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Development of a New Rice Beverage by Improving the Physical Stability of Rice Slurry

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Abstract

“Rice slurry” made from brown rice with wet stone milling, which was developed as a new liquid food material. Raw brown rice is hard to be chewed and eaten unlike cooked rice. Therfore, “rice milk”, a beverage made from rice slurry, was developed to ingest raw brown rice. The rice particles in the rice slurry settled to the bottom when the slurry was allowed to remain for several hours. Two conditions, overly fine particles or an increase in the viscosity, suppress the sedimentation velocity of the particles. A separated milling method was established, which reduced the particle size to less than 20 μm. Moreover, the sedimentation velocity decreased exponentially with the viscosity and was steady at more 80 mPa･s when the concentration of xanthan gum exceeded 0.1 wt%. A sensory evaluation indicated a favorable rate of 55.6% for the rice slurry containing 0.3 wt% xanthan gum.

Keywords: rice slurry, wet stone milling, separated milling method, sensory evaluation

1. Introduction

Rice has been used as a staple food in Japan since ancient times. However, the consumption of rice, which was maximized at 118.3 kg per person in 1963, has recently decreased to 59.5 kg in 2010 (MAFF, 2012). In addition, the number of abandoned rice paddies that are no longer cultivated has increased twofold between 1990 and 2010 (MAFF, 2011a). A Japanese official document for agriculture and food states that a reduction in the self-sufficiency rate of Japanese food is a serious problem, and Japan is obligated to ensure the future reliability of the food supply (MAFF, 2011b). A reliable rice supply can mitigate the observed reduction, and an increase in the level of rice consumption is desired. These improvements can be achieved by establishing new demands for rice, instead of rice flour and bioethanol. Thus, “rice slurry” was developed as new liquid food material to replace rice flour. Rice slurry is made from brown rice with wet stone milling. Rice slurry can be used to make processed food for which rice flour is unsuitable, such as pudding, ice cream, and beverages.

Brown rice contains multiple functional ingredients: GABA (gamma-aminobutyric aci d), resistant starch, γ-oryzanol, and tocotrienol (Taniguti et al, 2012). Non-heated raw brown rice is ideal for health because these ingredients can be lost by heat. However, raw brown rice is unfit for consumption because it is too hard. Thus, beverages made from rice slurry were investigated as a way to eat raw rice. The beverage was defined as “rice milk”. However, using rice slurry for food materials was difficult because the rice slurry was not physically stable. The rice particles in the rice precipitate when the slurry is allowed to rest for an extended period of time. Equation (1) shows Stokes's law for the sedimentation velocity of particles in a solution.

$$Vs = \frac{D_p{}^2(\mathrm{p_p} - \mathrm{p_f})\mathrm{g}}{18\eta} \qquad \text{...... Eq.(1)}$$

where Vs is the sedimentation velocity, D_p is the particle size, p_p and p_f are the density of the particles and solution, respectively, g is the gravitational acceleration, and η is the viscosity. The law shows that two conditions, overly fine particles and an increased viscosity, suppress the sedimentation velocity of the particles.

In this study, the investigation of the milling conditions was carried out to generate fine rice particles. Also, the effect of a thickener on the physical stability was examined. The milling conditions were defined to result in a particle size of less than 20 µm, which ensures that the particles are fit for consumption (Inoue, 2011). In addition, the possibility of developing rice milk for human consumption was investigated through a sensory evaluation.

2. Material and Methods

2.1 Materials

Hokuriku 193 brown rice (Indica rice, crop in NARO Hokuriku research center in 2011) was used in this study. The rice can cut the cost of processing because the yield is larger. Furthermore the rice contains more protein and fatty acids than regular rice.

2.2 Material preparation

Brown rice

The brown rice was washed by hand, dried completely, and pasteurized wet at 70℃ and 95% humidity for 180 min. The wet pasteurization uses a low temperature and high humidity, which prevents the starch in the rice from gelatinizing. Thus, the pasteurized rice can be used as the raw rice material. The rice was soaked for 300 min at 2℃.

White rice

The brown rice material was washed by hand, dried completely, and separated into white rice and rice bran with a rice sweeper (PK-30A, Taiwa Seiki Corporation). The white rice was pasteurized and soaked at same conditions as the brown rice.

Rice bran

Rice bran was pasteurized at same conditions as above and mixed with water at a ratio of 1:5 (w/w).

2.3 Wet stone milling system

Rice can be milled either by dry milling or wet stone milling (Naganuma, 2003). Dry milling uses dried materials, and wet stone milling uses soaked materials with flowing water. Soaking and flowing water can soften the rice and improve the efficiency of the milling process. Figure 1 shows a drawing of the layout of the improved electric stone mill system used in this experiment. The rice feeder equipment feeds the rice matelials, and the tubing pump simultaneously feeds water to the stone mill. The electric motor only rotates the lower stone mill. The rice slurry can be obtained by simultaneously milling rice materials and water. Three stone mills with different grooves and exterior contact surfaces were used and classified in ascending order of their contact surfaces: Mill A(38 cm^2), Mill B(111 cm^2), and Mill C(207 cm^2). Figure 2 shows the lower mill of Mill A and Mill C. The radius of these stone mills is 12 cm. The upper and lower stones were used with the same groves as one set. A smaller contact surface mills materials with particle sizes on the order of millimeters, while a larger contact surface mills particles with sizes on the order of micrometers.

2.4 Wet stone milling condition

Brown rice slurry

The brown rice slurry was defined as the rice slurry made from the brown rice materials with wet stone milling. Initially, the feeding rate of water was set to 40, 90, 130, and 190 mL/min, and the material feeding rate was set to 18 or 24 g/min. The rotational speed of the mill could be set between 20 and 50 rpm. At the aforementioned conditions, the rotation speed of the mill was set to 20 rpm to investigate the effect of the water and material feeding rates. Mill A was used for milling.

