JARQ 50 (1), 23 – 31 (2016) http://www.jircas.affrc.go.jp

REVIEW
Characteristics of Rice Flour Suitable for the Production of Rice Flour Bread Containing Gluten and Methods of Reducing the Cost of Producing Rice Flour

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Abstract
The production of various rice flour-based food products such as bread, noodles, and cakes is expected to increase the consumption of rice and the utilization of rice paddies in Japan. This paper reviews studies conducted on the characteristics of rice flour and the rice cultivars suitable for the production of rice flour bread containing gluten. The challenges of reducing the cost of producing rice bread are also reviewed. The production of rice flour bread containing gluten of a highly specific loaf volume requires the use of rice flour with a low damaged starch content that can be produced by jet milling wet rice after water or enzyme treatment. The amylose content of rice flour affects the quality of bread, including its shape and hardness. Rice flour with an amylose content of 16% to 20% forms a chewy and moderately soft bread. When rice flour with a low damaged starch content (less than 5%) and a desirable amylose content (16% to 20%) is used, the production of rice flour bread containing gluten is easy without being different from how wheat flour bread is made. In order to reduce the cost of producing rice flour, high-yielding cultivars or a pin milling system using floury rice cultivars should be employed; high-yielding cultivars are now being used for the production of rice flour. With the pin milling system, rice flour belonging to the floury rice cultivar has a low damaged starch content. However, there is a need to develop a high-yield floury rice with reduced weight loss during polishing, as well as new polishing processes. Furthermore, the production of brown rice flour contributes to reducing the cost of producing rice flour because no polishing process is required. Brown rice flour with a low damaged starch content can be produced using a jet mill after soaking for more than 12 h. And given its favorable high nutritional properties, bread made from brown rice flour will prove appealing to consumers. Despite expectations of increasing of the consumption of rice through the use of rice flour as in the production of rice flour bread, the cost reduction of rice flour production and the development of delicious rice flour bread desired by consumers are still insufficient. By understanding the requirements of bread-making companies and obtaining a deeper knowledge about the quality characteristics of rice flour, such as amylose content and protein composition, the production of rice flour bread appealing to consumers can be expected.

Discipline: Food
Additional key words: damaged starch, amylose content, floury mutant rice, high-yielding cultivar, water soaking

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This review was partly supported by a grant from the Japanese Ministry of Agriculture, Forestry and Fisheries as part of the research project "Breeding and integrated research toward enhancing consumption of domestic farm products in the food service industry: 4. Rice."
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Received 3 December 2014; accepted 8 June 2015.

Introduction

The consumption and production of rice have gradually declined in Japan, leading to an increasing number of abandoned rice paddies. Rice has traditionally been used as boiled rice grain, and the use of rice flour as a staple food remains rare. However, the production of rice flour-based products such as bread, noodles, and cakes is expected to increase the consumption of rice and the utilization of rice paddies. Many bread-making companies are now producing rice flour-based bread and thus attracting the attention of consumers.

Three main types of rice flour bread are commonly produced: wheat/rice composite flour bread (made from mixed flour comprising 10% to 50% rice flour and wheat flour), gluten-free rice flour bread (made from previously gelatinized rice flour or rice flour with thickening additives), and rice flour bread containing gluten (made from rice flour with about 20% of wheat vital gluten being added). Of these three types, rice flour bread containing gluten is the easiest to produce. This paper reviews studies conducted on the characteristics of rice flour and the rice cultivars suitable for the production of rice flour bread containing gluten. Moreover, a method of reducing the cost of producing rice flour is also proposed.

1. Development of a new milling method suitable for rice flour bread

The traditional Japanese rice flour (called *joshinko*) is made from non-waxy rice, and processed into rice such confectionery products as dumplings or rice crackers. However, *joshinko* cannot be processed into other foods due to the differences in seed protein characteristics between rice and wheat. Wheat seed include gluten proteins. When water is added to gluten, it forms a network structure in bread dough, and thus the air bubbles that formed during fermentation are retained within the network structure, allowing the dough to rise. In contrast, rice seed does not include gluten proteins. Therefore, in order to successfully product bread from rice flour, wheat flour, wheat vital gluten, or a thickener must be added (Takano et al. 1986a, 1986b, Yamauchi et al. 2004).

