Ultra–fine Pulverization of Rice: Effects on Hydration Properties and Enzymatic Hydrolysis

Md. Sharif HOSSEN1, Itaru SOTOME1, Makiko TAKEAKA1, Seiichiro ISOBE1,2, Mitsutoshi NAKAJIMA1,2, Naoto SHIMIZU1,2, and Hiroshi OKADOME1,3

1National Food Research Institute, National Agriculture and Food Research Organization, Tsukuba, Ibaraki 305–8642, Japan
2Graduate school of Life and Environmental Sciences, University of Tsukuba, Tsukuba, Ibaraki 305–8572, Japan
3Graduate School of Agriculture, Hokkaido University, Hokkaido, 060–8589, Japan

We studied the hydration properties and enzymatic hydrolysis of micro– sized rice flour obtained by dry jet-pulverization to find new applications for the flour in the food industry. Ultra–fine rice flour (both white and brown) with a mean size of <5 μm was far more dispersible than coarser flours (15–120 μm). Dispersibility increased with finer mean particle size and higher starch damage. The ultra–fine flour also had the highest solubility, swelling power, water absorption index, and glucose release. Dry jet-pulverization to <5 μm mean size and consequent starch damage to (>30%) decreased enthalpy and gave very different hydration properties and enzymatic hydrolysis than in coarser flours.

Key words: Dispersibility, Solubility, Starch damage, Enthalpy, Ultra–fine, Flour, Released glucose, Dry pulverization

1. Introduction

Rice starch, the main component of rice, has traditionally been used as an anti– lumping agent in grated cheese, as a thickener in dairy products, as an anti– salt ing agent in baked products, to replace lipids in margarine, to increase the juiciness of cooked meats, and to increase the freeze– thaw stability of frozen product [1,2]. Rice products are used in gels, puddings, ice creams, and baby formulas because of their nutritional content, hypoallergenicity, colorlessness, and blandness [3]. Different pulverization methods are used to prepare flours ranging from coarse to fine. As the per capita consumption of rice has been falling in Japan in recent years [4], new uses of rice flour in foods could maintain production. Pulverization could achieve this, as it affects physicochemical properties such as pasting properties, starch damage, hydration properties, flowability, and bulk density [5–9]. Ultra–fine pulverization may allow novel uses of rice flour, however flours with a mean size of <10 μm have not found practical applications yet because their merits have not been clarified.

Ultra–fine pulverization altered the thermal and digestion properties of rice starch and wheat starch [10,11]. Comparison of the nutrient contents and enzymatic hydrolysis of micrometre– and submicrometre– sized rice flours revealed that ultra–fine flours prepared from raw, heat–gelatinized, and fermented rice had altered nutrient contents and increased release of reducing sugars [12].

Reducing the mean size of micro– pulverized rice particles changed the pasting properties and increased the starch damage, dramatically so at <10 μm mean size [7]. Ultra–fine pulverization may improve the water absorption, solubility, and water uptake capability of rice flour, all of which are important in food processing. Here, we elucidated the effects of size reduction and starch damage on the hydration, thermal property and enzymatic hydrolysis of dry–pulverized rice flours (<10 μm mean size) and their correlations, with the aim of finding new applications or processing properties of the flour for use in the food industry.

2. Materials and methods

2.1 Materials

Brown rice of the non–waxy japonica cultivar Koshihikari, grown in 2007 in Ibaraki prefecture, Japan, was bought from the local market and stored at 5°C until use. A commercial rice starch (CS) (Sigma S7260) was used for comparison of some properties.
2.2 Experimental and analytical methods

2.2.1 Pulverization, size distribution, and morphology

Polishing of brown rice, pulverization, size distribution analysis, and moisture content analysis were done according to the methods described in Hossen et al. [7]. Both brown and white rice flours of different mean sizes were prepared in two kinds of mills. Hammer milling: A water-cooled hammer mill (1018–S–3; Yoshida Seisakusho Co., Ltd., Tokyo, Japan) was used to prepare particles ranging in mean size from 100 to 50 μm, sorted by screens of the hammer mill (2 mm, 1 mm and 0.7 mm screens to obtain ≥100 μm, ≥70 μm, and ≥45 μm, respectively, with a constant feed rate). The yields of the flour were between 92 to 95%.

