Changes in the Texture and Viscoelastic Properties of Bread Containing Rice Porridge during Storage

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The objective of this study was to investigate the effects of rice porridge on the texture and viscoelastic properties of bread during storage. Three types of bread, wheat flour bread, 15% rice flour bread, and 15% rice porridge bread, were prepared. After baking and storing the bread for 24 h, 48 h, and 72 h at room temperature, we measured the texture and viscoelastic properties of the bread crumbs by texture profile analysis (TPA) and creep test. The 15% rice porridge bread showed a significantly higher specific volume and maintained softer crumbs than the other two types (p < 0.05). It also had a slightly stickier texture than the others. It can be concluded that rice porridge improves the specific volume, texture, and viscoelastic properties of bread crumbs during storage.

Key words: rice bread; gelatinized rice; gelatinization; aging; texture profile analysis (TPA)

Rice is the leading food crop in most countries in Asia, including Japan, owing to climatic conditions and geographical features. Although Japan is almost 100% self-sufficient in rice, it still relies heavily on the import of some other products, including wheat, soybean, and corn. Also, it is one of the world’s largest importers of food, and its food self-sufficiency rate on a calorie basis is the lowest among the developed countries. Rice consumption in Japan has fallen to half of what it was in the late 1950s due to Westernization of the traditional diet.1,2 To alleviate the food supply problem, the Ministry of Agriculture, Forestry and Fisheries of Japan has announced a new policy, the “2008 New Agricultural Policy for the 21st Century,” which aims at promoting baked goods made from rice flour and at establishing a stable food supply system that supports domestic rice consumption. Hence, partially replacing wheat flour with rice flour in bakery products is now attracting attention in Japan.

Making rice flour bread of good quality, however, is beset with many technological difficulties such as low specific volume and early firming of bread crumbs during storage.2,3 Moreover, considering the mechanical procedure of rice milling, the cost of rice flour is higher than that of wheat flour. How to bring down the cost and improve the quality of rice flour bread is now under study. Okunishi4 has reported that using cooked rice as a substitute for 10% to 30% of wheat flour is effective in maintaining a high specific volume of bread with good results on sensory evaluation tests. However, rice granules remain on the crumbs even after baking. The gelatinization characteristics of starch affect the texture of bread, and hence are considered to be related to bread quality, including the ability to retard staling.5 Naito et al.6 have reported that gelatinized starch granules can sustain gas pressure during expansion at the early stage of baking, which results in uniform gas cells under the crust, resulting in bread with a sticky texture and good expansion characteristics. Moreover, Shibata et al.7 have reported that the addition of gelatinized rice in the form of gelatinized rice flour or rice porridge to dough materials can improve loaf volume and crumb softness.

Although rice porridge bread shows better sensory evaluation features than rice flour bread, it remains to be determined whether rice porridge bread is resistant to firming. Bread staling is a significant factor that leads to decreases in bread texture quality.8 Little information is available as to how the physical properties of bread containing gelatinized rice starch change over time. Our objective in this study was to investigate the effects of rice porridge on the texture and viscoelastic properties of bread and to compare them with those of wheat flour and rice flour bread during storage.

Materials and Methods

Rice porridge cooking. Polished rice (150 g) (Koshi-hikari, cultivated in Ibaraki Prefecture, Japan) was cooked in 600 g of water (rice:water = 1:4 in weight) using an electric rice cooker (NP-NA10, Zojirushi, Tokyo) in rice porridge mode. After cooking, the rice porridge was cooled for 1 h to 28 ± 2°C.