For the second milling condition, the water feeding rate was set to 40 mL/min, and the materials feeding rate was either 18 or 24 g/min. The rotational speed of the mill was set to either 20, 30, 40, or 50 rpm to investigate the effect the milling speed. Mill A was used for milling.

White rice slurry

The white rice slurry was defined as the rice slurry made from white rice materials with wet stone milling. To investigate the effect of the material feeding rate, the water feeding rate was set to 40 mL/min, the material feeding rate was either 15, 25, 35, or 45 g/min, and the milling speed was 50 rpm. Mill A was used for milling.

Rice bran slurry

The rice bran slurry was defined as the rice slurry made from the rice bran materials with wet stone milling. The particle size of the rice bran materials was less than 500 µm after being separated from the brown rice. Mill B and Mill C fit effectively ground the rice bran to micrometer-sized particles. The rice bran could not be fed with the rice feeder equipment due to its oil content, which made it sticky. Thus, the rice bran materials that were mixed with water were fed with the tubing pump used to feed water. The material feeding rate was set to 40 mL/min, and the milling speed was 50 rpm. Mill A, Mill B, and Mill C were used to investigate the effect of the contact surface.

2.5 Mixed rice slurry and rice milk

Brown rice is composed of white rice and rice bran at a ratio of 9:1. The mixed rice slurry was defined a mixture of the white rice slurry and the rice bran slurry at a solid content ratio of 9:1.

The rice milk was defined as a mixture of the mixed rice slurry and additional water at a solid:liquid ratio of 1:9, which is the solid:liquid ratio of standard milk.

2.6 Modifying viscosity

The viscosity of the mixed rice slurry was modified with a thickener, namely pure xanthan gum, at 0.1, 0.2, and 0.3 wt%.

2.7 Particle size and particle size distribution

The particle size（D50 and D75）and particle size distribution were measured by a laser diffraction particle size analyzer (SALD-2200, Shimadzu corporation) in wet measurement mode.

D50 is known as the median diameter, defined as the average particle size by mass; D75 is defined as the particle size corresponding to 75% of the particles being undersized by mass.

2.8 Viscosity

The viscosity was measured using a Brookfield-type viscometer (DV-E, Brookfield Engineering) at 25℃ and 12 rpm .

2.9 Particle density

The dried solid content was obtained by drying the mixed rice slurry with an oven at 110℃ for 5 hours, and the particle density was measured using a pycnometer.

2.10 Sensory evaluation

Four rice slurries mixed with xanthan gum concentrations of 0, 0.1, 0.2, and 0.3 wt% were evaluated. The panel consisted of 27 people, 12 men and 15 women, and the average age was 23.6 years. A 7-point scaling method was used to evaluate the mixed rice slurry containing xanthan gum. The slurry containing 0.1 wt% xanthan gum was evaluated and allocated an average of 4 points. Five evaluation criteria were used: powderless, aftertaste, ability to drink, smell, and total taste. Moreover, materials were ranked as part of a comprehensive evaluation. Significant differences were determined by using Microsoft Excel® (Microsoft Corporation).

3. Result and Discussion

3.1 Effect of milling conditions on the particle size of the brown rice slurry

Figure 3 shows the particle size (D50 and D75) of the brown rice slurry produced with different water feeding rates. The particle size correlated positively with the water feeding rate at each material feeding rate. This result suggests that increasing the water feeding rate discharges the rice particles to the outside of the stone mill before they are sufficiently milled. Moreover, these findings suggest that extended milling can effectively refine the particle size. Based on these results, the water feeding rate was set at 40 mL/min. The particles generated with a material feeding rate of 18 g/min were finer than those generated at a water feeding rate of 24 g/min. This difference could be attributed to a subtle gap introduced by the stack of materials between the upper and lower stone mills at 24 g/min. The rice slurry is a non-Newtonian and Bingham plastic fluid. Equation (2) shows the relationship between the viscosity and shearing stress in

Bingham plastic fluids:

$$\tau = \tau_0 + \eta \frac{\partial u}{\partial y} \qquad \text{......... Eq.(2)}$$

where τ is the shearing stress (N/m^2), τ_0 is the yield strength(N/m^2), η is the non-Newtonian viscosity (Pa・s), u is the shear rate (m/s), and y is the distance (m). For simplicity, the shear rate and the distance in this equation should be replaced with the milling rotation (rpm) and the gap (m) between the upper and lower stone mills while materials are milled, respectively. The equation suggests that two unit operations, decreasing the gap and increasing the milling speed, are important for improving the shearing stress and effective in refining/decreasing the particle size.

Figure 4 shows the particle size (D50 and D75) of the brown rice slurry as a function of the milling speed. The minimum D50 and D75 values of the brown rice slurry were 6.2 μm and 45.4μm, respectively. This size is smaller than that of usual rice flour, which is 100~400 μm in size (Shoji, 2012), but bigger than the set point of 20 μm. The D75 value inversely correlated with the milling speed at each material feeding rate. The two feeding rates (18 and 24 g/min) did not show differences at speeds exceeding 30 rpm. More than 30 rpm rotaion had an effect on milling of the material uniformly, because of the improvement the shearing stress. Nevertheless, increasing the milling speed shortened the milling time, which contradicts previous suggestions. These results suggest that shear stress had a more significant effect on the wet stone milling system than the milling time.

Figure 5 shows the particle size distribution of brown rice slurry at 50 rpm. Two peaks were obtained at 6.1μm and 153.4μm. Kainuma and Tanaka (2009) reported that the minimum particle size of a rice starch particle is 5μm , and Juliano (1985) reported that the size of soluble protein in rice is approximately 1-2μm . The peak at 6.1μm indicates that the principal ingredient of white rice is starch.

In contrast, the peak of 153.4μm corresponds to rice bran in the absence of white rice. Refining brown rice to particles smaller than 20 μm appears to be difficult, which complicates the production of slurry from rice bran compared to white rice.

