Palatable and Bio-Functional Wheat/Rice Products Developed from Pre-Germinated Brown Rice of Super-Hard Cultivar EM10

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It became possible to produce high-quality and bio-functional wheat/rice bread and wheat/rice noodles by blending, pre-germinated and cooked brown rice of a super-hard cultivar with wheat flour. Super-hard rice (SHR) is not suitable for table rice because of its low palatability. Nevertheless, it was found to be suitable as a blending material for bread-making or noodle-making due to its hard texture and high content of resistant starch. We developed a novel rapid germination method to improve the quality and to save the time needed for germination. By blending pre-germinated and cooked SHR (30% w/w on a dry basis) as a rice gel with wheat flour (70% w/w on a dry basis), the bread became very soft and any hardening after bread-making was markedly retarded. Similarly, blending pre-germinated and cooked SHR as a rice gel with wheat flour gave high-quality noodles with a similar texture to that of durum semolina noodles. The resistant starch of the SHR-blended bread and noodles was also markedly increased. White waxy rice (9%) soaked and cooked with the pre-germinated brown rice of SHR (21%) produced a rice gel that was very useful as a material for bread-making and noodle-making by blending with wheat flour (70%) to prepare soft, tasty and bio-functional wheat/rice bread and wheat/rice noodles.

Key words: bread; noodle; super-hard rice; cooked rice; germination

Weat is the most suitable crop for bread making. Bread is prepared from hard wheat flour through a process involving scaling, dough processing, proofing, baking and cooling. Gluten contains hundreds of protein components which are present either as monomers or, linked by inter-chain disulfide bonds, as oligomers and polymers. High-yielding and low-cost rice is a promising crop to prepare bread for those people living in the tropical or semi-tropical regions.

Rice bread has been investigated for the last 50 years and in many subsequent studies. Gluten is not formed during dough preparation as the protein composition and properties of rice are different from those of wheat. It has been reported that the quality of bread made from 20% rice and 80% wheat flour was acceptable, but that of bread made from 30% rice and 70% wheat was not acceptable. Morita has replaced a part of the wheat flour with un-germinated or germinated brown rice flour for bread-making and reported that 10% or 20% replacement gave good results, while 30% substitution caused extremely lower expansion of the bread volume.

Steamed bread is popular in north-eastern Asia in place of leavened hearth bread in USA and Europe. A rice-pulse combination or the extrusion process has been used to compensate for the lack of gluten in rice bread. Various gums, surfactants, hydrophilic polymers, or super-hard wheat flour has been reported to be effective to improve the dough property of rice flour with less or without any gluten.

Bread as well as noodles are major foodstuffs throughout the world. Rice noodles is one of the most popular foods in Asia, and high-amylose rice is suitable as a material for making noodles. Diabetes is one of the life-style diseases, so preventing such diseases is very important to support the development of curing technology. Low glycemic index (GI) food inhibits the rapid increase of blood glucose. The effects of test cereal breakfasts differing in the glycemic index and content of indigestible carbohydrates on day-long glucose tolerance have been reported. The use of low GI bread in place of high GI bread has been reported to be effective for lowering the blood glucose level.

Several studies have been reported on high-resistant-starch rice, and high-amylose and high-dietary-fiber rice that have been developed by physical or chemical mutation. The super-hard rice cultivar, EM10, was developed by Satoh by chemical mutation (the MNU treatment) at Kyushu University in Japan. EM10 lacks starch branching enzyme Iib, which lowers the amount of short-chain glucans (a degree of polymerization lower than 17) and induces resistance to gelatinization. The amylopectin of EM10 has more long-chain glucans, making the texture very hard and non-sticky after cooking and giving unacceptable palatability as cooked rice. Nevertheless, EM10 is promising as a material for such low-GI foods, as bread and noodle, to prevent diabetes, because it contains a substantial amount of resistant starch even after cooking.

