Effects of γ -irradiation on the quality changes of fresh noodles prepared from wheat cultivated with N-fertilization treatments

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Abstract Quality changes of fresh noodles prepared from wheat cultivated with N-fertilization treatments, followed by γ -irradiation were investigated. The protein content of the KPS60 was the highest of all treated samples, and protein contents of wheat cultivated with N-fertilizer was increased. γ -Irradiation did not affect the protein contents of the samples. However, the water holding capacity and resistant starch contents was increased by irradiation. The dry gluten and wet gluten contents of samples were further increased by γ -irradiation. The pasting properties were influenced by γ -irradiation but not N-fertilization. The hardness of noodles made with irradiated wheat flour was decreased, but the degree of decrease was small compared with that of viscosity. The gumminess and chewiness of noodles made with irradiated flour having higher protein content and WG showed also higher score. Thus, treatment of wheat flour with N-fertilization and γ -irradiation may improve the quality of Korean-style noodles during storage.

Keywords: Korean wheat cultivar, wheat protein, N-fertilization, γ -irradiation, fresh noodle quality

Introduction

Cereal grains, such as wheat, rice, and barley, are major food crops worldwide. Among these grains, wheat has important functionality when formed into dough and exhibits advantageous properties, such as viscoelasticity and extensibility. Its properties can be attributed to the presence of gluten proteins (gliadin and glutenin) in wheat flour (1,2). Because of these properties, wheat flour can be used to make various types of processed foods, such as bread, noodles, and cookies.

Noodles are a popular staple food made from wheat flour and are prepared using only two main ingredients, wheat flour and water (3). Various types of noodles can be prepared, including fried, dry, fresh noodles, buckwheat vermicelli, and starch vermicelli, using different manufacturing processes. In Korea, most noodles are consumed as fried, fresh or dry noodles (4). Importantly, wheat protein is the main factor affecting dough and noodle quality, as shown by evaluation of the color, surface appearance, texture, and sensory properties of noodles prepared with wheat flour containing different protein contents (5).

The growth of wheat cultivars is affected by genetic, climatic, and environmental factors, and changes in these factors can alter the components of wheat flour, including the protein contents, which greatly influence the final quality of processed wheat-based food products (6,7). For example, the protein contents in wheat grain are

increased by N-fertilization, thereby improving noodle texture (8,9). Additionally, various types of insects and microorganisms may spoil wheat grains after harvesting, causing problems during storage and resulting in lower yields and reduced shelf-life. (10,11). Accordingly, various types of treatments have been examined for application in food storage.

γ -Irradiation is a type of non-thermal treatment that can effectively eliminates insects, microorganisms, and viruses and improve food safety (12). Moreover, γ -irradiation could be a substitute for highly toxic fumigants, such as methyl bromide and phosphine, which are used for insect control during the storage of cereal grains (13). However, γ -irradiation generates free radicals, which can break chemical bonds and affected the starch properties of various irradiated foods (14,15).

In this study, we aimed to investigate the physicochemical properties of wheat cultivated with increased N-fertilization, followed by γ -irradiation. Additionally, we evaluated changes in the quality of Korean-style fresh noodles made using treated Korean winter wheat flour during storage.

Materials and Methods

Sample preparation The Korean winter wheat variety Keumkang

was obtained from the Department of Rice and Winter Cereal Crop, National Institute of Crop Science (Jeonju, Jeonbuk, Korea). The basic cultivation conditions with increasing N-fertilizer were determined using the methods of Lee and Kang (16). The base fertilization (BF) used in this study was based on an N, P, and K source, supplied at 22.00, 65.11, and 15.33 g/m², respectively. For treatment, KSM20 and KSM60 were cultivated under 20 and 60% more N-fertilizer as supplementary manuring period (SM), respectively, compared with BF. The KPS20 and KPS60 were cultivated with increased N-fertilization 20 and 60%, respectively, at the panicle initiation stage (PS) compared with BF. The harvested wheat cultivars were dried and then milled using a Buhler milling machine (MLU-202; Buhler, Uzwil, Switzerland). The samples were placed in plastic bags and stored at 4°C until use.

Irradiation Wheat flour was packed in polyethylene bags and irradiated in a cobalt-60 γ -irradiator (Point Source AECL, IR-79; MDS Nordion International Co. Ltd., Ottawa, Canada) at an ambient temperature at the Korea Atomic Energy Research Institute (Jeongeup, Korea). The applied doses in this study were 0, 5, and 10 kGy, and the dose rate was 10 kGy/h. The non-irradiated control (0 kGy) was kept outside the irradiation chamber under the same conditions of temperature and humidity as the irradiated sample.

Approximate composition, resistant starch (RS) contents, and water holding capacity (WHC) of wheat flour The approximate compositions of the samples, including moisture, ash, and crude protein contents, were measured using the official methods of the American Association of Cereal Chemists (AACC) (17). The resistant starch contents were determined using a commercially available Megazyme resistant starch assay kit (K-RSTAR; Megazyme International, Bray, Ireland).

