Rice varieties in relation to saltine rice cracker quality

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ABSTRACT
Three varieties of dry-milled rice flour – Angemi (low amylose), Saemimyun, and Saegoami (high amylose) – were compared with wheat flour for cracker manufacture. A method to prepare saltine crackers with rice flour, hydroxyl propyl methyl cellulose, sugar, and controlled water addition using one-stage fermentation with gelatinization prior to lamination of fermented dough was developed. Stickiness of gelatinized laminated sheets and cracker volume and thickness were highest in Angemi ($P < .05$), and hardness and fracturability were highest in Saemimyun crackers. Amylose content negatively correlated with cracker volume ($P < .05$) and thickness ($P < .05$), whereas damaged starch content positively correlated with cracker moisture content ($P < .01$) and negatively with hardness ($P < .01$) and fracturability ($P < .001$). It was observed that both amylose and damaged starch contents of flour affect rice cracker quality.

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Introduction

Traditional rice crackers are called arare and senbei (made from glutinous and non-glutinous rice, respectively).\textsuperscript{[1]} The processing method, texture, and flavor of these products are different from those of western crackers. Rice flour is steamed, kneaded, cooled, dried, and baked.\textsuperscript{[2]} A few patents have been issued for Japanese rice cracker manufacturing methods, including a technique of making senbei in different shapes,\textsuperscript{[3]} a method of manufacturing non-glutinous rice crackers by milling non-glutinous rice,\textsuperscript{[4]} and production of a high-amylose rice cracker with dietary fiber.\textsuperscript{[5]}

Western style wheat crackers can be divided into three types: saltine cracker (soda cracker), chemically leavened cracker, and enzyme cracker. Saltine crackers are distinguished by light and flaky textures and the long fermentation time of the sponge and dough processes.\textsuperscript{[6]} Sponge fermentation is a very important process owing to effects on the unique flavor and crispy texture. As fermentation time increases, the acidification caused by flour proteolytic enzymes reduces the pH of the sponge to approximately 4.1.\textsuperscript{[7]} The resulting enzymatic reaction is responsible for the rheological changes in cracker sponges.\textsuperscript{[8]} High-quality saltine cracker flour requires relatively high gluten strength, within the class of soft wheat, and low water absorption capacity.\textsuperscript{[9]} Gluten development is facilitated in cracker dough compared to cookie dough because the sugar concentration is usually much lower in a typical cracker formula than a typical cookie formula.\textsuperscript{[10]} Water absorption for cracker flour is considered to be the minimum, rather than the maximum, to produce crackers with 2 %–4% final moisture.\textsuperscript{[11]} Optimum water absorption in cracker dough produces a dough that is wet enough to form a sheet yet dry enough to avoid the formation of an elastic dough.\textsuperscript{[11]}

Although methods to produce traditional wheat saltine crackers have been developed, there is no consensus method for producing crackers with other cereals besides wheat flour. Han et al.\textsuperscript{[12]} developed gluten-free crackers using pulse flours containing < 1% xanthan gum. Li et al.\textsuperscript{[13]} observed that limited gluten strength and high levels of water absorption in whole-wheat flour inhibits formation of...
the gluten network, which results in reduced oven spring of saltine cracker baking. Although no studies on the manufacture of western style saltine crackers using rice flour have been reported, the making of bread using yeast-fermented rice similar to saltine cracker provides information regarding yeast-leavened rice products. Rice with a 20–25% (w/w) amylase content (AC) is best for making yeast-leavened rice bread with a softer texture and larger volume compared to rice with lower or higher AC.\[14–19\] Gluten is the major structure-forming protein present in yeast-leavened wheat bread and is responsible for its viscoelastic properties. However, rice protein cannot form a network capable of holding fermentation gases. Thus, the AC of rice controls the expansion volume during the popping of heated raw rice and the texture of yeast-leavened rice bread.\[17–19\]

Few studies have focused on the quality characteristics of rice flour saltine cracker. In the present study, we developed a benchtop method for gluten-free saltine crackers to substitute rice for wheat flour. We also investigated the effects of rice varieties on saltine rice cracker baking quality and identified the specific characteristics that contribute to rice saltine cracker quality.

