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Article

Physico-chemical Properties of Giant Embryo Brown Rice (Keunnunbyeo)

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Brown rice with a giant embryo (GE) was observed on the quality parameters of the enlargement of embryo, nutritional components, and physical properties, in comparison to normal embryo brown rice (NE). Also, the effects of germination on the quality parameters were examined. GE embryo was approximately 2.68 times larger than of NE rice. Total free sugars were significantly higher in GE rice (71.96 vs. 41.17 mg/100 g), and germinated rice increased in fructose, but decreased in sucrose and maltose. No significant difference in mineral contents was found in GE and NE rice and their germinated rice, whereas a significant increment was observed on reducing sugars and gamma-amino butyric acid (GABA) contents in GE rice. The lower water absorption index (WAI) of GE rice resulted in relatively lower pasting viscosity, whereas the increased WSI in germinated rice might be attributable to the significant increment of soluble components in GE rice.

Key words: *giant embryo brown rice, nutrients, GABA, physical properties, pasting properties.*

Brown rice grains contain more nutritional components, such as dietary fiber, phytic acids, vitamin B and E and gamma aminobutyric acid (GABA), than the ordinary milled rice grains.[1)] These bio-functional components exist mainly in germ and bran layers in brown rice which are supposed to be removed by milling ordinary rice. In spite of the elevated content of bio-functional components, brown rice is not considered suitable as table rice because of its dark appearance and hard texture. Germination treatment has recently been widely used to improve texture and nutritional functions of brown rice. In germinated cereal grains, hydrolytic enzymes are activated and decompose starch, non-starch polysaccharides and proteins, which leads to the increase in oligosaccharides, and amino acids in barley, wheat, oat and rice.[2-5)] The decomposition of high molecular weight polymers during germination leads to the generation of bio-functional substances and the improvement of the organoleptic qualities due to softening of texture and increasing of flavor in some cereal grains.[6,7)] Choi *et al.*[8)] suggested that germinated brown rice is rich in α-amylase, can be consumed as supplementary foods. Thus, germinated brown rice has recently been recognized as a cereal source having high potential to process into a value-added product.

The nutrient contents and physical functions in rice can be improved by biofortification through cultivar selection and breeding, which is an important approach to both the quantity and quality of human foodstuff.[9)] Recent scientific technology in rice research made it possible to enhance the nutritional value of rice through genetic modification of an existing cultivar. Traditional plant-breeding techniques explore rice germ plasm or cultivars with nutritionally enhanced varieties and breed these with the most commonly grown rice cultivars to enhance the nutrient content of the grains. Rice varieties with higher iron and zinc contents, higher lysine and low phytic acid have been developed with this technology.[8)] In addition, rice mutants with giant embryo have been induced and are being used to develop rice with new physiological functions.

The present study was conducted to compare the nutrient contents and physical properties of brown rices with a giant embryo (GE) and a normal embryo (NE) and also to observe the changes in the nutrients and physical properties by germination.

Materials and Methods

Brown rice plants. Brown rice with a giant embryo (Keunnunbyeo) and a normal embryo (Ilpumbyeo), classified into japonica rice variety, were grown at the National Institute of Crop Science, RDA, Suwon, Korea during the 2004 growing season. Ilpumbyeo is japonica-type rice cultivar, and also the leading Korean rice with good eating quality. Rice paddies stored at 15°C were dehusked using a rice sheller (Model SY88-TH, Ssangyong Ltd., Incheon, Korea) for the preparation of brown rice.