Nevertheless, bread made from *joshinko* lacks sufficient expansion despite the addition of gluten due to its the large particle size compared with that of wheat flour. Thus, the development of a new milling method capable of producing rice flour with a small particle size similar to that of wheat flour is required. The Niigata Agricultural Research Institute Food Research Center (Niigata, Japan) has recently developed new milling methods for producing rice flour with a small particle size suitable for the production of rice flour bread. These methods include water-soaking milling and enzyme-treatment milling, where rice grains are soaked in water or an enzyme solution such as pectinase, followed by grinding using a jet mill under wet conditions (Arisaka et al. 1992a, Egawa et al. 1995, Morohashi et al. 2000). Because the wet rice grains are soft, fine rice flour with a small particle size is obtained.

2. Characteristics of rice flour suitable for the production of rice flour bread containing gluten

Several studies have been conducted to assess the characteristics of rice flour produced by the water-soaking milling and enzyme-treatment milling methods mentioned above, as well as the rice constituent properties that affect baking quality.

(1) Damaged starch content

Using various rice flours prepared by different mills and milling methods, the relation between the rice flour properties and specific loaf volume (SLV) of one-loaf of bread made from rice flour with wheat vital gluten were evaluated (Araki et al. 2009); a significant negative correlation was observed between damaged starch content and SLV (Fig. 1). Damaged starch corresponds to starch granules damaged by pressure and heat during the milling process. Rice flour prepared by the enzyme-treatment milling method had a low damaged starch content, and bread made from this flour exhibited a large SLV. This rice flour mainly consisted of compound starch granules, aggregated polyhedral single starch granules, and smooth-surface cells surrounded by the cell wall (Fig. 1A). In contrast, rice flours (including *joshinko*) prepared by pin milling and other methods all had a high damaged starch content, and breads made from these flours exhibited small SLVs. Rice flour with a high damaged starch content contained large- and small- sized fractured cells with a rough cell surface (Fig. 1B) or only consisted of extremely fine irregular particles without an apparent rice starch structure (Fig. 1C). These studies therefore show that damaged starch content is an important characteristic of rice flour that affects final bread SLV.

The damaged starch granules had higher water absorption and a rougher surface than intact starch granules (Araki et al. 2009, Arisaka et al. 1992b, Takano et al. 1986a, 1986b). Naganuma (2003) reported that the degree of damaged starch affects not only water absorption but also the gelatinization properties of rice flour. The gelatinization temperature of rice flour with high damaged starch content is low (Naganuma 2003). In wheat flour bread, the starch gelatinization properties are related to specific loaf volumes in breads (Sandstedt 1961), and the gelatinized starch gel in bread dough lowers the bread-making quality (Naito et al. 2005, Yamauchi et al. 2014).

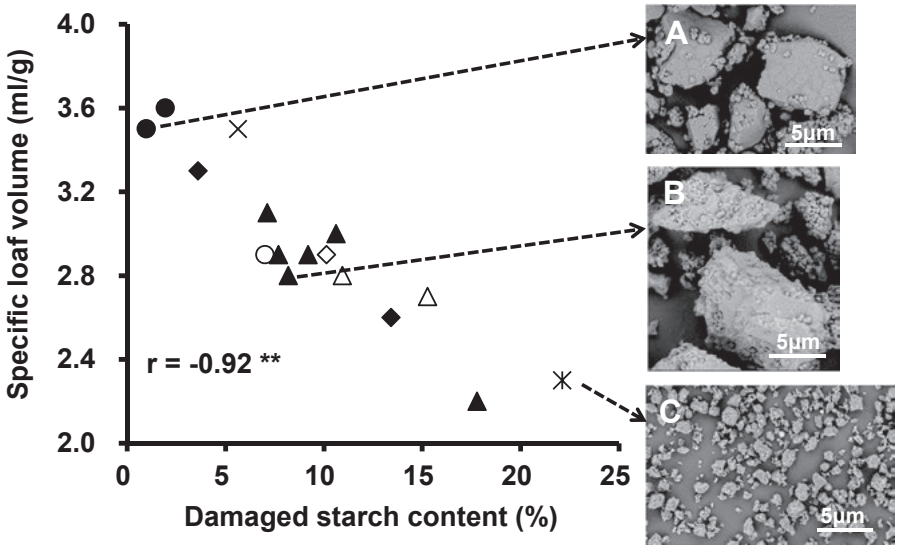

Fig. 1. Relation between specific loaf volumes of rice flour bread and damaged starch content, and rice flour particle structures. ** is significant at P = 0.01.