Pre-germinated brown rice (PGR) is prepared by soaking the brown rice in water, which activates glutamate decarboxylase, and the gamma amino butyric acid (GABA) content in pre-germinated brown rice is...
increased to twice that in ordinary brown rice and ten times that in white rice.27,28) The palatability of PGR, is improved compared with ordinary brown rice due to the activated enzymes, which partially decompose the starch. This starch decomposition leads to the generation of a substantial amount of glucose and other oligosaccharides, as well as to softening the texture of the cooked rice. The GI value of PGR is about 60% that of ordinary white rice, making it likely to retard the increase of blood sugar after a meal.21) The development of low GI wheat/rice bread by using super-hard rice is promising route to prevent people from contracting diabetes. Since the palatability and bio-functionality was improved by germinating brown rice, super-hard EM10 rice, was supplemented with wheat flour to produce more suitable as PGR.

Germination in warm water for a long time cause microorganisms to increase rapidly, sometimes resulting in, the problems with hygiene.28) Moreover, the flavor of cooked PGR deteriorates after soaking for a long time.28) We searched in the present study for a novel method to prepare PGR without soaking for a long time. Preventing the problems of off-flavor and microorganism infestation during long-term germination in warm water was investigated by testing a novel germination method of soaking SHR for a short time and then gradually heating.

Materials and Methods

Materials. EM10 super-hard rice and Hoshiyutaka high-amylose rice were cultivated in an experimental field of Kyushu University in 2008. Koganemochi waxy rice and Milkyqueen semi-waxy rice were cultivated in an experimental field of Crop Science Institute at Tsukuba in 2008. Koshikihari high-quality rice was cultivated in an experimental field of Hokuriku University in Joetsu in 2008. The wheat flour for bread making, Camellia (Nishin Flour Milling Co.), dry yeast (Pioneer Planning Co.), sugar (Nisshin Seito Co.), sodium chloride (Ajinomoto Co.), desalted butter (Yukijirushi Co.) and skim milk (Morinaga Milk Industry Co.) were commercially available products.

Preparation of the rice samples. The brown rice was polished by an experimental friction-type rice milling machine (Yamamotoseisakusho Co., Tendoh, Japan) to a milling yield of 90–91%, and its moisture content was adjusted to 13.5% in an artificial environment room (Sanyo Medicaystems Co., Tokyo, Japan). Rice flour was prepared by an SFC-S1 cyclone mill (Udy, Fort Collins, USA) with a screen of 1-mm diameter pore size.

Measurement of the pasting properties of the rice and wheat flour samples blended with rice flour. The pasting properties of the rice flour and wheat flour samples blended with various types of rice flour were measured with an RVA Super 4 rapid-visco-analyzer (New-port Scientific, Warriewood, Australia). A programmed heating and cooling cycle was followed as outlined in the procedure of Toyoshima et al.29) EM10, Hoshiyutaka, Koshikihari and Koganemochi were used as samples to compare the various rice cultivars. The Camellia sample of wheat flour was used as a control. In order to clarify the change in pasting properties by blending wheat and rice under different cooking conditions, the blends of wheat (70%) and 5-min-cooked SHR (30%), wheat (70%) and 35-min-cooked SHR (30%), and wheat (70%) and mode 2-cooked SHR (30%) were subjected to the RVA measurements. In the case of the 5-min-cooked rice, it was heated from room temperature to 97 °C for 1 min and maintained for 3 min at 97 °C, before being kept for 1 min in the apparatus after heating. In the case of the 35-min-cooked rice, it was heated from room temperature to 97 °C for 10 min and maintained for 15 min at 97 °C, before being kept for 10 min in the apparatus after heating. Cooked rice was then lyophilized and mixed with wheat flour.

