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Effects of transglutminase on the quality of white salted noodles made from Korean wheat cultivars

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Abstract

The objectives of this study was to investigate the influences of increasing levels of transglutaminase (TG) on dough rheological properties and the characteristics of white salted noodles regarding two Korean wheat cultivars, cvs. Keumkang and Younbaek, and commercial wheat flour for noodle making (Com), and to evaluate quality of white salted noodles from 13 Korean wheat flours with the 0.4% TG treatment. In Keumkang, Younbaek and Com, wet gluten, mixing time and mixing tolerance increased as the addition of TG increased from 0.2 to 0.6%, compared to those of wheat flours with no TG treatment. No significant differences in SDS-sedimentation volume and water absorption for the mixograph of flours was found in the addition of TG. Lightness of the noodle dough sheet increased as the addition of TG increased, although water absorption, thickness of the noodle dough sheet and cooking loss did not change with increased TG treatments. White salted noodles with 0.4% of TG treatment showed greater elasticity and harder texture of cooked noodles than those of no TG treatment. There were no consistent differences in the texture of cooked noodles from between 0.4 and 0.6% TG treatment. In noodle characteristics with 0.4% TG treatment of 13 Korean wheat cultivars, developed after 2000, lightness of noodle dough sheet and hardness of cooked noodles with 0.4% TG treatment (81.50 and 3.80 N, respectively) were higher than that of no treatment of TG (80.83 and 3.51 N, respectively) at $P < 0.05$. No significant effects of TG treatment were found in other characteristics.

Introduction

Transglutaminase (TG: protein-glutamine γ-glutamyl transferase, EC 2.3.2.13) catalyzes the formation of nondisulfide covalent cross-linking between ε-amino group on peptide-bound glutaminyl residues and a β-carboxyamide group on protein-bound glutamine residues in the protein fractions (Motoki and Seguro, 1998; Kuarishi *et al*., 2001). TG may produce beneficial effects in the rheological and baking properties of the flour through the formation of large insoluble polymers in dough, which its effect is comparable to chemical oxidizing improvers (Motoki and Seguro, 1998; Kuarishi *et al.*, 2001). TG has been proved to be a potential enhancer of baking properties because a very small dosage can cause obvious alterations on dough properties compared to chemical oxidizing improvers (Tseng and Lai, 2002). TG has modified the viscoelasticity of wheat flour dough, which increased mixing time, mixing tolerance, and decreased water absorption, extensibility and stickiness (Gerrard *et al.*, 1998; Tseng and Lai, 2002; Basman *et al*., 2002; Bauer *et al*., 2003; Rosell *et al*., 2003; Seo *et al*., 2003; Bonet *et al.*, 2006; Caballero *et al.*, 2007). TG treatment in bread doughs produced a significant improvement of bread volume, and texture and grain of crumb (Gerrard *et al.*, 1998; Gerrard *et al.*, 2000; Basman *et al*., 2002; Bauer *et al.*, 2003; Caballero *et al.*, 2007). In addition to the effect regarding yeast-raised bread products, TG treatment also prevented the depression of sponge cake after baking and improved loaf volume of puff pastry and croissants (Gerrard et al., 2000).

TG is utilized widely in the production of noodles and pasta in Japan because TG treatment improves texture in noodles/pasta manufacturing (Kuarishi *et al*., 2001). TG treatment was beneficial to avoid breaking the dried noodles during packing and shipping (Shiau and Chang, 2013). Cooking loss was reduced by TG treatment because starches in noodle dough are better held in the gluten network and reduced solid loss into the boiling water, which the surface of noodles is less sticky and reducing bulkiness, and then the cooking yield of noodles also is improved (Kuarishi *et al*., 2001). TG treatment of noodles including instant noodles and pasta prevented deterioration of texture after cooking and increased hardness and elasticity and decreased stickiness of cooked noodles (Sakamoto *et al*., 1996; Gan *et al*., 2009; Choy *et al.*, 2010; Shiau and Chang, 2013).

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It is expected that the cross-linkings introduced by TG are heat-stable and reduced leaching of starchy materials onto the noodles (Wu and Corke, 2005).

White salted noodles are popular in Korea and quality improvement of wheat for making noodles with desirable processing quality and textural properties of cooked noodles is receiving increased attention by wheat breeders in Korea (Park *et al.*, 2006). Enhancement of noodle making processing and the texture of cooked noodles from Korean wheat have been very important in increasing consumption of Korean wheat products. However, most Korean wheat cultivars and advanced lines have showed inferior noodle color to commercial noodle wheat flours as well as lower loaf volume and harder crumb firmness than commercial bread flours in spite of the similar protein content (Park *et al.*, 2006). Dough stability and texture of cooked noodles as well as sensory characteristics could be improved by the addition of TG to Korean wheat cultivar, cv. Geuru (Seo *et al*., 2003). The benefit treated with TG in noodles made from Korean wheat flours could be preferable to both manufacturers and consumers. Therefore, this study was conducted to investigate the influences of increasing levels of TG on dough rheological properties and the characteristics of white salted noodles of two Korean wheat flours compared to commercial noodle flour, and to evaluate the quality of white salted noodles from 13 Korean wheat cultivars, which developed after 2000, through the optimum TG treatment in order to provide useful information for improving wheat quality for making noodles in wheat breeding programs and expanding the utilization of Korean wheat flours.

