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End-Use Properties of Korean Waxy Wheat Lines

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ABSTRACT ; End-use properties of six Korean waxy wheat lines and their parental plants were evaluated in this study. Korean waxy wheat lines showed unsuitable characteristics for end products, such as sticky crumb of bread, sticky cooked wet and dry noodles and small cookie diameter. Korean waxy wheat lines produced lower loaf volume and less desirable crumb grain structure of bread, and lower chewiness of cooked wet and dry noodles than their parental plants even though Korean waxy wheats were much higher in protein content and SDS-sedimentation volume than their parental plants. We observed adverse effects of high flour protein content in Korean waxy wheat lines, such as smaller cookie diameter and harder snapping force than those produced from their parental plants.

Keywords : waxy wheat, end-use properties, bread, noodle, cookie

Granule-bound starch synthase (GBSS; EC 2.4.1.21), which is known as the waxy (Wx) protein, is responsible for the synthesis of amylose in wheat (Yamamori et. al., 1994). Waxy wheat lines, which are free of amylose, have been produced by crossing Kanto107 (null in *Wx-A1* and *Wx-B1)* as the pollen parent and using BaiHuo (null in *Wx-D1)* as the seed parent, and selecting F_2 progenies which lack the three GBSS isoforms (Nakamura *et al.*, 1995; Yamamori *et al.*, 1995). Waxy wheat lines were also produced by treating seeds of the double null genotypes with the mutagen, ethyl methane sulphonate (Oda *et al.*, 1992). Waxy wheat, which lacks of all three GBSS, produces amylose-free starch.

Flour and starch of waxy wheat lines could have some unique characteristics compared with non-waxy flours and starch. Yasui *et al.* (1996) reported that the apparent amylose content (1.2-2.0%) of waxy wheat was much lower (26.0-28.4%) than that of their non-waxy parents. They also reported that waxy wheat lines were lower in lipids content compared to their non-waxy parents, but that the amylopectin of waxy wheat lines was structurally identical to that of the parents. Waxy wheat lines had lower amylose content and higher peak viscosity than those of other wheat flours (Kiribuchi-Otobe *et al.*, 1997). Fujita *et al.* (1998) reported that no difference was found in the mean granule diameter of each of the waxy wheat sample when compared to reference non-waxy wheat. Yasui *et al.* (1999) reported that waxy wheat lines showed lower starch and higher β-glucan content than non-waxy parental plants. They also reported that waxy wheat lines had higher swelling power than their parental plants. No difference was found in protein content between waxy wheat lines and their parental plants (Yasui *et al.*, 1999).

In Korea, waxy wheat lines have been developed with genetic recombination through crosses between partial waxy wheat lines, Kanto107, BaiHuo and Korean wheat cultivars. Korean waxy wheat also had unique characteristics of flour and starch. Korean waxy wheat lines have lower amylose content (3.20%), higher starch swelling power (25.15%), lower starch and flour pasting temperature (61.37°C and 65.85°C), and higher starch pasting peak viscosity and breakdown (246.60 RVU and 161.50 RVU) than those of their parental plants. In addition to high swelling and pasting properties, Korean waxy wheat lines had higher protein content and SDS-sedimentation volume than those of their parental plants.

Food producers, wheat breeders and numerous researchers have recently focused on the availability of waxy wheat lines for improvement of end-use quality of wheat, since waxy wheat could have potential commercial uses. However, there is little information about the end-use quality of waxy wheats. In this study, physicochemical properties of end-use products such as bread, Korean style noodles and cookies, made of Korean waxy wheat lines were examined to evaluate end-use properties and to predict possible utilization of waxy wheats.