Rice cooking and preparation of the gelatinized rice paste. Each type of milled rice (22.5 g; Koshikihari, Hoshiyutaka, Koganemochi and Milkyqueen) was mixed with the brown SHR rice (52.5 g), water (300 ml) was added, and the mixture incubated at 45 °C for 30 min by a Taitec water bath with a Personal ll shaker, before being soaked at 57 °C for 2 h in the experimental MIR-262 incubator (Sanio). The pre-germinated brown rice (0.2 mm of sprouts) and milled rice grains were then gelatinized by cooking with the experimental cooking system equipped with a thermal controller (Takehoko Scientific Co., Niigata, Japan). The cooking conditions were as follows:

Mode 1: Rice grains were heated at 4.77 °C/min to 60 °C, then at 2.82 °C/min from 60 °C to 80 °C, and finally at 0.85 °C/min from 80 °C to 97 °C, before being maintained 97 °C for 20 min.

Mode 2: Rice grains were heated at 2.08 °C/min to 60 °C, 1.22 °C/min from 60 °C to 80 °C, and 0.68 °C/min from 80 °C to 97 °C, then maintained at 97 °C for 35 min.

Mode 3: Rice grains were heated at 3.48 °C/min to 60 °C, 0.90 °C/min from 60 °C to 80 °C, and 1.70 °C/min from 80 °C to 97 °C, then maintained at 97 °C for 20 min.

The cooked rice grains were then mashed with a THM 500 stick-blender (Tescom Co., Tokyo, Japan).

Measurement of the physical properties of the cooked rice grains. The physical properties of the cooked rice grains were measured by the high-compression/low-compression method with a Tensipresser (My Boy System, Taketomo Electric Co., Tokyo, Japan) under the same conditions as those described in our previous study.30)

Bread-making. Based upon the recipe for wheat bread, 30% of each rice flour sample and 70% of wheat flour were blended and subjected to the bread-making process described next. The recipe for the bread was as follows: 175 g of wheat flour (Camellia), 75 g (dry matter) of rice paste, 17 g of sucrose, 8.5 g of skim milk powder, 15 g of salt-free butter, 1.5 g of NaCl, 2.7 g of commercial dried yeast, and an appropriate amount of de-ionized water. Water in the dough for bread-making is very important as a plasticizer, solvent, a generator of gluten1 and to adjust the physical properties of the dough and subsequent bread. We selected after the many experiments, as reported in our previous study, the most suitable amount of water for each rice sample to make bread.14) It was found beneficial in the present study to add the pre-germinated and gelatinized rice to the wheat flour for improving the bread texture and retrogradation. After measuring the moisture content of the gelatinized rice gel, we added to it (3/7 × 100%) of wheat flour on a dry matter basis, before adding a suitable amount of water during kneading. The amount of water added for each rice cultivar was determined by measuring the texture of the dough with a Tensipresser as reported in our previous study.14)

Each dough sample was then baked with an SD-BT103 automatic home bakery machine (Panasonic Co., Kadoma, Japan) based on the straight dough procedure. The time set for bread-making, involving dough processing, proofing, and baking, was 5 h.

Preparation of wheat/rice noodles. Based on the preparation method for wheat noodles, to 175 g of strong wheat flours (Camellia) was added 75 g of each kind of gelatinized rice gel (a blend of 52.5 g of cooked pre-germinated SHR brown rice and 22.5 g of cooked white rice, each on a dry basis) and 10 g of sodium chloride, and the dough kneaded for 45 min with an SD-BH101 automatic bread bakery system (Panasonic, Kadoma, Japan). The final moisture content of the dough was adjusted to 40%. Thereafter, the dough was stood overnight in a refrigerator. The dough was then put twice through the roll (100mm in width and 2 mm of clearance) and finally cut by the blade to a width of 2.2 mm. The noodles were heated for 2 min in boiling water and then cooled for 1 min in water at 20 °C. These noodles were then measured for their physical properties, chemical components and eating quality.

Measurement of the moisture content of the dough and bread. Each dough sample and bread (2 g) were put in an aluminum cup and dried at 135 °C for 3 h in an oven.

