. 2019). The average amylose content of Korean wheat cultivars except these two partial waxy wheat cultivars was 28.1%, which was similar to that of SRW wheats. Peak viscosity, holding strength, and final viscosity of Korean wheat flours ranged from 218.96 to 298.71 RVU, from 134.35 to 174.44 RVU, and from 230.08 to 326.17 RVU, respectively (Table 2). Breakdown and setback of Korean wheat flours ranged from 73.68 to 131.67 RVU and from 95.73 to 151.73 RVU, respectively. Usg3612 showed higher flour viscosities than Tv8535, which these pasting properties were similar to those of Korean wheats, except in Hojoong and Joongmo2012. Hojoong showed the higher peak viscosity and breakdown than other Korean wheats, and Joongmo2012 showed lower setback.

Amylose content was positively correlated with final viscosity ($r = 0.695$, $P < 0.01$) and setback ($r = 0.865$, $P < 0.001$). Amylose content was highly correlated with final viscosity and setback, and starch with low amylose content reduces the amount of leached amylose during chilling (Sasaki et al. 2000). No significant relationships were found between amylose content and other pasting properties. Reduced amylose content consistently increased peak viscosity and breakdown of starch in 26 Korean wheats and in 54 doubled haploid lines (Heo et al. 2012; Kang et al. 2012). Peak viscosity, holding strength and final viscosity were negatively correlated with WSRC and SCSRC in Argentinian wheats (Moiraghi et al. 2013). There were no significant correlations between pasting properties, including peak viscosity, holding strength, and final viscosity, and two SRCs, WSRC and SCSRC, in this study due to the narrow range of these pasting properties of Korean wheats in spite of containing partial waxy wheats. Therefore, further study should be considered to identify the relationship among these properties using various wheat cultivars. Amylose content was under positive correlation with WSRC in Japanese near-isogenic soft wheat lines (Nishio et al. 2011). In this study, no significant relationships were found between amylose content and four SRC parameters, because of the narrow variation in amylose content and SRC values.

Pancake quality

Top and bottom surface, and side views of pancakes are shown in Fig. 1. The specific volume, height and diameter of pancakes ranged from 95.9 to 103.97 mL/g, from 37.8 to

Table 2 Dough and pasting properties of 13 Korean wheat cultivars and two U.S. soft red winter wheats^a