Jet milling: A jet mill (IDS-2; Nippon Pneumatic Mfg. Co., Ltd., Osaka, Japan) was used to pulverize rice by releasing compressed air from a nozzle, slamming the rice into a ceramic board at faster velocity. The flour is slammed repeatedly, and the fine flour is collected from a cyclone classifier of the jet mill. Ultrafine particles ranging in mean size from 50 to 3 μm were obtained by using the jet mill, different size particles were obtained by changing the distance between the nozzle and the ceramic board impact plate with different pressure and feed rate. To obtain targeted 3 μm, 15 μm, and 35 μm particles, the nozzle stagnation pressure were 0.65 MPa, 0.42 MPa and 0.30 MPa and the distance between the nozzle and the impact plate were 62 mm, 92 mm, and 149 mm respectively. The feed rates were 6 kg/h, 12 kg/h and 12 kg/h to get ≥3 μm, ≥15 μm, and ≥30 μm particles, respectively.

The size distribution of the pulverized flour samples was measured using a laser diffraction particle size analyzer (SALD-2100; Shimadzu Co., Kyoto, Japan). Sonic measurements were performed to avoid the aggregation of the flours. D90 (A particle size value indicating that 90% of the distribution is below this value), D50 (A particle size value indicating that 50% of the distribution is below this value), D10 (A particle size value indicating that 10% of the distribution is below this value), and the mean size were calculated on the basis of the obtained particle size distribution curve.

Flour samples were ion–sputter–coated with gold and observed by scanning electron microscope (SEM; JSM-5600LV, JEOL, Tokyo, Japan). The CS was pulverized three times in a one–pass jet mill (Co–jet systemα MK III; Seishin Ent. Co. Ltd., Japan) to prepare pulverized finer rice starch (PS).

2.2.2 Components of rice flour

Protein: The nitrogen content of the sample was measured with a protein analyzer (FP-528, LECO Corp., St. Joseph, MI, USA) using EDTA as a standard. The protein content of each sample was obtained by multiplying the nitrogen content by the conversion factor 5.95.

Amylose: Amylose contents were measured according to a standard method [13]. Absorbance was measured at a wavelength of 620 nm. Amylose type III from potato (Sigma–Aldrich, St. Louis, MO, USA) was used as a standard. Amylose contents of samples were determined from a standard curve and are expressed as a dry–weight percentage.

2.2.3 Hydration properties

Water absorption index (WAI), solubility, and swelling power (SP) were determined by the method of Anderson et al. [14]. Each pulverized sample (2.5 g) was suspended in 30 mL of distilled water (30°C) in a 50–mL pre–weighed centrifuge tube by vortex mixing. The tubes were held in a 30°C water bath for 30 min with intermittent stirring. The suspension was centrifuged for 10 min at 3000 × g and the supernatant was decanted into a pre–weighed 50–mL beaker. The weight of the precipitate was used to calculate the WAI, which was calculated as (weight gain by absorbing water) / (dry weight of sample, dwb). The supernatant was dried at 95°C, and the weight of dried solids was used to determine the solubility:

\[ W_{dm} = W_S (1 - MC/100) \]  

Solubility (%) = \( W_{sup} \times 100 \) / \( W_{dm} \)  

Swelling power = \( W_{sup} / W_{dm} (100 - \text{solubility}) \)

Where, \( W_{dm} = \) weight of dry matter, \( W_S = \) weight of sample, \( MC = \) moisture content of sample (dry basis), \( W_{sup} = \) weight of dried supernatant, and \( W_{sup} = \) weight of centrifuged swollen granules (precipitate).

