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ORIGINAL ARTICLE

Physicochemical Properties of Low-Phytate Rice Cultivar, Sang-gol

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Abstract Phytic acid in grains affects the bioavailability of minerals and nutrients in monogastric animals. Physicochemical properties of Sang-gol, a low-phytate rice cultivar developed to decrease anti-nutrient effect of phytic acid, were compared with those of its parent rice cultivar Il-pum. The amylose content of Sang-gol was lower, but its crude protein content was not significantly different compare with Il-pum. Texture profiles of cooked rice, except for hardness, adhesiveness and chewiness, did not show any differences. The hardness, adhesiveness and chewiness of the Sang-gol were lower than that of Il-pum. Pasting characteristics, peak viscosity, trough, and final viscosity of Sang-gol were higher, and breakdown was lower, as compared to Il-pum. Setback of Il-pum was significantly (p <0.01) lower than Il-pum. The pasting temperatures of Sang-gol and Il-pum were very similar (68.1 and 68.0°C), respectively.

Keywords low phytate rice · physicochemical · Sang-gol

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Introduction

Grains store phosphorus in the form of phytic acid (*myo*-inositol 1,2,3,4,5,6-hexa*kis*phosphate), which accounts for 50–80% of total phosphorus. Phytic acid accounts for 1–2% of the dry weight of grains. During sprouting, it is degraded into inorganic phosphate and provides myo-inositol and mineral cations used for growth (Ockenden et al., 2004). The complex of phytic acid and mineral elements, in the form of phytin, results in a marked reduction in bioavailability of nutrients for humans and other monogastric animals by altering the solubility, chemical properties, digestion, and absorption of minerals (Leytem et al., 2007). Phytate-induced low nutrient uptake can contribute to the major public health problems of iron and zinc deficiencies in populations relying on grains and legumes (Raboy, 2001).

Rice is one of the three major food crops and accounts for 60% of the crop production in Asia. Ninety percent of the world's rice is produced in Asia. Rice supplies 23% of the food energy and 16% of the protein worldwide and is also a major source of micronutrients, such as iron, zinc, calcium, and vitamins (Liang et al., 2009). In areas where rice is a staple food, many people suffer from iron and zinc deficiencies, especially in children and pregnant women (Bilgicli et al., 2006). Therefore, researchers had been investigating methods to reduce the level of phytic acid and to ameliorate the mineral utilization rate. Many artificial methods have been developed to improve the nutritional value of rice, including selection of high mineral rice cultivars or low-anti-nutritional factor cultivars (Liang et al., 2007), minimization of mineral loss through dry friction polishing (Liang et al., 2008), introduction of a fungi-derived phytase gene into rice cultivars, which is expressed during growth and aids in the degradation of phytic acid during digestion in the animal intestine (Ye et al., 2000), and the reduction of phytic acid through wet processing. We recently reported the development of an Il-pum-derived low-phytate rice cultivar, Sang-gol, which was generated by treating an Il-pum fertilized egg with *N*-methyl-*N*-nitrosourea (Ham et al., 2007); Sang-gol showed 50% lower level of phytic acid compared with its parent cultivar, Il-pum. In addition, no differences on agricultural characteristics were observed between these two cultivars (Li et al., 2008). The objective of the present study was to provide basic information on new applications, usages, and processes for Sang-gol by analyzing physicochemical properties and pasting characteristics.

Materials and Methods

Low phytic acid mutant cultivar, Sang-gol and its parent cultivar, Il-pum were cultivated on farmland of Kangwon National University in 2007, harvested, and stored at low temperature. The milled rice was used.

Scanning electron microscopy (SEM). Scanning electron micrographs were obtained with a scanning electron microscope (ISI-SS130, Akashi, Japan). Translucent and chalky grain flour was suspended in ethanol to obtain a 1% suspension. One drop of flour-ethanol solution was applied on an aluminum stub, and the flour was coated with gold-palladium (60:40). An accelerating potential of 5000 V was used during micrography.