Germination of brown rice. Brown rice (50 g each) was put in a perforated nylon bag, soaked in 2.0 *l* of distilled water

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Abbreviations: GABA, gamma amino-butyric acid; GE, giant embryo brown rice; NE, normal embryo brown rice; WAI, water absorption index; WSI, water solubility index for 3-4 hr at room temperature. After draining the distilled water, rice samples were germinated in an incubator at 28-30°C for 24 and 48 hr, respectively. During germination, distilled water was sprinkled 3-4 times a day to prevent surface drying. The sampled germinated brown rice was dried in a freeze-drier (KR/PVTFD 10A, Ilsin Lab Co., Ltd., Ibamri, Korea) at the condenser temperature of −84°C and vacuum of 5.0 mTorr. The prepared germinated brown rice was ground for analysis using a grinding mill (Cyclotec™ 1093 sample mill, Foss Tecator Co., Hillerod, Denmark).

Determination of minerals. Rice flour (1.0 g) was decomposited with a sulphuric-nitric acid for mineral analysis.[10] The acid treated samples were filtered through an ashless filter paper (Whatman No. 40), and subjected to mineral analysis using an Inductively Coupled Plasma Atomic Absorption Spectrometer (GBC Integra XL, GBC Scientific Equipment Pty, Ltd., Hampshire, IL, USA).

Determination of free sugars. AOAC official method 982.14[11] with a slight modification was applied for free sugar measurements. Free sugars were determined by HPLC (Waters 410, Waters Co., MA, USA) system equipped with a refractive index detector (Waters 410, differential refractometer) operated at 39°C, and a column (YMC-pack, polyamine II, S-5 μm 12 mm, 250 × 4.6 mm I.D.) operated at 35°C. Acetonitrile and H_2O (85 : 15 v/v) were used as the mobile phase with a flow rate of 1.5 m*l*/min and an injection volume of 20 μ*l*. Glucose, fructose, sucrose, and maltose were used as external standard sugars for the calibration. Measurements were repeated three times for each sample.

Determination of GABA. GABA contents and its changes during germination were measured by a 1.0 m*l* assay system in spectrophotometric GABA determination at 340 nm.[12] An UV-visible spectrophotometer (US/Evolution 500, Thermo Electron Corp., Waltham, MA, USA) was used for measurement. Nutrient contents were determined in triplicate measurements.

Determination of water absorption index (WAI) and water solubility index (WSI). WAI and WSI were determined by the method of Jin *et al.*[13] with a slight modification. Rice flour (3.0 g) was dispersed in 30 m*l* distilled water with heating in a water bath at 60°C for 1 hr. The dispersion was centrifuged at 3000 × g for 15 min. After draining the supernatant carefully, the hydrated residue was weighed for WAI determination, and the solid content of the drained supernatant was calculated as WSI.

$$\text{WAI (g/g)} = \frac{\text{(wt. of water uptake in hydrated residue)}}{\text{(wt. of rice sample)}}$$

$$\text{WSI (\%)} = \left[\frac{\text{(wt. of dissolved solids in supernatant)}}{\text{(wt. of sample)}}\right] \times 100$$

Determination of pasting properties. Paste viscosity was determined using a Rapid Visco™ Analyser Series 4 (Newport Scientific Pty. Ltd., Warriewood, Australia) according to the AACC 61-02 method[14]. The recorded viscosity parameters were peak viscosity, hot viscosity, final viscosity, and their derived parameters of breakdown and setback. All parameters were determined in arbitrary Rapid Visco Units (RVU), and results were the means of triplicate measurements.

Statistical analysis. Means were calculated from the obtained data, and significant mean difference between samples was evaluated by conducting Duncan's multiple comparison test at 5% significance level using a SAS program (version 8.01, SAS Inc., Cary, NC, USA).