Cultivar	Mixograph		Amylose (%)					Rapid visco analyser			
	Water absorption (%)	Mixing time (min)	Mixing tolerance (mm)	Peak viscosity (RVU)	Holding strength (RVU)	Final viscosity (RVU)	Breakdown (RVU)	Setback (RVU)			
Korean											
Baekjoong	55.75 ± 0.82	3.83 ± 0.19	15.83 ± 2.29	28.47 ± 1.10	235.44 ± 4.13	155.42 ± 5.67	295.19 ± 4.99	80.02 ± 4.99	139.77 ± 0.95		
Goso	56.50 ± 1.64	2.93 ± 0.53	7.08 ± 1.43	29.16 ± 0.80	266.10 ± 3.51	173.42 ± 5.22	312.11 ± 6.69	92.69 ± 6.69	138.69 ± 2.23		
Hojooong	56.50 ± 1.64	3.88 ± 0.36	9.31 ± 1.18	23.35 ± 1.56	298.71 ± 5.90	167.04 ± 12.34	282.19 ± 13.21	131.67 ± 13.21	115.15 ± 1.57		
Joa	56.50 ± 1.64	2.52 ± 0.51	5.08 ± 1.19	27.98 ± 0.23	275.96 ± 3.60	162.06 ± 10.97	299.79 ± 16.93	113.90 ± 16.93	137.73 ± 6.05		
Jojoong	58.88 ± 1.24	3.09 ± 0.10	11.66 ± 0.97	27.72 ± 0.94	260.94 ± 17.87	163.40 ± 3.47	294.25 ± 9.13	97.54 ± 9.13	130.85 ± 5.81		
Jokyung	56.00 ± 2.19	2.85 ± 2.03	16.54 ± 2.19	28.90 ± 1.08	218.96 ± 4.56	138.58 ± 3.07	278.98 ± 6.86	80.38 ± 6.86	140.40 ± 3.91		
Joongmo2008	68.03 ± 2.92	4.27 ± 0.09	9.83 ± 0.98	27.45 ± 0.57	223.73 ± 4.02	150.04 ± 9.53	271.90 ± 4.74	73.68 ± 4.74	121.86 ± 5.96		
Joongmo2012	56.00 ± 1.10	4.47 ± 0.05	14.01 ± 3.87	20.67 ± 0.30	242.73 ± 4.26	134.36 ± 16.78	230.08 ± 13.30	108.38 ± 13.30	95.73 ± 3.62		
Jopoom	58.13 ± 0.21	3.88 ± 0.52	14.63 ± 3.69	27.96 ± 0.36	231.65 ± 14.64	135.50 ± 3.45	267.33 ± 14.20	96.15 ± 14.20	131.83 ± 10.86		
Keumkang	58.13 ± 0.97	3.68 ± 0.25	10.25 ± 0.42	27.46 ± 0.67	241.73 ± 5.58	158.04 ± 3.27	295.42 ± 6.83	83.69 ± 6.83	137.37 ± 10.05		
Suan	56.63 ± 2.61	3.33 ± 0.85	14.96 ± 2.54	27.04 ± 0.12	248.56 ± 4.57	159.50 ± 2.85	306.19 ± 3.28	89.06 ± 3.28	146.69 ± 1.39		
Uri	54.00 ± 0.00	1.00 ± 0.00	9.17 ± 0.91	29.03 ± 0.48	282.54 ± 5.85	174.44 ± 2.59	326.17 ± 3.42	108.10 ± 3.42	151.73 ± 1.82		
Younbeak	56.50 ± 0.55	3.88 ± 0.36	10.79 ± 4.61	28.14 ± 0.31	225.07 ± 1.23	147.61 ± 2.04	275.04 ± 4.09	77.46 ± 4.09	127.44 ± 3.41		
U.S.											
Tv8535	55.00 ± 1.10	2.00 ± 1.10	12.42 ± 0.38	28.71 ± 0.48	207.96 ± 3.92	110.94 ± 8.03	226.31 ± 8.06	96.88 ± 6.43	115.27 ± 0.58		
Usg3612	54.50 ± 0.55	0.90 ± 0.11	9.09 ± 0.64	28.20 ± 0.49	254.98 ± 23.61	154.04 ± 18.64	282.90 ± 19.93	101.00 ± 5.02	128.96 ± 1.34		
LSD ^b	1.83	0.78	2.75	0.89	8.78	8.83	10.86	12.47	6.25		

^aValues are averages of two crop years and mean ± SD from triplicate determinations per year^bLSD means least significant difference ($P = 0.05$), and difference between two means exceeding this value is significant

Fig. 1 Pancakes prepared from 13 Korean wheat cultivars and U.S. soft red winter wheats, showing large differences in color, shape, diameter, and stack height (a) and Pearson's correlation coefficient on

scatter plot across pair-wise comparison among 13 Korean wheat cultivars, and asterisks indicate significance; *, **, and *** at $P < 0.05$, $P < 0.01$, and $P < 0.001$, respectively (b)

61.7 mm, and from 88.5 to 108.1 mm, respectively, in Korean wheat cultivars (Table 3). Specific volume of Jokyung and Joongmo2008 (103.20 and 103.97 mL/g, respectively) was similar to that of SRW wheats (103.83 and 103.73 mL/g, respectively), while other Korean wheats show lower specific volume. Goso, Hojoong, Joa, Joongmo2012 and Uri showed similar height of pancake to SRW wheats (35.80 and 38.65 mm, respectively), other Korean wheats showed thicker pancake than soft red wheats. Uri showed similar diameter of pancake to SRW wheats (110.64 and 111.23 mm, respectively), other Korean wheats showed smaller diameter of pancake than SRW wheats.