Chemical properties. Amylose content of the powdered samples from the two cultivars was determined following the method of Juliano (1979). Flour samples were also evaluated for their crude protein content (N × 5.95) using American Association of Cereal Chemists (2000) methods.

Textural analysis. Textural properties of the milled rice were determined with a textural analyzer (TA-XT2, Stable Microsystem Ltd, Godalming, UK). A stainless steel cylinder with 40 mm diameter was used to conduct the back extrusion test. Cooked rice samples (50 g each) were cooled to room temperature, placed inside the test cylinder, and pressed with 150 g weight for 30 s before conducting the test. A 20-mm diameter ebonite probe was used to compress grains at test speed of 1.0 mm/s. The textural parameters of hardness (height of the force peak on cycle 1), adhesiveness (negative force area of cycle 1), springiness, cohesiveness (ratio of the positive force areas of cycles 1 and 2), gumminess (hardness × cohesiveness), chewiness, and resilience were computed using the Texture Expert software supplied with the instrument. All textural analyses were replicated ten times, and results were presented as mean values.

Viscoamylography. The rice flour pasting properties were determined using a Rapid Visco Analyzer (RVA, Model 3D, Newport Scientific Pty, Ltd., Warriewood, Australia) with the Thermocline software program for Windows and following the AACC protocols (2000). Rice samples were first milled to white rice using a Satake Rice Machine (Satake Corporation, Hiroshima, Japan), and then ground to flour with a Cyclone Sample Mill (UDY Corporation, Fort Collins, CO) and sieved through a 100-mesh. Three grams flour of each sample was weighed into an aluminum canister when the samples achieved 14% moisture, to which 25 mL distilled water was added. A paddle was placed in the canister, and its blade was vigorously jogged up and down through the sample for ten times. The idle temperature was set at 50°C, and the following 12.5-min test profile was performed: held at 50°C for 1.0 min, linearly increased to 95°C in 3.8 min, held at 95°C for 2.5 min, linearly increased to 50°C in 3.8 min, and held at 50°C for 1.4 min. The peak, holding, and final viscosities, and pasting temperature were determined using the analysis Window of the Thermocline software program (Newport Scientific Pty. Ltd.). RVA instrument provided the following parameters: peak viscosity (PV), the highest viscosity during “heating”; trough (T), the lowest viscosity following the PV; breakdown (BD), PV minus T; final viscosity (FV), the viscosity at the completion of the cycle; and setback (SB), FV minus PV. The viscosity values were shown as RVU units.

Statistical analysis. Data represent averages of triplicate observations unless otherwise stated. Pearson correlation coefficients for relationships between various flour properties and the factor analysis were determined with the SAS Enterprise Guide 3.0 (SAS Institute Inc., Cary, NC) program.

Results and Discussion

Phytic acid is a constituent of plant seeds and chelates Ca^{++}, Fe^{++}, and Zn^{++}, which affect the mineral utilization rate of human and other monogastric animals (Leytem et al., 2007). Low phytate content crop lines, such as corn (Raboy et al., 2001), rice (Raboy et al., 2001), barley (Dorsch et al., 2003), soybean (Yuan et al., 2009), and wheat (Guttieri et al., 2004), had been developed to remedy this anti-nutritional effect and to enhance the metabolic utilization rate of minerals. Sang-gol is a high-yield and medium-late maturity cultivar breed from the mutation of Il-pum was treated with *N*-methyl-*N*-nitrosourea to develop the mutant low phytic acid cultivar, Sang-gol (Ham et al., 2007; Li et al., 2008). The parent rice cultivar Il-pum possesses low amylose levels and a low viscosity temperature and is characterized by glossiness, fluffiness, and a good palate (Choi, 2002). In the present study, the physicochemical properties of Sang-gol and Il-pum were compared and investigated as to how the mutation affects the palate of the cooked rice.