The water holding capacity of the samples was determined using the methods of Medcalf and Gilles (18) and Kim and Shin (19). The samples (1 g) were mixed with 40 mL of distilled water, stirred at room temperature for 1 h and centrifuged at 2,000×g for 30 min. The water holding capacity was calculated using the following equation:

Water holding capacity (%) = (weight of precipitate – weight of samples) / weight of samples × 100

Gluten properties, pasting profiles and scanning electron microscopy (SEM) The gluten index (GI), wet gluten content (WG), dry gluten content (DG), and water binding in wet gluten (WB) of the samples were analyzed using a Glutomatic system (Glutomatic; Perten Instruments, Hägersten, Sweden). The pasting properties of sample suspensions (4 g sample in 25 mL distilled water, sample based on 14% moisture) were measured with a Rapid Visco Analyzer (RVA 4500; Perten Instruments). The microstructural properties of wheat flour were determined using SEM (S4800EDS; Hitachi Ltd., Tokyo, Japan). For SEM, samples were dried, mounted on aluminum stubs, and coated with a thin film of gold. The microstructures of the

cutting plane were analyzed using SEM.

Quality evaluation of fresh noodles Noodles were prepared using the methods of Baik *et al.* (20), Kang *et al.* (21), and Lee and Kang (16), with some modifications. The thickness and color of the noodle sheets, the turbidity of boiled noodle water, and the textural properties of cooked noodles were measured during storage at 10°C. The thickness and color values of the noodle sheets were measured with a Model G Peacock dial thickness gauge (Ozaki Mfg Co., Ltd., Tokyo, Japan) and a spectrophotometer (CM-5; Konica Minolta Inc., Tokyo, Japan), respectively. The noodles were boiled in water (500 mL) at 100°C for 5 min. After boiling, the noodles were immediately cooled in water at room temperature, and the absorbance of the boiled water at 675 nm was recorded using a UV-spectrophotometer (UV-1800; Shimadzu Co., Tokyo, Japan) as the turbidity value. The textural properties of cooked noodles were investigated using texture profile analysis (TPA) with a texture analyzer (TA1; Lloyd Instruments Ltd., Fareham, UK) equipped with a 500 N load cell. The samples (five noodle strands) were compressed up to 70% at a crosshead speed of 10 mm/min and evaluated with a cylindrical stainless steel probe measuring 20 mm in diameter.

Statistical analysis The experimental data are reported as the means and standard deviations. The significance of differences was determined using analysis of variance with SAS software (version 7.0; SAS Institute Inc., Cary, NC, USA), and significant differences between mean values were identified using Duncan's multiple comparison tests at the 5% probability level.

Results and Discussion

Approximate composition, WHC, and RS contents of wheat flour samples The approximate composition, WHC, and RS contents of the samples are shown Table 1. The water and ash contents of the samples were 13.34–14.97 and 0.38–0.47%, respectively. The protein contents of the KPS60 (11.58%) were the highest score and the protein contents of KPS20 were lower than those of KSM20, KSM60, and KPS60. The protein contents of wheat cultivated with adding N-fertilizer as the supplementary manuring period (SM) were not different; however, that of wheat cultivated with added N-fertilizer at the panicle stage (PS) were increased in a concentration-dependent manner ($p < 0.01$). The protein contents of the samples were not affected by γ -irradiation treatment. However, the WHCs were influenced by γ -irradiation treatment. The WHC of KSM20 and KPS20 were 94.63% and 95.69%, respectively; these values were higher than those of the other samples. Moreover, exposure to 10 kGy irradiation tended to increase the WHC. The RS contents of the samples also varied with fertilization and γ -irradiation treatment, with values of 0.231, 0.243, and 0.260 g/100 g samples for KSM60, KPS20, and KPS60, respectively. However, the RS contents of irradiated

Table 1. Approximate composition, water holding capacity, and resistant starch of wheat flour with N-fertilization and γ -irradiation treatments