The batter density of sponge cake, which measures the viscosity of the batter similar to pancake, was positively correlated with SRC values except LASRC, and protein and damaged starch contents in soft wheats (Moiraghi et al. 2013). However, specific volume of pancakes had no relationship with solvent retention capacity, protein properties, dough properties, and pasting properties of flour in this study. The reason seems to be the differences in the manufacturing process of the sponge cake and pancake and only soft wheats were used in the evaluation. Pancake diameter was negatively correlated with the specific

volume of pancake which was highly correlated with the density of batter (Kiszonas et al. 2015). No significant relationship was between those parameters because of Korean wheats used in this study carrying soft and hard texture in grain hardness (Park et al. 2010). Pancake diameter was negatively correlated with pancake height, which this relationship was agreed with previous report (Bettge 2014). Pancake height was under positive correlation with protein content ($r = 0.614$, $P < 0.05$) and dry gluten content ($r = 0.596$, $P < 0.05$) in Fig. 1b. Pancake height was also positively correlated with SRC values, except in SucSRC. Pancake diameter was negatively correlated with only WSRC ($r = -0.596$, $P < 0.05$). Diameter and height of pancake were influenced by protein content rather than the protein qualities in the U.S. soft wheat (Fajardo and Ross 2015). These parameters of pancake were also correlated with WSRC and SucSRC, which is related to amount of protein and arabinoxylan content, but not correlated with LASRC, which is associated with gluten properties (Fajardo and Ross 2015).

Hardness, springiness, cohesiveness and adhesiveness of baked pancake from Korean wheats ranged from 4.31 to 6.03 N, from 0.74 to 0.91, from 0.65 to 0.75, and from -68.41 to -31.96 N $\times$ mm, respectively (Table 3).

Table 3 Characteristics of pancake making and texture properties of baked pancake of 13 Korean wheat cultivars and two U.S. soft red winter wheats^a

Cultivar	Specific volume (mL/g)	Height (mm)	Diameter (mm)	Texture profile analysis			
				Hardness (N)	Springiness (ratio)	Cohesiveness (ratio)	Adhesiveness (N × mm)
Korean							
Baekjoong	101.41 ± 1.92	50.54 ± 8.18	95.64 ± 4.29	5.62 ± 1.40	0.80 ± 0.06	0.71 ± 0.01	− 42.64 ± 4.69
Goso	100.24 ± 0.70	41.02 ± 8.47	102.58 ± 4.24	5.74 ± 2.09	0.87 ± 0.03	0.75 ± 0.02	− 58.17 ± 22.44
Hojoong	101.99 ± 1.71	45.11 ± 8.88	98.24 ± 6.94	4.09 ± 0.93	0.83 ± 0.01	0.74 ± 0.04	− 68.41 ± 28.27
Joa	99.34 ± 0.43	42.17 ± 7.27	101.76 ± 3.52	5.43 ± 1.34	0.83 ± 0.02	0.75 ± 0.03	− 66.41 ± 20.58
Jojoong	101.26 ± 1.16	61.72 ± 11.11	88.48 ± 6.00	5.10 ± 1.91	0.74 ± 0.06	0.65 ± 0.02	− 57.63 ± 17.01
Jokyung	103.20 ± 2.08	50.00 ± 12.80	97.02 ± 7.87	4.54 ± 0.19	0.86 ± 0.07	0.75 ± 0.07	− 53.97 ± 10.89
Joongmo2008	103.97 ± 1.56	57.19 ± 7.42	93.70 ± 3.37	5.39 ± 1.94	0.76 ± 0.07	0.69 ± 0.02	− 66.52 ± 15.30
Joongmo2012	95.87 ± 0.26	43.54 ± 8.40	96.31 ± 7.14	4.31 ± 1.33	0.75 ± 0.04	0.68 ± 0.01	− 53.22 ± 34.79
Jopoom	98.12 ± 0.67	48.85 ± 6.74	98.42 ± 7.67	5.93 ± 1.72	0.81 ± 0.06	0.71 ± 0.01	− 51.68 ± 11.62
Keumkang	101.33 ± 1.37	48.99 ± 7.32	96.26 ± 4.53	5.63 ± 1.57	0.79 ± 0.07	0.69 ± 0.03	− 31.96 ± 9.26
Suan	101.84 ± 1.03	49.12 ± 11.36	96.28 ± 5.45	5.71 ± 1.51	0.81 ± 0.03	0.71 ± 0.03	− 55.70 ± 14.57
Uri	101.28 ± 2.78	37.78 ± 4.98	108.14 ± 2.50	4.88 ± 1.05	0.92 ± 0.02	0.79 ± 0.03	− 35.48 ± 18.10
Younbeak	101.22 ± 0.61	51.84 ± 5.86	95.65 ± 2.31	6.03 ± 2.05	0.78 ± 0.07	0.69 ± 0.01	− 48.57 ± 24.93
U.S.							
Tv8535	103.83 ± 1.35	38.65 ± 2.65	110.64 ± 2.65	5.16 ± 0.58	0.90 ± 0.01	0.77 ± 0.03	− 43.11 ± 3.11
Usg3612	103.73 ± 1.27	35.80 ± 3.42	111.23 ± 3.42	4.91 ± 1.58	0.93 ± 0.01	0.81 ± 0.05	− 38.03 ± 20.84
LSD ^b	1.66	9.96	6.21	1.79	0.06	0.03	22.54

