Technical paper

Bread-Making Quality of Wheat/Rice Flour Blends

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The bread-making quality of rice flour was evaluated by conducting baking tests using strong wheat flours blended with various quantities of rice flour containing 15% gluten (rice flour). The dough properties and bread qualities obtained from these blends were analyzed. The characteristics of dough and bread changed according to the increase in the blended percentage of rice flour used. The water absorption of blends increased rapidly and the Farinograph characteristics were similar to those of weak flour in that the dough became less pliable and more fragile. The gas retention properties of the dough evaluated using the vacuum expansion method and gassing power after 2 h of fermentation decreased greatly. The appearance and crumb grain of the bread became rough, and the specific loaf volume (SLV) decreased. The upper crust was slightly reddish white, and the crumb grain was somewhat dusty. The sugar and amino acid contents in the bread decreased and the amount of maltose, glutamate, glycine, alanine, and phenylalanine decreased drastically. The texture of the bread was very soft at first, however, the bread rapidly hardened when stored. During the storage, the bread had high cohesiveness and showed high recovery when compressed.

Keywords: bread, rice, flour, bread-making quality, blended flour.

Introduction

The per capita consumption of rice in Japan has been declining for the past many years. In 2001, it had decreased to about 60% in comparison to that of the peak period. Although the policies to reduce rice cultivation have been implemented, the recent yield of rice has been high and the crop is currently overproduced. It is very important to develop an effective means of using the excess of rice.

In the meantime, the consumption of wheat flour, especially flour for bread, is increasing constantly as Japanese adopt eating habits derived from the European and American living style; more than 1.2 million tons of wheat flour is currently consumed in Japan. This makes it necessary to develop a bread-making method that utilizes rice flour and to create a consumer demand for this product. Generally speaking, the bread-making quality of wheat flour blended with rice flour is far inferior to that of bread made from wheat flour alone and that the quality of the resulting bread is much lower. There have been several studies of breads made from wheat and rice flour blends as well as gluten-free rice breads (Nishita *et al.*, 1976; Takano *et al.*, 1986a; Takano *et al.*, 1986b; Yehia *et al.*, 1990; Haque *et al.*, 1994). Some are concerned with wheat flour blended with rice flour at a low ratio; others investigated gluten-free bread baked

from formulas based on rice flour and polysaccharide or soybean flour, etc. Therefore, little research on wheat and rice flour blends with a high percentage of rice flour has been done. One reason is that the bread-making quality of conventional rice flour is remarkably low compared with wheat flour.

However, a new method of milling rice to improve the bread-making quality of rice flour has been developed and is receiving national attention (Arisaka *et al.*, 1992; Egawa *et al.*, 1995). In this new process, an air-flow mill is used to grind rice grains, which have been treated with enzymes such as pectinase and hemicellulase. The bread-making quality of this new rice flour has been demonstrated to be better than that of conventional rice flour, Joshinko, thus enabling the blending of a high percentage rice flour.

In this study, we conducted bread-making tests with flour blends that included the new rice flour and Hard Red Winter (HRW) and examined how rice flour blending influenced bread-making quality and the characteristics of bread.

Materials and Methods

Preparation of flours and materials HRW was obtained from the Japanese Food Agency. This grain was milled at a Bühler test mill (Bühler Inc., Switzerland) and a 60% extraction flour (flour) was obtained. The commercial new rice flour, powder rice C, and gluten, H type, were

purchased from Niigata Flour Milling Co., Ltd. (Niigata) and Yokoyama Milling Co., Ltd. (Sapporo), respectively. In the former company, this new rice flour was specially milled in an air-flow mill after pectinase treatment and made from the most popular Japanese rice, Koshihikari, by the method of Egawa *et al.* (1995). The characteristics of this flour were small particle size and smooth particle surface, and this rice flour has better bread-making quality than Joshinko. In the latter company, the gluten was separated from imported hard flour and prepared by freeze-drying. As the original protein of rice is assumed to contribute little to bread-making quality, usual rice bread is produced using rice flour containing about 15% gluten. In this study, the protein content of H type gluten based on 13% water content was about 80%, and the protein content derived from added gluten in rice flour containing this 15% gluten becomes 12.1%, which is similar to that of HRW (11.7%). Therefore, the rice flour containing 15% gluten (rice flour), which is a general formulation in Japan, was used in the following experiments.