Samples ¹⁾	Irradiation dose (kGy)	Moisture (%)	Crude Ash (%)	Crude Protein (%)	WHC (%)	Resistant Starch (g/100 g samples)
KSM20	0	13.63±0.04 ^{de2)}	0.38±0.01 ^{bc}	10.12±0.04 ^b	94.63±3.44 ^{bc}	0.205±0.03 ^e
KSM60		14.79±0.15 ^a	0.40±0.05 ^{abc}	10.26±0.04 ^b	91.56±0.11 ^c	0.231±0.02 ^{de}
KPS20		14.02±0.21 ^{bc}	0.47±0.06 ^a	9.69±0.09 ^c	95.69±0.33 ^{bc}	0.243±0.03 ^{cde}
KPS60		13.15±0.00 ^f	0.41±0.03 ^{abc}	11.58±0.15 ^a	93.24±1.82 ^c	0.260±0.01 ^{cde}
KSM20	5	13.78±0.11 ^{cd}	0.39±0.01 ^{bc}	10.16±0.02 ^b	94.01±1.08 ^{bc}	0.276±0.03 ^{bcd}
KSM60		14.78±0.21 ^a	0.34±0.01 ^c	10.19±0.10 ^b	92.45±2.50 ^c	0.236±0.06 ^{de}
KPS20		13.85±0.01 ^{cd}	0.44±0.06 ^{ab}	9.79±0.06 ^c	96.08±2.01 ^{bc}	0.294±0.01 ^{bcd}
KPS60		13.62±0.01 ^{de}	0.44±0.02 ^{ab}	11.56±0.07 ^a	93.44±0.68 ^{bc}	0.275±0.02 ^{bcd}
KSM20	10	13.65±0.04 ^d	0.42±0.01 ^{bc}	10.10±0.01 ^b	94.68±1.67 ^{bc}	0.358±0.11 ^a
KSM60		14.97±0.11 ^a	0.38±0.01 ^{bc}	10.23±0.05 ^b	100.83±0.16 ^a	0.268±0.02 ^{bcd}
KPS20		14.18±0.13 ^b	0.43±0.00 ^{ab}	9.71±0.11 ^c	98.37±1.06 ^{ab}	0.305±0.01 ^{abc}
KPS60		13.34±0.23 ^{ef}	0.41±0.03 ^{abc}	11.67±0.07 ^a	94.75±1.02 ^{bc}	0.330±0.01 ^{ab}

¹⁾KSM20, cultivated under 20% more increased N-fertilizer as supplementary manuring period; KSM60, cultivated under 60% more increased N-fertilizer as supplementary manuring period; KPS20, cultivated with increased N-fertilization 20% at the panicle initiation stage; KPS620, cultivated with increased N-fertilization 60% at the panicle initiation stage.

^{2)a-f}Different letters within the same column differ significantly ($p < 0.01$).

samples tended to increase following γ -irradiation regardless of N-fertilization. The RS contents of KSM20 with 0 kGy was 0.205 g/100 g samples, whereas RS contents of KSM20 with 10 kGy was 0.358 g samples. Rozbicki *et al.* (22) reported that protein contents and quality could be improved by crop management practices, particularly the N-fertilization level, as supported by our findings. In our study, increase of wheat protein contents was influenced by addition time and amount of N-fertilizer during cultivation. We found that adding N-fertilization at PS influenced the wheat grain composition such as protein contents. In previous studies, carbohydrate, fat, protein, ash, and moisture contents were found to be unchanged after γ -irradiation (13,23). In our study, the WHC and RS contents of samples were increased by irradiation treatment. Consistent with our study, the water absorption capacity of irradiated chickpea flour is increasing owing to the formation of sugars such as dextrin, maltose, and glucose (23). Azzhe and Amr (24) reported that increased water absorption of irradiated semolina could be due to increased damaged starch accompanied by production of higher levels of reducing sugars. Resistant starch content increased by 10 and 50 kGy irradiation in both potato and bean starches (25). However, in contrast to these findings, Agúndez-Arvizu *et al.* (13) showed that the absorption and mixing tolerance of irradiated commercial wheat flour are not altered by 1.0 kGy irradiation. Depolymerization or abscission of polymers such as amylose and amylopectin chains, by irradiation is responsible for the reduction in water binding capacity (26). In this study, among of many factors, the increased WHC of samples could be representative of the increased RS, which was generated by free radicals by radiation exposure. Indeed, Sirisoontaralak and Noomhorm (27) reported that water absorption was increased with irradiation and starch fragmentation from irradiation results in increased water binding capacity. Moreover, the WHC and emulsion stability of pork sausages has been shown to be increased by

addition of cassava-modified starch (28).

Gluten properties of wheat flour Kuan *et al.* (15) reported that variation of food protein by irradiation were accompanied by deamination, decarboxylation, reduction of disulfide linkages, oxidation of sulfhydryl groups, modification of amino acid moieties, valence changes in coordinated metal ions, peptide-chain cleavage, and aggregation of protein. The WG, DG, and WB of KPS60, which exhibited higher protein contents, were higher than those of KSM20, KSM60, and KPS20 and were further increased by irradiation (Table 2). The WBs of KSM60, KPS20, and KPS60 after irradiation with 10 kGy were 19.05, 18.65, and 23.40, respectively; these values were higher than those of non-irradiated samples and samples irradiated with 5 kGy. Additionally, WB was increased by γ -irradiation in a dose-dependent manner. In contrast, the GlIs of KPS20 and KPS60 with 10 kGy irradiation were 57.76 and 42.23, respectively, demonstrating that the GlIs of irradiated samples were decreased by γ -irradiation treatment. The GlIs of KSM20, KSM60, KPS20, and KPS60 were 92.18, 97.40, 95.87, and 91.52, respectively, demonstrating that addition of N-fertilizer did not affect this parameter. In contrast to our results, a previous report showed that the wet gluten contents of irradiated semolina were not affected by up to 2.5 kGy irradiation, but that wet gluten was significantly decreased by 5 kGy irradiation owing to damage to the gluten network structure (24). However, Kökselt *et al.* (10) demonstrated that there was no observable effect of irradiation on gliadine proteins but that the glutenin concentration was decreased as the γ -irradiation dose increased, consistent with the degradation of glutenin by depolymerization or disaggregation. Irradiated food proteins have been shown to cross-link or degrade the proteins, depending on the dose delivered, exposure time, exposure conditions, and type of food proteins used (15). In our study, the WG and DG of irradiated samples were increased, similar