A: enzyme-treatment milling rice flour; B: *joshinko* flour; C: fine rice flour.
●: pectinase-treatment and jet milling (wet); ○: soaking and jet milling (wet); ◆: jet milling (dry); ◇: pin milling (dry); ▲: soaking and roll milling (wet) sold as *joshinko*; △: soaking and roll milling (wet) sold as *joyoko*; ✳: hammer milling (dry) and jet milling (dry); ✕: not available.

Therefore, it is speculated that the damaged starch in bread dough with rice flour creates a gel-like gelatinized starch that degrades the gluten network of bread dough with the rice flour. On the other hand, Takano *et al.* (1986b) reported that rice flour with a rather high 10-20% damaged starch content was suitable for a wheat/rice (80:20) blend of flour bread. In their case, the damaged starch is mainly considered to be decomposed maltose, which is used as an energy source for yeast during fermentation, through amylase activity derived from wheat flour. Therefore, the damaged starch content in the wheat/rice (80:20) blend of flour dough would not significantly affect bread-making quality. However, as the amylase activity of rice flour is very low compared with that of wheat flour (Lorenz & Saunders 1978; Takano *et al.* 1980), and as the rice flour bread dough does not contain wheat flour with high amylase activity, the damaged starch in rice flour dough may hardly be decomposed dextrin or maltose. These results suggest that a high damaged starch content significantly affects the great lowering of bread-making quality when using rice flour dough.

(2) Particle size distribution profile

In the particle size distribution profile, the wheat flour used for bread making (Nisshin Seifun Group, Japan) showed a peak centered at approx. 80 μm and a shoulder at 20 μm (Fig. 2D), with a median flour particle size of 58.5 μm. The rice flours prepared by the various mills and milling methods differed in both the particle size distribution profile and median flour particle size (Araki et al. 2009). For rice flours, the particle size distribution profile of rice flour suitable for bread produced by the enzyme-treatment milling method showed peaks centered at approx. 20 μm and 60 μm, along with a smaller number of large-sized particles >100 μm (Fig. 2A) and a median flour particle size of 33.0 μm. The *joshinko* flour showed a peak centered at approx. 150 μm and a shoulder at 20 μm, with a median flour particle size of 74.1 μm (Fig. 2B). The ratio of particles larger than 100 μm in rice flour produced by enzyme-treatment milling was relatively smaller than that in the *joshinko* flour. The fine rice flour prepared by jet milling after hammer milling under dry conditions showed a peak centered at approx. 8 μm (Fig. 2C), with a median flour particle size of 5.6 μm. No significant correlation was found between SLV and median particle size (Araki et al. 2009). Takano et al. (1986b) also reported that a wheat/rice (80:20) composite flour bread (made from rice flour with a high number of large-sized particles) showed a smaller SLV compared with that made from flour with a low number of large-sized particles. Therefore, the particle size distribution profile is also an important factor affecting SLV. However, the mechanism whereby the large-sized particles reduce SLV is not clear. It is thus necessary to clarify the effect of particle size on water absorption and the pasting

