Original paper

Improvement of the Bread-making Properties of Stored or Dry-heated Rice Flour with Sucrose Fatty Acid Ester

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Baking with bread dough containing fresh rice flour/fresh wheat gluten flour was found to produce good quality rice bread. However, bread dough containing stored rice flour displayed inferior bread-making properties. The stored rice flour exhibited hydrophobicity, which is known to be closely associated with inferior bread-making properties. To reduce the hydrophobicity of the stored rice flour, various amounts of sucrose fatty acid ester (SFAE) were added during an oil-binding test. When 0.5 mL of 2.7% SFAE solution was added to the stored rice flour in the oil-binding test, the hydrophobicity of the rice flour disappeared. Thus, the addition of SFAE to stored rice flour improved its bread-making properties. Dry-heated rice flour demonstrated the same poor rice bread-making properties as stored rice flour. The addition of SFAE to dry-heated rice flour in the oil-binding test reduced the hydrophobicity of the flour.

Keywords: hydrophobicity, bread-making with rice flour/gluten flour, oil-binding ability, SFAE (sucrose fatty acid ester), rice flour proteins

Introduction

Bread dough consisting of fresh rice flour and wheat gluten flour was found to make good quality rice bread. The viscoelasticity of the gluten protein in the rice bread dough has an important influence on its bread-making properties. Tabara et al. (2015) and Nakagawa et al. (2016) reported that the state of rice flour changed from hydrophilic to hydrophobic during long-term storage at room temperature (at 15°C for several months or 35°C for 14 days) or dry-heating at 120°C for 2 h, and these changes resulted in the loss of the rice flour’s superior bread-making properties (increased bread height and specific volume). It is known that the increases in the hydrophobicity of rice flour that occur during storage or dry-heating are closely associated with the deterioration of the bread-making properties of such flour. In addition, it was reported by Nakagawa et al. (2016) that rice flour hydrophobicity is caused by changes in rice proteins. Wheat gluten is composed of gliadin and glutenin fractions. Gliadin contains lower molecular weight proteins with smaller sulfhydryl (SH) groups and is highly viscous, whereas glutenin is composed of higher molecular weight proteins with a higher SH content and displays marked viscoelasticity (Atwell 2001). It is known that the marked influence of gluten proteins on bread-making is caused by the high molecular weight glutenin fraction, specifically the disulfide linkages formed by glutenin protein subunits. In previous study, the viscoelasticity of a wheat glutenin fraction was decreased by adding dry-heated rice flour in a mixograph test (Nakagawa et al. 2016). Furthermore, DDD (6, 6'-dihydroxy-2, 2'-dinaphtil disulfide) staining by the method of Morton (1969) showed that the number of SH groups was increased in dry-heated rice flour. An increase in the number of SH groups present in stored rice flour

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could cause a reduction in the amount of glutenin protein, and hence, the addition of stored rice flour to the glutenin fraction could decrease the viscosity of any dough produced from such a mixture to almost zero. The proteins in stored rice flour can be broken down with 0.2% NaOH solution, and deproteinized rice flour displayed the same bread-making properties as unstored rice flour/fresh gluten flour (Nakagawa et al., 2016). However, this method requires a large amount of alkali solution. Seguchi and Matsuki (1977) observed that the hydrophobicity induced in wheat starch granules by chlorination disappeared after the addition of sucrose fatty acid ester (SFAE). Tabara et al. (2014) reported that SFAE adsorbed to hydrophobic dry-heated (120°C, 10 – 120 min) wheat starch granules, and they estimated the hydrophobicity of wheat starch granules by measuring the number of SFAE sucrose moieties. So, SFAE could block the SH groups in rice flour, thereby preserve its bread-making properties.

In this study, we determined the amount of SFAE in aged rice flour required to block hydrophobic sites using the method of oil-binding ability, and ascertained the preservation of reasonable bread-making properties.

