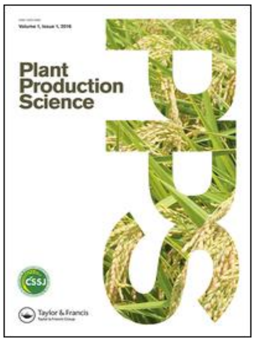

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Physicochemical Properties of Eight Popular Glutinous Rice Varieties in Korea

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Abstract: The physicochemical properties of eight popular glutinous rice varieties (Hwasunchal, Dongjinchal, Sangjuchal, Seolhyangchal, Jinbuchal, Sangnamchal, Hangangchal, Milyang-167) in Korea were evaluated. The starch granules in Seolyangchal, Sangnamchal, Hangangchal, and Milyang-167 rice showed greater crystallization than that of the other varieties, which were more loosely packed with larger air spaces in between granules. Dongjinchal rice showed lowest amounts of potassium and calcium with 44.51 and 3029.50 ppm, respectively. This variety also exhibited the highest sugar content with 1.30–16.82 μg g^{-1} and fastest hydrolysis rate of 771.5 mg g^{-1}. Sangnamchal, Sangjuchal, and Jinbuchal varieties showed abundant amounts of essential amino acids and highest pasting values (73.6°C, 3.0 min). On the other hand, lowest pasting values (69.6°C, 2.7 min) and total amino acid content of 452.61 ng mg^{-1} were observed in Milyang-167 rice. Hwasunchal and Sangnamchal samples contained the highest concentration of unsaturated fatty acids with 760 mg g^{-1} and lowest level of saturated fatty acids with 230 mg g^{-1}. The highest viscosity values were obtained in Hangangchal variety, while the lowest values were found in Jinbuchal sample. This study illustrates the wide variation in the physicochemical properties of the glutinous rice varieties analyzed. The results could serve as baseline information for the quality evaluation of rice with unique characteristics suitable for specialty food processing.

Key words: Chemical composition, Glutinous rice, Physical property, Rice endosperm.

Rice (*Oryza sativa* L.) is one of the leading food crops of the world and is the staple food of more than half of the world's population. Thousands of rice varieties are available throughout the world and glutinous rice (*Oryza sativa var. glutinosa*) is one of the most popular varieties. Commonly known as sticky or waxy rice, glutinous rice is a type of short- or long-grained rice that is especially sticky when cooked. It is used in preparing many kinds of traditional Asian desserts. The rice is often mildly sweetened during the cooking process, in which case it may be served as "sweet rice". It is also used in making rice wine, sushi, rice balls, and rice cakes (Wittenberg, 2007). Furthermore, waxy rice flour is utilized in various processed foods such as thickener for sauces and gravies, and as tenderizing agent in frozen foods (Hsieh and Luh, 1991; McKenzie, 1994).

Glutinous rice differs from other types of rice in that the grain starch contains essentially no amylose (0–2% dry basis) and high amount of amylopectin (Juliano, 1979), which is responsible for the sticky quality of cooked glutinous rice. The starchiness in sticky rice gives it a distinct opaque whiteness different from the more translucent appearance of regular rice grains (Wittenberg, 2007). However, sticky rice becomes translucent, while regular rice turns opaque white, when cooked. Despite the very low-amylose and high-amylopectin contents, each waxy rice variety gives different eating quality characteristics to the processed rice products (Kim et al., 1996; Keeratipibul et al., 2008). Such differences in the quality of rice products from waxy rices are correlated with other physicochemical characteristics such as alkali digestibility, gel consistency, and gelatinization temperature of the rice starch (Kim et al., 1996). Significant positive or negative correlations were found in water absorption rates of rice grain, physical properties of cooked rice, and viscogram characteristics of rice flour (Choi, 2002). The suitability of rice for processing various kinds of traditional rice foods is highly dependent on its grain and starch properties. It is therefore important to elucidate the physicochemical properties of glutinous rice in order to evaluate its potential uses and applications in food processing.

This study was conducted to characterize the physicochemical properties of glutinous rice varieties that are popular in Korea. Specifically, it aimed to compare the

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morphological characteristics, starch and flour properties, and nutritional quality among the glutinous varieties. The results of this study could serve as baseline information for the quality evaluation and selection of glutinous rice with unique characteristics suitable for specialty food processing.