Materials and Methods

Materials

Two Korean wheat cultivars, cvs. Keumkang and Younbaek, were obtained from the National Institute of Crop Science (Suwon, Korea). Commercial flour for making white salted noodles was kindly provided by Samyang Milmax (Chenan, Korea). These wheat flours were used to determine the effect of TG on dough rheological properties and the quality of white salted noodles through the various TG treatments. ACTIVA® STG-M which is designed for the improvement of pasta and noodle texture with an activity of 28 U/g, according to the manufacture's data, was obtained from Ajinomoto Co., Inc. (Tokyo, Japan). TG was added at three levels (0.2, 0.4 and 0.6%) based on the flour weight basis (14% mb) and wheat flour without TG was used for the control.

Thirteen Korean wheat cultivars were used to evaluate dough rheological properties and the quality of white salted noodles with an optimum amount of TG treatment (4 g/Kg wheat flour, 14% mb). Grains of these cultivars were obtained from the National Institute of Crop Science (Suwon, Korea). Two kilograms of wheat were conditioned overnight to reach 15% moisture content and then milled with a feed rate of 100 g/min and with roll settings of 8 and 5 in break rolls and 4 and 2 in reduction rolls. Wheat was milled to about 60% extraction on a Bühler experimental mill according to the AACCI Approved Method 26-31.01 (AACC I, 2010).

Analytical methods

Moisture, protein and ash contents of wheat flour were determined according to AACCI Approved Methods 46-30.01, 39-11.01 and 08-01.01, respectively (AACC I, 2010). Amylose content of prime starch was determined by the iodometric method described by Morrison and Laignelet (1983). Damaged starch content was determined by the procedure described by Gibson *et al.* (1992), using an enzymatic assay kit (MegaZyme Pty., Australia). Lightness of flour was measured by Minolta CM-2002 (Minolta Camera Co., Japan) with an 11 mm measurement aperture. Particle size distribution of flour was measured by the multi-wavelength laser particle size analyzer LS13320MW (Beckman Coulter, Inc. USA). 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 gluten content was evaluated with a Glutomatic keeping the volume of Glutomatic wash solution at 4.8 mL for all samples, according to the AACCI Approved Method 38-12.02 (Morrison and Laignelet, 1983). Water absorption and mixing properties of flours were determined using a 10 g mixograph (National Mfg. Co., Lincoln, NE), according to AACCI Approved Method 54-40.02 (AACC I, 2010).

Preparation of white salted noodles

White salted noodles were prepared with optimum water absorption of noodle dough according to the procedure of Park *et al.* (2003). Commercial wheat flour for noodle making, which requires 34% absorption to produce uniform, smooth and nonsticky dough, was used as a reference for comparison to other flours during the determination of optimum water absorption for noodle making. Flour (100 g, 14% moisture basis) was mixed with a predetermined amount of sodium chloride solution in a pin mixer (National Mfg. Co., USA) for 4 min at a head speed of 86 rpm. The concentration of sodium chloride solution used for making noodles with different absorptions was adjusted to produce a 2.0% result in the noodle dough. Dough was passed through the rollers of a noodle machine (Ohtake Noodle Machine Mfg. Co., Japan) at 65 rpm with a 3 mm gap; dough was folded and pressed between the sheeting rollers. The folding and sheeting were repeated twice. The dough sheet was rested for 1 hr and then subjected to three additional presses at progressively decreasing gaps of 2.40, 1.85 and 1.30 mm. After the final pressing, the thickness of the dough sheet was immediately measured by a micrometer dial thickness gauge (Peacock Dial Thickness Gauge G, Ozaki Mfg. Co., Japan). A piece of noodle sheet was placed in plastic bags for determination of color. Lightness of the dough sheet was measured by Minolta CM-2002 (Minolta Camera Co., Japan) with an 11 mm measurement aperture. The rest of the dough sheet was cut with no. 12 cutting rollers into noodle strands of about 30 cm in length with a 0.3 x 0.2 cm cross section.