Measurement of the physical properties of the baked bread. The physical properties of the bread crumb were measured by the continuous progressive compression (CPC) method with a My Boy...
Tensipresser (Taketomo Electric Co., Tokyo, Japan) under the same conditions as those used in our previous study. Each bread sample was 3 cm square and 1.5 cm in thickness. The measurements were made five times. The firming degree of bread is defined as the ratio of bread toughness on the 4th day after preparation to the bread toughness one day after preparation at room temperature (20°C).

**Measurement of the physical properties of the noodles.** The physical properties were again measured by the continuous progressive compression method with the Tensipresser. A 15 g amount of noodles was put into the aluminum sample cup (4.4 cm in diameter, 1.1 cm in height) and the noodles were subjected to the measurement process. The bite speed was 3 mm/s, bite repeating was 5 times, distance was 35 mm, and clearance was 1 mm. Measurements were taken five times, and the data were statistically analyzed by the software provided with the Tensipresser.

**Specific volume of the bread.** The volume of the bread was measured by the plant seeds method. Three loaves of bread for each sample were used and mean value and standard deviation were calculated for each sample.

**Measurement of the resistant starch.** The resistant starch in the sample was measured according to the AOAC method by a resistant starch assay kit (Megazyme, Wicklow, Ireland). Each sample (100 mg) was digested by pancreatin and amyloglucosidase, and glucose was measured by spectrophotometry at 510 nm.

**Measurement of glucose and glutamic acid.** To a lyophilized sample (0.1 g) was added 1 ml of 60% ethyl alcohol and the glucose was extracted by rotation at 20°C for 1 h. The solution was centrifuged (1500 g for 15 min) and the resulting supernatant was used as the sample solution for measurement. The glucose content in the sample solution was measured by the NADPH enzyme assay method with a glucose assay kit (Roche, Darmstadt, Germany). The glutamic acid content was measured by the phormazan enzyme assay method with a glutamic acid assay kit (Roche, Darmstadt, Germany).

**Statistical analyses.** All the results were subjected to a statistical analysis by Tukey’s multivariate method provided in Excel Statistics (ver. 2006, Microsoft Corporation, Tokyo, Japan).

### Results and Discussion

**Physical properties of the cooked rice grains**

Measurement of the physical properties of the cooked rice grains by the low-compression/high-compression method with the Tensipresser showed the SHR grains (EM10) to have extraordinarily hard and non-sticky properties (H1, 280 gw/cm²; S1, 1.3 gw/cm²) compared with waxy rice (Koganemochi: H1, 39 gw/cm²; S1, 8.3 gw/cm²), low-amylose rice (Milkyqueen: H1, 71 gw/cm²; S1, 13.9 gw/cm²), premium Japonica rice (Koshihikari: H1, 78 gw/cm²; S1, 11.2 gw/cm²) and even hard indica/japonica hybrid rice (Hoshiyutaka: H1, 92 gw/cm²; S1, 2.9 gw/cm²). Nishi and others have reported SHR to have fewer branched short glucans and more long chains in the amylopectin of the starch. SHR is therefore resistant to gelatinization and when cooked is very hard and non-sticky. Since cooked SHR rice was hard and tough, it seemed that SHR could be suitable for use as a material for wheat/rice bread or wheat/rice noodles to compensate for the weak dough blended with rice.

**Pasting properties of the rice flour from various cultivars**

The pasting properties of the various rice flour samples measured by RVA are shown in Fig. 1A. As Morris has reported, the pasting properties by RVA are good indices for the processing suitability of the wheat cultivars. Koshihikari showed the typical RVA profile of Japonica rice, which revealing a high peak viscosity and high break-down. Milkyqueen, a low-amylose rice, showed a slightly higher peak viscosity and lower final viscosity than Koshihikari. Hoshiyutaka, a high-amylose rice, showed a slightly lower peak viscosity and higher final viscosity. Koganemochi, a waxy rice, showed a markedly lower peak viscosity and lower final viscosity. EM10, SHR, showed a lower peak viscosity and markedly higher final viscosity.