MATERIALS AND METHODS

Korean waxy wheat lines

Six Korean waxy wheat lines, SW97108-B-WV-18-B

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(Urimil//Kanto107/BaiHuo), SW97129-B-WV-23-B (Alcahnmil//Kanto107/BaiHuo), SW97132-B-WV-17-B (Alchanmil//Kanto107/BaiHuo), SW97110-B-WV-9-B (Geurumil//Kanto107/BaiHuo), SW97111-B-WV-3-B (Geurumil//Kanto-107/BaiHuo) and SW97112-B-WV-21-B (Geurumil//Kanto107/BaiHuo), were obtained from the National Crop Experiment Station, Suwon, Korea. Waxy lines and their parental cultivars and lines, Kanto 107, BaiHuo, Alchanmil, Geurumil, and Urimil, were grown in Suwon (Upland Crop Experimental Farm of National Crop Experimental Station) in 1998. Two standard wheat flours, commercial flours for Japanese udon and hard red spring wheat flour for baking, were obtained from Western Wheat Quality Laboratory (Washington State University, Pullman, U.S.A.).

Analytical methods

Wheat was milled to about 60% extraction on a Bühler experimental mill. Protein content (N × 5.7) was determined by boric acid modification of the Micro-Kjeldahal method. Ash content was determined by AACC approved methods 08-01 (AACC, 1983). Amylose content was determined according to the procedure of Morrison and Bernard (1983) with a primary starch. The primary starch was prepared by the procedure of South and Morrison (1990). SDS sedimentation test was performed according to the procedure of Axford *et al* (1979). Water-washed prime starch of Korean winter wheat cultivars and Korean commercial flours was isolated by AACC approved methods 38-10 (AACC, 1983). Swelling power of starch was measured following the procedure described by Crosbie (1991). Peak viscosity of starch was measured by RVA-3 using 3.0 g of starch suspended in 25.0 ml of water. The temperature profile of RVA was followed according to the procedure described by Battey *et al.* (1997).

Bread baking

The bread baking formula and procedures were followed according to the straight-dough methods described by Finney (1984) and AACC approved methods 10-10A (AACC 1983). Immediately after the bread was removed from the oven, the loaf volume was measured by rapeseed displacement and the bread was weighed. After cooling for two hours at room temperature, the bread was mechanically sliced to about 12.50 mm thick and stored in a plastic bag for 24 hours for measuring crumb firmness and structure. Crumb grain score was evaluated on a six-point scale of 0 to 5, in which 0 and 5 indicate unsatisfactory and outstanding crumb grain, respectively. Crumb firmness of bread was measured with a Texture Analyser (TA-XT2*i*, Version 1.17, Stable Micro Systems, England) according to the procedures described by Baker *et al.* (1988).

Noodle making and texture of cooked noodles

Korean style noodles were prepared according to the method described by Toyokawa *et al.* (1989). Three hundred grams of flour (13.5% moisture basis) were mixed to 34% absorption with a 6% sodium chloride solution in a KitchenAid mixer (Hobart Mfg. Co., Ohio, USA) attached with a flat beater for 2 min at slow speed, and then for 4 min at medium speed. The dough was passed through the rolls of a noodle machine (Hyundai Menki Mfg. Co., Seoul, Korea) at a 3.00-mm gap. The dough sheet was then folded and put through the sheeting roll twice. After 2 hr resting time, the noodle sheets were put through the sheeting rolls five times at progressively smaller gap settings of 2.50, 2.00, 1.50, 1.25 and 1.00 mm, respectively. The sheet was cut through no. 28 cutting rolls into strips approximately 30 cm in length with a 1.00 × 1.10 mm cross section. For the test of wet cooked noodles, one half part of the noodle sheets were kept in plastic bags and stored at 4°C until cooked. For the dry noodles, the other half parts of sheets were dried for 2 days at room temperature.

Wet and dry Korean style noodles (30 g) were cooked in boiling distilled water (1 L) and rinsed with cold water for 1 min. Cooking time of noodles was the time required for the white core in the noodle strand to disappear. Cooking time was determined by squeezing noodle strands between a pair of glass plates. The measurement of TPA of cooked noodles was based on the procedures described by Baik *et al.* (1994) with a Texture Analyser. From force-time curves of the TPA, the hardness, springiness, cohesiveness, gumminess, chewiness and adhesiveness were determined according to the description of Baik *et al.* (1994).