Cooking loss and textural properties of cooked noodles

Raw noodles (20 g) were cooked for 18 min in boiling distilled water (500 mL) and then rinsed with cold water. Two replicates of cooked noodles were evaluated by texture profile analysis (TPA) using a TA-XT2 Texture Analyzer (Stable Micro Systems, England) within 5 min after cooking. A set of five strands of cooked noodles was placed parallel on a flat metal plate and compressed crosswise twice to 70% of their original height using a 3.175 mm metal blade at a speed of 1.0 mm/sec. From force-time curves of the TPA, hardness, springiness and cohesiveness were determined according to the description of Park *et al.* (2003). TPA of cooked noodles was also determined after soaking in 70◦C water for 10 min to determine the changes of texture during serving of cooked noodles.

Cooking loss was determined by the modification of Wu and Corke (2005). Raw noodles (20 g) were cooked for 18 min in boiling water (200 mL) then rinsed with distilled water gently for 1 min then drained for 30 s. All the water (about 1000 mL) was placed in a tared beaker (W1, g) evaporated using a hot-plate to approximately 50 mL and then dried at 45◦C to constant weight (W2, g). The moisture content of the white salted noodles was determined (W3, g). The cooking loss was calculated as:

$$\text{Cooking loss (\%)} = [(W2 - W1) / (20 - W3)\ \text{kg kg}^{-1}] \times 100$$

Statistical analysis

All tests were run at least in triplicate in a completely randomized design. Statistical analysis of data was performed by SAS software (SAS Institute, Cary, NC) using Duncan's multiple range test. Differences were considered significant at $P < 0.05$.

Results and Discussion

Properties of wheat flour and dough

Four characteristics of two Korean wheat cultivars and commercial noodle flour are summarized in Table 1. Keumkang, a hard white winter wheat, is leading wheat cultivars in Korea and is generally used for yellow alkaline noodles, and Younbaek is suitable for making white salted noodles. Protein content of Keumkang was higher (12.84%) than that of Younbaek (9.93%) and commercial noodle flour (10.20%). Commercial noodle flour showed lower ash and amylose content (0.41 and 24.21%, respectively) and higher damaged starch content (6.59%) than Korean wheat cultivars (0.47%, > 26.69% and < 6.06%, respectively). Commercial noodle flour showed a higher lightness value (91.75) than Korean wheat cultivars (< 89.96). Commercial flours for making white salted noodles are null in the *Wx-B1* allele of granule bound starch synthase, which is probably responsible for the soft texture of cooked noodles, along with ≈10% protein content of wheat flour (Hou, 2001). Commercial noodle flours had higher damaged starch content than US wheat cultivars with similar protein content and quality (Park *et al.*, 2003).

SDS-sedimentation volume, wet gluten content and mixograph properties of wheat flour with different TG content are summarized in Table 2. SDS-sedimentation and wet gluten content of Keumkang (51.00 ml and 28.80%, respectively) were higher than those of Younbaek (30.33 ml and 20.65%, respectively) and commercial noodle flour (29.00 ml and 23.90%, respectively). Commercial noodle flour showed a higher wet gluten content than Younbaek, although these wheat flours had similar protein content and SDS-sedimentation volume. Commercial noodle flours could be mixtures of soft and hard wheat flours, because their composition of high molecular weight glutenin subunit (HMW-GS) contained both 2 + 12 and 5 + 10 at Glu-D1 loci, and 7 + 8 and 17 + 18 at Glu-B1, and their score of HMW-GS was higher than club and soft wheat cultivars (Park *et al.*, 2003). Wet gluten content slightly increased as the addition of TG increased, whereas there were

Table 1. Flour characteristics of two Korean wheat flours and commercial wheat flour for noodles

Flour	Ash (%)	Protein (%)	Amylose (%)	Damaged starch (%)	Lightness
Keumkang	0.47±0.00a[b]	12.84±0.21a	26.83±0.34a	5.34±0.20c	89.96±0.10b
Younbaek	0.47±0.00a	9.93±0.11b	26.69±0.45a	6.06±0.04b	88.98±0.01c
Com[a]	0.41±0.00b	10.20±0.02b	24.21±0.27b	6.59±0.08a	91.75±0.05a

[a]Com = commercial wheat flours for making white salted noodles.
[b]Values followed by the same letters are not significantly different at P < 0.05.

Table 2. Effect of transglutaminase on SDS-sedimentation volume, wet gluten content and mixograph properties from two Korean wheat flours and commercial wheat flour for noodles