Dispersibility was measured by the method of Lee et al. [15]: 0.1 g of flour was dispersed in 50 mL of phosphate–buffered saline solution (pH 7.4) at room temperature. The mixture was stirred at 500 rpm for 10 min, then 1 mL of the suspension was collected in a cuvette and the absorption was measured at 650 nm by a UV–VIS spectrophotometer. The turbidity profile of the suspension was recorded for 25 min at 5–min intervals.

To find the optimum particle size to remain in stable suspension, we measured the size distribution of parti-
cles in the suspension of each sample (including CS and PS) at 0 and 25 min with a particle size analyzer (SALD 2100; Shimadzu Co., Kyoto, Japan) and calculated the mean size.

2.2.4 Thermal properties

Thermal properties were measured with a differential scanning calorimeter (EXSTAR DSC 6220; SH NanoTechnology Inc. Tokyo, Japan) according to the method described by Islam et al. [16]. Pulverized rice flour (3 mg dry basis) was placed in a 15-μL aluminum cell, and a calculated amount of distilled water was added to it by micropipette to prepare a 10 mg sample with 70% moisture content. The carefully sealed sample cell was then placed in the DSC chamber with an empty reference cell. The sample temperature was raised from 30 to 140°C at 10°C/min. Three gelatinization temperatures—Ts (onset), Tp (peak), and Tc (conclusion)—were determined from the DSC curve, and the enthalpy associated with starch gelatinization (ΔH, J/g on dry basis) was calculated as the area under a line drawn between Ts and Tc.

2.2.5 Starch damage

Starch damage was determined according to AACC method 76-31 [17] with a starch damage assay kit (Megazyme International Ireland, Ltd., Bray, Ireland). 100 mg of rice flour and starch control (supplied with the assay kit) were put into two thick-walled glass centrifuge tubes and were incubated with 1 mL fungal α-amylase at 40°C for exactly 10 min. 8.0 mL of diluted sulphuric acid solution was added (0.2% v/v) to each tube after exactly 10 min from the time of addition of the fungal α-amylase. The tubes were centrifuged at 3,000 rpm for 5 min. 0.1 mL of the supernatant solution was transferred to the bottom of two test tubes. 0.1 mL of amyloglucosidase solution (2 U) was added to each tube and incubated them at 40°C for 10 min. 4.0 mL of glucose oxidase peroxidase (GOPOD, supplied with the kit) reagent solution was added to each tube (including glucose standards and reagent blank tubes) and the tubes were incubated at 40°C for 20 min. The absorbance of all solutions was measured at 510 nm against a reagent blank using UV–VIS spectrophotometer. Starch damage of each sample was calculated using the absorbance.

2.2.6 Enzymatic hydrolysis with α-amylase

The method of Zhang et al. [18] was used to determine enzymatic hydrolysis. Ts 100 mg (dry basis) of flour in a 15-mL centrifuge tube we added 7.5 mL of 6.7 mM NaCl in 20 mM phosphate–buffered saline (PBS; pH 6.9). The mixture was suspended by shaking and vortexing. We then added 120 units (120 U/mL in PBS) of pancreatic α-amylase (from a resistant starch assay kit; Megazyme International Ireland, Bray, Ireland) to the tube. The tube was then incubated in a shaking water bath at 37°C to maintain the starch in suspension. After 16 h. 2.5 mL of 1.0% (v/v) H2SO4 was added to stop the enzymatic hydrolysis. The sample was then centrifuged at 3255 × g for 10 min. Then 0.1 mL of supernatant and 0.1 mL of amyloglucosidase enzyme (20 U/mL in PBS) were mixed in a test tube and held at 40°C for 10 min. Into three new test tubes, 0.1 mL of standard glucose solution (1.5 mg/mL; Megazyme) and 0.1 mL of PBS were added. Reagent blank was prepared with 0.2 mL of sodium PBS. To each test tube 4 mL of glucose oxidase–peroxidase reagent was added. After incubation at 40°C for 20 min, the absorbance of all test tubes was measured at 540 nm with a UV–VIS spectrophotometer. The glucose released from the enzymatic reaction was measured using the following equation based on Raabo and Terkdalsen [19].