Cookie baking

Cookie formula and baking procedures were followed as described by Finney *et al.* (1950) in micro method III. Baked cookies were rested for 2 hr at room temperature and measured for the cookie diameter and thickness. The top grain of the cookie was evaluated on a six-point scale of 1 to 6, in which 1 and 6 represent unsatisfactory and outstanding crumb grain, respectively. For cookie hardness, a three-point break was performed as described by Gaines *et al.* (1992) using a Texture Analyser. Maximum peak force was measured when the cookies were snapped by the HDP/VB probe (Blade set) on a separated bottom support. Cookie hardness was calculated according to the equation described by Gaines *et al.* (1992).

Statistical analysis

Data analysis were performed by the SAS Package (SAS, 1995) using analysis of variance (ANOVA), and Fishers least significant difference procedure (LSD).

RESULTS AND DISCUSSION

Bread baking properties of korean waxy wheats

Baking properties such as water absorption, dough mixing time, dough proof height, bread loaf volume, crumb grain score and crumb firmness of Korean waxy wheat lines, SW97129-B-WV-23-B, SW97132-B-WV-17-B and SW97112-B-WV-21-B and their parental plants are summarized in Table 1. Water absorption and mixing time were determined based on appearance and handling properties of dough during mixing by experienced personnel through trial and error. Water absorption of Korean waxy wheat lines ranged from 68.4% for SW97129-B-WV-23-B and SW97112-B-WV-21-B to 68.7% for SW97132-B-WV-17-B. Dough mixing time of Korean waxy wheat lines ranged from 510 sec for SW97112-B-WV-21-B to 765 sec for SW97132-B-WV-17-B. Dough proof height of waxy wheat lines ranged from 11.0 cm for SW97129-B-WV-23-B and SW97132-B-WV-17-B to 11.5 cm for SW97112-B-WV-21-B. Bread loaf volume of Korean waxy wheat lines ranged from 770 cc for SW97132-B-WV-17-B to 800 cc for SW97112-B-WV-21-B. Crumb firmness of Korean waxy wheat lines ranged from 0.74 N for SW97129-B-WV-23-B to 0.88 N for SW97112-B-WV-21-B.

Korean waxy wheat lines showed unsatisfactory crumb grains such as relatively large and non-uniform crumb structure (Fig. 1). Waxy lines had higher baking water absorption and mixing time than non-waxy wheat flours. Korean waxy wheat lines showed lower bread loaf volume (781 cc) and crumb firmness (0.80 N) than those of their parental plants. Non-waxy parental plants showed unsuitable bread making properties with lower bread loaf volume and poor crumb grain structure, due to low protein content and quality compared with hard red spring wheats. Among the parental plants, however, BaiHuo showed higher loaf volume (941 cc) and lower crumb firmness (1.65 N) than others, probably due to high protein content. Even though waxy wheat had higher protein content and SDS-sedimentation volume, they produced smaller bread with poor crumb grain than their parental plants. Korean waxy wheat lines showed lower crumb firmness than their parental plants. The bread crumb of waxy wheat lines was stickier than that of their parental plants.

Bread loaf volume generally increases with increasing protein content, and is also influenced by both the content and quality of protein. Good bread loaf volume has invariably been accompanied by more satisfactory crumb grain

Table 1. Characteristics of flours and bread baked from flours of Korean waxy wheat lines and their parental plants.