Table 2. Gluten properties of wheat flour with N-fertilization and γ -irradiation treatments

Samples	Irradiation dose (kGy)	Wet Gluten Content (%)	Dry Gluten Content (%)	Water Binding in Wet Gluten (%)	Gluten Index
KSM20	0	26.25±0.21 ^{de1)}	9.05±0.07 ^{fg}	17.20±0.14 ^{de}	92.18±1.65 ^a
KSM60		26.60±1.56 ^{de}	9.20±0.28 ^{efg}	17.40±1.27 ^{cde}	97.40±0.91 ^a
KPS20		25.20±0.85 ^{de}	8.80±0.14 ^g	16.40±0.71 ^e	95.87±2.39 ^a
KPS60		31.70±0.57 ^{abc}	10.70±0.14 ^c	21.00±0.42 ^b	91.52±3.86 ^a
KSM20	5	27.45±0.49 ^{cde}	9.55±0.07 ^{df}	17.90±0.42 ^{cde}	90.88±1.71 ^{ab}
KSM60		26.05±0.78 ^{de}	9.30±0.42 ^{efg}	17.65±0.21 ^{cde}	95.15±3.13 ^a
KPS20		26.25±0.07 ^{de}	9.15±0.21 ^{dfg}	17.10±0.14 ^{de}	90.85±5.41 ^{ab}
KPS60		33.20±0.85 ^{ab}	11.30±0.14 ^b	21.90±0.71 ^{ab}	69.71±1.41 ^{cd}
KSM20	10	23.95±6.43 ^e	9.85±0.21 ^d	18.75±1.34 ^{cd}	78.97±14.43 ^{bc}
KSM60		28.95±0.35 ^{bcd}	9.90±0.14 ^d	19.05±0.21 ^c	65.49±5.93 ^d
KPS20		28.30±0.71 ^{cde}	9.65±0.07 ^{de}	18.65±0.64 ^{cd}	57.76±1.31 ^d
KPS60		35.35±1.20 ^a	11.95±0.35 ^a	23.40±0.85 ^a	42.23±4.64 ^e

¹⁾a–g Different letters within the same column differ significantly ($p < 0.01$).

to the results for the WHC and RS contents. These effects may be related to modified proteins composition or polymerization, which could be varied in response to N-fertilization or γ -irradiation. However, additional studies are needed to better elucidate the changes such as protein composition, molecular weight, and polymerization of in response to N-fertilization or γ -irradiation. The chemical reactions of proteins in response to irradiation are affected structure; the state of the protein, e.g., fibrous, globular, native, or denatured; composition; wet or dry conditions in the liquid state; and irradiation conditions (15,29)

SEM and pasting properties of wheat flour The Keumkang wheat grains had a round and smooth surface, regardless of N-fertilization (Fig. 1). However, γ -irradiated wheat flour exhibited irregular shapes and cracks within the grains, with more effects observed as the irradiation dose increases. The effects may have been related to the RS contents, which were increased by 10 kGy irradiation. Lee and Kang (16) reported that the microstructures of Hojung and Backjoong wheat flours, which contain high protein contents, were more uniform and round. Additionally, the granular morphology of irradiated samples is affected by the dry or suspension state (25). Similar to our results, Gani *et al.* (30) demonstrated that surface cracks in irradiated bean granules are apparent when up to 20 kGy irradiation was applied; this level of irradiation was highly energetic and penetrating. Additionally, irradiated rice starch has been shown to have a smaller size than non-irradiated rice starch, and the size was decreased and the irradiated dose was increased (31). However, Atrous *et al.* (25) demonstrated that the crystallinity of wheat starch was not changed by 50 kGy γ -radiation treatment.