Amount of glucose

\[
\frac{(\Delta A_{540} \text{ of sample}) \times (\text{mg glucose in standard})}{\Delta A_{540} \text{ of standard} \times 0.9}
\]

0.9 (% of 102/180) Adjustment from free glucose to anhydro glucose

\[\Delta A_{540} \text{ of sample=absorbance of the sample solution at 540 nm} \]

\[\Delta A_{540} \text{ of standard=absorbance of the standard solution at 540 nm} \]

Amount of glucose determined by multiplying the dilution factor made in sample preparation.

2.2.7 Statistical analyses

Results are reported as means and standard deviations. Data were analyzed by analysis of variance (ANOVA). Differences between means were tested by Duncan’s new multiple range test (P ≤ 0.05). Correlations were performed as appropriate in SPSS v. 17.0 software (SPSS Inc., Chicago, IL, USA).

3. Results and discussion

3.1 Size distribution and components of the pulverized rice flour

The size distribution, component, starch damage and gelatinization enthalpy are given in Table 1. For each pulverizing method (hammer mill and jet mill), three different mean size samples were obtained for each of the brown rice and the white rice. The jet mill (codes with J in the middle) gave the smallest mean sizes. The ratio of D90 to D10 shows that the jet mill created particles with more uniform size distribution, as the lower ratio value
indicated the uniformity of size [20]. The ratios of D90 to D10 of brown rice flours were higher than those of white rice flours and the difference of the particle size distribution was seen in spite of same pulverization condition. The brown rice flours included more protein than the white rice flours as brown rice flour contains the bran. However, bran contains not only protein but also other components such as lipid and fiber, and it is considered that these components affected particle size distribution after pulverization. The degree of starch damage increased as the mean particle size decreased and the flour with the smallest mean size indicated highest starch damage. The amylose content was also slightly lower in the flour with the smallest mean size. It is reported that ultra-fine pulverization disrupts the ordered structure of starch granules [21]. Therefore, it is considered that the rapid increase of starch damage and the slight decrease of amylose content in the flour with the smallest mean size were occurred by structure breakage of the starch granules.

3.2 Morphological observations of the pulverized rice flour

At $\times$2000 magnification, the coarsest white rice flour (WHL) showed a range of particle sizes with irregular shapes (Fig. 1). In contrast, at $\times$1000 magnification, the finest white rice flour (WJS) showed a uniform particle size, in agreement with the particle size distribution (Table 1). These results indicate that the hammer mill gave a wider size distribution than the jet mill. At $\times$2000 magnification, the WJS clearly included broken granules of $< 5 \, \mu m$ across. The equivalent brown rice flour (BJS) also showed broken granules (not shown in the figure). At a diameter of 2 to 5 $\mu m$, the rice starch granule is one of the smallest [22]. The broken granules in WJS are close to this size; however it is difficult to tell from the micrograph whether they are starch or other components. So we compared them with the purified CS (commercial starch) granules and the PS (pulverized starch) granules (Fig. 1). The starch granules in CS were $\sim 5 \, \mu m$ in diameter and nearly all were intact. However, some of the starch granules in PS were broken and measured $< 5 \, \mu m$. Rice starch granules are aggregated in the kernel from at least 16 individual starch units [23]. Chemical isolation of the CS granules separates them into single units, which many of the smallest particles ($< 5 \, \mu m$) in WJS resemble (Fig. 1). We considered that most of the particles $< 5 \, \mu m$ across in WJS were broken starch granules, single starch units, or even broken single units, fragmented by pulverization in the jet mill. Therefore, it was considered that the starch damage was highest for the flours with the smallest mean size ($< 5 \, \mu m$, WJS or BJS) due to the breakage of the glycosidic bonds and the crystalline structure of the starch granule.