As shown in Fig. 1A, the breakdown of SHR, EM10 was very low, which means that the gelatinized starch granule was resistant to breaking down by stirring. These pasting properties are similar to other high-amylose or high-resistant-starch rice.

In addition to the hard and tough properties of the cooked rice grains already mentioned, it seemed that EM10 would be suitable for blending with wheat flours to make wheat/rice bread or wheat/rice noodles, because its gelatinized starch gel was tough and would maintain a firm dough texture.

The pasting properties of the blended wheat/rice flour samples (7:3, by weight) were measured by RVA. Table 1 shows the pasting properties of wheat/rice flour samples blended with glutinous rice (Koganemochi) or SHR (EM10) were similar to those of wheat flour. We compared the pasting properties of the wheat/rice flour samples blended with raw rice flour and cooked rice gel. As shown in Table 1, all the rice samples with wheat flour blended with the cooked rice gel and not as the raw flour showed a lower final viscosity, which is an indicator of the retrogradation. Furthermore, as shown in Table 1, a comparison among the same rice cultivar gave a setback value for sample 8 (gelatinized EM10) lower than that for sample 3 (raw EM10). Rice bread has the problem of its texture becoming harder 3–4 days after bread-making, so that cooked rice would be more suitable than raw rice to reduce the retrogradation of starch after bread-making.

**Pasting properties of the wheat flour samples blended with various cooked rice gels**

The pasting properties of the wheat flour samples blended with rice gel cooked under the different conditions were measured by RVA. As shown in Fig. 1B, the final viscosity, an indicator of the degree of retrogradation, of the samples became lower in the order of cooking conditions a, c and d. The longer the rice cooking time was, the lower the final viscosity became. This shows why the cooked rice gel would be more suitable than raw rice flour as a material. Cooked rice would be better than raw rice to prevent hardening of the wheat/rice bread after bread-making as the starch of the cooked rice gelatinized well. Mode 2 cooking was not only useful to rapidly prepare the pre-germinated brown rice but also provided properly cooked rice as a material to inhibit hardening of the wheat/rice bread.

**Resistant starch in the cooked rice grains**

SHR had a markedly higher amount of resistant starch than the other rice grains as shown in Fig. 2. The amount of resistant starch in cooked pre-germinated
SHR rice was 8.3%, this being about 4 times that in high-amylose rice, Hoshiyutaka (2.1%) and 8 times that in premium Japonica rice, Koshihikari (0.95%). SHR showed a very high amount of resistant starch even after cooking by blending with cooked soft rice grains. Yang has reported the starch properties of mutant rice which was rich in resistant starch. Our SHR showed a higher content of resistant starch after cooking than the high-resistant-starch rice, Rs 111, reported by Yang et al.23) The improved method determining the resistant starch content of rice and rice products showed that the resistant starch decreased after making rice crackers.32) Although germination and cooking decreases the resistant starch in the rice grains,20) SHR maintained a very high amount of resistant starch after germination and cooking. The use of low-GI bread in the place of high-GI bread has been reported to be effective to lower the blood glucose level.26) Bread from wheat and SHR therefore seems to be promising for the prevention of diabetes.