**Materials and methods**

**Materials**

Two *indica* rice varieties (*Saegoami* and *Saemimyun*) grown at the Department of Functional Crop, National Institute of Crop Science (Milyang, South Korea), and a commercially milled *japonica* rice variety, *Angemi* (Hwanon Rice Processing Complex, Uiseong, Korea), were analyzed. Commercial bread flour was obtained from Samyang (Incheon, Korea). The following ingredients were purchased: yeast (Saf instant yeast, Saflevure, Marcq, France), shortening (Alps shortening-200, Samyang Welfood, Incheon, Korea), sodium bicarbonate (Yuchung Food, Daegu, Korea), salt (Saohp, Seoul, Korea), sugar (Baek-sul white sugar, CJ Cheiljedang, Seoul, Korea), and food-grade hydroxyl propyl methyl cellulose (HPMC; Anyaddy CN40H, Samsung Fine Chemicals, Ulsan, Korea).

**Preparation of rice flour**

Polished rice kernels were ground with a centrifugal force mill (KCFM-48, Korea Medi, Daegu, Korea), passed through a 115-mesh sieve (<125 µm), vacuum-packed in plastic bags, and stored at 4ºC until use in the experiments. The moisture and protein contents of flour were determined by AACC-approved Method 44-15A and 46–10, respectively.\[20\]

**Analysis of flour properties**

Amylose and damaged starch contents were analyzed using Megazyme kits (Megazyme International, Wicklow, Ireland) K-AMYL 04/06 and K-SDAM02/2008, respectively. The AC assay procedure was a modification of a concanavalin-A method described by Yun and Matheson.\[21\] The damaged starch content was determined using the AACC-approved method 76–31.01.\[20\] The water absorption index (WAI) of the rice flour was determined using the AACC-approved method 56–30.\[20\] The pasting properties of rice flour samples were determined using AACC-approved method 61–02\[20\] with a rapid visco analyzer (RVA; RVA Tecmaster, Newport Scientific, Warriewood, Australia). Peak viscosity (PV), holding strength or hot paste viscosity (HPV) at the end of holding at 95ºC, breakdown (BD; PV–HPV), final viscosity at 50ºC or cool paste viscosity (CPV), and setback (SB; CPV–PV) were recorded. All measurements were performed in triplicate.

**Preparation of saltine crackers**

Preparation and baking of control wheat saltine crackers was performed according to the one-stage fermentation method of cracker making as shown in Table 1.\[22\] Preliminary trials determined the
optimum formula for rice cracker based on end-product quality as shown in Table 1. Manufacturing gluten-free yeast-leavened bread from rice presents a considerable technical difficulty because gluten is the important structure-forming component. Thus, Nishita et al.\cite{23} developed a formula for yeast-leavened rice bread with the addition of HPMC. Accordingly, this study added 1% HPMC to compensate for the absence of gluten in the rice flour. In addition, 2% sugar was added as a nutrient for fermentation, and moisture was increased to 110% of the dried rice flour weight, as water absorption of rice flour is greater than that of wheat flour. A laboratory-scale, 100% rice saltine cracker-making process is illustrated in a schematic diagram in Figure 1. Although rice crackers were manufactured using the one-stage fermentation method\cite{19} of wheat crackers, the method was revised owing to the dough texture of rice. The dough were kneaded for 2 min with a dough mixer (Micro Mixer, National MFG, Lincoln, NE, USA), scraped off the edges. This process was repeated for 4 min and then for 2 min. The kneaded dough was placed into a beaker covered with cheesecloth, which was then placed in the fermenter (Softmill, Dae Hung, Seoul, Korea) for 18 h of fermentation (30 ± 2°C, 85 ± 5 relative humidity). As the fermented rice dough was too sticky to laminate, the dough was sealed to prevent an increase in moisture, incubated at 100°C for 20 min, and gelatinized to reduce its stickiness. Subsequently, as for wheat crackers, the roller interval was set at 2.5 mm, and the dough was rolled once, folded in half, and laminated; this process was repeated 5 times. After setting the roller interval at 3.0 mm, the dough was rolled 3 times and placed on the cutting mold (cutter-docker, 50 mm in width, 50 mm in length, 13 holes) to be cut into cracker shapes. Finally, crackers were placed on the baking rack, baked at 245°C, cooled in a desiccator at 25°C to reduce moisture absorption from the air, and used in the experiments.