Flour properties The flour protein content was measured using the Dumas combustion method with Rapid N (Elementar GmbH, Hanau, Germany). The ash content was measured according to the American Association of Cereal Chemists (AACC) method (1991a). The Farinograph properties were measured with a Farinograph (Brabender, Inc., Germany) by the AACC method (1991b). The data of protein, ash and Farinograph were shown on a 13.0% moisture base. The gelatinization characteristics of flours were measured with a Rapid Visco-Analyzer 4D (RVA) (Newport Scientific Pty. Ltd., Australia) by the method of Ishida *et al.* (2003).

Dough properties The physical properties of dough were measured using 10 g after bench time according to the method of Yamauchi *et al.* (2001). Three 10 g samples of dough were formed into strips 7 cm × 2.5 cm after being rolled twice through 2.49 mm rolls. They were then stretched at a speed of 5 mm/s with a plunger (p-21) by RHEONER (model RE 33005, Yamaden Co., Ltd., Tokyo). From the force-deformation curves, the breaking force, breaking deformation and breaking energy of dough were determined. The vacuum expansion of dough (gas retention) was measured using the method of Yamauchi *et al.* (2000), which required 20 g of dough following proofing. Gas retention was evaluated by measuring the maximum volume of dough in a cylinder under low pressure. The total gassing power at 30°C for 1, 2 and 3 h was measured with a Fermograph II (ATTO Co., Ltd., Tokyo) with 20 g of dough after bench time.

Bread-making and bread evaluation The bread-making tests were conducted using the no-time method according to the following standard white bread formulation with HRW as a control: 200 g of flour, 10 g of sugar, 10 g of shortening, 4 g of salt, 4 g of yeast, 100 ppm of ascorbic acid and a suitable quantity of water (Yamauchi *et al.*, 2000). The most appropriate water absorption in the bread-making tests was estimated using a Farinograph at 500 BU. The dough was mixed for an optimal time to just

beyond peak development, which is indicated as the peak of the current curve of the mixing motor. The dough was divided into two 100 g pieces, rounded, and allowed to rest for 20 min in a fermentation cabinet at 30°C. The pieces were panned and proofed at 38°C and 85% humidity for 70 min, and then baked at 200°C for 25 min. The sliced grain of the breads was copied using a copy machine to evaluate the crumb grain. The SLV after cooling at room temperature for 1 h after baking was measured by rapeseed replacement method. Color (L^* , a^* , b^*) of the top crust and crumb was measured using a spectral diffraction colorimeter (CM-202, Minolta Co., Ltd, Osaka) and expressed as the following values: white-black (lightness, L^*), red-green (a^*), yellow-blue (b^*) (Wyszecki and Stiles, 1982). The moisture content of the bread was measured twice using bread crumbs dried for 3 h at 135°C. It is said that the crust color of rice flour bread is generally inferior to bread of wheat flour and the color is whitish. The sugar and amino acid in the bread, which seem to greatly affect this coloring reaction, were measured by the following methods. To determine the levels of these ingredients, 1 g of bread crumbs was suspended in 5 ml of distilled water and homogenized by using an ultrasonic processor VC 130 (Sonics and Materials, Inc., CT, USA). The homogenates were centrifuged at $10,000 \times g$ for 5 min, and the resultant supernatants were filtered through a 0.45 μm omnipore membrane filter (Millipore, Tokyo). The glucose, fructose, sucrose and maltose contents of the filtrate were determined by HPLC with a TSK gel Amide-80 column (Tosoh, Tokyo); the mobile phase was 80% (v/v) acetonitrile/water, and the pump was set at a flow rate of 1.0 ml/min. The amount of sugar in the samples was determined using standardization with external glucose, fructose, sucrose, and maltose. The amino acid content of the filtrate was determined in high-speed separation using the amino acid analysis system (ALC-1000, Shimadzu, Kyoto) which employed an amino acid analysis column (6.0 mm × 10 cm, Na-type sulfonized polystyrene, 3 μm) by the OPA method (post-column fluorescence coloring with an ortho phthalaldehyde reagent). The amount of amino acid in the samples was performed using standardization with amino acid standard solution (Type H, Wako Pure Chemical Industries, Ltd., Osaka). The staling characteristics of bread were evaluated by measuring the hardness and cohesiveness of crumbs using a method developed by Yamauchi *et al.* (1999). Breads were stored in polyethylene bags at 20°C for 3 days. Measurements were carried out approximately daily. The loaves were cut into 2 cm-thick slices, and a square (3 cm × 3 cm) of the crumbs was cut from the center. The hardness and cohesiveness of six crumbs were measured by twice compressing the crumbs of 2 cm to 1 cm.