^aValues are averages of two crop years and mean $\pm$ SD from triplicate determinations per year

^bLSD means least significant difference ($P = 0.05$), and difference between two means exceeding this value is significant

Usg3612 showed softer and tender texture of baked pancake than Tv8535, because Usg3612 had lower hardness and higher springiness and cohesiveness than Tv8535. Hojoong and Joongmo2012 showed softer texture of baked pancake (4.09 and 4.31 N, respectively) than other Korean wheats, which reduced amylose content could be influenced texture of baked pancake. Hojoong showed higher springiness and cohesiveness of baked pancake from Joongmo2012, Hojoong had lower springiness and similar cohesiveness compared to SRW wheats. Goso, Joa, Jokyung and Uri showed similar springiness and cohesiveness of baked pancake to SRW wheats. There was no significant difference in adhesiveness of baked pancake among Korean wheats and SRW wheats.

Springiness of baked pancake was positively correlated with cohesiveness of baked pancake ($r = 0.975$, $P < 0.001$) and pancake diameter ($r = 0.884$, $P < 0.001$). Hardness of baked pancake was correlated with amylose content ($r = 0.623$, $P < 0.05$, Fig. 1b), and breakdown and springiness of baked pancake were correlated with final viscosity and setback in pasting properties of flour. Springiness of baked pancake was under negative correlation with protein content ($r = -0.580$, $P < 0.05$), SDS sedimentation volume ($r = -0.563$, $P < 0.05$), and dry gluten content ($r = -0.594$, $P < 0.05$). Springiness and cohesiveness of baked pancake were also under negative correlation with mixing time in Mixograph ($r = -0.766$, $P < 0.01$ (Fig. 1b), $r = -0.716$, $P < 0.01$, respectively). Hardness of baked pancake was not correlated with protein content and related properties, although hardness of baked bread and cooked noodles were influenced by protein content and quality in Korean wheat cultivars (Kang et al. 2010b).

Principal component analysis was performed to verify multivariate correlations between flour characteristics, including physicochemical, and dough and pasting properties of flour, and pancake quality attributes (Fig. 2). Principal components 1 and 2 explained 54.2% and 27.0% of total variation, respectively. Specific volume of pancake was positively correlated with amylose content and pasting properties of flour except for the peak viscosity. Diameter of pancake was positively correlated with peak viscosity of flour, and negatively correlated with protein and dry gluten content, SDS sedimentation volume, SucSRC and LASRC, which these parameters were positively correlated with pancake height. The parameters related to hardness of baked pancake were the same as those related to specific volume of batter. Other textures of baked pancake showed the same tendency as the parameters correlated with pancake diameter. Compared with two SRW wheats, most Korean wheat cultivars showed different diameter of pancake and texture of cooked pancake, except for the hardness. In Korean wheat, Hojoong and Joongmo2012 showed

different characteristics in those parameters. Joa and Uri, two Korean wheat cultivars showed similar characteristics to Tv8535 in those pancake quality attributes. Reduced amylose content, such as waxy and partial waxy wheats, generally increased in water absorption for dough or sheet of making bread or noodles and reduced hardness of baked bread and cooked noodles (Kang et al. 2012; Baik et al. 2003). Therefore, amylose content and pasting properties could affect batter flow and texture of baked pancake, as protein content and related properties affect pancake making processing and texture of baked pancake.