Materials and Methods

1. Rice sample and preparation

Eight glutinous rice varieties (Hwasunchal, Dongjinchal, Sangjuchal, Seolhyangchal, Jinbuchal, Sangnamchal, Hangangchal, and Milyang-167) were obtained from Korea Rural Development Administration (RDA). They were all grown in Korea under the same cultivation conditions. The rice samples were milled using a testing rice miller (MC-90A, Toyo Co., Japan) and stored at -20ºC in brown glass bottles until used. Rice starch was prepared from the rice grains using the alkali method described by Yamamoto et al. (1973). Briefly, milled rice was steeped in 3–4 volumes of 50 mM lithium hydroxide solution at 4ºC for 12 hr to soften the endosperms. The liquid was drained and the endosperms were ground lightly with mortar and pestle. Isoamyl alcohol, acetone, and ethyl alcohol were added to eliminate protein and lipid of endosperm and the mixture was washed with distilled water. The precipitate was collected and dried in a cabinet dryer at 30ºC. The starch was stored in a desiccator until analysis.

2. Scanning electron microscopy

Rice grains were fractured in the midregion using a razor blade by applying slight pressure to the top of the grain. The fractured rice grains and rice starch samples were mounted on a circular aluminum specimen stub and gold-coated in a vacuum using sputter coater. The rice and starch granular structures in the center part of the grain were examined using an environmental scanning electron microscope (S-570, Hirachi, Japan) operating at 15 kV.

3. Mineral content analysis

A 1.2 g each of rice powder was placed in Teflon container and digested with 5 mL concentrated nitric acid at 100–150ºC. The residual acid was vaporized and 30 mL distilled water was added. Samples were analyzed using ICP (Optima 3200 RL). The amount of each trace element was measured based from the standard curve of standard minerals.

4. Determination of free amino acid composition

Rice endosperm samples were powdered and added to pyrolyzed borosilicate vial and dried under vacuum. Each vial was placed in a vacuum hydrolysis vessel with constant boiling 6 N HCl. After the vapor hydrolysis samples were dried, they were derivatized with methanol: H_2O: triethylamine:phenylisothiocyanate (7:1:1:1 v/v/v/v) and subjected to HPLC analysis. The HPLC (SMART/HPLC 1100, Amersham Pharmacia Biotech Inc., USA) was equipped with a variable wavelength detector (HP 1100 Series, 254 nm) and waters symmetry C_{18} column (4.6×250 mm, 5 μm). Samples were eluted with linear gradients using acetonitrile: H_2O (60:40 v/v) with a flow rate of 1 mL min^{-1}. The amino acids were quantified from HPLC chromatograms based on the peak area compared with that of the standard.

5. Determination of fatty acid composition

Rice grains were ground and 1 g of sample was mixed with chloroform:methanol (2:1 v/v) to obtain the lipid extracts (Folch et al., 1957). The fatty acid composition of the lipid extracts was determined according to the method described by Chung (1991). Briefly, the lipid extracts were saponified with 0.1 N potassium hydroxide in methanol at 70−75°C and followed by methanolysis with 1.2 M hydrochloric acid in methanol at the same temperature. The methyl esters of fatty acids were extracted with n-hexane prior to GC-MS analysis. The gas chromatograph (6890 plus, Hewlett Packard, Co., USA) was equipped with a DB-225 capillary column (30 m×0.25 mm×0.25 μm) and coupled with a mass spectrometer (JMS700, Jeol, Japan). The column temperature was held at 140ºC for 1 min, then increased up to 200ºC at a rate of 1ºC min^{-1}, and finally increased to 230ºC at a rate of 10ºC min^{-1} and held for 10 min. Helium was used as the carrier gas and the flow rate was 1 mL min^{-1}.

6. Analysis of non-starch polysaccharide

The sugar content of non-starch polysaccharide was determined by using the method described by Englyst et al. (1992) with some modifications. Powdered rice samples (200 mg) were added with 2 mL dimethyl sulfoxide and vortexed 2 or 3 times during 30-min period at boiling water bath. Termamyl:sodium acetate (0.6:100.0 v/v) solution (8 mL) was added and the mixture was transferred to a 50°C-water bath after 10-min standing. Pancreatin: H_2O: pullulanase solution (1.2:12.0:2.5 w/v/v) was added, followed by 40 mL absolute ethanol after 30 min. The mixture was transferred in ice-water for 30 min and centrifuged at 1500 g for 10 min. The clear supernatant liquid was added with 40 mL ethanol (85 mL L^{-1}) and 20 mL acetone, placed in a water bath (80ºC), and mixed to dryness. Sulfuric acid (5 mL, 12 M) was added to the residue and the mixture was kept at 35°C for 1 hr. Distilled water (25 mL) was rapidly added to the mixture and placed in boiling water bath for 1 hr. After cooling, allose internal standard (1 mg mL^{-1}) was added to 3 mL of the cooled hydrolysates and to 3 mL of standard sugar mixture. A 1-mL of ammonia solution (12.5 M) was added, followed by 5 μL of antifoam agent octan-2-ol and 0.2 mL of ammonia-sodium tetrahydroborate solution. The mixture was placed in water bath (40°C) for 30 min and added with 0.4 mL glacial acetic acid. A 0.5-mL of the sample mixture was placed into a 30-mL glass tube and mixed with 0.5 mL 1-methyl imidazole and 5 mL acetic anhydride. After 10 min, 0.9 mL of absolute ethanol and 0.5 mL bromophenol blue solution were added and mixed. The tubes were placed in ice-water and added with 5 mL potassium hydroxide (7.5 M). After 2 min, another 5 mL of potassium hydroxide was added and the solution was left standing until the separation into 2 phases was complete. The supernatant was analyzed using gas chromatography equipped with DB-225 capillary column and coupled to a mass spectrometer. The column was held at 150°C for 2 min, then increased up to 230°C at a rate of 4°C min^{-1} and held for 10 min. Helium was used as the carrier gas and the flow rate was 1 mL min^{-1}.