Statistical analysis Gas retention, gassing power, moisture content, sugar and amino acid measurements were made in duplicate. Measurements of the dough's physical properties and SLV were performed in triplicate. The color of crust and crumb, and the hardness and cohesiveness of crumb were measured six times. All the above data were shown as mean ± standard deviation (SD) and the data except

of Figs 3 and 4 were evaluated by variance analysis using Duncan's multiple range test.

Results

Flour properties The various blend characteristics are shown in Table 1. The protein and ash contents of the blends increased and decreased, respectively, as the volume of rice flour used in the blend increased. The protein and ash contents of HRW were 11.7% and 0.45% and those of rice flour were 16.1% and 0.28%. From the above results, the reason the protein content rose and the ash content decreased as the mixing ratio of rice flour increased was that it contained a high ratio (16.1%) of protein and a low level (0.28%) of ash. With increased volume of rice flour in the blend, the Farinograph characteristics of blends showed properties similar to those of weak flour. However, the water absorption of blends increased significantly from 65.5 to 78.0 when the percentage of used rice flour was higher differing from weak flour. The gelatinization characteristics of 100% HRW were typical of hard wheat flour with a small peak viscosity and breakdown. The properties of rice flour were typical of Japonica rice flour exhibiting

high peak temperature, peak viscosity and breakdown, and small setback compared with 100% HRW as the control (Oda *et al.*, 1980). The blended flours, obtained by mixing HRW with rice flour, had reasonable medium properties of HRW and rice flour, as described above.

Dough properties of trial flour The physical property, vacuum expansion (gas retention), and gassing power of dough made from various blends are shown in Table 2. In terms of the physical properties of dough, breaking force and breaking energy increased with a rice flour blend of up to 50% rice flour blend. These values decreased with blends using more than 50%. Breaking deformation decreased with the percentage of rice flour used. From these results, the total physical properties of dough made from blends with high rice flour content (high rice blend) lacked pliability and were fragile. The vacuum expansion of dough made from various blends rapidly decreased as the percentage of rice flour increased. These results showed that the gas retention of dough declined with increase in the ratio of rice flour. The gassing power of dough made from various blends except of 100% rice flour was greater than 100% HRW as control until 1 h of fermentation, and thereafter

Table 1. Properties of various rice flour blends.

	100% HRW	75% HRW 25% RF	50% HRW 50% RF	25% HRW 75% RF	100% RF
Protein content (%)	11.7	12.8	14.1	15.0	16.1
Ash (%)	0.45	0.40	0.35	0.31	0.28
Farinograph					
Ab ^(a)	65.5	68.5	69.5	73.0	78.0
DT (min) ^(b)	21.5	13.0	10.8	2.0	1.7
Stability (min)	10.3	11.4	8.3	2.2	1.0
TI (FU) ^(c)	11.0	10.0	18.0	29.0	135.0
TB(min) ^(d)	30.0	20.5	18.8	3.7	2.5
RVA					
PT (°C) ^(e)	68.9	71.0	71.4	76.3	75.1
PV (RVU) ^(f)	183.2	194.7	220.5	229.4	257.0
BD (RVU) ^(g)	56.1	66.1	83.0	95.5	117.0
SB (RVU) ^(h)	105.7	106.5	105.0	97.3	91.2

Rice flour (RF) contains 15% gluten. HRW: Hard Red Winter, RF: rice flour containing 15% gluten, (a) Water absorption, (b) Development time, (c) Tolerance index, (d) Time to breakdown, (e) Peak temperature, (f) Peak viscosity, (g) Breakdown, (h) Setback

Table 2. Properties of doughs made from various rice flour blends.