Cultivar/Line	Protein (%)	Amylose (%)	SDSS† (ml)	Starch: Swelling Power (%)	Starch: Peak Viscosity (RVU)	Dough: Water Absorption (%)	Dough: Mixing Time (Sec)	Dough: Proof Height (Cm)	Bread Loaf Volume (cc)	Crumb: Grain Score	Crumb: Firmness (N)
SW97108-B-WV-18-B	13.45	3.39	81.67	26.02	-	-	-	-	-	-	-
SW97129-B-WV-23-B	12.44	2.24	78.67	24.55	180.50	68.41	720	11.0	773	-	0.74
SW97132-B-WV-17-B	12.96	3.61	87.00	24.40	176.00	68.72	765	11.0	770	-	0.79
SW97110-B-WV-9-B	12.10	4.20	75.67	24.52	315.50	-	-	-	-	-	-
SW97111-B-WV-3-B	12.99	2.32	81.00	25.69	263.50	-	-	-	-	-	-
SW97112-B-WV-21-B	12.87	3.42	78.00	25.73	297.50	68.41	510	11.5	800	-	0.88
Kanto107	10.72	19.39	73.33	14.25	240.50	58.46	180	10.5	860	2.33	2.61
BaiHuo	12.56	30.62	68.00	15.36	217.50	59.00	242	11.3	941	2.67	1.65
Urimil	8.62	28.71	62.67	11.42	197.50	57.33	190	10.3	795	1.33	4.50
Geurumil	10.42	31.50	62.67	12.60	188.50	58.51	232	11.0	883	2.00	2.19
Alchanmil	10.34	29.80	88.00	13.35	215.50	58.69	242	11.0	858	2.00	3.69
LSD‡	0.31	1.21	0.01	0.41	9.81	0.00	10.42	0.23	33.14	0.65	0.13
COM§	10.17	26.49	64.00	16.23	221.50	58.52	215	11.0	853	3.6	4.39
HRS	12.50	-	81.00	-	-	60.20	517	11.5	1073	5.00	1.31

†SDSS = SDS-sedimentation volume.
‡Least significant difference (P = 0.05). Differences between two means exceeding this value are significant.
§COM = commercial flours for Japanese udon; HRS = hard red spring wheat standard flours for baking.