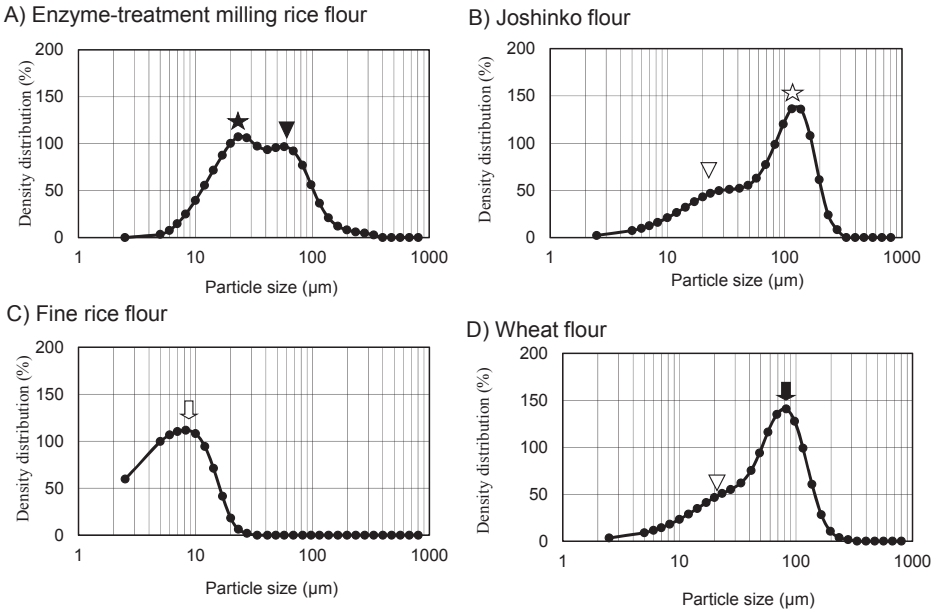

Fig. 2. Particle size distributions of rice flours. Density distribution (%) indicates particle quantity per μm in each classification of particle size.

⇩: a peak centered around 8 μm; ▼: a peak around 60 μm; ▮: a peak centered around 70-80 μm;
★: a peak centered around 20 μm; ☆: a peak centered around 150 μm; ▽: a shoulder centered around 20 μm.

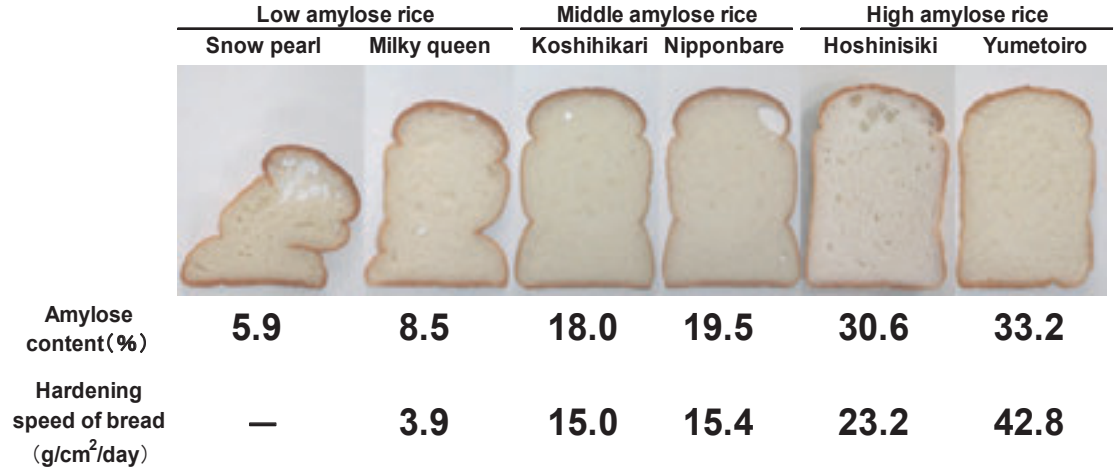

Fig. 3. Shapes and hardening speeds of rice flour bread with gluten produced using varying amylose content.

property.

(3) Amylose content and protein composition

The rice cultivars with starch and protein properties suitable for the production of rice flour bread have recently been selected and developed (Takahashi et al. 2009) (Fig. 3). Starch—the main ingredient of rice flour—is generally composed of amylose (consisting of long straight glucose chains) and amylopectin (consisting of branched glucose chains). The ratio of amylose to amylopectin (i.e. amylose content) is one of the most important characteristics in food processing, and affects the pasting property of starch. Rice flour was prepared from multiple cultivars showing varying amylose content (6% to 36%), and rice flour bread containing glutens were made from these rice flours. With a low amylose content, the bread tended to concave easily along its sides. *Snow pearl*, *Hanaemaki*, and *Milky queen* are examples of rice cultivars available in Japan with a low amylose content (6% to 10%), and are famous for their high degree of stickiness when cooked as boiled rice. Bread made from these rice flours tends to exhibit a low SLV, although rice flour bread with a low amylose content has a soft

and chewy texture unlike that of wheat bread. In contrast, bread with a high amylose content (> 30%) shows a very good shape, but soon becomes stale due to retrogradation. Rice flour that contains a medium amylose content (16% to 20%) forms a chewy bread with moderate softness (Takahashi et al. 2009) (Fig. 3). This characteristic suggests that popular Japanese rice cultivars such as *Koshihikari* and *Nipponbare* are suitable for the production of rice flour bread due to their medium amylose content (16% to 22%). Storage rice proteins include albumins, globulins, prolamins, and glutelins. Rice flours produced from rice lines with varying composition ratios of these proteins were used for the production of rice flour bread. As a result, rice flour bread made from low glutelin rice was found to retain its softness (Takahashi et al. 2009), thereby suggesting that the low glutelin rice cultivar is suitable for rice flour bread.