	100% HRW	75% HRW 25% RF	50% HRW 50% RF	25% HRW 75% RF	100% RF
Physical properties					
BF(N) ^(a)	2.37 ± 0.04	2.34 ± 0.14	3.05 ± 0.23***	2.80 ± 0.29*	2.59 ± 0.31
BD(mm) ^(b)	44.0 ± 1.8	45.5 ± 3.8	38.6 ± 2.4*	37.8 ± 2.1**	35.9 ± 3.0***
BE(J) ^(c)	5.76 ± 0.47	5.80 ± 0.21	6.26 ± 0.50**	5.60 ± 0.24	4.99 ± 0.30***
Vacuum expansion (ml/20 g dough)	127.5 ± 3.5	120.5 ± 3.5	112.5 ± 3.5*	110.0 ± 7.1*	100.0 ± 2.8***
Gassing power (ml/20g dough)					
1h	31.9 ± 0.5	33.1 ± 0.3*	33.4 ± 0.5**	33.3 ± 0.2*	31.0 ± 0.1
2h	73.7 ± 0.9	72.5 ± 0.7	68.7 ± 0.4***	65.2 ± 0.2***	59.8 ± 0.7***
3h	108.8 ± 1.3	106.6 ± 0.6	100.4 ± 0.8***	96.1 ± 0.4***	87.4 ± 1.4***

Each value is the mean ± SD. The value with*, **, *** are mean significant difference from the 100% HRW as control at $p < 0.05$, 0.01, 0.005, respectively (dough's physical properties: $n = 3$, vacuum expansion and gassing power: $n = 2$). HRW: Hard Red Winter, RF: rice flour containing 15% gluten, (a) Breaking force, (b) Breaking deformation, (c) Breaking energy.

significantly decreased as the volume of rice flour was higher.

Quality of bread made from rice flour blends The appearance and crumb grain of breads made from various blended flours are shown in Fig. 1. The SLV, color and moisture are shown in Fig. 2 and Table 3. The appearance and crumb grain of bread became rougher, and the SLV decreased greatly as the percentage of rice flour increased. However, in the case of blends up to 50%, there was not a large degradation of SLV. The lightness (L^*) and the redness (a^*) of the bread's top crust, respectively, increased and decreased significantly as the volume of rice flour used increased. The color of the bread's crumb grain changed as follows: a small increase in L^* , an increase of a^* , and a decline in b^* . To the eye, the color of the upper crust was slightly reddish-white. The crumb grain was somewhat dusty and the color changed to slightly light and red, and somewhat less yellow as the volume of rice flour increased. The water content of the bread increased significantly with rice flour volume. It was assumed that the increased water content reflected the rise in water absorption observed in high rice blends. The sugar and amino acid contents of breads made from various flour blends are shown in Tables 4 and 5. Three kinds of sugar, glucose, fructose, and maltose, were detected, but no sucrose. All three sugars, particularly maltose, decreased as the percentage of rice flour used rose. The total amino acid content in breads made from various flour blends also decreased significantly with the percentage of rice flour used as well as the total sugar content. As the percentage of rice flour increased, the content of each amino acid except of proline, leucine and tyrosine decreased. Especially notable were glutamic acid, glycine, alanine, and phenylalanine. The hardness and cohesiveness of breads during storage are shown in Figs. 3 and 4. In the first stage, the hardness of bread made from a high rice blend decreased, but the change in hardness or staling

Fig. 2. Specific loaf volume of breads made from various rice flour blends. Vertical bar is SD of each value. Values with *, **, *** are mean significant difference from the 100% HRW as control at $p < 0.05$, 0.01, 0.005, respectively ($n = 3$). HRW: Hard Red Winter, RF: rice flour containing 15% gluten.

Fig. 3. Changes in hardness of breads made from various rice flour blends during storage. Vertical bar is SD of each value. HRW: Hard Red Winter, RF: rice flour containing 15% gluten, ○: 100% HRW, ×: 75% HRW: 25% RF, □: 50% HRW: 50% RF, ◇: 25% HRW: 75% RF, △: 100% RF.

Fig. 1. Appearance and crumb grain of breads made from various rice flour blends. HRW: Hard Red Winter, RF: rice flour containing 15% gluten.

Fig. 4. Changes in cohesiveness of breads made from various rice flour blends during storage. Vertical bar is SD of each value. The symbols are shown in Fig. 3.

that occur during storage increased significantly in proportion to the content of rice flour used. These results basically agreed with those reported by Takano *et al.* (1986a). As rice flour content increased, so did the value attached to the cohesiveness of bread. This result indicated that breads produced from a high rice blend had a particularly high recovery after being compressed.