Pasting properties, including peak viscosity (PV), trough viscosity, breakdown viscosity (BD), final viscosity (FV), and setback viscosity (SB) were dramatically decreased by γ -irradiation, regardless of N-fertilization (Table 3). The PVs of KSM20 and KSM60 were 2,811 and 2,860 cp, respectively, which were higher than those of KPS20 or

KPS60. The FVs were 3,561 and 3,615 cp, respectively. The SB of non-irradiated KSM60 was the highest of all samples at 1,545 cp, but decreased to 459 cp after irradiation with 10 kGy. SB is an important factor in starch-based foods and was related to starch retrogradation. Importantly, the SB of wheat flour was decreased by γ -irradiation, which can positively affect the decreased retrograde and textural properties of wheat-based foods. The peak time and PT did not differ after N-fertilization; however, the PT of wheat starch decreased from 67.75 to 64.58°C following irradiation. Notably, the pasting properties of KSM60 were the least affected by γ -irradiation. These results indicated that the final wheat product made with irradiated wheat flour may exhibit improved textural qualities owing to the lower PV, FV, SB, and PT. Bhat *et al.* (6) reported that the PV of the native wheat flour ranges from 1,492 to 1,804 cp; in contrast, we found a range of 2,767 to 2,860 cp for the PV. Additionally, Sirisoontarak and Noomhorm (27), Bashir and Haripriya (23), and Bhat *et al.* (6) reported lower pasting properties after irradiation, similar to our findings. Lower SBs indicate improved quality of whole wheat flour-based foods in terms of texture and physical properties. Changes in the starch viscosity and reduced SB of wheat flour by γ -irradiation can be explained by the depolymerization of irradiated starch, which is dependent on the irradiation dose level (23,32). Moreover, the decreases in SBs and FVs occur as a result of reordering or polymerization of amylose and amylopectin, e.g. degradation or shortening of amylopectin branch chains (33). Similar to our results, a previous report showed that the PT of samples is lower following irradiation (23). Wani *et al.* (34) reported that the decrease in PT may be explained by degradation of starch, particularly amylopectin. However, the enthalpy required to melt the crystalline structure of wheat starch by 50 kGy irradiation is not different from that of native starch (25). Additionally, the PV, FV, SB, BD, and consistency viscosity of rice were decreased by irradiation, whereas the SB was markedly increased after one year of storage (27).

Fig. 1. Scanning electron micrograph of wheat flour cultivated N-fertilization, followed by γ -irradiation treatment. (A) KSM20 with 0 kGy irradiation, (B) KSM20 with 5 kGy irradiation, (C) KSM20 with 10 kGy irradiation, (D) KSM60 with 0 kGy irradiation, (E) KSM60 with 5 kGy irradiation, (F) KSM60 with 10 kGy irradiation, (G) KPS20 with 0 kGy irradiation, (H) KPS20 with 5 kGy irradiation, (I) KPS20 with 10 kGy irradiation, (J) KPS60 with 0 kGy irradiation, (K) KPS60 with 5 kGy irradiation, (L) KPS60 with 10 kGy irradiation. Magnification used was 5,000 $\times$.

Table 3. Pasting properties of wheat flour with N-fertilization and γ -irradiation treatments

Samples	Irradiation dose (kGy)	Viscosity (cp)					Peak Time (min)	Pasting Temp ($^{\circ}$ C)
		Peak	Trough	Breakdown	Final	Setback		
KSM20	0	2,811 $\pm$ 1.15 ^{b1)}	2,035 $\pm$ 23.76 ^b	775 $\pm$ 24.91 ^{bc}	3,561 $\pm$ 28.54 ^b	1,526 $\pm$ 15.10 ^b	6.47 $\pm$ 0.01 ^a	67.48 $\pm$ 0.39 ^a
KSM60		2,860 $\pm$ 19.00 ^a	2,070 $\pm$ 28.84 ^a	790 $\pm$ 9.85 ^{ab}	3,615 $\pm$ 30.99 ^a	1,545 $\pm$ 6.35 ^a	6.47 $\pm$ 0.01 ^a	67.42 $\pm$ 0.53 ^a
KPS20		2,780 $\pm$ 16.52 ^c	1,997 $\pm$ 40.53 ^c	783 $\pm$ 24.11 ^{bc}	3,505 $\pm$ 24.06 ^c	1,508 $\pm$ 16.80 ^c	6.44 $\pm$ 0.04 ^a	67.75 $\pm$ 0.05 ^a
KPS60		2,767 $\pm$ 8.49 ^c	2,009 $\pm$ 2.12 ^{bc}	759 $\pm$ 6.36 ^c	3,501 $\pm$ 4.95 ^c	1,492 $\pm$ 7.07 ^d	6.47 $\pm$ 0.01 ^a	67.35 $\pm$ 0.57 ^a
KSM20	5	1,348 $\pm$ 7.55 ^d	551 $\pm$ 13.58 ^d	797 $\pm$ 13.43 ^{ab}	1,194 $\pm$ 7.02 ^d	643 $\pm$ 6.56 ^e	5.69 $\pm$ 0.04 ^{bc}	65.75 $\pm$ 0.52 ^b
KSM60		1,350 $\pm$ 4.36 ^d	543 $\pm$ 5.69 ^{de}	807 $\pm$ 2.31 ^a	1,195 $\pm$ 4.04 ^d	651 $\pm$ 2.52 ^e	5.73 $\pm$ 0.01 ^b	65.70 $\pm$ 0.52 ^b
KPS20		1,294 $\pm$ 9.29 ^e	519 $\pm$ 5.00 ^{ef}	775 $\pm$ 4.62 ^{bc}	1,143 $\pm$ 1.53 ^e	624 $\pm$ 4.16 ^f	5.64 $\pm$ 0.04 ^c	65.73 $\pm$ 0.51 ^b
KPS60		1,244 $\pm$ 10.97 ^f	508 $\pm$ 13.05 ^f	737 $\pm$ 2.08 ^d	1,113 $\pm$ 11.50 ^f	605 $\pm$ 3.61 ^g	5.69 $\pm$ 0.04 ^{bc}	65.15 $\pm$ 0.01 ^c
KSM20	10	830 $\pm$ 2.52 ⁱ	213 $\pm$ 1.00 ^{hi}	617 $\pm$ 2.08 ^f	603 $\pm$ 1.73 ⁱ	390 $\pm$ 1.00 ^j	5.07 $\pm$ 0.01 ^f	65.13 $\pm$ 0.03 ^{bc}
KSM60		1,000 $\pm$ 3.51 ^g	272 $\pm$ 4.16 ^g	727 $\pm$ 3.21 ^d	731 $\pm$ 4.58 ^g	459 $\pm$ 8.39 ^h	5.16 $\pm$ 0.04 ^d	64.88 $\pm$ 0.56 ^c
KPS20		887 $\pm$ 6.11 ^h	241 $\pm$ 1.15 ^h	645 $\pm$ 5.03 ^e	654 $\pm$ 2.52 ^h	413 $\pm$ 3.61 ⁱ	5.13 $\pm$ 0.01 ^e	65.05 $\pm$ 0.03 ^{bc}
KPS60		788 $\pm$ 13.89 ^j	203 $\pm$ 4.93 ⁱ	585 $\pm$ 17.01 ^g	572 $\pm$ 3.06 ^j	368 $\pm$ 2.08 ^k	5.09 $\pm$ 0.04 ^{ef}	64.58 $\pm$ 0.55 ^c