Flour	Transglutaminase[b] (%)	SDS sedimentation (ml)	Wet gluten (%)	Mixograph		
				Water absorption (%)	Mixing time (min)	Mixing tolerance (mm)
Keumkang	0.0	51.00±1.00a[c]	28.80±0.20c	63.17±0.29a	4.03±0.06b	19.33±1.15bc
	0.2	51.00±1.00a	29.30±0.10b	63.50±0.29a	4.07±0.12b	20.00±1.73b
	0.4	51.00±1.00a	29.75±0.25ab	63.83±0.50a	4.13±0.06b	19.67±1.53b
	0.6	50.33±0.58a	29.80±0.50a	63.83±0.29a	4.67±0.15a	22.00±1.00a
Younbaek	0.0	30.33±0.58b	20.65±0.05g	59.50±0.50b	3.57±0.06ef	20.33±0.58ab
	0.2	30.00±1.00b	21.30±0.10f	60.00±0.00b	3.67±0.06de	20.00±1.00b
	0.4	29.67±0.76b	21.25±0.25f	59.83±0.29b	3.73±0.06cd	19.67±0.58b
	0.6	29.67±1.15b	21.20±0.30f	59.83±0.29b	3.73±0.12cd	20.00±1.00b
Com[a]	0.0	29.00±0.00b	23.90±0.00e	59.50±0.50b	3.43±0.12fg	17.33±0.58d
	0.2	29.17±0.29b	24.45±0.58e	59.67±0.58b	3.40±0.00g	17.67±1.15cd
	0.4	29.50±0.50b	24.75±0.05d	59.83±0.76b	3.40±0.17g	17.00±1.00c
	0.6	29.67±0.58b	24.75±0.05d	60.00±1.00b	3.83±0.06c	19.33±0.58bc

[a]Com = commercial wheat flours for making white salted noodles.
[b]Transglutaminase (28U/g) addition was 2, 4, 6g/kg in wheat flour, respectively.
[c]Values followed by the same letters are not significantly different at P < 0.05.

no consistent differences in SDS-sedimentation volume among flours with different amounts of TG in wheat flour. TG could be attributed the compounded bonded to gluten during wet extraction of gluten from wheat flour, which is in agreement with the previous reports (Rosell *et al*., 2003; Bonet *et al*., 2006). The amount of wet gluten increased with the addition 1% of TG (100 Unit/g), while higher levels (1.5% and 2.0%) had decreased wet gluten content (Rosell *et al*., 2003). Gluten index values after the addition of TG also increased in previous results (Rosell *et al*., 2003; Bonet *et al*., 2006), but the gluten index did not evaluated in this study.

Water absorption and mixing time of the mixograph of Keumkang (63.17% and 4.03 min, respectively) was higher than those of Younbaek and commercial noodle flour (59.50% and < 3.57 min, respectively). The mixing tolerance of commercial noodle flour (17.33 mm) was lower than that of Keumkang (19.33 mm) and Younbaek (20.33 mm). In the mixograph properties of wheat flours with TG treatments, the addition of TG did not influence on the water absorption of the mixograph. Keumkang with the addition 0.6% of TG showed a longer mixing time and mixing tolerance of the mixograph (4.67 min and 22.00 mm, respectively) compared to the addition of lower levels (< 4.13 m in and < 20.00 mm, respectively). Mixing time of the mixograph of commercial noodle flour with the addition 0.6% of TG (3.83 min) was higher than that of other TG treatments (3.40 min). However, mixing time of the mixograph was not influenced by the addition of TG in Younbaek and the addition of TG did not affect the mixing tolerance of the mixograph of Younbaek and commercial noodle flour.

Gerrad *et al.* (1998) reported that the structural change of gluten due to the TG cross-linkage increased water holding capacity and TG had a profound influence on the decrease of water absorption for dough. The effects of TG treatment on the rheological properties of dough were different depending on dose and cultivar characteristics (Basman *et al.*, 2002; Bauer *et al*., 2003; Larre´ *et al.*, 2000; Autio *et al*., 2005). Kho and Ng (2008) reported that the addition of TG (2000 ppm with 0.1 U/mg of activity) did not obviously affect the mixing properties of soft and hard wheat flours. They also proposed that the mixing time might have been insufficient to show the effect of TG with a low level (2,000 ppm) on the dough properties in the mixogram because the reaction of TG in wetted flour takes time (Kho and Ng, 2008). Bauer *et al*. (2003) also reported that there was no difference in the mixing properties of dough in farinogram with the addition of a lower level of TG (13.5 ppm, 9.9 U/mg) but did observe significant differences with a high level of TG (> 45.0 ppm, 9.9 U/mg). Seo *et al.* (2003) reported that the addition of TG (3,000 - 7,000 ppm, 17.13U/g) had no impact on physical properties in dough made with the imported wheat flour (mixed wheat flour Australian standard white and Australian hard), while significant change in dough stability and valorimeter value is observed in dough prepared Korean wheat flour, cv. Geuru. However, the addition of TG (10,000 ppm) in Geuru decreased dough stability (Seo *et al*., 2003). Dough development time and stability values initially increased with increasing levels of TG with very low levels (< 0.5%), but decreased at higher TG levels (Basman *et al*., 2002). TG activity was 28 U/g and levels were from 0.2 to 0.6% in this study, which TG activity was lower but levels were similar to previous reports (Basman *et al.*, 2002; Bauer *et al*., 2003; Seo *et al*., 2003; Kho and Ng, 2008). Water absorption did not change by the addition of TG and only Keumkang with the addition 0.6% of TG showed higher mixing time and mixing tolerance of the mixograph than other treatments.