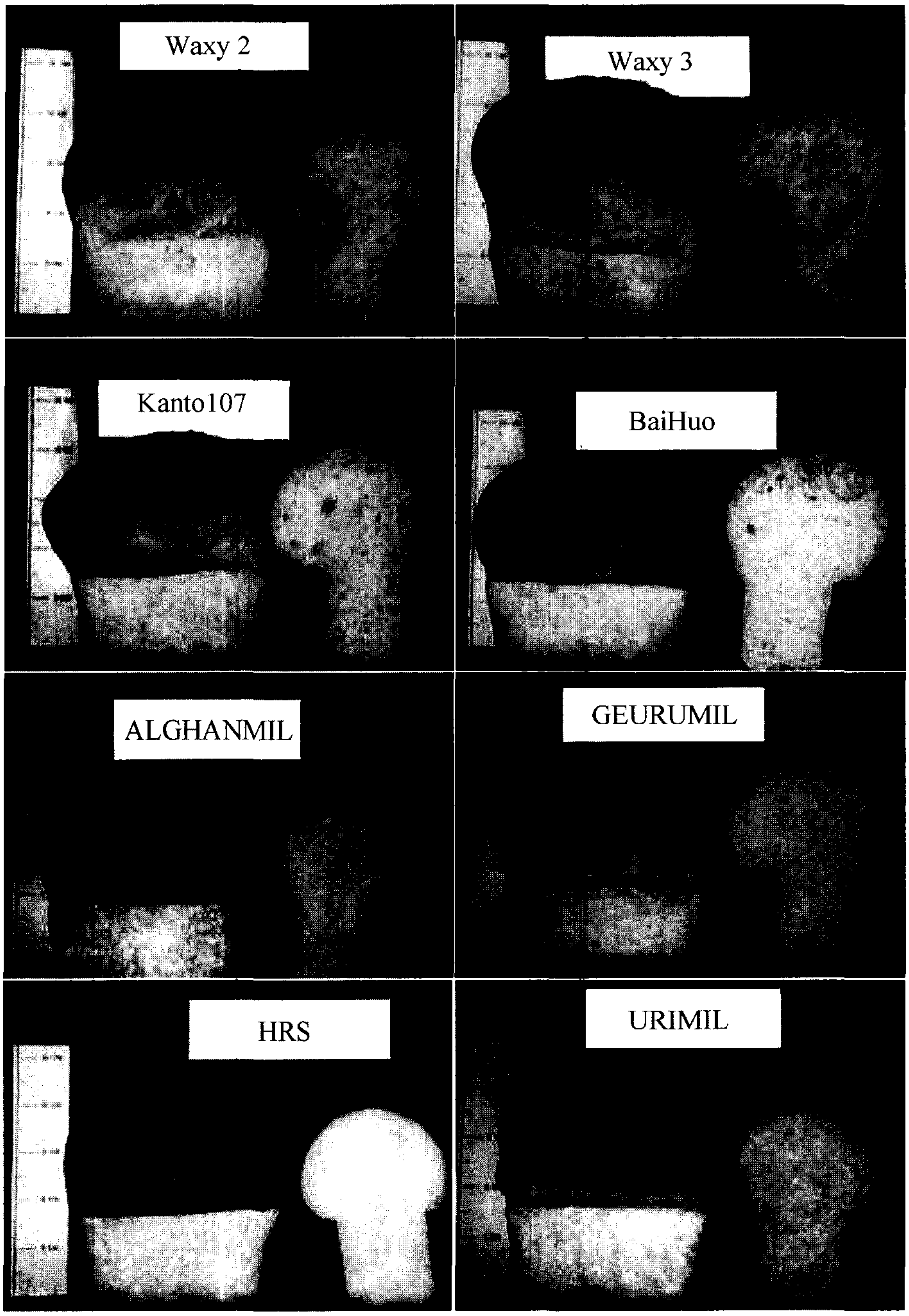

Fig. 1. The comparison of bread crumb grain of Korean waxy wheat lines and their parental lines. Waxy 2; SW97129-B-WV-23-B, Waxy3; SW97132-B-WV-17-B. HRS, Hard Red Spring (Wheat Standard Flours for Baking).

and somewhat whiter or less creamy crumb color than poor loaf volume of bread (Finney *et al.*, 1987). Crumb firmness has been shown to be influenced by interactions among swollen starch granules, and partial solubilization of starch molecules and protein during baking (Maleki *et al.*, 1980). Martin *et al.* (1991) proposed that, during baking, the weaker interactions between starch and gluten result in reduced bread firming because interactions occurred between gluten and starch, in which gluten was the continuous phase and remnants of starch granules were the discontinuous phase. Flour and starch of waxy wheat lines could have some unique characteristics compared with non-waxy flours and starch. Waxy wheat flours contain lower amylose, lipids and starch content and higher β-glucan content compared to their non-waxy parents, albeit they have structurally identical structure in amylopectin compared to non-waxy wheat flours (Yasui *et al.* 1996; 1999). Waxy wheat starch shows higher peak viscosity than non-waxy wheat starch (Kiribuchi-Otobe *et al.*, 1997). Waxy starch swells greatly and would disintegrate at lower temperature because α-amylase is still active, and amylopectin molecules would be hydrolyzed by active α-amylase in swelled and disintegrated waxy starch granules (Yasui *et al.*, 1999). Although flour characteristics of waxy wheats, such as lipids, starch and β-glucan content were not measured in this study, protein content and quality of waxy wheats, as well as interactions between protein and other components of flours should be considered for the improvement of bread baking quality of waxy wheats. Bread baking properties of Korean waxy wheat lines were very poor and further study of waxy flour properties should be considered for the utilization of waxy wheat lines.

Cooking time and texture of cooked noodles of korean waxy wheats

Cooking time and texture profile analysis (TPA) parameters of Korean style cooked wet and dry noodles made from Korean waxy wheat lines and their parental lines are summarized in Tables 2 and 3. Cooking times of wet and dry noodles made from waxy wheat lines were 150 sec and 300 sec, respectively, which are much shorter than cooking times of noodles produced from non-waxy parental wheats. Reduced cooking time could be related to the low pasting temperature of waxy wheat flours. Cooking times of wet noodles were similar in parental wheat flour, Kanto107, which had lower amylose content than other parental lines, and which exhibited shorter cooking time than other parental lines. Accordingly, waxy wheat lines could be suitable for production of noodles with short cooking time.