3.2 Effect of the separated milling

A fine rice slurry was generated using a separated milling method to mix the white rice slurry and rice bran slurry after separately milling the white rice and rice bran materials. Figure 6 shows the particle size (D50 and D75) of the white rice slurry produced at different material feeding rates. The feeding rate did not significantly affect the particle size. The D50 and D75 particle sizes were confirmed to be 5.0 μm and 8.5 μm, respectively. This result shows that the rice starch was milled to particle sizes near 5.0 μm, as mentioned above.

Figure 7 shows the particle size distribution of the white rice slurry at a material feeding rate of 35 g/min as well as the particle size distribution of the brown rice slurry from Figure 5. The result shows that the majority of particles were now larger than 5μm, while fewer particles exceeded 100 μm in size. These results also suggest that particles larger than 100 μm primarily consisted of rice bran.

Figure 8 shows the particle sizes (D50 and D75) of the rice bran slurry produced with different stone mills. Mill A and Mill B did not show significant differences. Mill C yielded slurries with significantly smaller particles. However, the grooves clogged when materials were milled for more than 15 min because the fiber in the materials was denatured by the heat of the mill. These results show that milling with Mill C increases the shearing stress, frictional force, and the frictional heat, which entangles the fiber and gelatinates the starch.

Figure 9 shows the particle distribution of the rice bran slurry produced by the different stone mills. Increasing the contact surface decreased the number of particles that were 100μm in size, especially when the slurry was milled with Mill C. Vishwanathan *et al.* (2011) reported that the shearing stress and cutting force significantly affect the particle size of milled products. Nevertheless, the contact surface affects the shearing stress but not the cutting stress. We hypothesize that the compressive force of stone milling flattens the milled materials and reduces the gap, which decreases the particle size.

Figure 10 and Figure 11 respectively present the particle size (D50 and D75) and the particle distribution of the mixed rice slurry and the brown rice slurry. The D50 did not significantly differ among these slurries. However, the D75 of the mixed rice slurry was smaller than that of the brown rice slurry. Specifically, the D50 and D75 of the mixed rice slurry were 5.0 μm and 16.1 μm, respectively. The separated milling methods ensured that the particle size of the rice slurry was less than 20 μm of set point.

3.3 Effect of the viscosity on the sedimentation velocity

Equation (3) shows the relationship between the viscosity and sedimentation velocity, which is calculated by substituting using 1.55 g/cm^3 as the particle density, 5 μm as the particle size (D50), 0.997 g/cm^3 as the density of water, and 9.81 m/s^2 as the gravitational acceleration in Equation(1).

$$Vs = \frac{652.2}{\eta} \times 86.4 \qquad \text{………… Eq.(3)}$$

where Vs is sedimentation velocity (mm/day) and η is the viscosity (mPa・s). The sedimentation velocity is assumed to exponentially decrease with the viscosity and reach a constant value at 80 mPa・s.

Figure 12 shows the viscosity of the mixed rice slurries containing different concentrations of xanthan gum. The sedimentation velocity of the material without xanthan gum was not expected to decrease. However, the materials containing xanthan gum clearly showed a decrease in the sedimentation velocity. Materials that did not contain xanthan gum showed precipitated rice particles after resting for one day. However, this phenomenon was not observed in materials containing xanthan gum. Adding more than 0.1% xanthan gum physically stabilized the rice slurry.

3.4 Sensory evaluation

Table1 shows the result of the sensory evaluation and the favorable evaluation. In the sensory evaluation, the material without xanthan gum received significantly a higher grade than the others in powderless and aftertaste. Materials containing 0.1, 0.2, and 0.3 wt% xanthan gum did not differ. Hukai (1998) reported that the ideal viscosity of milk drinks consisting of mixed rice flour and milk was 15±5 mPa・s . As such, the materials that did not contain xanthan gum likely received high markings because their viscosity was close to 15±5 mPa・s.

Meanwhile, the material containing 0.3 wt% of xanthan gum received a significantly higher grade than the others in smell and total taste in the sensory evaluation, and obtained the highest favorability rate of 55.6%. The second most favorable material did not contain xanthan gum and received a 29.6% favorability rating. This result differed from the Hukai report. Many panelists indicated that the 0.3 wt% xanthan gum was favorable because they could “feel the thickness of rice”, while the material that did not contain xanthan gum was “easy to drink”. However, many panelists indicated that the material that did not contain xanthan gum was also “tasteless and weak”. These opinions suggest that the viscosity significantly impacts the taste of rice milk. The “thickness” likely is a preferred characteristic because Japanese people usually do not eat rice thinned with water. Japanese people sometimes consume Okayu, which is a rice porridge steamed with water at a ratio of approximately 1:6. However, the rice to water ratio of this slurry is 1:10. The “thinness” of this solution was not palatable to the Japanese public. Based on these findings, the material containing 0.3 wt% was deemed most suitable to be used as rice milk, not only due to its physical stability but also its high favorability rating.

However, Takahashi *et al* (1999) reported that sensory evaluations based only on one dynamic characteristic were not appropriate . This study only evaluated changes in viscosity, and flavors were not added. Cooked rice is usually sweet; however, this rice milk was not sweet because it was obtained from unheated raw rice. Future sensory evaluations should consider additional flavors as well as the viscosity.

4. Conclusions

The decreasing consumption of rice is a serious problem in Japan. Thus, a “rice slurry” was developed as a new liquid food material to replace rice flour. We investigated the milling conditions to create fine rice particle smaller than 20 μm and the effects of a thickener to improve the physical stability of the slurry. In addition, this rice milk was subjected to a sensory evaluation.

The minimum D50 and D75 of the brown rice slurry were 6.2 μm and 45.4μm, respectively, with a water feeding rate of 40 mL/min and milling speed of 50 rpm. Milling brown rice finer than 20 μm appears to be challenging.