A desirable amylose content must therefore be ensured for the proper production of bread. A mixed rice flour with varying amylose content may be effective to adjust and stabilize that content. And because the composition of rice storage proteins also affects the properties of the bread, it is important to prepare bread using a suitable composition of proteins such as low glutelin.

3. Methods of reducing the cost of producing rice flour

The rice properties that lead to rice flour with a fine and less damaged starch through pin milling under dry conditions have been investigated (Ashida et al. 2009, 2010, Ashida 2014). The properties of rice flour bread made from high-yielding cultivars (Aoki et al. 2010, 2012) and the effects of water soaking on the bread-making quality of brown rice flour (Hamada et al. 2012) were also investigated, in order to ensure a stable supply of rice flour at a low price.

(1) Use of floury rice

At present, the rice flour used for the production of bread is mainly produced by the jet milling of wet rice after water or enzyme treatment. These milling processes produce a superior fine flour with little starch damage, but require expensive milling facilities and entail complicated operations such as drying the flour and handling wastewater. Rice flour can also be produced by pin milling under dry conditions. The resultant flour is coarser with more damaged starch as compared with enzyme-treated milled flour, thereby making it difficult to produce high SLV bread from pin-milled rice flour. However, pin milling is less expensive than jet milling, very simple, and entails no complicated operations. If pin milling could produce rice flour suitable for the production of bread, the milling costs would be greatly reduced.

In general, non-waxy rice grains with a large opaque portion in the endosperm, such as milky white and large white-core rice, are called floury rice. The white opaque part of a floury rice grain is due to loosely packed starch granules; thus, floury mutant rice grains exhibited lower grain hardness compared with translucent wild-type rice grains (Ashida et al. 2009) (Fig. 4). Therefore, floury mutant rice grains form a fine rice flour with low starch damage, although milled by pin milling under dry conditions. The SLV of rice flour bread made from pin-milled floury mutant rice was comparable to that made from enzyme-treatment milled translucent wild-type rice (Ashida

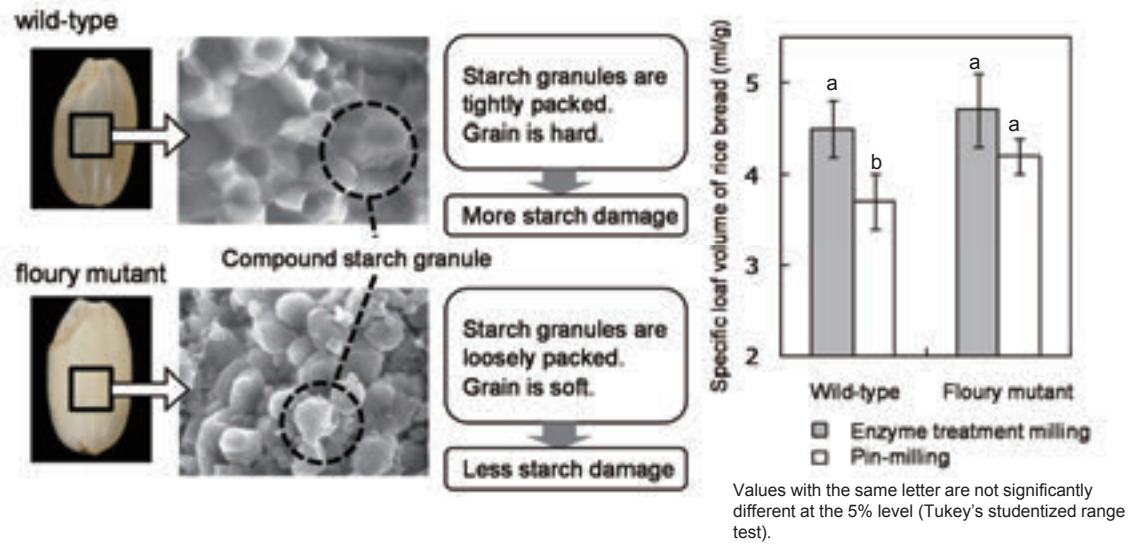

Fig. 4. Grain structure and milling properties of floury mutant rice.