Characteristics of noodle dough and texture of cooked noodles

Characteristics of the noodle dough sheet, cooking loss and texture of cooked noodles prepared with different TG content are summarized in Table 3. Optimum water absorption of Keumkang and Younbaek was 32 and 34%, respectively. TG decreased water absorption of noodle dough only at the 1% level, consistently with previous results in white salted noodles (Wu and Corke, 2005). However, the differences in optimum water absorption of noodle dough with the addition 0.2 - 0.6% of TG

Table 3. Effect of transglutaminase on the characteristics of noodle dough sheet, cooking loss and texture of cooked noodles from two Korean wheat flours and commercial wheat flour for noodles

Flour	TG[b] (%)	Noodle Dough Sheet			Cooking loss (%)	Texture of Cooked Noodles[d]			
		Abs[c] (%)	Thickness (mm)	Lightness		HD (N)	SP (Ratio)	CO (Ratio)	AD (N×mm)
Keumkang	0.0	32.00b[e]	1.85±0.02a	80.60±0.42h	5.56±0.18ab	4.85±0.03c	0.92±0.00cd	0.63±0.01e	-0.06±0.01a
	0.2	32.00b	1.86±0.03a	81.62±0.02g	5.41±0.11bc	4.91±0.06c	0.93±0.01abc	0.66±0.01c	-0.07±0.01ab
	0.4	32.00b	1.86±0.01a	84.64±0.22e	5.59±0.14ab	5.13±0.01b	0.93±0.01abc	0.65±0.01cd	-0.06±0.00a
	0.6	32.00b	1.84±0.03ab	83.52±0.31f	5.39±0.04bc	5.53±0.23a	0.92±0.01cd	0.62±0.01f	-0.07±0.00ab
Younbaek	0.0	34.00a	1.77±0.00de	80.39±0.16h	5.51±0.10bc	3.90±0.02f	0.91±0.00d	0.63±0.00e	-0.07±0.00b
	0.2	34.00a	1.79±0.03cde	85.15±0.09de	5.78±0.33a	4.03±0.03ef	0.92±0.01cd	0.63±0.01e	-0.07±0.02b
	0.4	34.00a	1.76±0.04e	85.69±0.31d	5.59±0.12ab	4.23±0.04d	0.94±0.01a	0.64±0.00de	-0.07±0.01b
	0.6	34.00a	1.77±0.02e	86.73±0.00bc	5.56±0.17ab	4.32±0.03d	0.93±0.01abc	0.63±0.00e	-0.07±0.01b
Com[a]	0.0	34.00a	1.80±0.05bcde	84.83±1.48e	5.27±0.18c	3.73±0.05g	0.92±0.01cd	0.69±0.00b	-0.07±0.01b
	0.2	34.00a	1.82±0.03abcd	87.50±0.09ab	5.51±0.04bc	3.91±0.07f	0.93±0.00abc	0.69±0.00b	-0.07±0.01b
	0.4	34.00a	1.80±0.02bcde	88.07±0.07a	5.41±0.07bc	4.05±0.12ef	0.94±0.01a	0.70±0.00a	-0.08±0.00b
	0.6	34.00a	1.83±0.02abc	86.53±0.15c	5.43±0.04bc	4.19±0.12de	0.94±0.00a	0.68±0.00b	-0.08±0.02b

[a]Com = commercial wheat flours for making white salted noodles.
[b]Transglutaminase (28U/g) addition was 2, 4, 6g/kg in wheat flour, respectively.
[c]Abs = optimum water absorption of noodle dough sheets.
[d]HD = hardness, SP = springiness, CO = cohessiveness, AD = adhessiveness.
[e]Values followed by the same letters are not significantly different at $P < 0.05$.