Breadmaking processes. The formulations of the three types of bread are shown in Table 1. Wheat flour (Camellia, Nissin Flour Milling, Tokyo, Japan), rice flour (Hakurikikomeko, Namisato, Tochigi, Japan), and dry yeast (Super Camellia, Nisshin Foods Group, Tokyo, Japan) were used. Except for quantity and type of rice, all the ingredients were the same. To maintain the same 65% water ratio (flour basis) among the different types of bread dough used, the amount of water lost through evaporation during rice cooking was added to the rice porridge.
The bread samples were prepared by a straight-dough procedure. The purpose of mixing is to produce a smooth, homogeneous dough. To achieve similar smoothness and homogeneity, it is necessary to modify the mixing process for wheat flour dough to match that for rice flour and rice porridge dough (Table 2). The mixing times for rice flour and rice porridge dough were determined so that the condition of the dough in the various mixing stages became similar to that of wheat flour dough. After mixing, the dough was placed in a fermentation cabinet for bulk fermentation at 27 °C at 75% RH for 80 min, and divided into four unit pieces of 420 g. The dough pieces were rounded and allowed to rest for 20 min at 27 °C at 75% RH. They were then put in a molder (Oshikiri Machinery, Kanagawa, Japan), folded into a cylindrical shape, and proofed in a trapezoid pan at 38 °C at 85% RH for 45–50 min until the top of the dough reached the upper edge of the pan. Baking was then done in a conventional oven (Revent International, Stockholm, Sweden) at 200 °C for 20 min. After cooling for 1 h, the bread samples were packed into Ziplock bags (material, LDPE) and stored at room temperature over a 3 d storage period. 

### Specific volume, crust color, and moisture content of the loaves.

The loaves were measured 1 h after baking. Volume, weight, and specific volume were determined using a laser volume measurement unit (Selnc-WinVM2100A, Astex, Tokyo, Japan). The color of the bread crust was measured with a hand spectrophotometer (NF 333, Nippon (Selnac-WinVM2100A, Astex, Tokyo, Japan). The color of the bread crust. We consider that the color difference between the crust. We consider that the addition of gelatinized starch can facilitate the modification process for wheat flour dough to match that for rice flour and rice porridge dough. The mixing times for rice flour and rice porridge dough were determined so that the condition of the dough in the various mixing stages became similar to that of wheat flour dough. After mixing, the dough was placed in a fermentation cabinet for bulk fermentation at 27 °C at 75% RH for 80 min, and divided into four unit pieces of 420 g. The dough pieces were rounded and allowed to rest for 20 min at 27 °C at 75% RH. They were then put in a molder (Oshikiri Machinery, Kanagawa, Japan), folded into a cylindrical shape, and proofed in a trapezoid pan at 38 °C at 85% RH for 45–50 min until the top of the dough reached the upper edge of the pan. Baking was then done in a conventional oven (Revent International, Stockholm, Sweden) at 200 °C for 20 min. After cooling for 1 h, the bread samples were packed into Ziplock bags (material, LDPE) and stored at room temperature over a 3 d storage period.

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Wheat flour bread (g)</th>
<th>Rice flour bread (g)</th>
<th>Rice porridge bread (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat flour</td>
<td>1000</td>
<td>850</td>
<td>850</td>
</tr>
<tr>
<td>Rice flour</td>
<td>0</td>
<td>150</td>
<td>0</td>
</tr>
<tr>
<td>Dry rice</td>
<td>0</td>
<td>0</td>
<td>150</td>
</tr>
<tr>
<td>Water</td>
<td>650</td>
<td>650</td>
<td>650</td>
</tr>
<tr>
<td>Sugar</td>
<td>60</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Salt</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Skim milk powder</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Shortening</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Dry yeast</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

*The water used to cook rice porridge and that added after cooking are included.

### Table 2. Various Mixing Processes for Making Bread Dough

<table>
<thead>
<tr>
<th>Mixing time (min)</th>
<th>Before adding shortening</th>
<th>After adding shortening</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat flour bread</td>
<td>L2, M4</td>
<td>L2, M5, H1</td>
</tr>
<tr>
<td>Rice flour bread</td>
<td>L2, M3</td>
<td>L2, M4, H1</td>
</tr>
<tr>
<td>Rice porridge bread</td>
<td>L3, M1</td>
<td>L4, M1</td>
</tr>
</tbody>
</table>

L, low speed (150 rpm); M, medium speed (250 rpm); H, high speed (370 rpm).

The results of color measurements are shown in Table 3 and cross sections of the bread samples are shown in Fig. 1. The specific volume of the rice flour bread was lower than that of wheat flour bread (p < 0.05) owing to a lack of wheat gluten in the former. However, the rice porridge bread showed a significantly (p < 0.05) higher specific volume (4.25 ± 0.03 cm³/g) than the wheat flour bread (4.12 ± 0.06 cm³/g) or the rice flour bread (3.86 ± 0.03 cm³/g).