7. Enzymatic hydrolysis of rice starch

Starch samples (100 mg) were placed in 15-mL screw-cap tubes. Acetic acid (4 mL L^{-1}, pH 4.8) and 59.9 unit of 5 g L^{-1} amyloglucosidase (Fluka, Switzerland) were added. The mixture was incubated with constant shaking at 37°C for 3 hr. After the enzyme hydrolysis, 100 μL of aliquot was transferred to clean 15-mL tubes and was added with distilled water. The sample was boiled for 10 min. The total concentration of carbohydrates in the samples was determined using the phenol-sulfuric acid method described by Dubois et al. (1956). The absorbance was measured at 490 nm against a glucose standard. In addition, the concentration of the liberated glucose as a result of enzymatic hydrolysis was determined by measuring the absorbance at 525 nm following the glucose-oxidase peroxidase method (Lloyd and Whelan, 1969).

8. Analysis of pasting properties of rice flour

The pasting properties of rice flour samples were measured using a Rapid Visco Analyzer (RVA, Newport, Australia). Three grams of flour slurry (130 mg g^{-1} dry basis, 2.5 mL deionized water) was placed in a disposable aluminum canister. The slurry was first held at 50°C for 1.5 min, heated to 95°C at a rate of 1°C min^{-1} and held for 2 min, and cooled to 50°C at a rate 12°C min^{-1} and held for 1.5 min. The temperature corresponding to the initial increase in viscosity was designated as the pasting temperature. Viscosity parameters (peak, trough, final, breakdown, and set back viscosity) were expressed in centipoises.

9. Statistical analysis

All experiments were done in triplicate (n=3) and the data obtained were analyzed statistically using the Statistical Analysis System for Windows V8. Analysis of variance and Duncan's multiple range test were employed.

Results and Discussion

1. Morphological properties

The scanning electron micrographs of the center of rice grains from eight glutinous varieties are shown in Fig. 1. The endosperms of the rice samples have relatively similar morphology when viewed under the scanning electron microscope. The endosperm region is composed of cell wall materials and starch granules that clustered into amyloplasts or compound starch granules. A closer observation on the starch granules revealed that the starch was mainly composed of polyhedral and irregular-shaped granules (Fig. 2), which is typical of many rice starches. Starches from Dongjinchal, Sangnamchal, Hangangchal, and Milyang-167 varieties were mostly composed of large polyhedral granules with few small and irregular granules, while the rest of the varieties consisted mainly of smaller polyhedral granules. It was also noted that the starch granules in Seolhyangchal, Sangnamchal, Hangangchal, and Milyang 167 appeared to have greater crystallization than that of the other varieties analyzed, which were more loosely packed with larger air spaces between granules. These variations in starch granule morphology may be due to the biological origin and physiology of rice. Furthermore, variations in the amylose and amylopectin contents of rice could also affect the starch granule size and shape of the samples (Svegmark and Hermansson, 1993).

2. Mineral content

Potassium (K), magnesium (Mg), and calcium (Ca) are the most abundant minerals found in rice (Rivero-Huguet, 2007). While these minerals are important for human health, Ca and K were reported to have negative effects on the overall palatability of rice (Horino and Okamoto, 1992). In this study, Dongjinchal variety showed the lowest K and Ca contents with 44.51 and 3029.50 ppm, respectively, while Jinbuchal rice contained the highest amount of K with 137.65 ppm (Table 1). Sangjuchal exhibited abundant amount of Ca with 3716.00 ppm but the least Mg content with 1302.00 ppm among the samples analyzed. Hwasunchal and Hangangchal varieties showed highest amount of Mg with 1584.00–1592 ppm. Results of this study suggest that Dongjinchal, with low amount of Ca and K and relatively high amount of Mg, has the best eating quality among the varieties analyzed.