Separated milling method was used to mix the white and rice bran slurries to establish a fine rice slurry after separately milling the white rice and rice bran materials. The minimum D50 and D75 of the mixed rice slurry were 5.0 μm and 16.1μm, respectively, which was less than 20 μm.

Stokes’s law predicted that the sedimentation velocity decreases exponentially with the viscosity and reaches a constant value at 80 mPa・s. The rice slurry was stabilized by adding more than 0.1% xanthan gum.

Materials that did not contain xanthan gum were rated higher in the sensory evaluation. However, the material that contained 0.3 wt% xanthan gum received the highest favorability rating of 55.6%.

The development of “rice milk” is expected to be improved by the addition of flavors and regulation of its composition.

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Figure captions

Fig.1. Improved electric stone system

①:Rotary rice feeding equipment ②:Motor ③:Stone mill ④:Tubing pump

⑤:Water tank ⑥:Rubber spatula ⑦Sample bottle

Fig.2. Picture of the lower stone of Mill A (upside) and Mill C (downside).

Fig.3. Relationship of the particle size (D50 and D75) of the brown rice slurry and the water feeding rates. ●, ■ indicate D75, and ○, □ indicate D50 at 24 and 18 g/min of the material feeding rate. The mill A was used.

Fig.4. Relationship of particle sizes (D50 and D75) of the brown rice slurry and the milling speed. ●, ■ indicate D75, and ○, □ indicate D50 at 24 and 18 g/min of the material feeding rate. The mill A was used.

Fig.5. Particle size distribution of the brown rice slurry at 50 rpm and different material feeding rates. Solid line and broken line indicate 18 and 24 g/min of rice feeding rate. The mill A was used.

Fig.6. Relationship of the particle size (D50 and D75) of the white rice slurry and material feeding rate. The mill A was used.

Fig.7. Particle size distributions of the white rice slurry at 35 g/min of the material feeding rate and the brown rice slurry in Fig.5. The mill A was used.

Fig.8. Relationship of the particle size of the rice bran slurry and stone mills.

Fig.9. Particle size distributions of the rice bran slurry milled with different stone mills.

Fig.10. Particle size (D50 and D75) of the mixed rice slurry and the brown rice slurry in Fig.5.

Fig.11. Particle size distributions of the mixed rice slurry and the brown rice slurry in Fig.5.