3.3 Hydration properties of the pulverized flours

The finest flours (WJS and BJS) had the highest water

<table>
<thead>
<tr>
<th>Table 1 Particle size distribution, components, starch damage and gelatinization enthalpy of pulverized rice flours.</th>
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<tbody>
<tr>
<td></td>
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<tr>
<td>White rice flour</td>
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<tr>
<td>WHL</td>
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<tr>
<td>WHM</td>
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<tr>
<td>WJS</td>
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<tr>
<td>Brown rice flour</td>
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<tr>
<td>BHL</td>
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<tr>
<td>BWM</td>
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<tr>
<td>BJS</td>
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</tbody>
</table>

W = white rice, B = brown rice, H = hammer mill, J = jet mill, L = large, M = medium, S = small.
absorption index (WAI), solubility, and swelling power (Table 2). Damage to starch caused by pulverizing increases absorption [24,25]. Thus, ultra-fine pulverization into particles smaller than individual starch units (Fig. 1) was responsible for these dramatic increases.

Intact starch granules are insoluble in cold water, but pulverization produces a water-soluble fraction composed of low-molecular-weight fragments released by the breakdown of regions around the α-(1→6) branch points of amylopectin double helices [26]. Hydroxyl groups exposed by the breakdown of glycosidic bonds are strongly hydrophilic, also increasing the solubility [21]. We consider that these phenomena occurred commonly in the finest flours. The solubilities of the brown rice flours were higher than those of the white rice flours. It was reported that rice bran powder exhibits higher water solubility than endosperm powder due to the existence of soluble fiber in the bran [15]. It is supposed that the brown rice flour indicate higher solubility because containing more bran than white rice flour.

The absorbance, and thus dispersibility, of the finest

Fig. 1  SEM of rice flours and starches. Codes as in Table 1. CS-Commercial starch, PS-Pulverized starch.
flours (WJS and BJJS) remained high over 25 min (Fig. 2). That of the second finest flours (WJM and BJM) started moderate and slowly declined. That of the rest started low and fell close to zero. Lee et al. [15] reported that ultra-fine flour (~10 μm) exhibits in the suspension for longer period than the coarser flours, however the optimum particle size to remain in suspension or the effect of damage starch on dispersibility were not reported. Hence, we investigated the optimum particle size. In the mid-sized flours produced by the jet mill (WJM and BJM), the mean size of the suspension was ~15 μm at 0 min, however decreased to ~7 μm at 25 min, along with absorbance (Fig. 3). This result shows that particles of ~7 μm mean size remained in suspension at

<table>
<thead>
<tr>
<th>White rice flour</th>
<th>Water absorption index</th>
<th>Solubility (%)</th>
<th>Swelling power</th>
<th>Brown rice flour</th>
<th>Water absorption index</th>
<th>Solubility (%)</th>
<th>Swelling power</th>
</tr>
</thead>
<tbody>
<tr>
<td>WHL</td>
<td>0.99 ± 0.01d</td>
<td>2.56 ± 0.09d</td>
<td>2.93 ± 0.02d</td>
<td>BHL</td>
<td>1.18 ± 0.03c</td>
<td>5.82 ± 0.52d</td>
<td>3.39 ± 0.03c</td>
</tr>
<tr>
<td>WHM</td>
<td>1.17 ± 0.02c</td>
<td>2.92 ± 0.12d</td>
<td>3.15 ± 0.03c</td>
<td>BHM</td>
<td>1.17 ± 0.02c</td>
<td>6.72 ± 0.33c</td>
<td>3.15 ± 0.05d</td>
</tr>
<tr>
<td>WHS</td>
<td>1.26 ± 0.02b</td>
<td>3.57 ± 0.10c</td>
<td>3.22 ± 0.02b</td>
<td>BHS</td>
<td>1.41 ± 0.03b</td>
<td>6.73 ± 0.14c</td>
<td>3.39 ± 0.03c</td>
</tr>
<tr>
<td>WJL</td>
<td>1.00 ± 0.01d</td>
<td>3.44 ± 0.08c</td>
<td>2.91 ± 0.02d</td>
<td>BJL</td>
<td>0.94 ± 0.03d</td>
<td>6.13 ± 0.25cd</td>
<td>2.84 ± 0.04e</td>
</tr>
<tr>
<td>WJM</td>
<td>1.19 ± 0.02c</td>
<td>3.72 ± 0.16b</td>
<td>3.20 ± 0.03bc</td>
<td>BJM</td>
<td>0.98 ± 0.02d</td>
<td>9.92 ± 0.18b</td>
<td>3.00 ± 0.03b</td>
</tr>
<tr>
<td>WJS</td>
<td>1.93 ± 0.03a</td>
<td>11.62 ± 0.21a</td>
<td>4.09 ± 0.04a</td>
<td>BJJS</td>
<td>1.73 ± 0.05a</td>
<td>14.11 ± 0.20a</td>
<td>3.94 ± 0.09a</td>
</tr>
</tbody>
</table>