Discussion

The above results indicated that the quality of bread made from a blend of rice and wheat flour could be partially improved by using the new enzyme-treated rice flour, followed by milling with an air-flow mill. This was because the quality of bread made with blends of up to 50% of this new rice flour did not decline significantly and comparatively good bread was obtained from 100% rice flour as shown Figs 1 and 2. In our experiment using 100% conventional rice flour, Joshinko, instead of the new rice flour, the SLV of bread was about 25% less than that of the new rice flour, and the appearance and crumb grain were very poor (data not shown). Those results indicate that the bread-making quality of this new rice flour is rather better than that of Joshinko mainly due to the difference in surface structure of the particles of the two rice flours. As the surface of particles of new rice flour is smoother than that of Joshinko (Arisaka *et al.*, 1992; Egawa *et al.*, 1995), the dough of the former forms rather a good dough structure

which is considerably good in gluten network and gas retention.

However, when this new rice flour was even used in the blend, the quality of bread made from blends with more than 50% rice flour was considerably degraded compared with that of 100% HRW as shown in Fig. 1. With increase in the quantity of rice flour used, Farinograph characteristics showed properties similar to those of weak wheat flour and the physical properties of the dough became less pliable and more fragile as shown in Tables 1 and 2. Especially, the dough made from blends with more than 75% rice flour had considerably less breaking deformation and breaking energy, and less vacuum expansion. These results coincided essentially with those reported by Takano *et al.* (1986b). From these results, it is assumed that the gluten network of the dough becomes weak and rough, and the dough's capacity to hold gas decreases when rice flour is used in the blend. Since the gassing power of dough also decreases according to the volume of rice flour used, the volume of dough after final fermentation is smaller in high rice blend dough, and this also seems to contribute to smaller SLV. He and Hosney (1991) reported that the gas retention and gassing power of dough have a significant relationship to the bread-making quality and SLV, and bread with less SLV is obtained from dough with less of these features. Therefore, the main changes that take place in dough when rice flour is used in the blend such as lower gas retention due to degradation of the gluten network and the decline in yeast gassing power contribute to the lower bread-making quality in blends that include rice flour.

The inferior upper crust color of bread made from rice and wheat flour blends in Table 3 seems to be caused by a reduction in reducing sugar and amino acid, which is related to the Maillard reaction. This is apparently due to the fact that the reducing sugar and amino acid contents of dough made from a high rice blend following proofing were lower than that of 100% HRW (data not shown). Furthermore, Johnson and El-Dash (1969) also report that the condensation of reducing sugar and free amino groups during baking is the most important reaction responsible for bread crust formation. The inferior color of crumb grain of bread made from rice flour blends in Table 3 seemed to be related

Table 3. Color and moisture content of breads made from various rice flour blends.

	100% HRW	75% HRW 25% RF	50% HRW 50% RF	25% HRW 75% RF	100% RF
Top color of bread					
<i>L</i> *	53.19 ± 0.72	55.03 ± 0.57**	55.27 ± 0.18**	58.30 ± 1.24***	58.03 ± 0.58***
<i>a</i> *	13.54 ± 0.38	12.71 ± 0.10***	12.46 ± 0.18***	11.13 ± 0.19***	10.98 ± 0.31***
<i>b</i> *	31.97 ± 0.44	32.20 ± 0.42	32.13 ± 0.31	32.00 ± 0.44	32.40 ± 0.27
Crumb color of bread					
<i>L</i> *	77.46 ± 1.39	77.32 ± 0.72	79.40 ± 2.03*	79.13 ± 1.64	78.70 ± 0.76
<i>a</i> *	-1.85 ± 0.06	-1.76 ± 0.06**	-1.60 ± 0.08***	-1.50 ± 0.04***	-1.49 ± 0.02***
<i>b</i> *	12.24 ± 0.40	10.80 ± 0.40***	10.21 ± 0.54***	9.26 ± 0.29***	8.93 ± 0.16***
Moisture content (%)	41.9 ± 0.91	43.2 ± 0.34***	43.4 ± 0.51***	44.4 ± 0.09***	46.1 ± 0.35***

Each value is the mean ± SD. The value with*, **, *** are mean significant difference from the 100% HRW as control at $p < 0.05$, 0.01, 0.005, respectively (color of crust and crumb: $n = 6$, moisture content: $n = 2$). HRW: Hard Red Winter, RF: rice flour containing 15% gluten.

to the inferior color of rice flour and added gluten, since this grain color of breads made from blends, a^* and b^* , declined significantly with increase in the amount of rice flour used.