### Analysis of cracker dough stickiness

Dough stickiness before baking was determined using a texture analyzer (TA Express; Texture Technologies, Scarsdale, NY, USA) equipped with a SMS/Chen-Hoseney dough stickiness cell (Texture Technologies). Gelatinized and laminated dough sheets were placed in a cell. Adhesiveness tests were conducted using a 35-mm aluminum cylinder at an approach speed of 2 mm s$^{-1}$, a target force of 50 × g, and a return distance of 50 mm, with a 5 kg load cell. The maximum force of dough adhesiveness was recorded as the dough stickiness. Analyzes were conducted five times.

### Analysis of cracker physical properties

Before analysis of moisture content and water activity, crackers were crushed with a mortar and pestle. Moisture content of crackers was determined using the AACC-approved Method 44-15A.\cite{20} Water activity was measured using a water activity meter (Rotronic Hygrometer, Rotronic, New York, NY, USA).

Thickness and width were measured using a Vernier caliper (Skyndex System 1, Skyndex, LLC, Albuquerque, NM, USA), and volume was determined using the rapeseed displacement test

| Ingredient                  | Wheat cracker (g) | Rice cracker (g) |
|-----------------------------|-------------------|------------------|
| Wheat flour (14% moisture)  | 100               | -                |
| Rice flour (14% moisture)   | -                 | 100              |
| Water                       | 33                | 94-96            |
| Shortening                  | 11                | 11               |
| Sodium bicarbonate          | 0.45              | 0.45             |
| Yeast                       | 0.7               | 1.7              |
| Salt                        | 1.6               | 1.6              |
| Sugar                       | -                 | 2                |
| Hydroxy propyl methyl cellulose | -           | 1                |
The width was the average of four edges of the quadrangular cracker, and the thickness was measured 5 mm away from the center of the quadrangular cracker. Data were obtained by averaging measurements from 20 random samples of each cracker.

Instrumental analysis of the hardness and fracture force of crackers were determined using a texture analyzer (TA Express; Texture Technologies) equipped with a three point bend rig according to Koh and Ng. The maximum force was recorded as hardness and the peak maximum force before fracture was recorded as fracturability. The measurement conditions of the test were compression mode, pretest speed 2.0 mm/s, trigger force 3 × g, test speed 0.5 mm/s, and test distance 6 mm. At least ten samples were analyzed for each cracker.

Figure 1. Schematic diagram of the cracker production flow used in bench-top processing.
**Statistical analyses**

All analyzes were repeated at least three times, and statistical analyses were performed using SPSS version 24.0. Analysis of variance (ANOVA) was used to test the differences among samples, whereas Duncan's multiple range test ($P < .05$) was used to perform multiple comparisons. To investigate the factors affecting rice cracker properties, rice flour, dough, and cracker data were evaluated using Pearson's correlation coefficient analysis. Wheat data were excluded from correlation analysis.