et al. 2010, Ashida 2014) (Fig. 4). However, the yield of floury rice was 80% lower than that of ordinary cultivars, floury kernels were easily broken during polishing, and the weight loss after polishing was larger compared with that of ordinary cultivars. Even if suitable rice flour for producing bread could be made from floury rice varieties with the low cost pin milling system, the current floury rice would not lead to a reduction in the price of rice flour due to the low yields of cultivation and the milling of existing floury rice varieties. Thus, it is necessary to develop a high-yield floury rice with less weight loss during polishing, as well as new polishing processes (Ashida 2014). *Hoshinoko* (*Hokkai303*), *Hokuriku-kona232*, and *Ouu-kona412* are floury rice cultivars/lines bred for use as rice flours.

(2) Use of high-yielding cultivars

A stable supply of rice at a low price is necessary to increase the consumption of rice flour. The cost of rice can be reduced by using high-yielding cultivars. The National Agriculture and Food Research Organization of Japan has bred many high-yielding cultivars suitable for various climates in Japan, with 20% to 30% higher productivity than that of the leading cultivars.

The rice grain appearance of some high-yielding cultivars is not good due to the white-core grains; however, fine rice flour with a smaller particle size can be obtained by grinding the rice grains into flour when using the enzyme-treatment method to prepare the rice flour (Fig. 5). The mean particle size of rice flour that forms the nine high-yielding cultivars ranged from 25 μm to 62 μm, thus offering particles small enough for making bread. The mean particle sizes of the seven high-yielding cultivars (except *Takanari* and *Hokuriku 193*) were smaller than that of *Koshihikari*. This is probably because the ratios of white-core rice are higher than those of the leading cultivars. The damaged starch content of the high-yielding cultivars was low as well as that of *Koshihikari*. Therefore, when the enzyme-treatment method is used, the high-yielding cultivars can produce rice flour suitable for the production of bread as well as the leading cultivars.

The amylose content of many high-yielding cultivars is slightly higher than that of such leading cultivars as *Koshihikari* (Aoki et al. 2012). Hence, the sides of rice flour breads made from high-yielding cultivars are less concave compared with those made from the leading cultivars. The use of high-yielding cultivars with a high amylose content leads to the production of breads prone