As shown in Tables 4 and 5, increasing the amount of rice flour caused a decline in the sugar content of breads made from blends. The reasons for the lower sugar content in high rice blend bread seem to be as follows. As it is reported that the α -amylase and β -amylase activity, which produce maltose from damaged starch, in rice flour is less than those in wheat flour (Lorenz and Saunders, 1978; Takano *et al.*, 1980), it is estimated that insufficient maltose is produced from damaged starch in high rice blend dough, as reported by Takano *et al.* (1980). Therefore, it is assumed that the yeast in dough consumes, in order of priority, other sugars except of less maltose and that the total sugar content of high rice flour blend bread results in a lower level than that of 100% HRW. The reason the amino acid content in a high rice flour blend bread is low is thought to be due to the lower content of amino acid in the dough after proofing compared with that of 100% HRW (data not shown).

Bread made from a high rice blend was soft at first and then rapidly hardened during storage as shown in Fig. 3. This phenomenon seems to be influenced by the following factors: (1) the breads made from rice flour blends are made with a low amylose (about 17%) rice flour,

Koshihikari, which slowly undergoes retrogradation; (2) water absorption by rice flour is very high, and the water content of bread produced from such blends is also high, and (3) these breads made from rice flour blends have a rough crumb grain and a low SLV as shown in Figs 1 and 2. Since it has been reported that bread made with low amylose flour and bread with high water content are soft and slow to stale and that bread with rough grain and low SLV is hard and stale rapidly (Axford *et al.*, 1968; Maleki *et al.*, 1980; He and Hoseney, 1990; Lee *et al.*, 2001; Bhattacharya *et al.*, 2002). The particular hardening phenomenon of that made from a high rice flour blend seems to be caused by a complicated balance of positive and negative effects which control bread staling. The positive effect such as making bread with low amylose flour contributes to the softness and slow staling of bread, while the negative effect such as a rough grain and low SLV contributes to the hardness and rapid staling. The cohesiveness of breads made from rice flour blends during storage was higher than that of 100% HRW as shown in Fig. 4. The high recovery of these breads after compression seems to be related to the starch gel properties of rice flour. This high recovery of the breads corresponds to the result that bread made from rice flour blend shows the texture like rice cake.

The characteristics of bread made from a high rice flour

Table 4. Sugar content of breads made from various rice flour blends.

	100% HRW	75% HRW 25% RF	50% HRW 50% RF	25% HRW 75% RF	100% RF
Glucose (mg/g)	9.3 $\pm$ 1.2	8.7 $\pm$ 1.1	8.9 $\pm$ 0.5	7.4 $\pm$ 2.6	7.0 $\pm$ 0.7
Fructose (mg/g)	15.1 $\pm$ 1.9	12.9 $\pm$ 2.0*	11.6 $\pm$ 0.9*	10.9 $\pm$ 1.2*	10.3 $\pm$ 0.3*
Maltose (mg/g)	13.7 $\pm$ 2.3	10.8 $\pm$ 1.3	8.6 $\pm$ 1.0**	5.8 $\pm$ 1.2***	2.1 $\pm$ 1.0***

Each value is the mean $\pm$ SD. The value with *, **, *** are mean significant difference from the 100% HRW as control at $p < 0.05$, 0.01, 0.005, respectively ($n = 2$). HRW: Hard Red Winter, RF: rice flour containing 15% gluten

Table 5. Amino acid content of breads made from various rice flour blends.