3. Free amino acid composition

Protein is the most abundant component in rice grain next to starch (Xie et al., 2008) and its nutritional quality depends on its amino acid composition and digestibility. The amino acid composition of glutinous rice samples are shown in Table 2. Significant variations in amino acid concentrations were obtained among the varieties

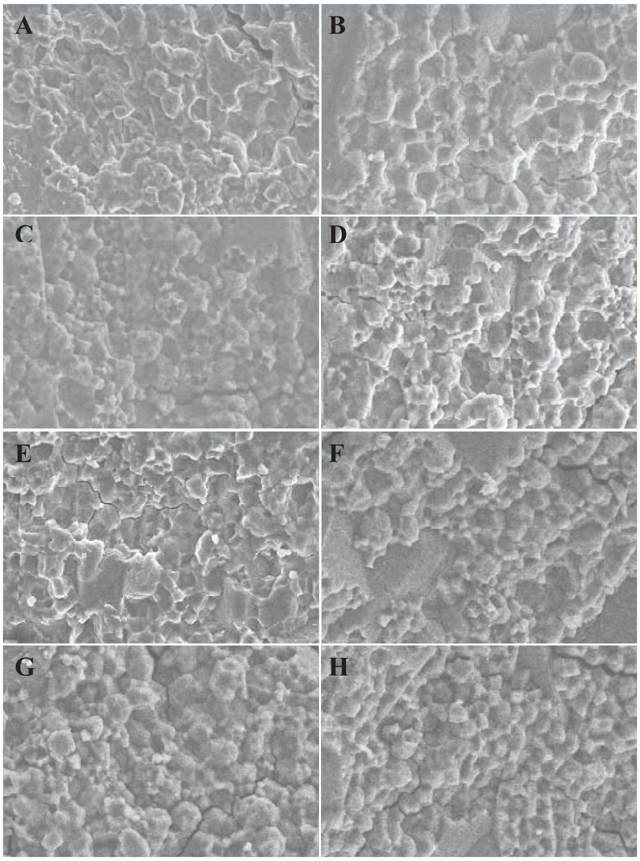

Fig. 1. Scanning electron micrographs of cross-sectioned glutinous rice grains (×1000): (A) Hwasunchal, (B) Dongjinchal, (C) Sangjuchal, (D) Seolhyangchal, (E) Jinbuchal, (F) Sangnamchal, (G) Hangangchal and (H) Milyang-167.

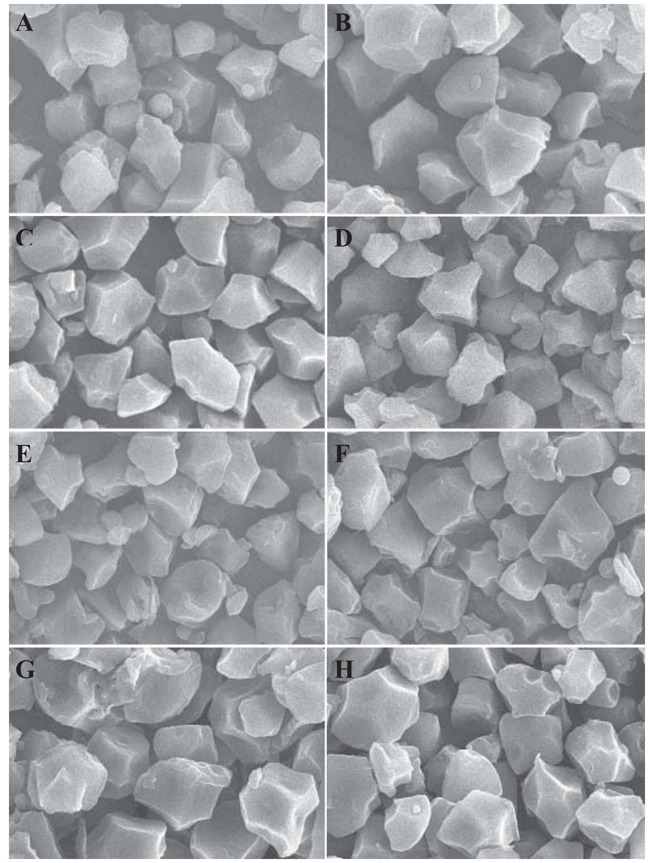

Fig. 2. Scanning electron micrographs of glutinous rice starches (×5000): A) Hwasunchal, (B) Dongjinchal, (C) Sangjuchal, (D) Seolhyangchal, (E) Jinbuchal, (F) Sangnamchal, (G) Hangangchal and (H) Milyang-167.

Table 1. Mineral content (ppm)[1] of glutinous rice.