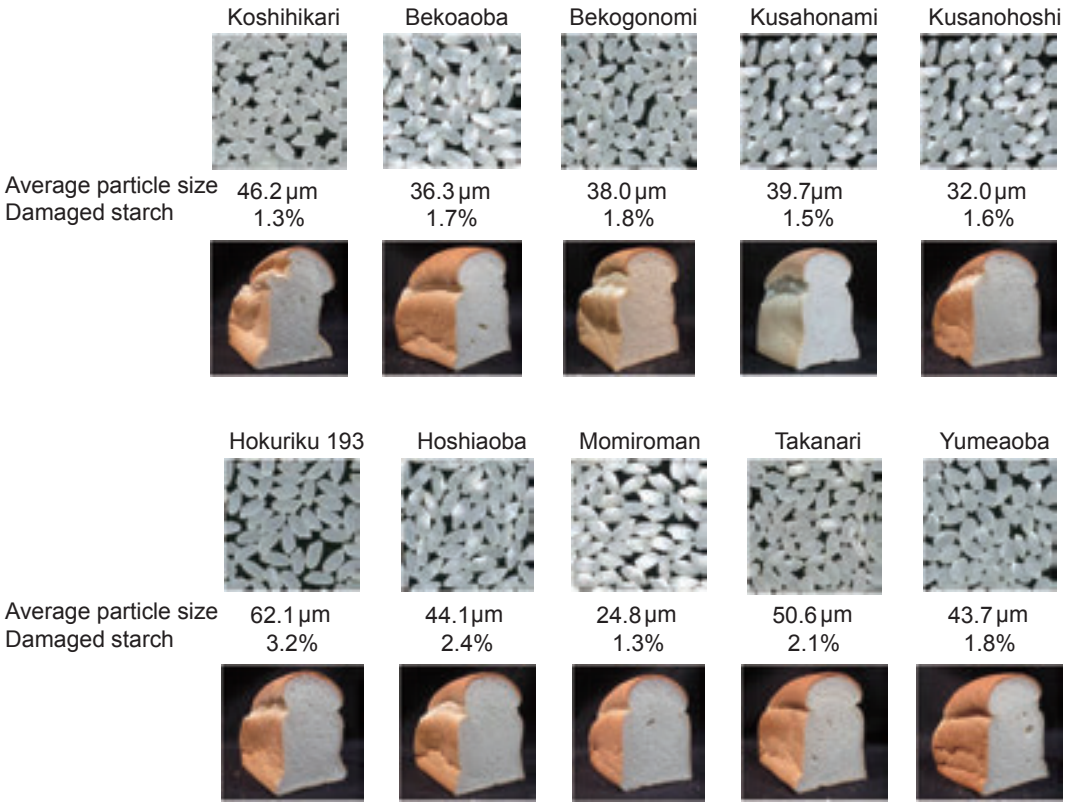

Fig. 5. Grain and flour properties of high-yielding cultivars, and shapes of rice flour bread with gluten. Rice flour was prepared by enzyme-treatment milling method.

Soaking time (h)	2	2	5	12	24	36	48
Specific loaf volume (ml/g)	4.20 ± 0.08	3.24 ± 0.06	3.58 ± 0.10	3.94 ± 0.13	4.03 ± 0.04	3.99 ± 0.13	4.04 ± 0.07
Damaged starch content (fw%)	2.0 ± 0.1	9.7 ± 0.4	7.4 ± 0.2	2.2 ± 0.0	2.3 ± 0.0	2.1 ± 0.1	1.9 ± 0.0

Fig. 6. Effects of water soaking on bread-making quality of *Koshihikari* brown rice flour.

to hardening, however, due to the high amylose content. Moreover, rice flour breads made from rice flour with high gelatinization temperatures (>70°C), indicating a high ratio of longer amylopectin chains, also have a high hardening rate (Aoki et al. 2010, 2012). Therefore, in order to develop and select the cultivars suitable for rice flour bread, the rice constituents, rice flour characteristics, and bread properties (including shape, hardness, and taste) must be examined in detail.

With regard to the shape and hardness of bread, cultivars with a medium amylose content (approx.16% to 20%) and low gelatinization temperatures (<70°C) are suitable for the production of rice bread. The high yielding cultivars that satisfy the conditions above are as follows: *Bekoaoba*, *Yumeaoba*, *Hoshiaoba*, *Kusanohoshi*, *Takanari*, and *Hokuriku 193*.

(3) Use of brown rice

The production of brown rice flour will also contribute to reducing the cost of producing rice flour because no polishing processes are required (Hamada et al. 2012). Brown rice provides more desirable nutritional properties and biofunctional components, such as inositol, dietary fiber, and gamma aminobutyric acid (GABA), as compared with white rice (Ohtsubo et al. 2005). The content of GABA (an important non-protein amino acid) in pregerminated brown rice is twice that in ordinary brown rice and ten times that in white rice (Saikusa et al. 1994). However, the use of brown rice flour with wheat and/or gluten as an ingredient in bread making remains limited (Okadome et al. 2007) due to tendency of preventing the dough to rise as compared with white rice flour. It was found that brown rice flour produced using a jet mill after soaking for more than 12 h allowed a better formulation of brown rice flour bread with SLV equivalent to that of bread made with white rice flour containing gluten (Hamada et al. 2012).