The external characteristics of polished rice of the cultivars Sang-gol and Il-pum are shown in Fig. 1. The grain surfaces of both cultivars were transparent and smooth. The grain size of Sang-gol (brown, 4.84 mm × 3.14 mm; milled, 4.69 mm × 2.82 mm, L × W) was slightly smaller than that of Il-pum (brown, 5.32 mm × 3.18 mm; milled, 5.06 mm × 2.98 mm, L × W). The optical microphotographs and SEM photographs of the Sang-gol and Il-pum samples are shown in Fig. 2. The structure of the Il-pum

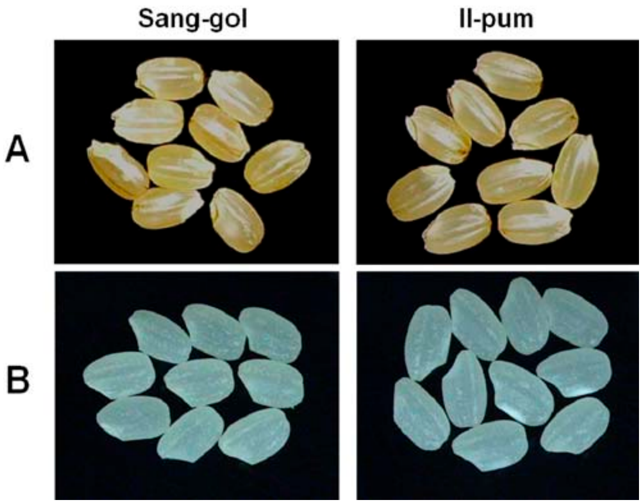

Fig. 1 External characteristics of brown rice and polished rice of Sang-gol and Il-pum. A, Brown rice; B, Polished rice.

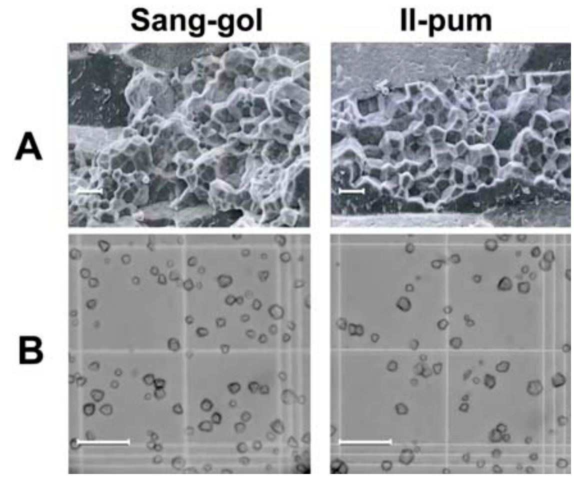

Fig. 2 Structures of rice starch. A, Scanning Electron Microphotographs of rice cultivars (×5000 magnification), scale bar indicates 10 μm; B, Optical microphotograph of rice cultivars (×100 magnification), scale bar indicates 25 μm.

starch granule was a polyhedron with pronounced edges compared to that of the Sang-gol starch granule. The optical microphotographs and SEM images also showed a reduced the granule size of the Sang-gol (4.33 μm) compared to that of Il-pum (5.25 μm).

The amylose and protein contents are one of the most important parameters that determine the taste and cooking quality of rice. The amylose level in Sang-gol was 18.6%, which was lower than the 19.8% level in Il-pum, and the crude protein contents were not significantly different in Sang-gol and Il-pum (6.81 and 6.78%, respectively) (Table 1).

The texture profiles of Sang-gol and Il-pum are showed in Table 2. The hardness, adhesiveness, and chewiness of Sang-gol were slightly lower than those of Il-pum, but with no statistically significant differences, and other texture profiles also showed no significant differences. Rice texture is affected by multiple factors; cooked rice with low amylose is soft and sticky, whereas rice with high amylose is firm and fluffy. Lyon et al. (2000) reported that sensory properties related to stickiness had statistically significant correlation coefficients with amylose and protein contents. Most hardness indices are positively correlated with amylose content, whereas indices of stickiness are negatively correlated with amylose content. Other important sensory textural characteristics, such as mouthfeel properties of residual loose particles, toothpack, and starchy mouthcoating showed significant correlation coefficients with protein content. According to these results, Sang-gol cooked rice, which is soft, sticky, and less chewy, showed significantly lower amylose content and hardness as compared to Il-pum. However, no difference in cohesiveness was observed, because the protein contents were not different between Sang-gol and Il-pum cooked rice.