Multiple regression analyses were conducted for pancake diameter and texture of baked pancake with physicochemical properties of flour as independent variables to predict parameters for pancake quality attributes (Table 4). Pancake diameter can be predicted from protein content, WSRC and mixing time of Mixograph ($R^2 = 0.727$), indicating that protein quantity and quality were the major factor determining pancake diameter. Hardness of baked pancake can be predicted from amylose content and breakdown of flour ($R^2 = 0.387$), indicating that amylose content and pasting properties were the major factor determining hardness of baked pancake. However, springiness and cohesiveness of baked pancake were mainly influenced by protein content and mixing time of Mixograph. Springiness of baked pancake can be predicted from protein content and mixing time of Mixograph ($R^2 = 0.577$), LASRC and SDS sedimentation volume together predicted cohesiveness of baked pancake ($R^2 = 0.882$). Regression models for specific volume of pancake and adhesiveness of baked pancake could not found in this study. These results indicate that protein content and related parameters, WSRC and LASRC, are the most influential predictable parameters of pancake diameter and elasticity of baked pancake. Protein quality, including Mixograph mixing time and SDS sedimentation volume, also can affect pancake diameter and elasticity of baked pancake. Softness of baked pancake was influenced by amylose content in this study. Further study could be required to elucidate the relationship between amylose content and texture of baked pancake using wheat flours with various amylose contents.

Korean wheat cultivars show higher protein content compared to SRW wheats. Hard wheat type of Korean wheat cultivars, carrying *Pina-D1b* or *Pinb-D1b* allele, showed smaller lower viscosity of batter, diameter of pancake, and harder texture of cooked pancake compared to pancake made from SRW wheats. Korean wheats with soft wheat texture, carrying *Pina-D1b* and *Pinb-D1b* alleles and low protein content were suitable for making pancake, comparable to SRW wheats. Partial waxy wheats showed softer texture of cooked pancake than others without any deleterious effect on the viscosity of batter and diameter of

Fig. 2 Principal component analysis for pancake quality attributes of Korean wheat cultivars. Abbreviations: WSRC, water solvent retention capacity (SRC); SucSRC, sucrose SRC; LASRC, lactic acid SRC; SCSRC, sodium carbonate SRC; SDSS, SDS sedimentation volume; MABS, water absorption of Mixograph; MTIME, mixing time of Mixograph; MTOL, mixing tolerance of Mixograph. Bold characters indicate quality attributes of pancake

Table 4 Regression equations of Korean wheat characteristics for prediction of pancake quality attribute

Quality attribute of pancake	Equation ^a	R ²	Prob > F
Diameter of pancake (D)	$D = -0.1146 \times \text{pro} - 0.5406 \times \text{wsrc} - 3.2977 \times \text{mtime} + 142.4716$	0.727	< 0.01
Hardness of baked pancake (HD)	$HD = 0.1111 \times \text{amy} - 0.0138 \times \text{brd} + 3.5470$	0.387	< 0.05
Springiness of baked pancake (SP)	$SP = -0.0068 \times \text{pro} - 0.0355 \times \text{mtime} + 0.9981$	0.577	< 0.01
Cohesiveness of baked pancake (CO)	$CO = -0.0215 \times \text{pro} - 0.0032 \times \text{lasrc} - 0.0517 \times \text{mtime} + 0.008 \times \text{sdss} + 1.1889$	0.882	< 0.001

^apro protein content, wsrc solvent retention capacity conducted with distilled water, mtime mixing time of Mixograph, amy amylose content, brd breakdown of flour, lasrc solvent retention capacity conducted with 5% lactic acid, sdss SDS sedimentation volume

pancake. Pancake quality could be predicted by protein content and quality parameters, and pasting properties using PCA and regression model. It would be considered to use these traits as the selection criteria in wheat breeding programs for improving pancake quality.

Acknowledgements This work was carried out with the support of “Cooperative Research Program for Agriculture Science & Technology Development (Project title: Establishment of quality criteria for high uniformity in end-use of Korean wheat cultivars, Project No. PJ011009), Rural Development Administration, Republic of Korea.

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