Results and Discussion

Approximate compositions of a giant embryo (GE) and normal embryo (NE) rice were presented in Table 1. The crude lipid content was slightly higher in GE rice, but crude protein contents were not significantly different between GE and NE rices. Enlargement of embryo of GE rice was compared to those of NE rice (Table 2). The embryo weight of GE and NE rice was 1.49 ± 0.26 and 0.62 ± 0.19 mg, respectively. Whereas, the single-grain weight of GE rice (20.98 ± 1.42) was lighter than that of NE rice (23.51 ± 1.63), indicating more weight on the endosperm of NE rice, and also more weight on starch than lipid, protein and fiber. The weight dependence on starch could be explained by the total

Table 1. Approximate compositions of giant embryo (GE) and normal embryo (NE) rice

Rice	Compositions (%)			
	Ash	Fiber	Lipid	Protein
GE	1.61 ± 0.04[a]	0.99 ± 0.04[a]	2.75 ± 0.04[a]	6.58 ± 0.15[a]
NE	1.63 ± 0.06[a]	0.82 ± 0.09[a]	2.39 ± 0.07[b]	6.27 ± 0.03[a]

[ab]Different letters in the same column are significantly different at $p \leq 0.05$

Table 2. Comparison of the embryo weight of giant embryo (GE) and normal embryo (NE) rice

Rice	Single-grain weight (mg)	Single-embryo weight (mg)	Ratio of the embryo to single grain (%)
GE	20.98 ± 1.42[b]	1.49 ± 0.26[a]	7.10[a]
NE	23.51 ± 1.63[a]	0.62 ± 0.19[b]	2.64[b]

[ab]Different letters in the same column are significantly different at $p \leq 0.05$

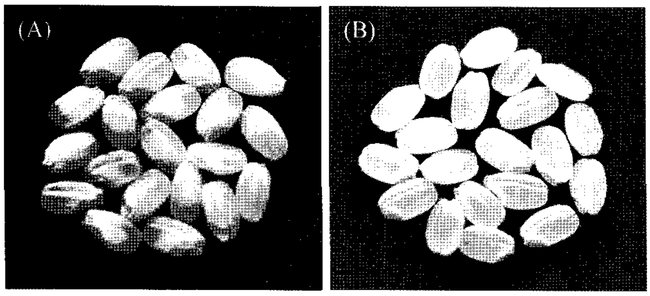

Fig. 1. Rice photos of giant embryo brown rice (A) and normal embryo brown rice (B).

carbohydrates contents of normal rice, which approximately was about 77.8 (%). The embryo weight of GE and NE accounts for 7.10% and 2.64% of the whole grain, which in turn indicated that the embryo of GE was approximately 2.68 times larger based on the weight difference than that of NE rice. Zhang *et al.*[9] examined two types of giant embryo rice, indica and japonica varieties, with their normal embryo rice. They reported that the ratio of the embryo to grain of GE and NE rice was 4.79% to 1.93% for japonica rice, accounting for 2.48 times larger embryo of japonica variety. Those results were quite in accordance with our results on GE and NE of which initial varieties were japonica rice. The rice photos of giant embryo brown rice (A) and normal embryo brown rice (B) are shown in Fig. 1. The photo of GE rice (A) clearly showed the enlarged embryo of GE rice compared to that of NE rice.

Nutrients change during germination. Contents of free sugars are shown in Table 3. Compared to rice with a normal embryo, GE rice has significantly higher free sugar contents in fructose, glucose, sucrose and maltose, accounting for the total free sugars of 71.96 (mg/100 g) for GE rice and 41.17 (mg/100 g) for NE rice. Increase in fructose contents during germination was observed, while the other sugars were decreased significantly by germination treatment. Glucose contents were not significantly changed in GE rice, while some increment was observed in NE rice, suggesting that larger endosperm of NE rice could contribute to the increase in glucose contents during germination. The disaccharides of sucrose and maltose were decreased in both germinated GE