We consider that the addition of gelatinized starch can facilitate the modification process for wheat flour dough to match that for rice flour and rice porridge dough. The mixing times for rice flour and rice porridge dough were determined so that the condition of the dough in the various mixing stages became similar to that of wheat flour dough. After mixing, the dough was placed in a fermentation cabinet for bulk fermentation at 27 °C at 75% RH for 80 min, and divided into four unit pieces of 420 g. The dough pieces were rounded and allowed to rest for 20 min at 27 °C at 75% RH. They were then put in a molder (Oshikiri Machinery, Kanagawa, Japan), folded into a cylindrical shape, and proofed in a trapezoid pan at 38 °C at 85% RH for 45–50 min until the top of the dough reached the upper edge of the pan. Baking was then done in a conventional oven (Revent International, Stockholm, Sweden) at 200 °C for 20 min. After cooling for 1 h, the bread samples were packed into Ziplock bags (material, LDPE) and stored at room temperature over a 3 d storage period.

#### Results and Discussion

#### Effect of rice porridge on specific volume

Good loaf volume and fine, silky crumbs are the two main contributors to bread quality. The experimental results for bread loaf volume, weight, and specific volume are shown in Table 3, and cross sections of the bread samples are shown in Fig. 1. The specific volume of the rice flour bread was lower than that of wheat flour bread (p < 0.05) owing to a lack of wheat gluten in the former. However, the rice porridge bread showed a significantly (p < 0.05) higher specific volume (4.25 ± 0.03 cm³/g) than the wheat flour bread (4.12 ± 0.06 cm³/g) or the rice flour bread (3.86 ± 0.03 cm³/g).

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#### Effect of rice porridge on crust color

The results of color measurements are shown in Fig. 2. All of the bread loaves had a golden-brown crust. The rice porridge bread showed significantly (p < 0.05) lower L* values (lightness) and lower b* values (blue indicates negative values and yellow indicates positive values) than the wheat flour bread and the rice flour bread. The presence of rice porridge yielded a slight increase in the dark color and blueness of the bread crust. We consider that the color difference between the rice porridge bread and the wheat flour bread was related to the Maillard reaction, that is, reducing sugars reacting with free amino acids in the proteins. It has been reported that both reducing sugars and free amino acids
are produced in great amounts during rice cooking.\textsuperscript{4,19} The chance of a Maillard reaction therefore rises in rice porridge bread during baking, causing the color of the crust become darker than that of the wheat flour bread.

**Moisture content**

Differences in the physical properties of baked bread can be caused by several factors, including different water percentages in the dough materials and moisture migration from crumbs to crust\textsuperscript{20} during bread storage. The changes in moisture content in the three types of bread over the 3 d storage ranged from 42.31\% to 42.33\% for the wheat flour bread, 42.57\% to 42.68\% for the rice flour bread, and 43.08\% to 43.00\% for the rice porridge bread. Although bread crumb hardening during storage is related to moisture loss in crumbs,\textsuperscript{20} such small changes have no significant effect\textsuperscript{21,22} on bread texture. In addition, the moisture differences among three types of bread were also small. On the whole, the moisture content was well controlled and was almost the same among the various samples over the storage period. This means that the differences and changes in texture and viscoelastic properties of the bread were caused by its materials, not by the moisture content.

**Changes in texture properties during bread aging**

Texture is the major criterion in assessing the eating quality of bread because of its close association with the consumer’s perception of freshness.\textsuperscript{23} An increase in crumb firmness is one of the most important quality indicators of bread staling.\textsuperscript{24} Hardening of bread during storage can be caused by many factors, including moisture migration from crumbs to crust.\textsuperscript{20,21} However, the effect of moisture loss on crumbs was negligible in this study. Figure 3 shows changes in the texture parameters of the bread crumbs during storage. For all types of bread studied, crumb firmness increased significantly ($p < 0.05$), while crumb cohesiveness and resilience decreased significantly ($p < 0.05$) over the storage period. In general, crumbs become harder and increases in crumb firmness are accompanied by a loss of resilience and cohesiveness during storage.\textsuperscript{25}