Table 4. Flour characteristics of 13 Korean wheat cultivars developed after 2000

Flour	Developed Year	Ash (%)	Protein (%)	Amylose (%)	Damaged starch (%)	SDS sedimentation (ml)	Lightness	Wet gluten (%)
Anbaek	2001	0.48±0.01a[a]	8.74±0.02i	25.61±0.63e	5.84±0.13b	20.00±0.00k	91.79±0.13f	13.80±0.20g
Baekjoong	2007	0.46±0.00b	8.39±0.04j	26.72±0.16abcd	4.74±0.19e	22.00±1.00j	92.21±0.10e	13.55±0.35g
Dajoong	2010	0.42±0.01d	10.13±0.00f	27.39±0.04ab	4.83±0.16e	34.00±0.00f	92.48±0.15cd	21.50±0.50c
Goso	2010	0.44±0.01c	10.12±0.03f	27.50±0.24a	5.39±0.23cd	30.50±1.50h	93.35±0.13a	20.90±0.00cd
Hanbaek	2008	0.48±0.00a	11.15±0.07d	26.01±0.00cde	7.50±0.33a	38.00±0.00c	91.77±0.06f	21.00±0.40cd
Jeokjoong	2007	0.44±0.00c	8.27±0.02k	26.80±0.00abc	4.71±0.09e	36.00±0.00e	92.66±0.07c	13.35±0.95g
Joa	2011	0.42±0.00d	9.90±0.05g	26.68±0.51abcd	2.78±0.20f	12.00±0.00l	93.46±0.13a	18.30±0.80e
Joeun	2000	0.45±0.01c	12.00±0.02a	23.37±0.43f	5.48±0.31bc	34.00±0.00f	91.70±0.15f	15.75±0.45f
Jokyung	2004	0.47±0.00ab	9.49±0.01h	26.95±0.00ab	5.44±0.13bc	32.00±0.00g	92.51±0.01cd	16.60±0.30f
Jonong	2003	0.45±0.01c	10.89±0.00e	25.61±0.24e	3.07±0.41f	29.00±0.00i	92.93±0.15b	23.60±0.40b
Jopoom	2001	0.42±0.01d	11.42±0.00b	27.07±0.28ab	4.98±0.28de	42.50±0.50a	92.42±0.09d	21.35±0.85c
Suan	2009	0.42±0.01d	11.29±0.03c	26.48±1.34bcde	4.98±0.15de	39.50±0.50b	92.15±0.16e	20.05±0.05d
Sukang	2008	0.44±0.01c	11.96±0.00a	25.89±0.35de	5.49±0.23bc	37.00±0.00d	91.69±0.00f	26.35±1.35a

[a]Values followed by the same letters are not significantly different at $P < 0.05$.

were not found in this study. Thickness of noodle dough from Keumkang (1.85 mm) was higher than that of Younbaek (1.77 mm) and commercial noodle flour (1.80 mm). Thickness of the noodle dough sheet of white salted noodles from Korean wheat flours positively correlated with protein content rather than protein quality properties (Park *et al*., 2006). However, thickness of noodle dough did not change by the addition of TG. Resting time of the noodle dough sheet could not be enough to gluten development treated with the TG amount in this study, like as the reaction of TG in wetted flour takes time in dough development of the mixograph (Kho and Ng, 2008).

Commercial noodle flour showed higher lightness value (84.83) than Korean wheat flours (< 80.60). Protein content of wheat flour also has a negative relationship with lightness of the noodle dough sheet in white salted noodles (Oh *et al*., 1985). Lightness of noodle dough from all wheat flours increased with as the addition of TG. Wu and Corke (2005) reported that lightness of dried white salted noodles increased with over 1.0% of TG (24 U/g activity). Brightness of instant noodles with 0.5% of TG treatment was higher than that of 1.0% of TG treatment because fat absorption in the making of instant fried noodles was reduced by treatment with TG (Choy *et al*., 2010). However, the color of alkaline noodles with soy protein isolates was adversely affected by TG treatments, which related to the dense structure of noodle dough and then produced deterioration in the color of the noodle (Gan *et al*., 2009).

Commercial noodle flour (5.27%) showed lower cooking loss than Korean wheat flour (> 5.51%). Cooking loss did not change with increased TG treatments, although Younabek with the addition 0.2% of TG was higher (5.78%) than without TG treatment (5.51%). Wu and Corke (2005) concluded that TG did not significantly influence the cooking loss of dried white salted noodles with the 0.1-2.0% of TG treatments. The cooking loss of TG treated dried noodles increased as compared to that of without TG treatment (Shiau and Chang, 2013). Commercial noodle flour showed lower hardness and higher cohesiveness (3.73 N and 0.69, respectively) of cooked noodles than Korean wheat flours (> 3.90 N and 0.63, respectively). Springiness and adhesiveness of commercial noodle flour (0.92 and -0.07 N×mm) were similar to those of Korean wheat flours (0.92 and -0.06 N×mm for Keumkang and 0.91 and -0.07 N×mm for Younbaek, respectively). Hardness of cooked noodles positively correlated with protein content in previous reports (Park *et al*., 2003; Oh *et al*., 1985). Commercial flour for noodle making contained low amylase content, due to the null characteristics in the *Wx-B1* allele of granule bound starch synthase, showed lower hardness of cooked noodles compared to flours with similar protein content (Park *et al*., 2003). As starch amylose content decreased, hardness of cooked noodles decreased and cohesiveness increased in partial waxy wheat flours (Baik *et al*., 2003). Hardness of cooked

Table 5. Characteristics of noodle dough sheet from 13 Korean wheat flours with different treatment of transglutaminase