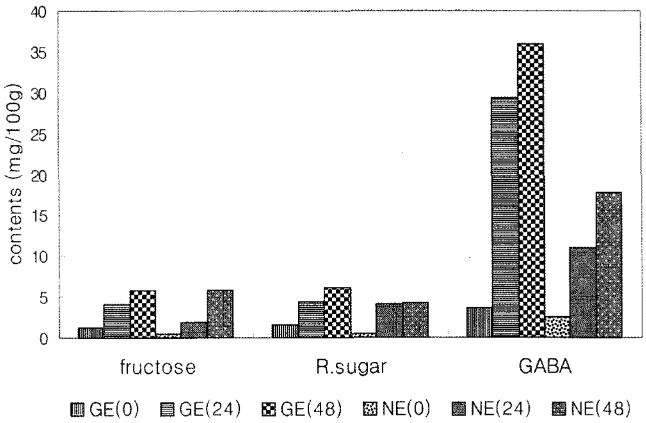

Fig. 2. Nutrient contents increased during germination at 24 hr and 48 hr in giant embryo (GE) and normal embryo (NE) rice.

and NE rice, indicating germination could be attributable to the decomposition of disaccharides into monosaccharides. But, there was not a significant indication of higher increment of fructose and glucose due to the decomposition of sucrose and maltose. Oomori *et al.*[15] reported that hydration of glycosidic bonds could convert disaccharides into monosaccharides, such as glucose and fructose, with different decomposition rates in different glycosidic bonds, noting sucrose was the most sensitive against temperature and hydrolyzed in the highest rate from the disaccharides observed in their study. Total free sugar contents (Table 3) were significantly higher in GE rice compared to that of NE rice, suggesting that higher sweet components in GE rice could promote the use of giant embryo rice in some cereal-based processed foods. The mineral and GABA contents along with their changes during germination are shown in Table 4.

It was found that mineral contents were not significantly different between GE and NE rice as well as their germinated rice. GABA contents in the raw rice of GE and NE rice were not significantly different. But as they were germinated, the GABA contents increased significantly in both rice types, indicating the increased GABA contents were clearly higher in GE rice compared to NE rice. Zhang *et al.*[9] reported that a giant embryo brown rice had more minerals than normal embryo brown rice. On the other hand, Shim *et al.*[16] observed

Table 3. Free sugar contents of giant embryo (GE) and normal embryo (NE) rice

Rice	Germination (hr)	Free sugars (mg/100g)				Total free sugars
		Fructose	Glucose	Sucrose	Maltose	
GE	0	1.22 ± 0.24^{cd}	15.49 ± 0.60^{ab}	22.01 ± 2.48^{a}	33.24 ± 3.17^{a}	71.96
	24	4.14 ± 0.29^{b}	17.46 ± 0.69^{a}	3.70 ± 0.14^{bc}	19.19 ± 2.27^{b}	44.49
	48	5.80 ± 0.89^{a}	15.83 ± 3.21^{a}	2.24 ± 0.46^{cd}	11.44 ± 1.95^{c}	35.31
NE	0	0.54 ± 0.11^{d}	6.07 ± 0.83^{c}	5.33 ± 0.76^{b}	29.23 ± 3.35^{a}	41.17
	24	1.82 ± 0.38^{c}	11.57 ± 1.04^{b}	3.09 ± 0.12^{c}	30.31 ± 1.70^{a}	46.79
	48	5.73 ± 1.09^{a}	15.38 ± 3.89^{ab}	0.57 ± 0.07^{d}	18.42 ± 3.47^{b}	40.10

[abcd]Different letters in the same column are significantly different at $p < 0.05$

Table 4. Mineral and GABA contents of giant embryo (GE) and normal embryo (NE) rice