The crumb firmness of the rice flour bread was significantly higher ($p < 0.05$) than that of the wheat flour bread, but the rice porridge bread was significantly softer ($p < 0.05$) than the other two types of bread throughout the 3 d of storage, as indicated by the firmness values (Fig. 3). Note that the addition of rice flour to the bread dough made the crumbs hard. By contrast, the addition of rice porridge improved the quality of the baked bread, in that it gave it a soft crust texture. These differences in texture might have resulted from gelatinization of the rice starch granules in the rice porridge bread. The crumb adhesiveness of the bread containing rice (rice flour bread and rice porridge bread) was significantly higher ($p < 0.05$) than that of the wheat flour bread over the storage period. Adhesiveness is defined as the force required to remove bread crumbs that

| Table 3. Loaf Volumes, Weights, and Specific Volumes of the Bread Samples |
|-----------------|-----------------|-----------------|-----------------|
| Wheat flour bread | Rice flour bread | Rice porridge bread |
| loaf volume (cm$^3$) | 1539.43 ± 22.52$^a$ | 1450.46 ± 9.83$^b$ | 1584.81 ± 10.38$^c$ |
| Weight (g) | 373.73 ± 1.62$^d$ | 376.16 ± 1.35$^e$ | 372.56 ± 1.25$^f$ |
| Specific volume (cm$^3$/g) | 4.12 ± 0.06$^g$ | 3.86 ± 0.03$^h$ | 4.25 ± 0.03$^i$ |

mean ± SD (n = 8). Values followed by different letters are significantly different ($p < 0.05$).

**Fig. 1.** Cross Section of Bread Made from Wheat Flour, 15% Rice Flour, and 15% Rice Porridge.

**Fig. 2.** L* a* b* Color of Crust. Values are a mean ± SD (n = 8). *Significant difference ($p < 0.05$).
adhere to the palate during mastication.\(^{26}\) The addition of rice to dough materials, then, should increase the sticky texture of the bread, making it like that of a marshmallow. On the second day of storage, the adhesiveness of the rice flour bread decreased substantially and remained low up to the third day. Nevertheless, adhesiveness remained highest in the rice porridge bread among the three types of bread, and it showed no sudden decrease over the storage period (Fig. 3, Adhesiveness). The use of rice porridge produced bread with a chewy mouth feel and that can maintain a sticky texture even with aging. These results are considered to be related to the malto-oligosaccharide in the rice porridge bread, which prevented bread retrogradation.\(^{27}\)

Changes in viscoelastic properties during bread aging

From a rheological standpoint, it is important to characterize the viscoelastic behavior of bread.\(^{22}\) Figure 4 shows changes in the viscoelastic properties of the bread crumbs during storage. On the first day, the
rice flour bread and the wheat flour bread had almost the same softness, but the rice porridge bread was much softer than both of these in all four respects. On the second day, the rice flour bread showed significantly \((p < 0.05)\) higher \(E_1\) and \(\eta_1\) than the wheat flour bread. This indicates that the firming rate of the rice flour bread was faster than that of the wheat flour bread. This can be attributed to the lack of gluten\(^{29}\) and retrogradation of the rice starch.\(^{29}\) Also, changes in the firming rate of the bread crumbs might be related to gluten-starch interactions, including hydrogen bondings between gluten and starch granules.\(^{30}\)

On the other hand, the rice porridge bread maintained significantly \((p < 0.05)\) the lowest \(E_0\), \(E_1\), \(\eta_1\), and \(\eta_N\) among the three types of bread throughout the 3 d of storage. It is remarkable that the rice porridge bread maintained softer crumbs than the others during the storage period.

The above differences might be explained by considering that gelatinized rice starch affects the size or number of pores under the crust,\(^{6}\) yielding a soft texture and stickiness in the bread. Moreover, it is assumed that during rice cooking, a large amount of malto-oligosaccharides is produced.\(^{31}\) This might be responsible for retarding bread retrogradation.\(^{27}\)

In this study, bread containing rice porridge showed an increase in specific volume and a slight increase in the dark color of the crust. Moreover, the addition of 15% rice porridge to the dough significantly improved the texture of the bread, in that soft, sticky crumbs give an agreeable mouth feel. Rice porridge bread also shows resistance against firming, and its soft, sticky texture was maintained for 3 d. We conclude that rice porridge bread has better features and softer textural properties through storage than rice flour bread or even wheat flour bread.

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References