Fig.12. Relationship of dropping velocity and viscosity of mixed rice slurry

Figure 1

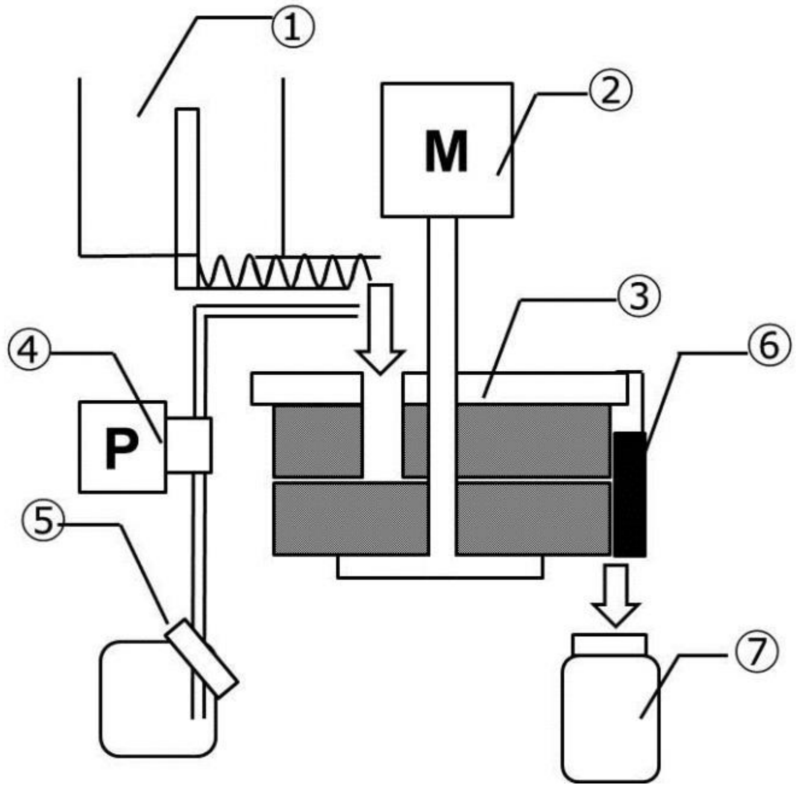


Figure 2

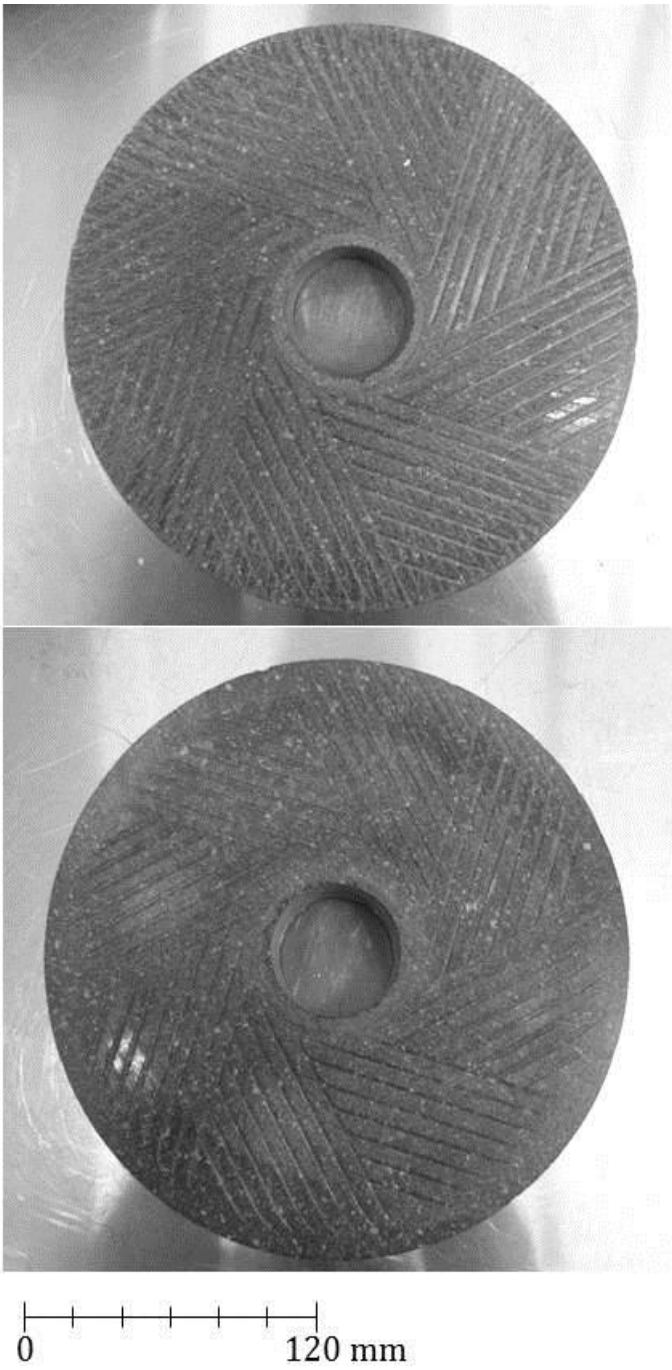


Figure 3

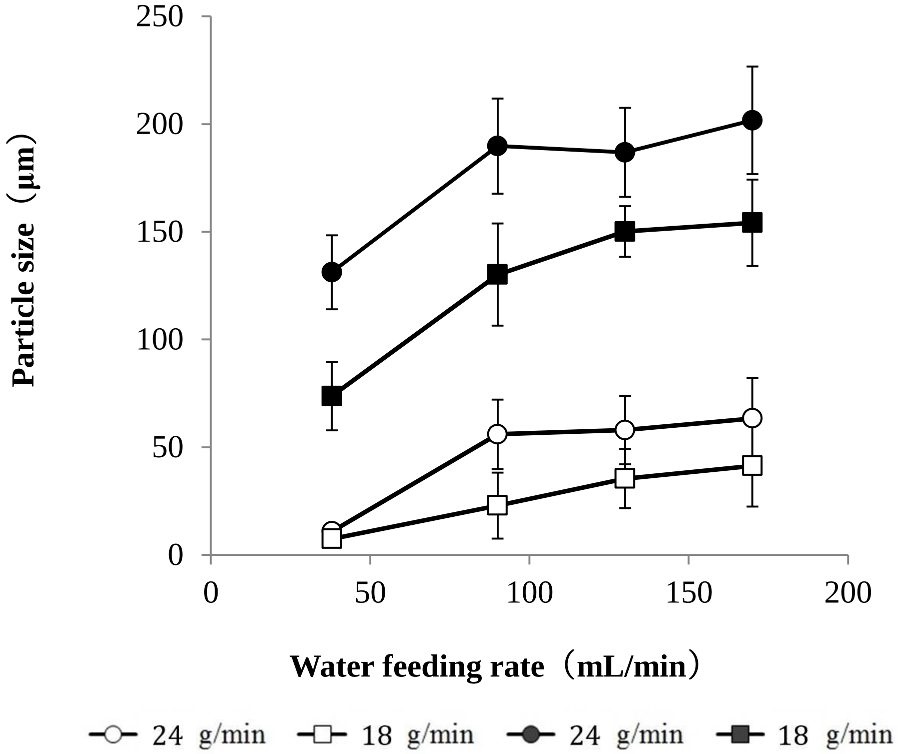
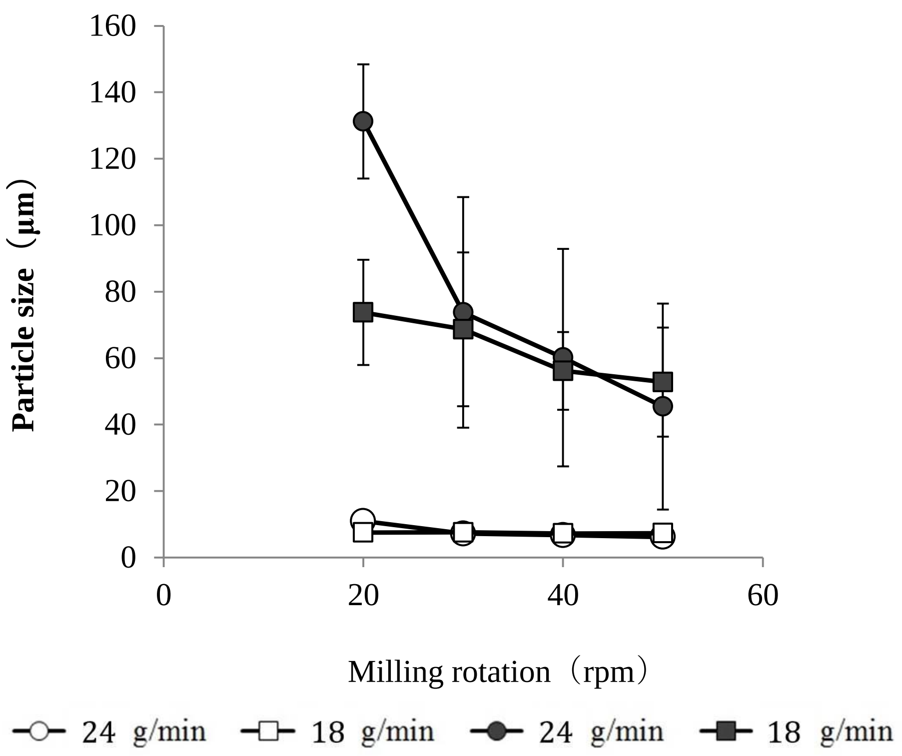
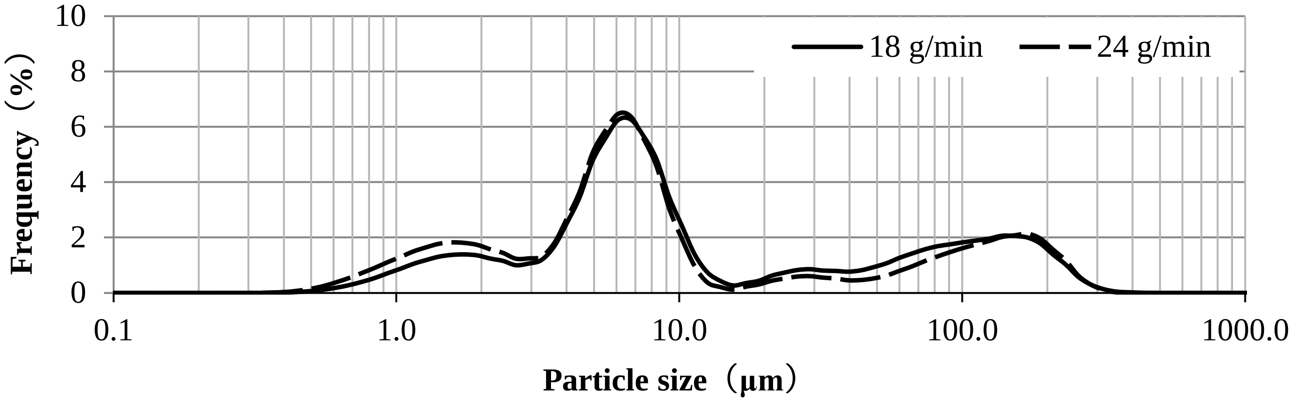