Materials and Methods

Materials Japonica type rice (Oryza sativa L. japonica, cv. Akimasari) was used in this experiment. Rice flour was prepared by Kumamoto Flour Milling Co., Ltd., Kumamoto, Japan. A general compositional analysis of the rice revealed the followings; moisture, 11.94%; protein, 6.70%; and ash content, 0.28%. The mean diameter of the rice flour particles (29.30 μm) was determined using a laser diffraction particle size analyzer (Mastersizer 2000; Malvern Instruments Ltd., Worcestershire, UK). We measured the moisture content of the rice flour according to the method of Tsutsumi and Nagahara (1961). The protein content was evaluated using the AACC International method (08-01, 2000) at a 14.0% moisture balance. Olive oil was purchased from Nissin Oilio Group, Ltd. (Tokyo, Japan). The olive oil was slightly yellowish in color, making it easier to identify. Gluten flour was purchased from commercial sources (Manildra Flour Mills Pty Ltd., Sydney, Australia).

Sucrose fatty acid ester (SFAE) SFAE (hydrophilic-lipophilic balance [HLB] value: 13) was purchased from Dai-ichi Kogyo Seiyaku Co., Ltd., Kyoto, Japan. The SFAE was mainly composed of sucrose fatty acid monoesters (monopalmitate and monostearate) (60%), and the ratio of palmitic acid to stearic acid was 3/7. The main ester was monostearate, and the mean molecular weight of the SFAE was 735.

Storage or dry-heat treatment of rice flour The treatment of rice flour (100 g) at 35°C for 14 days or at 120°C for 120 min was according to Nakagawa et al. (2016). The samples were treated in open to the atmosphere. The treated rice flour was left at room temperature for 1 h, and then stirred and sieved through an stainless steal sieve three times until use.

Determination of the oil-binding ability of treated rice flour The oil-binding ability of rice flour was measured by the method of Nakagawa et al. (2016), which was slight modification of the method (Seguchi 1984) for wheat starch granules. The rice flour (2.0 g), oil (4.0 mL), and water (20 mL) in a test tube were shaken vigorously on a shaker for 60 s. The oil bound to the rice flour sank in the water. The volume (mL) of the sunken oil/2 g rice flour was measured. SFAE was added to the oil-binding test as a 2.7% (w/v) aqueous solution at volumes of 0.1 (2.7), 0.3 (8.1), 0.4 (10.8), 0.5 (13.5), 0.7 (18.9), or 1.0 mL (27 mg).

Baking tests with rice flour/fresh gluten flour Baking tests were performed according to Nakagawa et al. (2016). Rice flour (moisture content: 13.3%; 179.62 g), fresh gluten (moisture content: 6.55%; 32.6 g), compressed yeast (6.5 g), sugar (10.9 g), salt (2.2 g), and water (163.1 mL) were mixed in a National SD BT103 automatic home bakery bread maker (Panasonic Corp., Osaka, Japan) for 25 min. The bread dough was then divided into 120-g pieces, rounded, molded, and placed in baking pans. The bread dough was next proofed for 70 min at 38°C, and baked at 210°C for 30 min in a DN-63 deck-style oven (Yamato Scientific Co., Tokyo, Japan). The pan was cooled for 1 h at room temperature. The bread height (mm) was measured using a Vernier caliper (1/20 mm), and specific volume (cm³/g) was measured using a 250 mL-measuring cylinder and an electric balance (d=0.01 g). Crumbs were visually evaluated. The bread volume was measured using the rapeseed displacement method. SFAE (0.12, 0.75, 1.00, 1.21, 1.50, 1.75, or 2.25 g) was added during the bread-making process.

Statistical analysis A statistical software package (Ver. 6.1, SPSS Inc., Chicago, IL) was used to perform the statistical analyses. All experiments were performed in triplicate.

Results and Discussion

Improvement of the bread-making properties of stored rice flour/fresh gluten flour by SFAE As indicated in Table 1, the poor bread-making properties (bread height: 50.77 mm and specific volume: 1.94 cm³/g) of bread dough made with stored (at 35°C for 14 days) rice flour/fresh gluten flour were gradually improved (to 55.14 mm and 2.08 cm³/g, 56.30 mm and 2.31 cm³/g, 60.92 mm and 2.45 cm³/g, and 63.24 mm and 2.57 cm³/g, respectively) with the addition of increasing amounts of SFAE to the rice flour (from 0 to 0.12, 0.75, 1.00, and 1.21 g of SFAE per 179.62 g of rice flour, respectively). In this experiment, SFAE with an HLB value of 13 was used because SFAE with lower HLB values, such as 9.5 or 11 proved difficult to dissolve in water, and SFAE with higher HLB values (15 and 19) exhibited lower hydrophobicity (Tabara et al., 2014).