¹⁾a-k Different letters within the same column differ significantly ($p < 0.01$).

Color values of boiled noodles made with treated wheat flour

The lightness values of fresh noodles made with KSM20 and KPS60 were 64.44 and 64.05, respectively, and were higher than those of other samples (Table 4). After storage for 3 days at 10 $^{\circ}$ C, the lightness of noodles was decreased, with less change observed in irradiated samples during storage than in non-irradiated samples. A similar pattern was observed for the redness of samples. Bashir and Haripriya

(23), who showed that the L value of starch was significantly decreased as the irradiation dose increased and that the b value increased as the irradiation dose increased. Additionally, Sirisoontarak and Noomhorm (27) reported that the value increased as the irradiation dose increased owing to breakdown of glycosidic and peptidic linkages during irradiation. This would cause Maillard reaction and result in the formation of colored compounds (27).

Table 4. Color value and turbidity of noodles made from wheat flour with N-fertilization and γ -irradiation treatments during storage at 10°C

Samples	Irradiation dose (kGy)	L*	a*	b*	Turbidity
0 day					
KSM20	0	64.44±1.12 ^{ab1)}	-2.47±0.12 ^{ab}	2.55±0.94 ^{bc}	0.056±0.01 ⁱ
KSM60		60.99±0.53 ^e	-2.67±0.05 ^{bc}	0.97±0.46 ^e	0.069±0.01 ^h
KPS20		61.85±0.73 ^{cde}	-2.71±0.06 ^{bc}	1.24±0.15 ^{de}	0.083±0.01 ^g
KPS60		64.05±1.24 ^{ab}	-2.53±0.05 ^{ab}	2.45±0.47 ^c	0.088±0.01 ^g
KSM20	5	63.06±1.51 ^{bcd}	-2.48±0.11 ^{ab}	2.03±0.63 ^{cd}	0.225±0.02 ^e
KSM60		64.17±0.33 ^{ab}	-2.48±0.04 ^{ab}	3.47±0.41 ^{ab}	0.213±0.01 ^f
KPS20		61.35±0.48 ^{de}	-2.72±0.22 ^{bc}	1.70±0.63 ^{cde}	0.234±0.01 ^e
KPS60		65.26±0.51 ^a	-2.37±0.12 ^a	3.64±0.67 ^a	0.208±0.01 ^f
KSM20	10	63.32±1.25 ^{bc}	-2.67±0.16 ^{bc}	1.83±0.45 ^{cde}	0.304±0.01 ^b
KSM60		62.72±1.31 ^{cde}	-2.83±0.13 ^c	2.06±0.18 ^{cd}	0.294±0.01 ^c
KPS20		61.64±0.74 ^{cde}	-2.67±0.20 ^{bc}	1.89±0.79 ^{cde}	0.338±0.01 ^a
KPS60		63.94±0.39 ^{ab}	-2.38±0.14 ^a	3.44±0.38 ^{ab}	0.247±0.01 ^d
3 day					
KSM20	0	59.27±1.34 ^{cd}	-2.82±0.09 ^{bc}	0.31±0.37 ^{de}	0.044±0.01 ^k
KSM60		59.00±0.26 ^d	-3.00±0.15 ^{de}	-0.15±0.53 ^e	0.050±0.01 ^j
KPS20		59.97±1.17 ^{bcd}	-3.04±0.06 ^e	-0.95±0.33 ^f	0.060±0.01 ⁱ
KPS60		60.32±1.50 ^{bcd}	-2.79±0.07 ^b	0.78±0.18 ^{bcd}	0.064±0.01 ⁱ
KSM20	5	60.29±0.81 ^{bcd}	-2.85±0.02 ^{bcd}	0.46±0.16 ^{cde}	0.134±0.01 ^g
KSM60		60.06±0.85 ^{bcd}	-2.92±0.09 ^{bcd}	0.27±0.29 ^{de}	0.126±0.01 ^h
KPS20		59.84±0.26 ^{bcd}	-2.81±0.10 ^{bc}	1.14±0.84 ^{bc}	0.152±0.01 ^f
KPS60		61.99±0.82 ^a	-2.78±0.16 ^b	1.15±0.39 ^{bc}	0.203±0.01 ^d
KSM20	10	59.91±0.42 ^{bcd}	-2.92±0.09 ^{bcd}	1.54±0.36 ^b	0.228±0.01 ^c
KSM60		59.57±0.32 ^{bcd}	-2.99±0.05 ^{cd}	1.36±0.21 ^b	0.249±0.01 ^b
KPS20		60.88±0.22 ^{abc}	-2.94±0.08 ^{bcd}	1.43±0.26 ^b	0.260±0.01 ^a
KPS60		61.04±1.22 ^{ab}	-2.49±0.09 ^a	3.67±0.42 ^a	0.192±0.01 ^e