Rice variety	K	Ca	Mg
Hwasunchal	117.55±0.49[g]	3631.00±1.41[f]	1592.50±9.19[f]
Dongjinchal	44.51±0.02[a]	3029.50±2.12[a]	1522.00±2.82[d]
Sangjuchal	87.39±0.04[c]	3716.00±2.82[g]	1302.00±4.24[a]
Seolhyangchal	113.20±0.14[f]	3633.00±3.76[f]	1405.00±0.70[c]
Jinbuchal	137.65±0.21[h]	3597.50±2.12[e]	1573.50±0.70[e]
Sangnamchal	105.40±0.28[e]	3555.50±0.70[d]	1364.50±2.12[b]
Hangangchal	73.95±0.01[b]	3466.50±2.12[c]	1584.00±1.41[f]
Milyang-167	95.28±0.02[d]	3259.00±1.41[b]	1529.50±2.11[d]

[1]Values are means of three replications±standard deviation. Means followed by different superscripts within the column are significantly different ($P<0.05$).

analyzed. Highest amount of total amino acids was observed in Sangnamchal variety with 745.65 ng mg^{-1}, followed by Seolhyangchal and Hwasunchal with 720.60 and 714.40 ng mg^{-1}, respectively. On the other hand, Milyang-167 contained the lowest total amino acid content with 452.61 ng mg^{-1}. Among the amino acids, glutamic (102.60–171.04 ng mg^{-1}), asparagine (48.33–182.33 ng mg^{-1}), and aspartic (65.84–115.66 ng mg^{-1}) acids were the most abundant in all the samples, while tryptophan is the limiting one. High amounts of essential amino acids were found in Sangjuchal, Jinbuchal, and Sangnamchal varieties. However, Milyang-167 showed the least concentrations of valine, leucine, phenylalanine, and lysine. With regards to non-essential amino acids, Sangnamchal variety also exhibited considerably higher asparagine, serine, histidine, and alanine contents

Table 2. Free amino acid composition (ng mg^{-1})[1] of glutinous rice.

Amino Acid	Hwasunchal	Dongjinchal	Sangjuchal	Seolhyangchal	Jinbuchal	Sangnamchal	Hangangchal	Milyang-167
CYS	6.39±0.06^{c}	4.58±0.00^{b}	8.49±0.01^{g}	6.97±0.00^{d}	8.02±0.02^{f}	7.22±0.01^{e}	4.53±0.04^{b}	4.37±0.07^{a}
ASP	106.96±0.12^{g}	91.26±0.05^{f}	85.56±0.04^{c}	115.66±0.02^{h}	89.11±0.19^{e}	65.84±0.19^{a}	71.47±0.55^{b}	86.81±0.06^{d}
GLU	159.25±0.43^{g}	149.13±0.27^{e}	151.84±0.05^{f}	171.04±0.04^{h}	144.94±0.05^{d}	143.34±0.70^{c}	112.66±0.32^{b}	102.60±0.09^{a}
ASN	113.26±0.07^{e}	48.33±0.24^{a}	115.45±0.63^{f}	101.85±0.00^{c}	83.73±0.39^{b}	182.33±0.29^{h}	140.82±0.30^{g}	108.55±0.60^{d}
SER	39.60±0.77^{e}	24.98±0.16^{c}	39.35±0.14^{e}	37.45±0.07^{d}	36.93±0.14^{d}	42.79±0.31^{f}	18.40±0.45^{b}	16.27±0.25^{a}
GLN	12.11±0.01^{d}	7.62±0.02^{a}	20.30±0.07^{g}	11.64±0.03^{c}	37.61±0.03^{h}	14.19±0.00^{f}	9.54±0.02^{b}	12.73±0.35^{e}
GLY	30.43±0.77^{f}	17.09±0.12^{b}	27.17±0.05^{e}	25.06±0.05^{d}	21.02±0.03^{c}	26.88±0.11^{e}	16.62±0.50^{b}	14.49±0.24^{a}
HIS	19.57±0.60^{f}	7.83±0.09^{a}	17.51±0.03^{d}	18.14±0.08^{e}	23.03±0.07^{g}	29.70±0.03^{h}	12.62±0.08^{c}	11.74±0.16^{b}
ARG	55.42±0.33^{e}	30.49±0.67^{c}	59.77±0.10^{g}	63.42±0.42^{h}	58.92±0.03^{f}	50.46±0.06^{d}	23.87±0.27^{b}	17.32±0.15^{a}
THR	15.86±0.03^{e}	7.96±0.02^{a}	16.42±0.04^{f}	15.82±0.07^{e}	13.35±0.06^{d}	15.75±0.07^{e}	9.63±0.02^{c}	9.19±0.05^{b}
ALA	66.15±0.36^{e}	38.43±0.02^{c}	65.27±0.17^{d}	67.31±0.16^{f}	65.22±0.74^{d}	70.37±0.04^{g}	28.78±0.37^{b}	22.45±0.33^{a}
PRO	35.39±0.58^{g}	14.96±0.02^{c}	23.64±0.04^{e}	25.17±0.07^{f}	21.30±0.20^{d}	25.14±0.09^{f}	10.49±0.06^{b}	109.70±0.02^{a}
TYR	13.33±0.02^{d}	8.01±0.07^{b}	14.44±0.04^{f}	15.88±0.06^{h}	14.21±0.05^{e}	15.73±0.05^{g}	8.25±0.04^{c}	5.87±0.08^{a}
VAL	16.02±0.03^{d}	11.85±0.12^{c}	16.20±0.07^{d}	16.36±0.08^{d}	16.52±0.69^{d}	18.19±0.29^{e}	10.66±0.02^{b}	9.82±0.01^{a}
MET	3.77±0.02^{a}	4.37±0.01^{c}	4.86±0.04^{e}	4.20±0.07^{b}	6.44±0.06^{h}	5.43±0.04^{f}	5.93±0.04^{g}	4.48±0.02^{d}
ILE	4.47±0.02^{a}	4.75±0.05^{b}	6.18±0.05^{d}	5.31±0.01^{c}	6.43±0.04^{e}	6.97±0.04^{f}	4.70±0.28^{ab}	4.75±0.01^{b}
LEU	4.95±0.01^{b}	5.07±0.07^{c}	5.93±0.02^{e}	5.68±0.05^{d}	8.57±0.04^{g}	7.51±0.01^{f}	3.88±0.00^{a}	3.83±0.01^{a}
PHE	5.23±0.03^{b}	5.75±0.01^{d}	5.57±0.04^{c}	5.22±0.03^{b}	7.23±0.04^{f}	6.98±0.09^{e}	3.84±0.02^{a}	3.79±0.01^{a}
TRP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LYS	6.20±0.07^{d}	4.898±0.02^{b}	1.55±0.05^{f}	8.22±0.04^{e}	13.41±0.04^{h}	10.79±0.07^{g}	5.51±0.22^{c}	3.83±0.02^{a}
Total	714.40±0.35^{f}	487.39±0.61^{b}	694.52±0.50^{e}	720.60±0.34^{g}	676.34±0.31^{d}	745.65±0.19^{h}	502.25±0.72^{c}	452.61±0.46^{a}