However, further addition of SFAE (1.50, 1.75, and 2.25 g) led to a worsening of the bread-making properties of the flour (to
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57.54 mm and 2.34 cm$^3$/g, 53.90 mm and 2.15 cm$^3$/g, and 50.40 mm and 1.80 cm$^3$/g, respectively) (Table 1). Thus, SFAE seems to ameliorate the hydrophobicity of stored rice flour at concentrations up to 1.21 g. On the other hand, the addition of more than 1.21 g of SFAE appeared to decrease the number of size of air bubbles in rice bread dough. The proteins in stored rice flour can be broken down with a 0.2% NaOH solution, and deproteinized rice flour displayed the same bread-making properties as unstored rice flour/fresh gluten flour (Nakagawa et al. 2016). SFAE, firstly, would bind to hydrophobic sites in the proteins, rendering the hydrophobic sites unavailable, and secondly, decrease the bread-making properties as a de-foaming agent.

**Table 1.** Effects of SFAE (g) on the bread-making properties of stored (35°C, 14 days) rice flour/fresh gluten flour

<table>
<thead>
<tr>
<th>SFAE (g)</th>
<th>Bread height (mm)</th>
<th>Specific volume (cm$^3$/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>50.77 ± 1.25c</td>
<td>1.94 ± 0.05c</td>
</tr>
<tr>
<td>0.12</td>
<td>55.14 ± 4.19b</td>
<td>2.08 ± 0.09b</td>
</tr>
<tr>
<td>0.75</td>
<td>56.30 ± 1.35b</td>
<td>2.31 ± 0.02b</td>
</tr>
<tr>
<td>1.00</td>
<td>60.92 ± 1.61a</td>
<td>2.45 ± 0.03a</td>
</tr>
<tr>
<td>1.21</td>
<td>63.24 ± 1.66a</td>
<td>2.57 ± 0.05a</td>
</tr>
<tr>
<td>1.50</td>
<td>57.54 ± 1.52b</td>
<td>2.34 ± 0.01b</td>
</tr>
<tr>
<td>1.75</td>
<td>53.90 ± 1.99b</td>
<td>2.15 ± 0.04b</td>
</tr>
<tr>
<td>2.25</td>
<td>50.40 ± 0.51c</td>
<td>1.80 ± 0.03d</td>
</tr>
</tbody>
</table>

Data are shown as the mean ± SD values of three measurements. Means followed by different letters are significantly different (P < 0.05) according to Bonferroni test.

**Table 2.** Effect of SFAE (g) on the bread-making properties of fresh rice flour/fresh gluten flour

<table>
<thead>
<tr>
<th>SFAE (g)</th>
<th>Bread height (mm)</th>
<th>Specific volume (cm$^3$/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>59.71 ± 0.95a</td>
<td>2.40 ± 0.04a</td>
</tr>
<tr>
<td>0.75</td>
<td>59.87 ± 1.43a</td>
<td>2.39 ± 0.05a</td>
</tr>
<tr>
<td>1.21</td>
<td>55.09 ± 0.66b</td>
<td>2.17 ± 0.02b</td>
</tr>
</tbody>
</table>

Data are shown as the mean ± SD values of three measurements. Means followed by different letters are significantly different (P < 0.05) according to Bonferroni test.

**Table 3.** Effects of SFAE (g) on the bread-making properties of heat-treated (120°C, 120 min) rice flour/ fresh wheat gluten flour

<table>
<thead>
<tr>
<th></th>
<th>Bread height (mm)</th>
<th>Specific volume (cm$^3$/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>59.71 ± 0.95b</td>
<td>2.40 ± 0.04b</td>
</tr>
<tr>
<td>120°C,120 min</td>
<td>56.78 ± 2.10c</td>
<td>2.03 ± 0.01c</td>
</tr>
<tr>
<td>+SFAE 1.09 g</td>
<td>66.08 ± 0.59a</td>
<td>2.58 ± 0.02a</td>
</tr>
</tbody>
</table>

Data are shown as the mean ± SD values of three measurements. Means followed by different letters are significantly different (P < 0.05) according to Bonferroni test.