Flour	Absorption (%)	Noodle Dough Sheet: Without Transglutaminase		Noodle Dough Sheet: 0.4% Transglutaminase	
		Thickness (mm)	Lightness	Thickness (mm)	Lightness
Anbaek	35.00a[a]	1.71±0.01c	78.91±1.09g	1.70±0.01f	79.66±0.60fg
Baekjoong	35.00a	1.72±0.01c	82.71±0.69b	1.72±0.01ef	83.18±0.41b
Dajoong	34.00b	1.71±0.02c	77.22±0.79h	1.71±0.02ef	77.75±1.08h
Goso	34.00b	1.71±0.02c	80.52±0.06ef	1.72±0.02ef	81.31±0.24de
Hanbaek	33.00c	1.89±0.05a	82.64±0.92b	1.89±0.06a	83.79±0.64b
Jeokjoong	35.00a	1.72±0.03c	82.27±0.24bc	1.71±0.01ef	83.31±0.61b
Joa	34.00b	1.79±0.01b	84.28±0.82a	1.81±0.02b	84.51±0.51a
Joeun	33.00c	1.78±0.02b	80.83±0.51de	1.76±0.02c	82.30±0.43c
Jokyung	34.00b	1.78±0.03b	80.81±0.30de	1.77±0.01c	81.71±0.51cde
Jonong	34.00b	1.73±0.01c	79.93±0.38f	1.74±0.01de	81.05±0.21e
Jopoom	33.00c	1.77±0.02b	80.53±0.53ef	1.81±0.02b	80.02±0.73f
Suan	33.00c	1.73±0.01c	81.62±0.96cd	1.72±0.02ef	81.95±0.64cd
Sukang	33.00c	1.77±0.01b	78.65±0.65g	1.76±0.01cd	79.00±0.58g

[a]Values followed by the same letters are not significantly different at $P < 0.05$.

Table 6. Texture of cooked noodles from 13 Korean wheat flours with different treatment of transglutaminase

Flour	Texture of Cooked Noodles: Without Transglutaminase			Texture of Cooked Noodles: 0.4% Transglutaminase		
	Hardness (N)	Springiness (Ratio)	Cohesiveness (Ratio)	Hardness (N)	Springiness (Ratio)	Cohesiveness (Ratio)
Anbaek	3.07±0.13e[a]	0.91±0.01abc	0.64±0.00bc	3.21±0.12f	0.90±0.01cd	0.64±0.00de
Baekjoong	2.45±0.11f	0.90±0.00bc	0.65±0.00a	3.21±0.21f	0.90±0.01d	0.64±0.01e
Dajoong	3.27±0.06d	0.92±0.01ab	0.66±0.01a	3.66±0.15e	0.92±0.02abc	0.64±0.01cde
Goso	3.55±0.07c	0.92±0.02a	0.65±0.01a	4.28±0.12b	0.91±0.01cd	0.65±0.01ab
Hanbaek	3.76±0.04b	0.91±0.01ab	0.65±0.01a	3.82±0.07d	0.91±0.02bcd	0.66±0.02ab
Jeokjoong	3.08±0.06e	0.90±0.01abc	0.65±0.01abc	3.52±0.10e	0.90±0.02cd	0.65±0.01abc
Joa	3.57±0.11c	0.90±0.02c	0.65±0.01abc	3.85±0.16d	0.91±0.02bcd	0.65±0.01abc
Joeun	4.07±0.09a	0.92±0.01a	0.65±0.00a	4.26±0.10b	0.93±0.01a	0.66±0.01a
Jokyung	3.21±0.06d	0.91±0.02abc	0.65±0.01a	3.55±0.07e	0.91±0.01bcd	0.65±0.00bcd
Jonong	4.15±0.03a	0.91±0.01abc	0.64±0.01c	4.11±0.04c	0.90±0.01cd	0.65±0.01abc
Jopoom	3.30±0.12d	0.92±0.02ab	0.65±0.01abc	3.59±0.05e	0.92±0.01abc	0.64±0.01cde
Suan	4.05±0.03a	0.92±0.01a	0.65±0.01ab	4.43±0.10a	0.92±0.01ab	0.65±0.01bcd
Sukang	4.14±0.18a	0.91±0.02ab	0.64±0.00abc	4.31±0.07ab	0.92±0.01ab	0.64±0.00cde

[a]Values followed by the same letters are not significantly different at $P < 0.05$.

noodles increased as the addition of TG increased in all three wheat flours. Springiness of cooked noodles from Younbaek and commercial noodle flour with the addition over 0.4% of TG increased compared to that of other wheat flours, although there was no significant difference in Keumkang. Cohesiveness of Keumkang and commercial noodle flours increased with the addition 0.4% of TG and then leveled off in 0.6% of TG treatment. No significant differences were found in cohesiveness of Younbaek. Adhesiveness of cooked noodles was not influenced by TG treatments in all three wheat flours. The adhesiveness of cooked dried white noodles was not affected by TG treatment (Shiau and Chang, 2013). Seo *et al.* (2003) proposed that textural properties of cooked noodles as well as sensory characteristics could be improved by the addition of 3,000-7,000 ppm (17.13 U/g activity) to Korean wheat flour, cv. Geuru. Shiau and Chang (2013) proposed that dried or cooked white noodles with good quality can be produced by incubating with 0.5-1.0% (25U/g) TG treatment for 30 min at 30◦C. White salted noodles with 0.4% of TG treatment could improve the lightness of the noodle dough sheet and elastic texture of cooked noodles, although hardness of cooked noodles increased in this study.