The SLV of *Koshihikari* brown rice flour breads containing gluten increased with longer soaking time (Fig. 6). The lowest SLV obtained was 3.24 ml/g after 2 h of soaking, which is generally sufficient time for white rice (4.20 ml/g). The flour from rice soaked for 5 h still resulted in insufficient bread expansion (3.58 ml/g), and SLV remained in the range of 3.94 to 4.04 ml/g after 12 h of soaking. Conversely, the damaged starch content value of brown rice flours showed a gradual decline with longer soaking time (Fig. 6). The flour made from rice soaked for 2, 5, and 12 h had 9.7%, 7.4%, and 2.2% damaged starch content, respectively. Brown rice flours milled after 12 h of soaking showed little difference in damaged starch content (1.9% to 2.3%, similar to that of white rice flour). These data suggest a strong association between the SLV of brown rice/gluten bread and the damaged starch content of brown rice flours (Fig. 6). This finding is consistent with a previous report demonstrating the relation between the SLV of white rice flour bread and the damaged starch content (Araki et al. 2009) [See Section 2, (1) Damaged starch content]. The present milling method provided brown rice flour with good nutritional and physical properties for the production of bread. However, lipid oxidation caused brown rice flour to deteriorate faster than white rice flour during storage. It is therefore necessary to clarify the relation between the degradation of brown rice flour and the bread quality. On the other hand, mutant rice lacking an oxidizing enzyme (lipoxygenase) has been developed (Suzuki et al. 1996, 1999). It might be effective to use such mutant rice to prevent the degradation of brown rice flour.

Conclusions

As mentioned above, there are some important rice flour requirements for the production of rice flour bread containing gluten. First, the production of rice flour bread with a high SLV requires the use of rice flour with a low damaged starch content (Araki et al. 2009), which can be produced by the jet milling of wet rice after water or enzyme treatment. Second, because the amylose content of rice flour affects the quality of bread, especially its shape and hardness (Takahashi et al. 2009), it is also important to use a rice cultivar having a desirable amylose content (16% to 20%). When rice flour with a low damaged starch content and a desirable amylose content is used, the production of rice flour bread containing gluten is easy without being different from how wheat flour bread is made.

The production of rice flour with a low damaged starch content is difficult, however, due to the expense of milling facilities and the need for such complicated operations as drying the flour and handling wastewater. Expanding the use of rice flour requires cost reduction and the use of simple milling operations in the production of rice flour. The use of high-yielding cultivars (Aoki et al. 2010) or pin milling systems using a floury rice cultivar (Ashida et al. 2009, 2010, Ashida 2014) might be able to contribute to cost reduction. High-yielding cultivars are now being used for the production of rice flour in order to reduce the price of rice. On the other hand, because the pin milling system is a comparatively cheaper and entails simple operation, the cost of producing rice flour could be reduced. Even when a pin milling system is used, the rice flour produced from the floury rice cultivar has a low damaged starch content. However, the development of high-yield floury rice, reduction in weight loss during polishing, and/or new polishing processes are required because the floury rice yield is generally low and floury kernels are easily broken during polishing. Furthermore, the production of brown rice flour will also contribute to reducing the cost of producing rice flour because no polishing processes are required (Hamada et al. 2012). Brown rice flours can be produced using a jet mill after soaking for more than 12 h. In addition, brown rice flours can provide added value and make the rice flour bread more appealing through the nutritional components contained in rice bran. In this paper, we have proposed the use of floury rice, high-yielding rice, and brown rice in order to reduce the cost of producing rice flour. It is therefore necessary to clarify and confirm that cost can be reduced when using a specific type of rice.

Despite expectations for increasing rice consumption through the use of rice flour as in rice flour bread production, the cost reduction of rice flour production and the development of delicious rice flour bread desired by consumers are still insufficient. However, the studies summarized in this paper suggest that the production of more consumer-appealing rice flour bread is possible through the assessment of rice flour and rice cultivar characteristics suitable for the production of rice flour bread. A rice cultivar (*Yumefuwari*) was recently developed as a special new variety for the production of rice flour (Tsuda 2014). Tsuda (2014) reported that the mean particle size of *Yumefuwari* rice flour made by the water-soaking milling method was 39 μm, which is smaller than that of *Akitakomachi* (79 μm). The damaged starch content of *Yumefuwari* rice flour was also less than 5% as well as that of *Akitakomachi* (Tsuda 2014). *Yumefuwari* makes it possible to produce rice flour suitable for bread making, characterized by a low damaged starch content and a small particle size, which mainly relate to floury rice characteristics. Moreover, a wheat/rice composite flour bread using *Yumefuwari* rice flour has a soft, moist, and sticky texture (Tsuda 2014).

A palatable, cost-effective, and healthy rice flour bread should be produced so as to entice consumers to purchase rice flour bread on a consistent basis. In order to achieve this, the requests from bread-making companies must be understood in addition to the quality characteristics of rice, such as the amylose content and protein composition.

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