[1]Values are means of three replications ± standard deviation. Means followed by different superscripts within the row are significantly different ($P<0.05$).

Table 3. Fatty acid composition (mg g^{-1})[1] of glutinous rice.

Fatty acid Composition	Hwasunchal	Dongjinchal	Sangjuchal	Seolhyangchal	Jinbuchal	Sangnamchal	Hangangchal	Milyang-167
Myristic acid, $C_{14:0}$	5.9^{a}	7.3^{b}	8.4^{b}	5.5^{a}	7.9^{b}	7.9^{b}	10.3^{c}	8.7^{b}
Palmitic acid, $C_{16:0}$	206.4^{ab}	225.0^{ab}	222.4^{ab}	220.0^{ab}	220.4^{ab}	196.4^{a}	248.6^{b}	251.6^{b}
Palmitoleic acid, $C_{16:1}$	1.6^{b}	1.2^{a}	1.6^{b}	1.4^{ab}	1.4^{ab}	1.4^{ab}	1.1^{a}	1.1^{a}
Stearic acid, $C_{18:0}$	21.3^{a}	22.5^{a}	21.6^{a}	23.8^{a}	32.8^{b}	25.6^{ab}	20.1^{a}	19.8^{a}
Oleic acid, $C_{18:1}$	393.1^{de}	373.8^{bcd}	361.3^{abc}	383.1^{cde}	349.8^{ab}	408.9^{e}	358.0^{abc}	343.9^{a}
Linoleic acid, $C_{18:2}$	349.6^{a}	350.3^{a}	360.0^{a}	344.1^{a}	363.4^{a}	339.0^{a}	343.0^{a}	351.2^{a}
Linolenic acid, $C_{18:3}$	12.4^{b}	12.9^{b}	14.4^{c}	10.3^{a}	14.2^{c}	12.9^{b}	12.0^{b}	15.8^{d}
Arachidic acid, $C_{20:0}$	5.5^{bcd}	3.7^{a}	6.0^{cd}	6.5^{a}	6.6^{d}	4.6^{abc}	3.9^{ab}	4.8^{abc}
Gadoleic acid, $C_{20:1}$	4.1^{bc}	2.9^{ab}	4.0^{bc}	4.9^{c}	3.2^{ab}	3.2^{ab}	2.6^{a}	3.0^{ab}

[1]Values are means of three replications. Means followed by different superscripts within the row are significantly different ($P<0.05$).

compared with the other varieties. On the other hand, aspartic, glutamic, arginine, and tyrosine were abundant in Seolhyangchal variety. These findings indicate that Sangnamchal and Seolhyangchal have superior nutritional quality to the other glutinous varieties in terms of amino acid composition.