250
200
150
100
50
0
0
50
100
150
200
Particle size（μm）
Water feeding rate（mL/min）
24 g/min
18 g/min
24 g/min
18 g/min

Figure 4



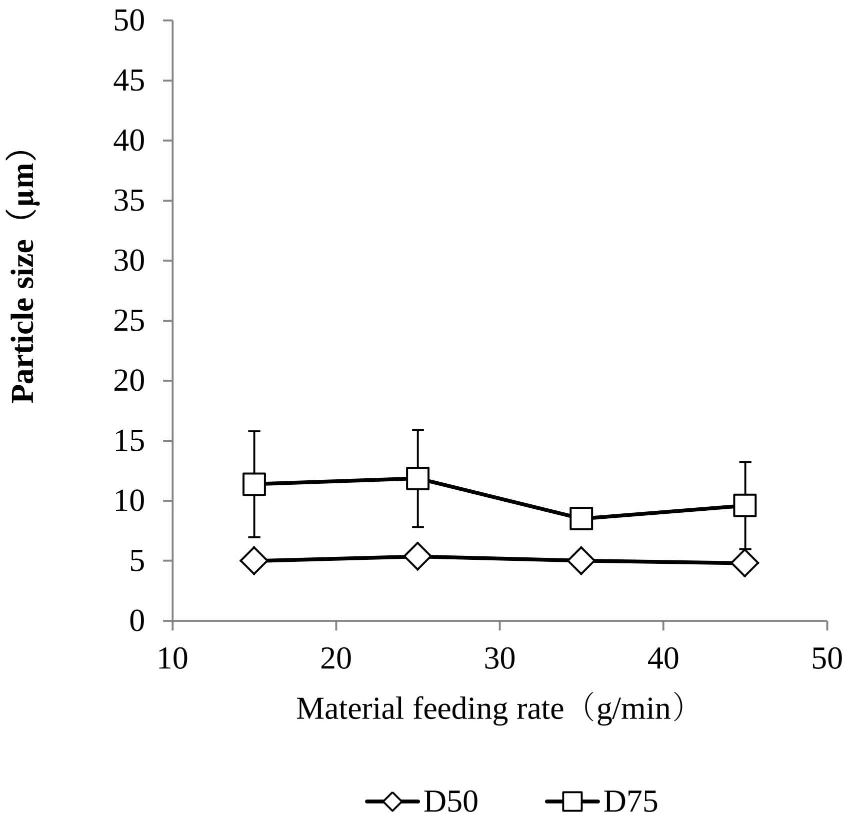
160
140
120
100
80
60
40
20
0
Particle size（μm）
0
20
40
60
Milling rotation（rpm）
24 g/min
18 g/min
24 g/min
18 g/min

Figure 5



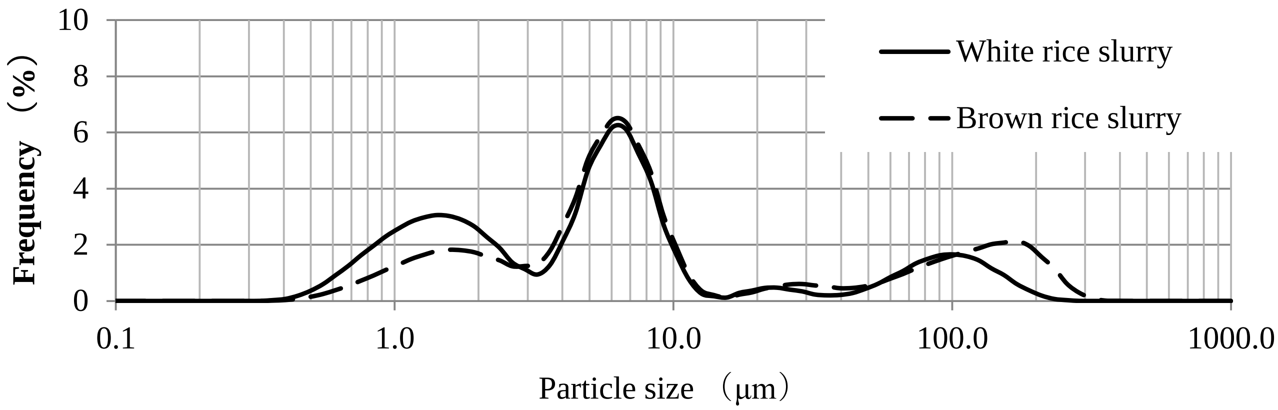
18 g/min
24 g/min
10
8
6
4
2
0
Frequency（%）
0.1
1.0
10.0
100.0
1000.0
Particle size（μm）