	100% HRW	75% HRW 25% RF	50% HRW 50% RF	25% HRW 75% RF	100% RF
Aspartic acid	14.0 $\pm$ 0.6	10.1 $\pm$ 0.2	6.0 $\pm$ 0.1	4.2 $\pm$ 0.2	3.5 $\pm$ 0.1
Threonine	14.9 $\pm$ 0.5	13.6 $\pm$ 1.0	5.7 $\pm$ 0.4	4.3 $\pm$ 0.1	3.7 $\pm$ 0.1
Serine	6.0 $\pm$ 0.2	5.0 $\pm$ 0.4	3.9 $\pm$ 0.2	3.5 $\pm$ 0.1	3.2 $\pm$ 0.1
Glutamic acid	99.3 $\pm$ 2.7	85.9 $\pm$ 5.1	73.7 $\pm$ 3.8	45.7 $\pm$ 1.3	36.1 $\pm$ 0.5
Proline	7.3 $\pm$ 0.2	4.4 $\pm$ 0.4	2.8 $\pm$ 0.2	3.0 $\pm$ 0.0	4.5 $\pm$ 0.3
Glycine	20.5 $\pm$ 0.8	17.9 $\pm$ 1.5	11.5 $\pm$ 0.6	6.3 $\pm$ 0.2	3.8 $\pm$ 0.1
Alanine	26.9 $\pm$ 0.4	20.1 $\pm$ 1.9	11.2 $\pm$ 0.9	7.7 $\pm$ 0.1	5.9 $\pm$ 0.0
Cysteine	1.6 $\pm$ 1.5	1.5 $\pm$ 1.5	1.3 $\pm$ 0.3	—	—
Valine	5.2 $\pm$ 0.0	4.7 $\pm$ 0.9	3.4 $\pm$ 0.5	2.9 $\pm$ 0.0	2.6 $\pm$ 0.2
Methionine	5.0 $\pm$ 0.6	3.9 $\pm$ 1.6	2.5 $\pm$ 0.8	1.0 $\pm$ 0.0	0.5 $\pm$ 0.3
Isoleucine	2.4 $\pm$ 0.5	2.1 $\pm$ 0.8	1.4 $\pm$ 0.2	1.1 $\pm$ 0.0	1.0 $\pm$ 0.1
Leucine	4.6 $\pm$ 0.7	4.1 $\pm$ 1.2	3.1 $\pm$ 0.3	2.3 $\pm$ 0.0	2.3 $\pm$ 0.1
Tyrosine	3.9 $\pm$ 2.0	2.7 $\pm$ 2.1	1.2 $\pm$ 0.3	0.9 $\pm$ 0.1	0.9 $\pm$ 0.0
Phenylalanine	24.7 $\pm$ 0.1	21.6 $\pm$ 2.5	16.7 $\pm$ 0.0	8.6 $\pm$ 4.3	8.0 $\pm$ 0.4
Histidine	10.5 $\pm$ 0.9	9.3 $\pm$ 0.8	7.7 $\pm$ 2.1	6.8 $\pm$ 1.3	5.8 $\pm$ 1.3
Lysine	10.7 $\pm$ 1.3	9.4 $\pm$ 1.6	9.2 $\pm$ 4.2	6.8 $\pm$ 3.8	5.7 $\pm$ 3.3
Arginine	20.1 $\pm$ 0.6	19.6 $\pm$ 0.9	17.5 $\pm$ 0.9	13.3 $\pm$ 0.3	8.2 $\pm$ 0.6
Total amino acid	277.6 $\pm$ 5.9	235.9 $\pm$ 19.5*	178.8 $\pm$ 15.2***	118.4 $\pm$ 6.9***	95.7 $\pm$ 4.5***

All data are expressed in $\mu\text{g/g}$ bread. Each value is the mean $\pm$ SD. The total amino acid value with *, **, *** are mean significant difference from the 100% HRW as control at $p < 0.05$, 0.01, 0.005, respectively ($n = 2$). HRW: Hard Red Winter, RF: rice flour containing 15% gluten, —: not detected.

blend may be summarized as follows: (1) bread qualities (appearance, crumb grain, and SLV) were inferior to those of 100% HRW; (2) the upper crust color of the bread was whitish and slightly red, and the crumb grain was somewhat dusty; (3) sugar and amino acid contents in the bread were lower than those of 100% HRW, and (4) while at first, the bread was quite soft and springy, it became much harder during storage and its cohesiveness was much greater. It is therefore concluded that while the advantage of softness and high springiness of rice flour bread is maintained, the quality of a high rice flour bread, especially appearance, crumb grain, SLV and crust color, needs to be improved further by various methods in order for this type of bread to become popular among Japanese people.