^{1)a-k} Different letters within the same column differ significantly ($p < 0.01$).

The turbidities of boiled water for noodles made from KPS20 and KPS60 were 0.083 and 0.088, respectively, which were higher than those of KSM20 or KSM60, and those for noodles made from KSM20, KSM60, KPS20, and KPS60 with 10 kGy irradiation were 0.304, 0.294, 0.338, and 0.247, respectively, demonstrating a dramatic increase with irradiation, regardless of treatment with N-fertilizer. Irradiation treatment has also been shown to increase the water solubility index of wheat flour (6), which could be attributed to breakage of the glycosidic bonds within starch and decreases in inter chain hydrogen bonds, contributing to increase polarity (35).

Textural profiles of cooked noodles made with treated wheat flour

Textural profiles of cooked noodles, including hardness, gumminess, chewiness, springiness, and cohesiveness are shown in Table 5. The hardness values of cooked noodles made from KSM20, KPS20, and KPS60 did not differ significantly; however, treatment with 10 kGy irradiation was decreased of hardness for all noodle samples. After 3 days of storage, the hardness, gumminess, and chewiness values of noodles made from KSM20, KSM60, KPS20, and KPS60 wheat flour were increased. Although γ -irradiation still decreased the hardness, gumminess, and chewiness of noodles after storage, the degree of decrease was small relative to the viscosity or GI of irradiated flour. The hardness (11.13 N) of noodle made with KSM 20 with exposure

to 10 kGy irradiation was highest among samples after 3 days of storage at 10°C. The gumminess and chewiness of noodles made with irradiated flour having higher protein content and WG were also higher. We considered that decreased hardness of fresh noodle and increased texture profiles of noodle during storage caused the changes of protein composition by γ -irradiation. The additional studies were needed to identified changes of protein composition by γ -irradiation. For shelf-life of fresh noodles, it was shorter than that of fried or dry noodles. Total aerobic, yeast and mold counts of pre-packed bread making wheat flour were reduced by the irradiation process (13). Our previous study indicated that the total aerobic bacteria and mold counts of noodle made with wheat flour were 2.48 and 2.75 log CFU/g, respectively. However, the total aerobic bacteria and mold counts of noodles made with irradiated wheat flour were 1.87 and 1.65 log CFU/g, respectively, after 3 days of storage at 10°C (data not shown). Total aerobic bacteria and mold counts of fresh noodle made with irradiated wheat were lower compared with noodle made with non-irradiated wheat flour. Liu *et al.* (35) demonstrated that the firmness, springiness, and chewiness of noodles made of ozone-treated wheat were higher than those of the control. In contrast, the firmness and stickiness of lasagna made with irradiated semolina was decreased with irradiation, possibly because of increased dextrin formation following irradiation (24).