Germination of SHR

Pre-germinated brown rice is usually prepared by soaking brown rice grains overnight at 30–40 °C.27) This takes long time, such as 12 h or 18 h, allowing microorganisms to considerably increase and deteriorating the quality of the germinated brown rice in terms of its flavor and texture.28) We therefore searched for a novel germination method. After soaking brown SHR rice grains for 30 min at 45 °C, they were next soaked for two hours at 37 °C, and then cooked under the three conditions shown in Fig. 3. Brown rice germinated well in the case of mode 2 as shown in Fig. 3. Physical properties of the cooked pre-germinated brown rice grains are shown in Table 2. The germinated brown rice grains prepared by mode 2 cooking showed a higher H1 balance (the ratio of stickiness S1 to hardness H1 was 0.0075 by a low-compression test with the Tensipresser) compared with the figures for mode 1 (0.0026) and mode 3 (0.0025) and a higher H2 balance (the ratio of stickiness S2 to hardness H2 was 0.073 by a high-
compression test with the Tensipresser) compared with the figures for mode 1 (0.013) and mode 3 (0.027). Pre-soaking the brown rice for 30 min at 45/°C was effective for absorbing a large amount of water into the brown rice grains and for activating the various enzymes. The reason for mode 2 showing the best germination is that the temperature rose slowly from 30/°C to 60°C, so that the various enzymes necessary for germination remained active for longer than under the other conditions. It took less than 7 h with our presoaking and mode 2 cooking which we call the rapid germination method. We have pointed out in the introduction that it takes 12–18 h for the usual germination of brown rice, which results in microorganism infestation and the generation of an off-flavor. Such infestation and off-flavor generation did not occur as a result of our rapid germination. Furthermore, brown rice grains pre-germinated by our rapid method contained more glucose (4.24 g/100 g), glutamic acid (24.26 mg/100 g) and resistant starch (7.84 g/100 g) than those (3.81 g/100 g, 10.6 mg/100 g, and 7.68 g/100 g, respectively) in brown rice grains pre-germinated by the ordinary soaking method (18 h). We do not have to change the soaking water so that our PGR contained more glucose and glutamic acid because it did not lose those tasty substances.

Suitable conditions for the preparation of wheat/rice bread

After being pre-treated (45°C for 30 min and 37°C for 120 min), 52.5 g of SHR grains and 22.5 g of milled rice grains of each cultivar were cooked with 300 ml of water for 2 h. The cooked rice was blended with 175 g of wheat flour after cooking. In order to prepare the highly-expanded bread, it was necessary to add the most suitable amount of water according to each rice cultivar.

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Table 1. Pasting Properties of Wheat and Blended Flour

1 Wheat (Camellia)
2 70% wheat and 30% Koshihikari white rice flour
3 70% wheat and 30% EM10 white rice flour
4 70% wheat and 30% Koganemochi white rice flour
5 70% wheat and 30% Hoshiyutaka white rice flour
6 70% wheat and 30% Milkyqueen white rice flour
7 70% wheat and 30% Koshihikari gelatinized white rice flour
8 70% wheat and 30% EM10 gelatinized white rice flour
9 70% wheat and 30% Koganemochi gelatinized white rice flour
10 70% wheat and 30% Hoshiyutaka gelatinized white rice flour
11 70% wheat and 30% Milkyqueen gelatinized white rice flour
12 70% wheat and 30% EM10 gelatinized pre-germinated brown rice flour
13 70% wheat and 30% Koshihikari gelatinized pre-germinated brown rice flour
14 70% wheat, 21% EM10 gelatinized pre-germinated brown rice flour and 9% Milkyqueen gelatinized white rice flour
15 70% wheat, 21% EM10 gelatinized pre-germinated brown rice flour and 9% Koganemochi gelatinized white rice flour
16 70% wheat, 21% EM10 gelatinized pre-germinated brown rice flour and 9% Koshihikari gelatinized white rice flour
17 70% wheat, 21% EM10 gelatinized pre-germinated brown rice flour and 9% Hoshiyutaka gelatinized white rice flour
The results of measurements reported in our previous study were used to select the most suitable amount of water to be added to the blend of wheat flour and cooked rice for each rice cultivar blended. The determined amounts of water were 88 ml for EM10 (75 g of SHR), 38 ml for Koshihikari, 44 ml for Koganemochi, 59 ml for Hoshiyutaka and 48 ml for Milkyqueen. Hard rice such as SHR or Hoshiyutaka required a larger amount of water than other soft-types of rice flour.

Effect of germination and cooking on the wheat/rice bread

Cross sections of the various kinds of bread prepared from wheat (70%) and various types of rice flour (30%, white rice, brown rice, pre-germinated brown rice or cooked and pre-germinated brown SHR) are shown in Fig. 4A. The loaf volume was highest in the case of cooked pre-germinated brown rice (the e, specific volume was 3.6), followed by uncooked white rice (d, 3.4), uncooked brown rice (c, 3.3), and uncooked pre-germinated brown rice (b, 3.0). Ordinary wheat bread produced a greater specific volume of 4.0 (a).