**Effects of SFAE on bread dough consisting of fresh rice flour and fresh gluten flour**  Bread dough consisting of fresh rice flour/fresh gluten flour exhibited advantageous bread-making properties (59.71 mm and 2.40 cm$^3$/g, respectively), as shown in Table 2. The addition of SFAE 1.21 g to the fresh rice flour caused the dough’s bread-making properties to worsen (to 55.09 mm and 2.17 cm$^3$/g, respectively). SFAE caused the deterioration of bread dough composed of fresh rice flour/fresh gluten flour. However, the bread-making properties of the bread flour supplemented with 0.75 g of SFAE to fresh rice flour were slightly more favorable than those of fresh rice flour/fresh gluten flour. Thus, the untreated rice flour had already started to exhibit low-level hydrophobicity.

**Improvement of the bread-making properties of dry-heated rice flour/ fresh gluten flour by SFAE**  Bread dough consisting of dry-heated rice flour/fresh gluten flour also displayed poor bread-making properties (56.78 mm and 2.03 cm$^3$/g, respectively); however, the addition of SFAE (1.09 g) improved the bread-making properties of the flour to 66.08 mm and 2.58 cm$^3$/g, respectively (Table 3 and Fig. 1). SFAE had a similar effect on dry-heated rice flour as for the stored rice flour. The central bread (120°C, 120 min) in Fig. 1 shows a bread crumb that has a...
tendency to fracture due to weakness in the gluten by dry-heated rice flour, so that the crust separates (an arrow mark) from the crumb (Eliasson and Larsson, 1993).

**Effects of SFAE on the oil binding ability of stored or dry-heated rice flour**

As shown in Table 4 and Fig. 2-A, the oil binding ability of the stored (35°C, 14 days) rice flour was calculated to be 13.7 mL oil/2 g rice flour, indicating increased hydrophobicity. The precipitated white layer showed a mixture of oil and hydrophobic rice flour in water (an arrowhead) (Fig. 2-A, left tube). The volume of 2.7% SFAE was increased from 0 to 0.3, 0.4, 0.5, and 1.0 mL, and the volume of oil/2 g stored rice flour was decreased from 13.7 to 11.5, 10.3, 5.7, and 5.0 mL, respectively, indicating that the addition of SFAE resulted in a loss of hydrophobicity. The height of the precipitated white layer gradually decreased and the released yellowish oil layer above the water increased by the addition of SFAE (Fig. 2-A). When 0.5 mL of SFAE were added, the oil-binding capacity of the flour fell markedly, and no further changes in the hydrophobicity of the flour were seen after the addition of 1.0 mL of SFAE. The addition of 0.5 mL SFAE per 2 g of rice flour (2.7%) abrogated the oil-binding ability of the rice flour. The latter figure was equivalent to 1.21 g in 179.62 g of rice flour (0.5 x 2.7/100 x 179.62/2 = 1.21 g) (Table 1). Thus, it was confirmed that the disappearance of the hydrophobicity from rice flour resulted in improvements in its bread-making properties. When dry-heated (120°C, 120 min) rice flour was examined in the oil-binding test, the addition of 0.4 - 0.5 mL of 2.7% SFAE solution ameliorated the hydrophobicity of the dry-heated rice flour (Fig. 2-B), and the addition of an equivalent amount of SFAE (1.09 g in 179.62 g of rice flour) to bread dough consisting of dry-heated rice flour and fresh gluten flour (Table 3) improved the bread-making properties of the dough. Increases in the hydrophobicity of stored or dry-heated rice flour are related to the worsening of rice bread-making properties.

To improve the bread-making properties of stored or dry-heated rice flour, SFAE was added to the rice flour during bread-making to reduce the flour’s hydrophobicity. The amount of SFAE needed to reduce the hydrophobicity of the flour to optimal levels was determined using the oil-binding test, and the calculated amount of SFAE was then added to bread dough consisting of stored or dry-heated rice flour/fresh gluten flour during the bread-making test. Finally, it was shown that the addition of SFAE enabled the production of high quality rice bread from stored or dry-heated rice flour.

**References**


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