Table 5. Texture profiles of cooked noodles made from wheat flour with N-fertilization and γ -irradiation during storage at 10°C

Samples	Irradiation dose (kGy)	Hardness (N)	Gumminess (N)	Chewiness (N)	Springiness	Cohesiveness
0 day						
KSM20	0	10.58±1.44 ^{ab1)}	4.40±1.20 ^{abc}	4.11±1.10 ^{abc}	0.94±0.02 ^a	0.41±0.06 ^{ab}
KSM60		10.43±0.81 ^{abc}	3.91±0.74 ^{bc}	3.68±0.81 ^{bc}	0.94±0.03 ^a	0.37±0.04 ^b
KPS20		10.79±0.90 ^{ab}	5.06±1.27 ^{ab}	4.67±1.24 ^{ab}	0.92±0.01 ^{ab}	0.46±0.08 ^{ab}
KPS60		11.34±0.02 ^{ab}	5.69±0.60 ^a	5.34±0.55 ^a	0.94±0.01 ^{ab}	0.50±0.05 ^a
5						
KSM20	5	10.19±0.68 ^{abc}	3.93±0.11 ^{bc}	3.67±0.10 ^{bc}	0.93±0.01 ^{ab}	0.39±0.03 ^b
KSM60		9.74±0.60 ^{bc}	4.11±0.87 ^{bc}	3.80±0.84 ^{bc}	0.93±0.02 ^{ab}	0.42±0.07 ^{ab}
KPS20		10.03±0.40 ^{bc}	4.20±0.56 ^{bc}	3.87±0.52 ^{be}	0.92±0.01 ^{ab}	0.42±0.04 ^{ab}
KPS60		11.74±0.66 ^a	5.31±0.24 ^{ab}	4.84±0.24 ^{ab}	0.91±0.02 ^b	0.45±0.05 ^{ab}
10						
KSM20	10	8.87±0.52 ^c	3.30±0.39 ^c	3.08±0.35 ^c	0.93±0.01 ^{ab}	0.37±0.04 ^b
KSM60		10.41±1.21 ^{abc}	4.47±0.90 ^{abc}	4.20±0.82 ^{abc}	0.94±0.01 ^{ab}	0.43±0.06 ^{ab}
KPS20		10.43±1.32 ^{abc}	3.98±0.47 ^{bc}	3.65±0.42 ^{bc}	0.92±0.01 ^{ab}	0.38±0.01 ^b
KPS60		10.38±0.45 ^{abc}	4.82±0.43 ^{ab}	4.52±0.37 ^{ab}	0.94±0.01 ^{ab}	0.46±0.04 ^{ab}
3 day						
0						
KSM20	0	11.45±0.44 ^{ab}	5.35±0.68 ^a	5.03±0.67 ^a	0.94±0.01 ^a	0.44±0.06 ^{ab}
KSM60		11.01±0.73 ^{abc}	5.66±0.35 ^a	5.30±0.29 ^a	0.94±0.01 ^a	0.52±0.06 ^a
KPS20		11.65±0.39 ^a	5.87±0.33 ^a	5.43±0.34 ^a	0.92±0.01 ^a	0.50±0.04 ^a
KPS60		11.58±0.48 ^a	5.70±0.46 ^a	5.27±0.51 ^a	0.92±0.02 ^a	0.49±0.05 ^a
5						
KSM20	5	10.86±0.42 ^{abcd}	3.49±0.06 ^d	3.20±0.07 ^c	0.92±0.01 ^a	0.32±0.02 ^c
KSM60		10.43±0.34 ^{bcd}	4.07±0.32 ^{bcd}	3.75±0.32 ^{bc}	0.92±0.02 ^a	0.39±0.02 ^{ab}
KPS20		10.59±0.65 ^{bcd}	4.09±0.13 ^{bcd}	3.78±0.16 ^{bc}	0.92±0.01 ^a	0.39±0.02 ^{ab}
KPS60		10.56±0.79 ^{bcd}	4.21±0.29 ^{bcd}	3.91±0.27 ^{bc}	0.93±0.02 ^a	0.40±0.06 ^{ab}
10						
KSM20	10	11.13±0.07 ^{abcd}	4.41±0.36 ^{bc}	4.11±0.39 ^b	0.93±0.01 ^a	0.40±0.03 ^{ab}
KSM60		10.47±0.18 ^{bcd}	3.64±0.54 ^d	3.36±0.47 ^c	0.93±0.02 ^a	0.35±0.05 ^c
KPS20		9.99±0.54 ^d	3.76±0.44 ^{cd}	3.52±0.43 ^{bc}	0.94±0.01 ^a	0.38±0.06 ^{ab}
KPS60		10.15±0.61 ^{cd}	4.56±0.21 ^b	4.19±0.25 ^b	0.92±0.01 ^a	0.45±0.01 ^{ab}

^{1)a-e} Different letters within the same column differ significantly ($p < 0.01$).

Additionally, Agúndez-Arvizu *et al.* (13) reported that the specific volume of Mexican bread did not differ when the bread was prepared with irradiated wheat flour.

In summary, our findings demonstrated that the physicochemical characteristics of wheat flour were influenced by N-fertilization and γ -irradiation. In particular, γ -irradiation increased the WHC, RS, WG, and DG of sample, but decreased the SB of samples in a dose-dependent manner. Consequently, wheat flour treated with N-fertilization and γ -irradiation may improve the quality of Korean-style noodles during storage.

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