The alpha-amylase activity of white rice is lower than that of brown rice, making the stronger dough texture of white rice than of brown rice yield the higher bread volume. In the case of cooked pre-germinated brown rice, alpha-amylase is denatured and the gelatinized SHR starch gives the most suitable dough properties compared with the other uncooked SHR dough, this leadings to the improved specific volume of the loaf.

### Table 2. Physical Properties of Cooked Pre-Germinated Brown Rice Grains

<table>
<thead>
<tr>
<th>Cooking conditions</th>
<th>Low compression test (25%)</th>
<th>High compression test (90%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Surface hardness (H1)</td>
<td>Surface stickiness (-H1)</td>
</tr>
<tr>
<td></td>
<td>[gw/cm²] SD</td>
<td>[gw/cm²] SD</td>
</tr>
<tr>
<td>Mode 1</td>
<td>420 115 1.03 0.15 0.0024 0.0010</td>
<td>2598 234 21.95 8.59 0.0085 0.0147</td>
</tr>
<tr>
<td>Mode 2</td>
<td>188 58 1.31 0.46 0.0069 0.0040</td>
<td>1865 213 136.80 47.98 0.0734 0.0270</td>
</tr>
<tr>
<td>Mode 3</td>
<td>385 108 1.06 0.15 0.0028 0.0010</td>
<td>2559 253 43.03 31.71 0.0168 0.0174</td>
</tr>
</tbody>
</table>

Physical properties of cooked rice grains were measured by the high-compression/low-compression method by Tensipresser.

Fig. 3. Cooking Conditions for Rapid Germination and Photographs of the Pre-Germinated Brown Rice Grains.

Fig. 4. Cross Section of the Wheat/Rice Bread Samples.

A, Wheat/rice bread (70% wheat and 30% rice). a, 100% wheat (Camellia); b, 70% wheat and 30% uncooked pre-germinated brown SHR; c, 70% wheat and 30% uncooked brown SHR; d, 70% wheat and 30% uncooked white SHR; e, 70% wheat and 30% cooked pre-germinated brown SHR. B, Wheat/rice noodles. 70% wheat, 21% cooked pre-germinated brown SHR, and 9% cooked white waxy rice.

Wheat/Rice Bread from Super-Hard Rice
An example of wheat/rice noodles is shown in Fig. 4B. High-amylose rice has been reported to be more suitable than low-amylose rice for rice noodles due to its lower stickiness.\textsuperscript{31} As shown in Fig. 4B, wheat/rice noodles prepared from 70% of wheat blended with 21% of SHR and 9% of waxy rice resulted in high acceptability due to the low-stickiness and elastic texture.

**Blending of two rice cultivars**

Although SHR is suitable for blending with wheat in terms of bread-making, its palatability as cooked rice is inferior to Koshikihari, the premium rice in Japan. In order to improve the palatability of the wheat/rice bread, we searched for the most suitable blend of the cooked rice gel with the cooked pre-germinated EM10 SHR brown rice. As shown in Table 1, blending 9% of the cooked white rice gel of Koganemochi (waxy rice) with 21% of the cooked pre-germinated EM10 brown rice gel and 70% of wheat flour, improved the pasting properties. It was apparent that the peak viscosity became higher and that the difference between the final viscosity and minimum viscosity became lower compared with using 30% of cooked pre-germinated EM10. We ascertained improvements of to the taste and texture of the wheat/rice bread by blending 9% of waxy rice with 21% of SHR.

**Physical properties of the wheat/rice bread**

The physical properties of the various kinds of wheat/rice bread are shown in Fig. 5A (samples A–G). Toughness indicates the work of stress against pressure and corresponds to the hardness of the bread or noodle. Compared with ordinary wheat bread, SHR blended bread had a harder texture as shown in Fig. 5A. Samples D, E, F and G in Fig. 5A all show lower toughness than that of sample B, meaning that the low-setback samples in the RVA analysis would lead to softer wheat/rice bread (Table 1 and Fig. 5A).