Table 1 Chemical properties of Sang-gol and Il-pum cultivars

Cultivars	Amylose (%)	Protein (%)
Sang-gol	18.6±0.49**	6.78±0.04
Il-pum	19.8±0.18	6.81±0.05

The quantitative data are presented as means ± SD of three independent experiments.
** $p < 0.01$, compare with Il-pum cultivar.

Table 1 showed the RVA profile parameters of Sang-gol and Il-pum. The trough, peak and final viscosity of Sang-gol were higher than those of Il-pum. Based on the breakdown, Sang-gol (32.0 RVU) tended to have a lower viscosity compared to that of Il-pum (42.7 RVU). The setback viscosity ($p < 0.01$) and peak time (6.89 min) of Sang-gol were significantly lower than those of Il-pum. However, no difference in the pasting temperatures of Sang-gol (68.1°C) and Il-pum (68.0°C) were observed. Pasting viscosity properties have been used to predict the end-use quality of cooked rice texture. In many food industries, analysis of pasting viscosity

Table 2 Texture parameters of cooked rice of Sang-gol and Il-pum

Cultivars	HRD (g)	ADH (g · s)	SPR (g · s)	COH (g · s)	GUM (g · s)	CHW (g · s)	RES (g · s)
Sang-gol	1.15±0.05	-1.30±0.02	0.80±0.04	0.31±0.03	0.36±0.05	0.29±0.02	0.041±0.00
Il-pum	1.30±0.03	-1.77±0.03	0.88±0.04	0.34±0.01	0.44±0.04	0.38±0.01	0.045±0.00

The quantitative data are presented as means ± SD of three independent experiments. Values are not significantly different ($p < 0.05$) between Sang-gol and Il-pum cultivars.
HRD, hardness; ADH, adhesiveness; SPR, springiness; COH, cohesiveness; GUM, gumminess; CHW, chewiness; RES, resilience.

Table 3 Amylogram characteristics of Sang-gol and Il-pum cultivars

Cultivars	Viscosity (RVU)					TTPV (min)	PT (ºC)
	PV	T	BD	FV	SB		
Sang-gol	215.2±5.86	183.2±6.15	32.0±1.18	272.3±7.97	89.1±2.02**	6.89±0.03*	68.1±0.09
Il-pum	209.3±1.97	166.6±4.51	42.7±5.89	267.2±1.60	100.5±3.06	6.54±0.12	68.0±0.03

The quantitative data are presented as means ± SD of three independent experiments. *p <0.05; **p <0.01, compared with Il-pum cultivar.
PV, peak viscosity; T, trough; BD, breakdown (PV–T); FV, final viscosity; SB, setback; TTPV, peak time; PT, pasting temperature.

is necessary for samples at different stages of processing. Lim et al. (1999) reported that reducing the protein content in rice flour increases its peak viscosity. In addition, Tan and Corke (2002) proposed that protein content was negatively correlated with the peak and hot paste viscosities. Furthermore, Lyon et al. (2000) found that protein content was negatively correlated with the adhesiveness of cooked rice. Protein content in the rice had more effect on cooking and eating quality than amylose content. The proteins are normally conjugated with phytic acid, and the reduction of phytic acid content will increase the content of soluble protein in rice (Li et al., 2008). Thus, it was expected that the change in the content of phytic acid brings about changes in the physicochemical properties of low-phytate rice. However, in the present study, Sang-gol rice, a low-phytate rice cultivar, was found to have similar physicochemical properties to those of its parent cultivar Il-pum. Furthermore, mutation did not affect the physicochemical properties of Sang-gol rice cultivar. This result is useful for increasing the availability by the food processing of Sang-gol rice cultivar.

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