Noodle characteristics with 0.4% of TG treatment

Flour characteristics of 13 Korean wheat cultivars, developed after 2000, were summarized in Table 4. The average of ash, protein, amylose, damaged starch content, lightness of flour, SDS-sedimentation volume and wet gluten were 0.45%, 10.29%, 26.31%, 5.02%, 92.39, 31.27 ml and 18.93%, respectively. Ash, protein and amylose content were 0.42 – 0.48%, 8.27 – 12.00% and 23.37 – 27.50%, respectively. Damaged starch, lightness of flour, SDS-sedimentation volume and wet gluten were 2.78 – 7.50%, 91.69 – 93.46, 12.00 – 42.50% and 13.35 – 26.35%, respectively. Protein content positively correlated with wet gluten and damaged starch correlated with lightness of flours and ash content, which agreed with previous reports (Park *et al*., 2003; Park *et al.*, 2006).

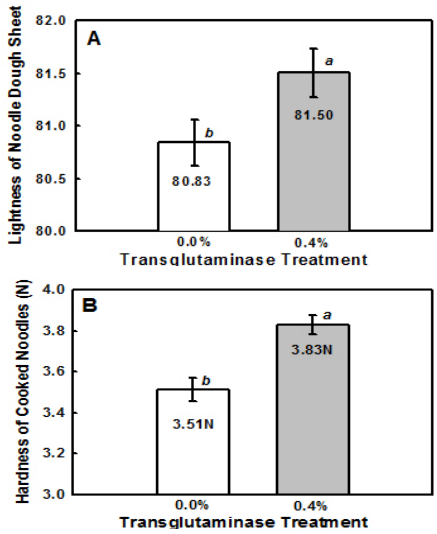

Figure 1. The differences in lightness of noodle dough sheet (A) and hardness of cooked noodles (B) between no TG treatment and 0.4% of TG treatment in 13 Korean wheat cultivars. Error bars indicate the standard error

Characteristics of the noodle dough sheet from 13 Korean wheat flours with different treatment of transglutaminase were summarized in Table 5. In the noodle dough sheet with no TG treatment, the average of optimum water absorption, thickness and lightness of the noodle dough sheet with no TG treatment were 33.85%, 1.76 mm and 80.84, respectively. Thickness of the noodle dough sheet with 0.4% TG treatment (1.76 mm) was the same as that of no treatment of TG. Lightness of noodle doughs with 0.4% TG treatment (81.50) was higher than that of no treatment of TG (80.83) at $P < 0.05$ (Figure. 1-A), although Wu and Corke (2005) proposed the difference in color appearance was not visually detectable as the change in lightness was less than 2 units. Higher lightness of noodles with 0.4% TG treatment compared to no TG treatment was the same result in Table 3. These results indicate that lightness of the noodle dough sheet could be improved with 0.4% TG treatment in Korean wheat cultivars.

Texture of cooked noodles from 13 Korean wheat flours with different treatment of transglutaminase were summarized in Table 6. Hardness of cooked noodles with 0.4% TG treatment was higher (3.83

N) than that of no TG treatment (3.51 N, Figure. 1-B), which 3.83 N is comparable to hardness of Com without TG treatment (Table 3). Increase of hardness for cooked noodles with 0.4% TG treatment was also found in Table 3. TG treatment could increase hardness of cooked noodles in Korean wheat cultivars. TG increased the hardness of dried white salted noodles (Wu and Corke, 2005). The increase in hardness with TG treatment was related to a stronger and tighter protein network between the starch granules which was responsible for limiting excessive water uptake during cooking (Kovács *et al*., 2004). Springiness and cohesiveness of cooked noodles with 0.4% TG treatment was higher than those of no TG treatment in Younbaek and Com (Table 3). However, neither springiness nor cohesiveness of noodles was affected by TG treatments in 13 Korean wheat cultivars. Springiness of cooked noodles regardless of TG treatments positively correlated with protein content and SDS-sedimentation volume. Park *et al.* (2006) reported that the springiness of cooked noodles positively correlated with the volume of SDS sedimentation in Korean wheat cultivars. Baik *et al.* (2003) proposed that the high cohesiveness of cooked noodles could also be attributed to starch characteristics. Therefore, the differences of springiness and cohesiveness of cooked noodles with 0.4% of TG treatments between Table 3 and Table 6 could be influenced by the protein characteristics and amylose content of Korean wheat cultivars.

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