4. Fatty acid composition

As shown in Table 3, the major fatty acids in the rice samples analyzed were oleic, linoleic, and palmitic acids. These three fatty acids accounted for about 94% of the total fatty acid content in the samples. Similarly, Kitta et al. (2005) and Taira and Maeshige (1979) reported that oleic, linoleic, and palmitic acids were the main fatty acids in non-glutinous rice varieties in Japan. A slight variation was

Table 4. Sugar content (μg g^{-1})[1] of non-starch polysaccharide in glutinous rice.

Rice variety	Rhamnose	Fucose	Ribose	Arabinose	Xylose
Hwasunchal	6.70 ± 0.10^g	5.30 ± 0.07^g	1.01 ± 0.03^f	13.36 ± 0.51^g	1.41 ± 0.05^g
Dongjinchal	8.56 ± 0.05^h	6.49 ± 0.11^h	2.52 ± 0.05^h	16.82 ± 0.18^h	1.30 ± 0.03^f
Sangjuchal	4.22 ± 0.05^f	3.70 ± 0.04^f	1.10 ± 0.03^g	9.08 ± 0.11^f	0.49 ± 0.02^b
Seolhyangchal	0.11 ± 0.00^b	0.11 ± 0.00^b	0.01 ± 0.00^a	0.19 ± 0.01^a	0.53 ± 0.02^c
Jinbuchal	0.49 ± 0.02^c	0.45 ± 0.02^c	0.14 ± 0.01^d	1.05 ± 0.03^c	0.37 ± 0.01^a
Sangnamchal	0.65 ± 0.02^d	0.54 ± 0.02^d	0.12 ± 0.01^c	1.30 ± 0.03^d	0.62 ± 0.02^e
Hangangchal	0.98 ± 0.03^e	0.73 ± 0.05^e	0.19 ± 0.01^e	2.16 ± 0.04^e	0.53 ± 0.02^c
Milyang-167	0.08 ± 0.00^a	0.07 ± 0.00^a	0.03 ± 0.00^b	0.23 ± 0.01^b	0.56 ± 0.02^d

[1]Values are means of three replications ± standard deviation. Means followed by different superscripts within the column are significantly different ($P<0.05$).

found in the fatty acid compositions among samples. Sangnamchal and Hwasunchal exhibited oleic acid contents of 408.9 and 393.1 mg g^{-1}, which were significantly higher than that of the other varieties. Hangangchal and Milyang-167 varieties contained the highest amounts of myristic acid with 10.3 mg g^{-1} and linolenic acid with 15.8 mg g^{-1}. Furthermore, these two varieties exhibited significantly higher palmitic acid content with 248.6–251.6 mg g^{-1} compared with Sangnamchal rice with only 196.4 mg g^{-1}. On the other hand, no significant difference was found in the linoleic acid content among samples. The results illustrate that the fatty acid composition in rice varies depending on the variety. In general, Hangangchal and Milyang-167 exhibited higher level of saturated (280 mg g^{-1}) and lower level of unsaturated (710 mg g^{-1}) fatty acids compared with the other varieties. Hwasunchal and Sangnamchal, on the other hand, showed the highest amount of unsaturated fatty acids with 760 mg g^{-1} and lowest saturated fatty acid content with 230 mg g^{-1}.

5. Sugar content of non-starch polysaccharide

The sugar content of the non-starch polysaccharide composition of the rice samples are presented in Table 4. Large variations were also found in the sugar content among the glutinous rice samples analyzed. Arabinose is the most abundant sugar in all the samples with concentrations ranging from 0.19–16.82 μg g^{-1}, followed by rhamnose with 0.08–8.56 μg g^{-1} and fucose with 0.07–6.49 μg g^{-1}. These three sugars, as well as arabinose, were found in highest amounts in Dongjinchal variety. Xylose concentration, on the other hand, was highest in Hwasunchal variety with 1.41 μg g^{-1}. Milyang-167 rice exhibited the lowest rhamnose and fucose contents, with 0.08 and 0.07 μg g^{-1}, respectively, whereas Seolhyangchal contained the least amounts of ribose with 0.01 μg g^{-1} and arabinose with 0.19 μg g^{-1}.

6. Hydrolysis rate

The hydrolysis rate of starch after 3 and 6 hr significantly differs among the varieties analyzed (Table 5). The rate of hydrolysis after 3 hr was fastest in Dongjinchal and Jinbuchal with 573.2 and 558.0 mg g^{-1}, respectively, whereas Hangangchal showed the lowest hydrolysis rate with 328.1 mg g^{-1}. After 6 hr, Dongjinchal still exhibited the highest hydrolysis rate with 771.5 mg g^{-1}, followed by Milyang-167 with 763.6 mg g^{-1}. On the other hand, a relatively lower hydrolysis rate of 620.3 mg g^{-1} was found in Sangjuchal variety. No significant difference in the hydrolysis rate was found among Seolhyangchal, Jinbuchal, and Sangnamchal varieties after 6 hr. These findings suggest that among the samples analyzed, Dongjinchal variety is the most digestible as manifested by its fast hydrolysis rate.