**Results and discussion**

**Flour and dough properties**

The moisture and protein content of wheat flour was significantly higher than that of rice flour (Table 2). The moisture and protein content of rice flour ranged from 6.61% to 7.01% and 7.31% to 7.10%, respectively. There were no significant differences in moisture and protein content between rice varieties. The AC of wheat flour varieties Saegoami and Saemimyun ranged from 26.02% to 28.06%, whereas the Angemi variety showed the lowest content at 19.15%. According to Perdon and Juliano,\[14\] the Angemi variety is considered low-amylose-content (9%-20%) rice, and the Saemimyun and Saegoami varieties high-amylose-content (25%-33%) rice. Rice with a 20%-25% (w/w) AC can be made into fermented rice cakes with a softer texture and larger volume compared to rice with a lower or higher AC.\[14,15\]

The damaged starch content of wheat flour was significantly lower than that of rice flour, and the damaged starch content of dry-milled rice flour increased significantly in the order of Saemimyun < Angemi < Saegoami. WAI of rice flour was also significantly increased in the same order. The WAI range was from 1.33 to 1.55, which was significantly higher than the WAI of wheat flour at 0.66 ($P < .05$). When starch granules are damaged, cleavage of small granules facilitates hydration and swelling during dough preparation, and thus damaged starch has a high water retention capacity.\[19,25,26\] The high levels of water-absorbing components such as arabinoxylans and damaged starch in whole wheat flour resulted in a dough too firm to expand, and thus the high WAI of whole wheat flour had a negative effect on saltine cracker quality.\[27\] Generally, whereas soft wheat flour is suitable for saltine crackers, wheat flour with a relatively higher gluten content and lower WAI is more suitable for cracker making.\[9\]

Gelatinization characteristics such as PV, HPV, CPV, BD, and SB were all higher in rice flour than in wheat flour (Table 3). The Saegoami variety, which had the highest AC, showed a similar pattern to that of wheat flour. In contrast, the Saemimyun variety had the highest viscosity, showing the largest difference from that of wheat flour.

The stickiness of cracker dough after lamination was the lowest in wheat flour. For rice dough, stickiness increased in the order of Angemi > Saemimyun > Saegoami. It was the highest in the Angemi variety, which has the lowest AC, and the lowest in the Saegoami variety, which has the highest AC. Because moisture in all dough is controlled in the beaker, it is thought that the difference in dough stickiness results from AC rather than moisture. These findings are consistent with those of Kohyama et al.,\[28\] who reported a decrease in stickiness with increasing AC in different rice varieties.

**Cracker properties**

Moisture content of wheat crackers was the highest at 5.55%, whereas that of rice crackers ranged from 3.53% to 4.23% (Table 4). Although the moisture content of Saemimyun crackers was the lowest, no significant difference was found among rice varieties. The water activity of the crackers ranged from 0.06 to 0.08, with no significant difference among samples.

The weight of the dough sheet before baking was the heaviest in wheat flour and the lightest in rice flour of the Saemimyun variety. Even though all conditions, such as roller interval and number
Table 2. Properties of flour and dough.

|          | Moisture (%) | Protein (%) | Amylose (%) | Damage starch (%) | WAI (g/g) | Stickiness (kg) |
|----------|--------------|-------------|-------------|-------------------|-----------|-----------------|
| Wheat    | 13.54 ± 0.40b | 12.2 ± 0.15b | 27.35 ± 0.54b | 8.31 ± 0.16a      | 0.66 ± 0.00a | 3.20 ± 0.00a    |
| Angemi   | 7.01 ± 0.23a  | 7.13 ± 0.02a | 19.15 ± 0.68a | 16.35 ± 0.71c     | 1.45 ± 0.01c | 17.75 ± 0.57d   |
| Saegoami | 6.87 ± 0.17a  | 7.31 ± 0.01a | 28.06 ± 0.96c | 17.24 ± 0.43d     | 1.55 ± 0.02d | 6.59 ± 0.22b    |
| Saemimyun| 6.61 ± 0.36a  | 7.10 ± 0.05a | 26.02 ± 0.49b | 13.62 ± 0.58b     | 1.33 ± 0.03b | 8.88 ± 0.86c    |

Data are expressed as mean ± standard deviation.