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References

- American Association of Cereal Chemists (1991a). Approved Methods of the AACC, Method 54-21, The Association, St. Paul, MN.
- American Association of Cereal Chemists (1991b). Approved Methods of the AACC, Method 08-01, The Association, St. Paul, MN.
- Arisaka, M., Nakamura, K. and Yoshii, Y. (1992). Production method of rice flour and its utilization as food. *Japan Tokkyo Koho*, 73, 797. Nov. 25 (in Japanese).
- Axford, D.W.E., Colwell, K.H., Cornford, S.J. and Elton, G.A.H. (1968). Effect of loaf specific loaf volume on the rate and extent of staling in bread. *J. Sci. Food Agri.*, **19**, 95–101.
- Bhattacharya, M., Erazo-Castrejon, S.V. Doehlert, D.C. and McMullen, M.S. (2002). Staling of bread as affected by waxy wheat flour blends. *Cereal Chem.*, **79**, 178–182.
- Egawa, K., Shishido, K. and Nakanura, K. (1995). Fine rice flour, the producing method, and the processed food using fine rice flour. *Japan Tokkyo Koho*, 100,002. Nov. 1.
- Haque, A., Morris, E.R. and Richardson, R.K. (1994). Polysaccharide substitutes for gluten in non-wheat bread. *Carbohydrate Polymers*, **25**, 337–344.
- He, H. and Hoseney, R.C. (1990). Changes in bread firmness and moisture during long-term storage. *Cereal Chem.*, **67**, 603–605.
- He, H. and Hoseney, R.C. (1991). Gas retention of different cereal flours. *Cereal Chem.*, **68**, 334–336.
- Ishida, N., Miura, H., Noda, T. and Yamauchi, H. (2003). Mechanical properties of white salted noodles from near-isogenic wheat lines with different Wx protein-deficiency. *Starch/Stärke*, **55**, 390–396.
- Johnson, J.A. and El-Dash, A.A. (1969). Role of nonvolatile compounds in bread flavor. *J. Agric. Food Chem.*, **17**, 740–746.
- Lee, M.R., Swanson, B.G. and Baik, B.K. (2001). Influence of amylose content on properties of wheat starch and bread-making quality of starch and gluten blends. *Cereal Chem.*, **78**, 701–706.
- Lorenz, K. and Saunders, R.M. (1978). Enzyme activities in commercially milled rice. *Cereal Chem.*, **55**, 77–86.
- Maleki, M., Hoseney, R.C. and Mattern, P.J. (1980). Effects of loaf volume, moisture content, and protein quality on the softness and staling rate of bread. *Cereal Chem.*, **57**, 138–140.
- Nishita, K.D., Roberts, R.L. and Bean, M.M. (1976). Development of a yeast-leavened rice-bread formula. *Cereal Chem.*, **53**, 626–635.
- Oda, M., Yasuda, Y., Okazaki, S., Yamauchi, Y. and Yokoyama, Y. (1980). A method of flour quality assessment for Japanese noodles. *Cereal Chem.*, **57**, 253–254.
- Takano, H., Koyanagi, Y. and Tanaka, Y. (1980). On the fermentation properties of wheat flour – yeast dough mixed with rice flour and its change in sugar content during fermentation. *Nihon Shokuhin Kogyo Gakkaishi*, **27**, 522–528 (in Japanese).
- Takano, H., Toyoshima, H., Koyanagi, Y. and Tanaka, Y. (1986a). Quality improvement of composite rice-wheat flour bread with the increase of rice replacement level. *Rept. Natl. Food Res. Inst.*, **48**, 52–62 (in Japanese).
- Takano, H., Toyoshima, H., Koyanagi, Y., Watanabe, A. and Tanaka, Y. (1986b). Effect on rheological properties and bread making properties of composite rice-wheat flour in relation to the difference in particle size of the rice flour. *Rept. Natl. Food Res. Inst.*, **48**, 43–51 (in Japanese).
- Wyszecki, G. and Stile, W.S. (1982). “Color science. Concept and Methods, Quantitative Data, and Formulae. 2nd ed.” John Wiley and Sons, New York.
- Yamauchi, H., Ichinose, Y., Takata, K., Iriki, N. and Kuwabara, T. (2000). Simple estimation of bread-making quality of wheat flour by modified expansion test under reduced pressure. *Nihon Shokuhin Kagaku Kogaku Kaishi*, **47**, 46–49 (in Japanese).
- Yamauchi, H., Ichinose, Y., Takata, K., Iriki, N., Shiina, T. and Kobayashi, T. (1999). A kinetic study on staling of white bread made by frozen dough method. *Nihon Shokuhin Kagaku Kogaku Kaishi*, **46**, 212–219 (in Japanese).
- Yamauchi, H., Nishio, Z., Takata, K., Oda, Y., Yamaki, K., Ishida, N. and Miura, H. (2001). The bread-making quality of a domestic flour blended with an extra strong flour, and staling of the bread made from the blended flour. *Food Sci. Technol. Res.*, **7**, 120–125.
- Yehia, G.M., Youssef, A.M.M., and El-Sahn, N.A. (1990). Bread like products from soybean-rice flour. *Nahrung*, **34**, 135–140.