Table 5. Hydrolysis rate of glutinous rice starches using glucoamylase.

Rice variety Variety	Hydrolysis rate (mg g^{-1})[1]	
	3 hr	6 hr
Hwasunchal	467.2 ± 19.7^d	664.8 ± 15.8^b
Dongjinchal	573.2 ± 21.1^f	771.5 ± 7.2^d
Sangjuchal	460.0 ± 4.1^d	620.3 ± 11.7^a
Seolhyangchal	410.1 ± 5.7^b	711.5 ± 13.9^c
Jinbuchal	558.0 ± 2.3^f	715.5 ± 20.8^c
Sangnamchal	530.2 ± 2.0^e	711.8 ± 1.2^c
Hangangchal	328.1 ± 11.0^a	647.0 ± 25.5^b
Milyang-167	432.6 ± 4.9^c	763.6 ± 15.9^d

[1]Values are means of three replications±standard deviation. Means followed by different superscripts within the column are significantly different ($P<0.05$).

7. Pasting properties

The pasting and viscosity values of different glutinous rice flours are shown in Table 6. The pasting properties are important indicators in determining the application values of flours and starches. Kang et al. (2006) reported that flour from glutinous rice varieties tend to exhibit lower pasting temperature compared to non-glutinous ones. In

Table 6. Pasting properties[1] of glutinous rice flours using rapid visco analyzer.

Rice variety	Pasting temperature (°C)	Pasting time (min)	Viscosity (cP)			
			Peak	Trough	Final	Breakdown
Hwasunchal	72.12±0.03[d]	2.87±0.00[c]	1133±1[e]	530±2[e]	666±2[e]	604±1[d]
Dongjinchal	69.77±0.03[b]	2.67±0.00[a]	1096±0[d]	460±4[c]	592±13[c]	636±4[e]
Sangjuchal	73.54±0.00[f]	2.99±0.00[e]	750±8[b]	360±1[b]	488±1[b]	390±9[b]
Seolhyangchal	72.82±0.04[e]	2.92±0.00[d]	1554±5[f]	822±2[g]	1026±1[g]	733±3[f]
Jinbuchal	73.57±0.04[f]	2.99±0.00[e]	494±1[a]	250±1[a]	361±1[a]	244±2[a]
Sangnamchal	73.61±0.01[f]	3.00±0.00[e]	948±5[c]	488±1[d]	634±1[d]	460±4[c]
Hangangchal	70.29±0.07[c]	2.72±0.01[b]	1974±6[h]	852±9[h]	1077±7[h]	1122±4[h]
Milyang-167	69.61±0.02[a]	2.67±0.00[a]	1805±1[g]	748±2[f]	942±1[f]	1058±4[g]

[1]Values are means of three replications±standard deviation. Means followed by different superscripts within the column are significantly different ($P<0.05$).

this study, a slight variation in the pasting properties was observed among the samples. Significantly higher pasting temperature and time of 73.6°C and 3.0 min, respectively, were observed in Sangjuchal, Jinbuchal and Sangnamchal varieties than that of the other samples. Lowest pasting values (69.6°C, 2.7 min) were found in Milyang-167 rice. With regards to viscosity parameters, highest peak (1974 cP), trough (852 cP), final (1077 cP), and breakdown (1122 cP) viscosities were obtained in Hangangchal rice, while the lowest viscosity values were recorded in Jinbuchal sample. The high breakdown viscosity of starch granules demonstrates the ease of these granules to be broken upon heating after the maximum swelling at the peak viscosity. Glutinous rice possesses this property which results in the stickiness of the paste.

Conclusion

The present study illustrated that the physicochemical properties significantly differ among the popular Korean glutinous rice varieties. Screening of physicochemical properties is necessary for quality evaluation and possible food industry applications of rice. The suitability of a particular rice cultivar for processing various kinds of traditional rice foods has been shown to be related to the grain properties (Choi et al., 1999). In addition, the quality of rice products made from glutinous varieties will greatly depend on the physicochemical properties, such as digestibility, pasting characteristics, mineral and sugar contents, and amino acid and fatty acid compositions, of the rice used. The results of this study could serve as basis for food processors in selecting glutinous rice with unique characteristics suitable for the intended specialty food. Furthermore, this could help plant breeders on how to continually refine and improve genetic traits of new varieties with the most desirable eating qualities.

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* In Korean with English abstract.
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