Figure 6



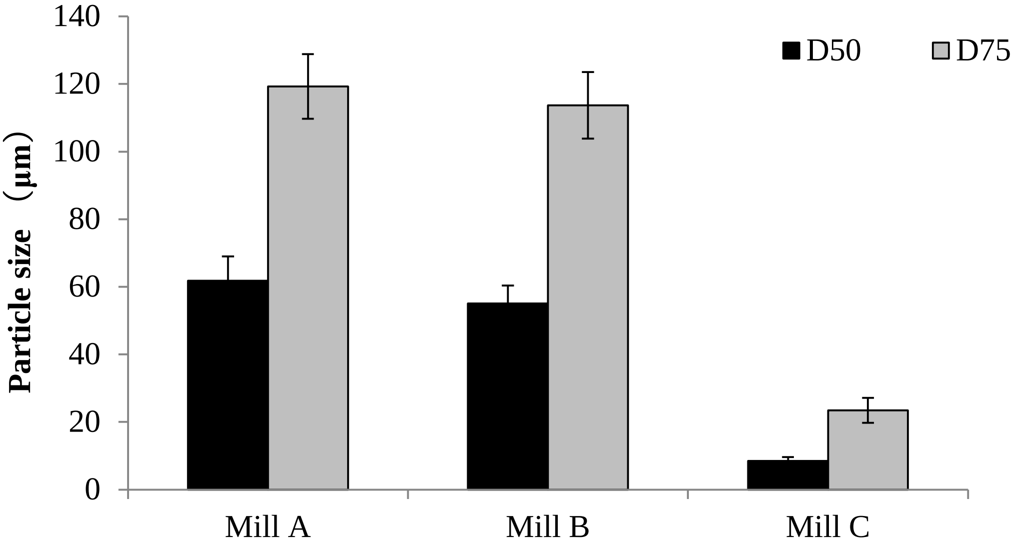
Particle size（μm）
50
45
40
35
30
25
20
15
10
5
0
10
20
30
40
50
Material feeding rate（g/min）
D50
D75

Figure 7



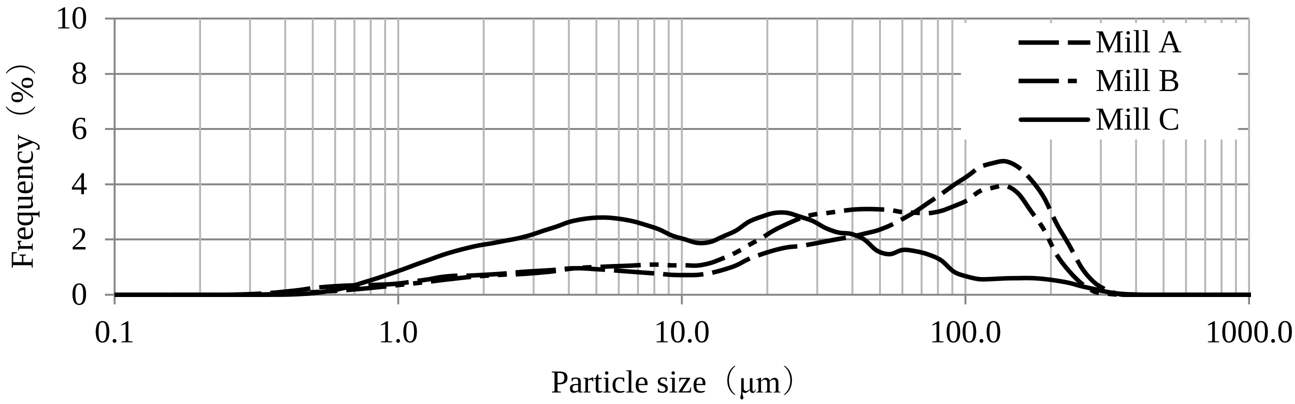
10
8
6
4
2
0
Frequency （%）
0.1
1.0
10.0
100.0
1000.0
Particle size （μm）
White rice slurry
Brown rice slurry

Figure 8



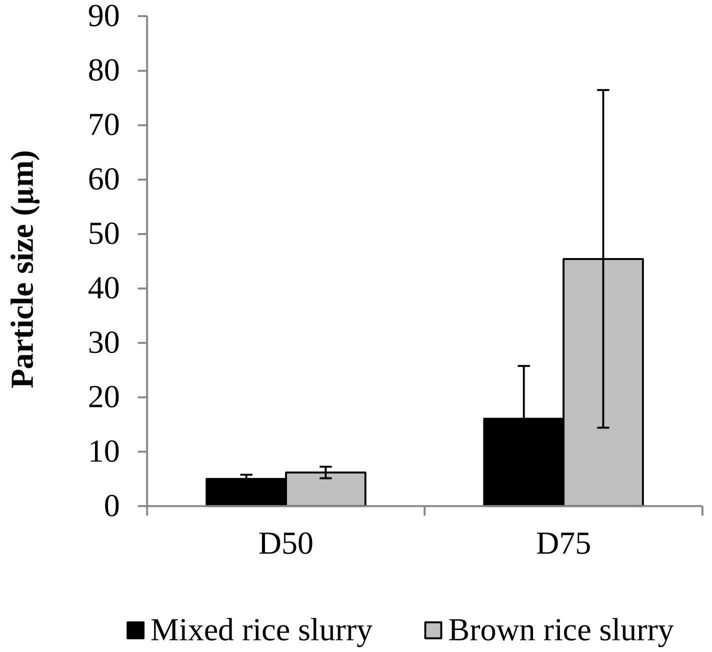
140
120
100
80
60
40
20
0
Particle size （μm）
D50
D75
Mill A
Mill B
Mill C