ab Means within columns without common lower case superscript letters differ significantly (P < 0.05; Duncan’s multiple range test).
Table 3. RVA pasting properties of flours.

|        | PV       | HPV      | CPV      | BD        | SB        |
|--------|----------|----------|----------|-----------|-----------|
| Wheat  | 116.22 ± 5.00a | 65.67 ± 1.88a | 125.53 ± 3.06a | 50.56 ± 5.09a | 59.86 ± 1.34a |
| Angemi | 208.31 ± 0.27c | 133.61 ± 2.19c | 219.47 ± 0.13c | 74.69 ± 2.36b | 85.86 ± 2.29c |
| Saegoami | 142.78 ± 0.88b | 96.56 ± 0.21b | 169.39 ± 1.04b | 45.72 ± 0.85a | 72.83 ± 1.23b |
| Saemimyun | 266.67 ± 1.67d | 181.56 ± 1.84d | 337.00 ± 1.92d | 85.11 ± 0.19c | 155.44 ± 1.27d |

PV: peak viscosity; HPV: hot paste viscosity; CPV: cold paste viscosity; BD: break down; SB: set back.

Data are expressed as mean ± standard deviation.

Means within columns without common lower case superscript letters differ significantly ($P < 0.05$; Duncan’s multiple range test).
Table 4. Physical properties of crackers.

|          | Moisture (%) | WA      | Weight I (g) | Weight II (g) | Volume (ml) | Thickness (mm) | Width (mm) |
|----------|--------------|---------|--------------|---------------|-------------|----------------|------------|
| Wheat    | 5.55 ± 1.37b | 0.08 ± 0.04a | 8.70 ± 0.33c | 6.37 ± 0.31c  | 12.11 ± 2.19c| 8.16 ± 1.41c | 46.46 ± 0.47c |
| Angemi   | 3.84 ± 0.31a | 0.06 ± 0.03a | 6.68 ± 0.39b | 3.52 ± 0.18b  | 4.43 ± 0.54b | 4.61 ± 0.53b | 44.78 ± 0.39a |
| Saegoami | 4.23 ± 0.27a | 0.06 ± 0.02a | 6.46 ± 0.23a | 3.31 ± 0.11a  | 3.67 ± 0.35a | 4.12 ± 0.32a | 44.65 ± 0.40a |
| Saemimyun| 3.53 ± 0.56a | 0.06 ± 0.02a | 6.35 ± 0.30a | 3.39 ± 0.21a  | 4.05 ± 0.46ab| 4.16 ± 0.40a | 45.06 ± 0.41b |

WA: water activity; Weight I: before baking; Weight II: after baking.
Data are expressed as mean ± standard deviation.

Means within columns without common lower case superscript letters differ significantly (P < 0.05; Duncan’s multiple range test).
of laminations, were the same, the rice flour dough sheet, which was measured after lamination and before baking, was lighter than that of wheat flour. The weight of wheat and rice crackers after baking decreased as a result of water loss. In particular, the weight of rice crackers was greatly reduced.

Thickness, width, and volume of rice crackers were significantly lower than those of wheat crackers. Dough spread affected width, and oven spring resulted in differences in thickness, with particularly large differences between rice and wheat crackers. Rice flour lacks a gluten network that can retain and maintain expanded gases; therefore, its oven spring was smaller than that of wheat crackers. Although HPMC supplements the role of gluten, rice crackers are still believed to have significantly lower thickness than wheat crackers. Among rice varieties, Angemi, which has low AC, resulted in significantly thicker crackers than Saegoami and Saemimyun, which have high AC. Although it has been reported that the AC of a rice variety has a significant effect on the yeast-fermented rice bread volume,[14–16] we believe that it did not have a significant effect on the volume of saltine crackers in our experiments.