Cooked wet noodles (Table 2) SW97129-B-WV-23-B (36.00 N) and SW97111-B-WV-3-B (35.26 N) showed higher hardness than other waxy wheats because of their high protein content and SDS-sedimentation volume. SW97111-B-WV-3-B (17.94 N) and SW97111-B-WV-17-B (17.68 N) showed higher gumminess than other waxy wheat lines and their parental plants, but there were no significant differences within waxy wheat lines in adhesiveness, cohesiveness and chewiness. Geurumil and Alchanmil showed higher hardness, gumminess and chewiness than other parental lines and waxy wheat lines, but there were no significant differences between waxy wheat lines and their parental lines in adhesiveness, cohesiveness and springiness. There were no significant differences in texture parameters of cooked dry noodles made from waxy wheat lines, and these lines showed lower TPA parameters than their parental plants.

Baik *et al* (1994) proposed that high starch swelling power and peak viscosity and breakdown of starch were prerequisites in the production of satisfactory oriental noodles. They also reported that high protein content and protein quality parameters were highly correlated with high hardness and chewiness of cooked noodles. Lee *et al* (1987) proposed that flours of protein content of 8-11% and high peak viscosity are desirable to give the best quality Korean dried noodles. In Korean style noodles, protein content and quality were

Table 2. Cooking time and texture profile analysis parameters of cooked wet noodles prepared from waxy wheat lines and their parental plants.

Cultivar/Line	Cooking Time (Sec)	TPA Parameters					
		HD† (N)	AD (N)	CO (Ratio)	SP (mm)	GU (N)	CH (N*mm)
SW97108-B-WV-18-B	150	30.76	-0.54	0.48	0.83	14.75	12.19
SW97129-B-WV-23-B	150	29.95	-0.60	0.48	0.88	14.49	12.69
SW97132-B-WV-17-B	150	36.00	-0.53	0.49	0.87	17.68	15.40
SW97110-B-WV-9-B	150	32.13	-0.46	0.49	0.88	15.89	13.97
SW97111-B-WV-3-B	150	35.26	-0.55	0.51	0.88	17.94	15.83
SW97112-B-WV-21-B	150	32.71	-0.45	0.52	0.91	16.88	15.28
Kanto107	210	35.37	-0.59	0.51	0.85	18.08	15.41
BaiHuo	210	39.77	-0.62	0.49	0.88	19.39	17.08
Urimil	210	35.29	-0.57	0.50	0.83	17.72	14.63
Geurumil	210	44.04	-0.57	0.53	0.86	23.31	20.08
Alchanmil	210	43.54	-0.50	0.52	0.85	22.54	19.21
LSD‡	0.00	1.74	0.06	0.03	0.02	1.36	1.20

†HD=Hardness, AD=Adhesive Force, CO=Cohesiveness, SP=Springiness, GU=Gumminess, CH=Chewiness.
‡Least significant difference (P=0.05). Differences between two means exceeding this value are significant.

Table 3. Cooking time and texture profile analysis parameters of cooked dry noodles prepared from Korean waxy wheat lines and their parental plants.

Cultivar	Cooking Time (Sec)	TPA Parameters					
		HD† (N)	AD (N)	CO Ratio	SP (mm)	GU (N)	CH (N*mm)
SW97108-B-WV-18-B	300	22.82	-0.39	0.50	0.84	11.43	9.58
SW97129-B-WV-23-B	300	22.53	-0.46	0.49	0.87	10.97	9.56
SW97132-B-WV-17-B	300	24.26	-0.34	0.51	0.87	12.22	10.69
SW97110-B-WV-9-B	300	23.57	-0.40	0.52	0.85	12.20	10.40
SW97111-B-WV-3-B	300	24.94	-0.40	0.50	0.86	12.36	10.69
SW97112-B-WV-21-B	300	22.75	-0.44	0.48	0.83	11.01	9.13
Kanto107	360	32.12	-0.37	0.55	0.91	17.70	16.15
BaiHuo	420	32.69	-0.29	0.57	0.91	18.76	17.07
Urimil	420	36.80	-0.53	0.51	0.84	18.76	15.68
Geurumil	420	38.60	-0.40	0.50	0.88	19.14	16.75
Alchanmil	420	38.15	-0.51	0.51	0.87	19.36	16.89
LSD‡	0.00	0.97	1.20	0.12	0.03	0.03	0.85