The specific loaf volume of wheat bread (sample A) was 4.2, EM10 (sample B) was 3.3, 30% Koshikihari (sample C) was 3.7, Koganemochi (sample D) was 3.6, Milkyqueen (sample E) was 3.7, 9% Koshikihari (sample F) was 3.7, and Hoshiyutaka (sample G) was 3.8.

According to Huang and Preston,\textsuperscript{30} Asian consumers prefer a softer tasting bread for which the crumb mouth-feel characteristics are highly important.

The addition of a soft white rice type, Koshikihari, Milkyqueen, Koganemochi or Hoshiyutaka, significantly improved the physical properties resulting in a texture comparable with that of wheat bread or even slightly softer.

**Firming degree of the bread**

It has been reported that rice bread or wheat/rice blended bread tends to go stale very rapidly, limiting its distribution.\textsuperscript{31} We measured the bread hardness on 4th day after bread-making. As shown in Fig. 5A (samples H–N), the wheat/rice bread samples (K, L, and M, blended with soft rice) had lower toughness than wheat bread. In particular, sample L (Koganemochi) had a remarkably soft texture compared with wheat bread. Sample I (SHR) showed a lower degree of firming (the ratio of toughness after one day to that of after 4 d) than wheat bread. Although wheat/rice bread tends to harden markedly compared with wheat bread, Takano has reported that pre-gelatinized rice resisted firming.\textsuperscript{30} It was clarified in the present study that blended pre-germinated brown rice with wheat after cooking was effective for bread making to prevent hardening, even in the case of SHR.
As shown in Fig. 6, the resistant starch content increased to 2.65% in the case of sample B, while sample A contained only 1.12%. Even after blending 9% of cooked white rice gel, the bread contained 1.75–2.10% of resistant starch. Resistant starch is not digested in the small intestine during the digestion process. It has been reported that it is useful to prevent obesity, diabetes in the small intestine during the digestion process. It has been reported that it is useful to prevent obesity, diabetes and colonic cancer. Our wheat/rice bread from SHR is promising not only as tasty bread but also as the health-oriented bread.

In the case of wheat/rice noodles, resistant starch was 1.8 (100% EM10), 1.5 (21% EM10 and 9% Koshihikari), 1.6 (21% EM10 and 9% Hoshiyutaka), 1.3 (21% EM10 and 9% Koganemochi), and 1.6 (21% EM10 and 9% Milkyqueen) times higher than that of ordinary wheat noodles as shown in Fig. 7. SHR seems promising as both a material for bread and also for noodles.

Moreover, our bread and noodles contained many tasty substances because the short soaking time for germination without changing the soaking water prevented the loss of such water-soluble components as glucose and glutamic acid.

It is necessary for us to try to increase the blending ratio of EM10 SHR to enhance the bio-functionality without any deterioration of the palatability of such rice products as bread and noodles.

**Conclusions**

Cooked pre-germinated SHR brown rice was added to wheat flour to improve the quality of blended wheat/rice bread and noodles. Resistant starch in the bread was markedly more when SHR was added. Suitable soaking and cooking condition were selected to rapidly prepare high-quality pre-germinated SHR brown rice. It was found after blending SHR with wheat that cooking and sufficient gelatinization of the rice starch was effective to improve the texture and to retard hardening after the...
bread had been baked. Furthermore, if white waxy rice was soaked and cooked with the pre-germinated brown SHR, the texture of the bread was very soft and resistant to hardening even up to the 4th day after bread–making. It became possible to produce high-quality and bio-functional wheat/rice bread or noodles by blending cooked pre-germinated brown SHR with wheat flour.

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References

16) Yamauchi H and Noda T, Japan Kokki Tokyko Koho, 208560 (July 29, 2004).