Mechanical measurement of the texture of crackers showed (Table 5) that hardness of wheat crackers was significantly higher than that of rice crackers, in the order of Saegoami < Angemi < Saemimyun < wheat flour. Fracture force was in the order of Angemi < Saegoami < Saemimyun < wheat flour. The Angemi and Saegoami varieties could be fractured with little force, having the highest fracturability. Accordingly, rice crackers made with these varieties had a low level of hardness and were fractured with a relatively low force.

Correlation analysis of rice flour, dough, and cracker characteristics showed (Table 6) that AC of flour had a significantly negative effect on dough and cracker weight, volume, and thickness. Damaged starch content of flour had a significantly positive correlation with cracker dough weight before baking and cracker moisture content and a negative correlation with cracker hardness and fracturability. WAI of flour had a significant correlation with cracker moisture content, but no significant correlation with volume and other properties of cracker was found. All paste properties of rice flour had a significant correlation with cracker moisture content, and HPV, CPV, and SB were

| Table 5. Mechanical properties of crackers. |
|---------------------------------------------|
| Hardness (kg) | Fracture force (kg) |
|----------------|---------------------|
| Wheat          | 6.54 ± 1.23c        |
| Angemi         | 1.58 ± 0.38a        |
| Saegoami       | 1.51 ± 0.20a        |
| Saemimyun      | 2.20 ± 0.61b        |

Data are expressed as mean ± standard deviation.

| Table 6. Correlation coefficient between properties of flour, dough, and cracker. |
|---------------------------------------------|
| Dough | Cracker |
| Stickiness | Weight I | Weight II | Volume | Thickness | MC | Hardness | Fracturability |
| AM | -0.97*** | -0.46 | -0.74* | -0.75* | -0.70* | 0.04 | -0.12 | -0.03 |
| DS | 0.03 | 0.56* | 0.30 | -0.29 | 0.09 | 0.88** | -0.66** | -0.80*** |
| WAI | -0.16 | 0.65 | 0.22 | -0.40 | -0.13 | 0.86** | -0.57 | -0.56 |
| PV | 0.24 | -0.62 | -0.20 | 0.53 | 0.09 | -0.90*** | 0.64 | 0.63 |
| HPV | 0.13 | -0.67* | -0.28 | 0.46 | -0.01 | -0.92*** | 0.63 | 0.65 |
| CPV | -0.02 | -0.77* | -0.39 | 0.35 | -0.10 | -0.92*** | 0.63 | 0.66 |
| B.D | 0.45 | -0.47 | -0.03 | 0.67* | 0.28 | -0.82** | 0.63 | 0.57 |
| S.B | -0.17 | -0.84** | -0.49 | 0.24 | -0.19 | -0.90*** | 0.61 | 0.66 |

AM: amylose; DS: damage starch; WAI: water absorption index; Weight I: weight before baking; Weight II: weight after baking; MC: moisture content.

Data are expressed as mean ± standard deviation.

*p < 0.05; **p < 0.01; ***p < 0.001
significantly correlated with cracker dough weight before baking. BD was correlated with cracker volume. Although a positive correlation has been described between AC and fermented rice bread volume, we found a negative correlation in rice crackers. AC affected the volume of both rice crackers and fermented rice bread, with a negative correlation with cracker volume. In addition, the damaged starch content of flour was correlated with cracker moisture and textural properties.

**Conclusion**

The present study developed a saltine cracker benchtop making method that replaces wheat flour with 100% rice flour. The fermented rice cracker dough was gelatinized only with its own moisture, which made it possible to laminate the rice dough without the stickiness problem. Unlike in rice bread, AC was negatively correlated with cracker volume expansion. One of the most important quality factors, cracker moisture content, was positively correlated with damaged starch content and flour water absorption index. In particular, damaged starch content correlated negatively with textural properties such as hardness and fracturability. Therefore, both damaged starch content and AC of rice flour can be used to predict rice cracker quality. Based on these findings, we suggest that saltine crackers should be manufactured with 100% rice using the process developed in this study involving lamination after gelatinization and both high- and low-amylose rice varieties.

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