†HD=Hardness, AD=Adhesive Force, CO=Cohesiveness, SP=Springiness, GU=Gumminess, CH=Chewiness.
‡Least significant difference (P=0.05). Differences between two means exceeding this value are significant.

highly correlated with chewiness of cooked noodles (*data not shown*). Chewiness of cooked wet and dry noodles of commercial flours for Japanese udon were 16.50 N and 16.98 N, respectively (Table 2 and 3). Among Korean waxy wheat lines, SW97110-B-WV-9-B, SW97111-B-WV-3-B and SW97112-B-WV-21-B had higher starch swelling power and peak viscosity than commercial flours for Japanese udon (Table 1). Despite their high protein content, waxy wheat lines showed lower chewiness of cooked wet and dry noodles (14.2 N and 10.01 N) than their parental plants. Waxy wheat flours contain little amylose in starch and have higher water holding capacity and moisture content of raw noodles, which could be responsible for low chewiness of cooked wet and dry noodles, as well as sticky feel of cooked noodles made from waxy wheat flours. Kanto107 showed similar protein content, starch swelling and peak viscosity to commercial flours for Japanese udon and produced noodles, comparable to those produced from commercial flours for Japanese udon. Since waxy wheat lines, of which starch is mostly composed of amylopectin, produce less desirable quality noodles, it will be crucial to find the proper amylose content, as well as protein content and quality for the improvement of the noodle quality and utilization of Korean waxy wheat lines.

Table 4. Cookie characteristics of Korean waxy wheat lines and their parental plants.

Cultivar/Line	Cookie Diameter (mm)	Cookie Thickness (mm)	D/T† (%)	Top Grain Score	Snapping Force (N)
SW97108-B-WV-18-B	76.61	9.79	7.64	2.00	55.64
SW97129-B-WV-23-B	76.43	9.94	7.65	2.00	45.74
SW97132-B-WV-17-B	76.75	10.20	7.54	2.00	57.59
SW97110-B-WV-9-B	79.42	9.82	8.04	2.00	46.90
SW97111-B-WV-3-B	77.58	9.68	8.26	2.33	42.57
SW97112-B-WV-21-B	78.85	9.46	8.37	2.00	42.71
Kanto107	85.88	8.12	10.63	4.00	34.31
BaiHuo	83.57	8.59	9.83	3.00	36.63
Urimil	90.65	7.82	11.59	6.00	32.03
Geurumil	81.35	8.89	9.42	4.33	36.96
Alchanmil	84.30	8.32	10.25	3.33	35.46
LSD‡	0.54	0.14	0.17	0.54	3.61

†D/T=Ratio of Thickness to Diameter of Cookie.
‡Least significant difference (P=0.05). Differences between two means exceeding this value are significant.