Figure 9



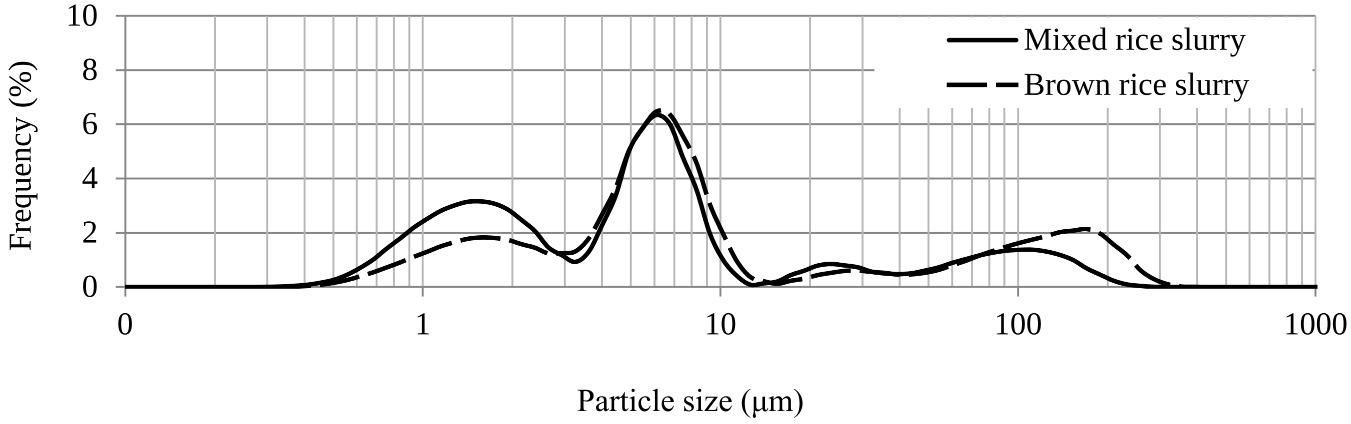
10
8
6
4
2
0
Frequency（%）
0.1
1.0
10.0
100.0
1000.0
Particle size（μm）
Mill A
Mill B
Mill C

Figure 10



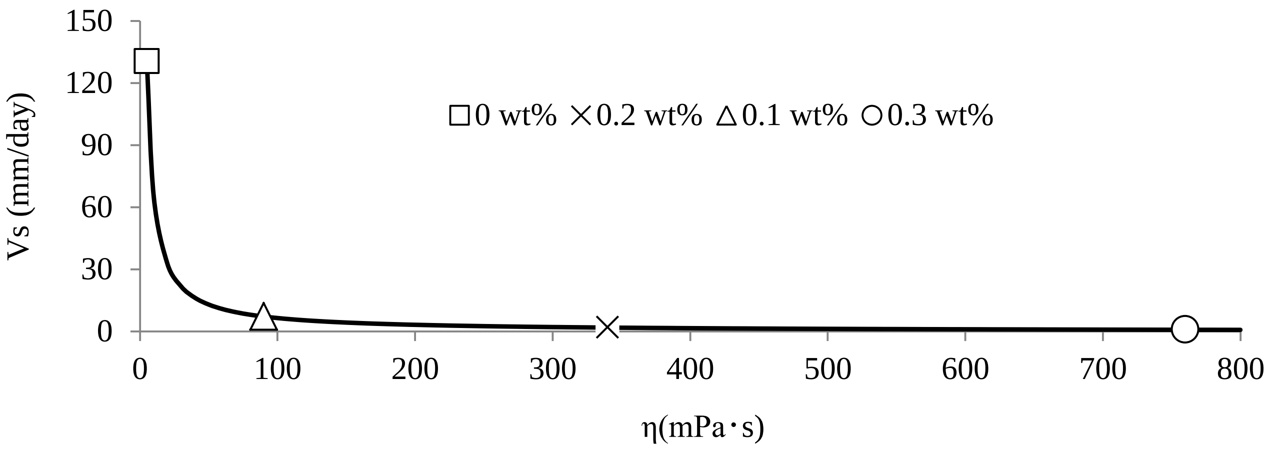
Particle size (µm)
90
80
70
60
50
40
30
20
10
0
D50
D75
Mixed rice slurry
Brown rice slurry

Figure 11



Frequency (%)
10
8
6
4
2
0
0
1
10
100
1000
Particle size (µm)
Mixed rice slurry
Brown rice slurry

Figure 12



150
120
90
60
30
0
Vs (mm/day)
□0 wt% ×0.2 wt% △0.1 wt% ○0.3 wt%
0
100
200
300
400
500
600
700
800
η(mPa･s)

Tables

Tabale 1. Result of Sensory evaluation and Favorable evaluation

Amount of xanthan gum (%)	sensory evaluation (pt.)					Favorable evaluation (%)
	Powder less	Aftertaste	Ability to drink	Smell	Total taste	
0	5.00[a] ±1.80	4.81[a] ±1.80	4.63[a] ±1.76	3.74[a] ±0.94	3.67[a] ±1.41	29.6
0.1	4[b]	4[b]	4[a]	4[a]	4[a]	3.70
0.2	3.96[b] ±1.32	3.67[b] ±1.30	4.04[a] ±1.29	4.11[a] ±1.22	4.11[a] ±1.31	11.1
0.3	4.19[ab] ±1.55	3.48[b] ±1.76	3.70[a] ±1.61	4.41[b] ±1.22	4.52[b] ±1.48	55.6

Each value of the sensory evaluation is the mean±SD
Means with the same latter are not significantly ($p>0.05$) different.