Rice	Germination (hr)	Contents (mg/100g)					
		K	Mg	Fe	Mn	P	GABA
GE	Raw	223.34 ± 33.36[a]	128.42 ± 16.53[a]	3.03 ± 0.37[a]	2.85 ± 0.37[a]	314.10 ± 50.37[a]	1.67 ± 0.05[c]
	1D	217.45 ± 72.29[a]	122.83 ± 20.82[a]	3.26 ± 1.41[a]	2.72 ± 0.70[a]	336.63 ± 54.26[a]	29.26 ± 7.25[a]
	2D	189.70 ± 10.43[a]	127.43 ± 10.36[a]	3.57 ± 0.09[a]	2.65 ± 0.32[a]	325.33 ± 1.52[a]	35.86 ± 6.40[a]
NE	Raw	234.17 ± 33.20[a]	123.21 ± 24.12[a]	3.70 ± 1.03[a]	3.38 ± 0.81[a]	302.78 ± 55.40[a]	1.58 ± 0.03[c]
	1D	232.20 ± 39.50[a]	124.01 ± 14.82[a]	4.00 ± 1.35[a]	3.43 ± 0.96[a]	312.69 ± 32.56[a]	10.95 ± 0.12[bc]
	2D	227.53 ± 47.39[a]	134.26 ± 4.80[a]	3.02 ± 0.55[a]	3.27 ± 0.89[a]	327.05 ± 15.94[a]	17.65 ± 0.47[b]

Table 5. Water absorption index (WAI), water solubility index (WSI), and rapid viscosity analysis (RVA)

Rice	Germination (hr)	WAI	WSI (%)	RVA parameters				
				Peak V	Hot V	breakdown	Cool V	setback
GE	0	2.24 ± 0.02[b]	5.39 ± 0.53[d]	185.42 ± 4.83[b]	89.84 ± 1.65[b]	95.58 ± 3.18[a]	170.63 ± 2.54[b]	-14.80 ± 2.29[b]
	24	1.71 ± 0.17[d]	15.59 ± 0.82[b]	20.50 ± 1.53[cd]	2.50 ± 0.47[c]	18.00 ± 1.06[d]	4.42 ± 0.59[c]	-16.09 ± 0.94[b]
	48	1.45 ± 0.01[c]	32.98 ± 0.89[a]	15.92 ± 0.35[d]	3.42 ± 0.23[c]	12.50 ± 0.59[d]	4.50 ± 0.11[c]	-11.42 ± 0.23[b]
NE	0	2.48 ± 0.02[a]	3.59 ± 0.12[d]	217.55 ± 25.99[a]	144.05 ± 19.27[a]	73.50 ± 6.72[b]	241.17 ± 23.81[a]	23.63 ± 2.18[a]
	24	2.11 ± 0.09[bc]	8.37 ± 0.53[c]	45.71 ± 2.06[c]	9.00 ± 1.30[c]	36.71 ± 0.76[c]	22.96 ± 1.82[c]	-22.75 ± 0.24[c]
	48	2.02 ± 0.09[c]	15.89 ± 1.93[b]	20.92 ± 4.72[cd]	2.54 ± .30[c]	18.38 ± 4.42[d]	4.42 ± 0.84[c]	-16.50 ± 4.71[b]

[abcd]Different letters in the same column are significantly different at $p < 0.05$

the mineral contents in acorn flour, suggesting that the rice varieties and cultivated-regions were the major factors in differentiating mineral contents in rice. Oh[17)] reported that GABA concentrations were enhanced in all of germinated brown rice when compared to non-germinated brown rice, also suggesting that when brown rice was germinated in the solution of chitisan/glutamic acid, GABA concentration significantly increased. In addition, Choi et al.[8)] investigated the effects of pretreatment conditions on GABA changes and reported that soaking brown rice in glutamate solution under anaerobic conditions increased GABA contents.

Physical properties change during germination. The analysis of water absorption index (WAI), water solubility index (WSI), and paste properties are shown in Table 6. Compared to NE rice, GE rice had lower WAI (2,48 vs. 2.24 g/g), but higher WSI (3.59 vs. 5.39%). As WAI measures the amount of water absorbed by starch, its value can be used as an index of gelatinization[18)], explaining lower gelatinization property of GE rice due to the lower starch contents compared to NE rice. As germination was proceeded over 48 hr, WAI of GE rice decreased significantly, whereas there was a little decrement in NE rice. On the other hand, the measured higher value of WSI of GE rice indicated that it has more soluble components. Germination was attributable to the increased WSI values in both rice samples, showing a significant increment in GE rice. It noted that the soluble components increased during germination, such as free sugars, reducing sugars etc., could be the major contribution to the increased WSI values. Kirby *et al.*[19)] reported that WSI measures the amount of soluble components released from starch, and often used as an indicator of degradation of molecular components.