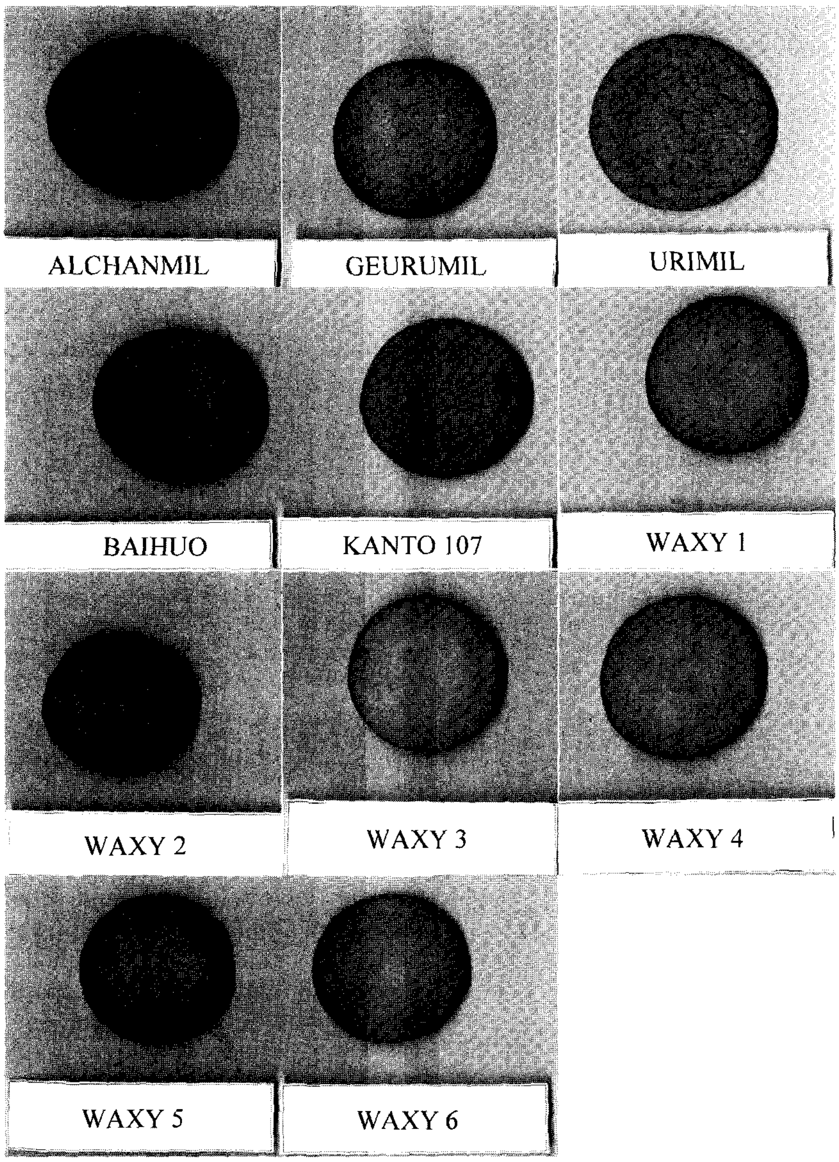

Fig. 2. Cookies baked from Korean waxy wheat lines and their parental plants. Waxy1; SW97108-B-WV-18-B, Waxy2; SW97129-B-WV-23-B, Waxy3; SW97132-B-WV-17-B, Waxy4; SW97110-B-WV-9-B, Waxy5; SW97111-B-WV-3-B, Waxy6; SW97112-B-WV-21-B.

Cookie baking properties of korean waxy wheats

Cookie baking properties, diameter, thickness, ratio of cookie diameter to cookie thickness, top grain score and snapping force of Korean waxy wheat lines and their parental lines are summarized in Table 4. Cookie diameter of Korean waxy wheat lines ranged from 76.43 mm in SW97129-B-WV-23-B to 79.42 mm in SW97110-B-WV-9-B. Cookie thickness of waxy wheat lines ranged from 9.46 mm for SW97112-B-WV-21-B to 10.20 mm for SW97132-B-WV-17-B. Ratio of cookie diameter to cookie thickness of waxy wheat lines ranged from 7.54 % for SW97132-B-WV-17-B to 8.37% for SW97112-B-WV-21-B. Top grain score of all waxy wheat lines, except for SW97111-B-WV-3-B, was 2.00. Snapping force of Korean waxy wheat lines ranged from 42.57 N for SW97112-B-WV-21-B to 57.59 N for SW97111-B-WV-3-B.

Fig. 2 shows that cookies made from Korean waxy wheat flours had smaller cookie diameter and poorer top grain than their parental lines. Urimil showed larger cookie diameter (90.65 mm) and lower snapping force (32.03 N) than others due to low protein content (Table 1). Korean waxy wheat lines showed smaller cookie diameter and higher snapping force than their parental plants. Among the parental plants, Kanto107 showed larger cookie diameter (85.88 mm) and lower snapping force (34.31 N).

Korean waxy wheat lines showed unsuitable cookie baking properties, with small cookie diameter, poor top grain score and hard snapping force, due to high protein content. Hoseney *et al* (1988) reported that protein content of flour gave negative effects on the cookie baking quality. High protein content of Korean waxy wheats led to high water absorption of flours and to high dough viscosity, which subsequently lowered the spread rate of cookie during baking.

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