The viscosity of rice paste depends on a large extent on the degree of gelatinization of the starch granules, granule size, and the extent of their molecular breakdown. Pasting properties of GE rice were observed to be slightly lower compared to that of NE rice. The peak viscosity of GE rice was lower than that of NE rice (185.42 ± 4.83 vs. 217.55 ± 25.99). The lower peak viscosity suggests that GE rice has a lower water-binding capacity compared to NE rice, implying that the lower WAI of GE could be due to its lower water-binding characteristic. Peak viscosities of germinated rice were dramatically decreased, compared to their corresponding un-germinated rice flour. Tipples[20)] reported that thermal and mechanical gelatinization of starch granules result in a structure breakdown with a subsequent loss of integrity and disintegration of the granule. Thus, gelatinized starch granules lose their ability to swell upon heating in water, which results in a lower hot-paste viscosity. In addition to peak viscosity, the observed paste properties of GE rice were lower in hot viscosity, cool viscosity and setback, but higher in breakdown than those of NE rice. This paste characteristics suggest that GE rice is to form more likely viscous-type paste instead of gel-type paste after cooling indicated by lower cool viscosity, to be less retrograded indicated by lower setback, and to be less resistant to high-temperature thinning indicated by higher breakdown.

Effects of germination on the nutrients. The effects of germination on the changes in nutrients focusing on increased nutrients are shown in Fig. 2. The major increased nutrients during germination were fructose, reducing sugars, and GABA. Upon 24 hr germination, the increased amounts of these nutrients relative to those in the non-germinated brown rice were 3.4 times for fructose, 2.75 times for reducing sugars, and 7.97 times for GABA. In contrast to the large increment on 24 hr germination, relatively small increment was observed on 48 hr germination. Among those nutrients, a significant increase was observed in GABA contents. The results of researches[9,21] conducted on GABA in brown rice were relatively in accordance to the result of this study.

There has been an increased interest in the utilization of GABA as a bioactive plant component due to the function of GABA, which is a non-protein amino acid, and is primarily produced from the α-decarboxylation of L-glutamic acid that is catalyzed by the enzyme glutamate decarboxylase (GAD). Satyanarayan and Nair[22] and Oh *et al.*[23] independently reported that extracts of the germinated brown rice were effective for the improvement of immunoregulatory action, possibly due to the enhanced levels of GABA and/or combined effects of several components including GABA. On the other hand, Park and Oh[24] produced a yogurt containing high GABA using lactic acid bacteria and germinated grown rice. Considering the increased population suffering from high blood pressure, new rice varieties with giant embryo are expected to assist in normalizing blood pressure as part of their diet. Also, enhancing GABA synthesis in germinated brown rice, as physiologically functional food material, may potentially benefit on GABA-rich functional food processing.

In conclusion, it was determined that brown rice with a giant embryo was characterized with 2.68 times enlarged embryo compared to the one with a normal embryo. Also, analysis revealed GE rice was significantly high in free sugars, reducing sugars and GABA contents, which were changed during germination. The effect of germination was found in the increased contents of fructose, reducing sugars, and GABA, suggesting the high potential use of germinated brown rice for good purposes. Recently, consumer demand for functional rice, which can have health benefits and disease prevention, etc, is rapidly increasing. In some Asian countries, eating brown rice as a staple food became popular because of the high nutrients contained in the embryo of brown rice. Thus, giant embryo rice can be a rice cultivar, providing more nutrients as well as functional benefits. From the viewpoint of supplying nutrients-rich rice types, germination of brown rice can be an effective method to enhance the nutrient contents in the brown rice, thus usable as a grain as well as an ingredient for a valid processing technology.

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