* Means of triplicates ± standard deviation. * Means within row in each group with different letters are different significantly at P < 0.05. Sample names are as described in Table 1.
Fig. 4 Enzymatic hydrolysis of white and brown rice flours pulverized by hammer mill and jet mill. Bars with the same letters are not different significantly at $P < 0.05$. Codes as in Table 1.

Fig. 5 Correlation of starch damage with different physical attributes of white and brown rice flours. Upper equations represent white rice; lower equations represent brown rice. 1 = hammer, large; 2 = hammer, medium; 3 = hammer, small; 4 = jet, large; 5 = jet, medium; 6 = jet, small.
25 min, when the coarser flours had settled out. In the finest flours produced by the jet mill (WJS and BJS), the mean size of the particles in suspension decreased a little at 25 min, however the particles remained in suspension. The mean size and absorbance of CS decreased a little at 25 min, however those of PS remained unaltered. The level of starch damage was higher in PS (17.1%) than in CS (5.9%), and that in the finest flours was much higher (WJS, 35%; BJS, 32%). From the above discussion, we found that both a small mean size (<5 µm) and a high degree of starch damage contributed greatly to maintaining dispersibility in suspension.

3.4 Enzymatic hydrolysis of the pulverized flours

Hydrolysis released the most glucose from the finest flours (WJS and BJS) (Fig. 4). Digestion of starch is affected by many factors, including the origin of the starch, the source of enzymes, substrate and enzyme concentrations, temperature, time, the presence of other substances in the starch, crystallinity of starch, and amylase–lipid complexes [27]. Pulverization makes crystalline starch non-crystalline, improving the accessibility of the substrate to enzymes [27], and increases the surface area [12]. These effects are enough to explain the greatest release of glucose from the finest flours.

3.5 Correlations between properties of the flours

We investigated the correlations between the mean particle size, amylase content, protein content, and starch damage of the flours on the one hand and the properties related to hydration and enzymatic hydrolysis on the other. Starch damage had the highest correlations with all the properties (Fig. 5). Except for the ratio of dispersibility, it showed a positive correlation with all properties (Table 3). Flours with >30% starch damage showed significant increases. White and brown flours showed similar regressions for dispersion at 25 min, swelling power, and WAI, indicating that these properties were determined only by starch damage. On the other hand, the white flour was less soluble and released more glucose than the brown flour. The difference can be explained by the greater starch content of the white flour. These results clearly show that micrometre–size rice flours with greater starch damage are more easily hydrolyzed than coarser flours.

![Fig. 6 Correlation of starch damage with the gelatinization enthalpy of white and brown rice flours.](image)

Table 3 Correlations between hydration properties, components, starch damage, and enzymatic hydrolysis of rice flours.

<table>
<thead>
<tr>
<th></th>
<th>Dispersibility at 0 min</th>
<th>Dispersibility at 25 min</th>
<th>Ratio of dispersibility (0 min/25 min)</th>
<th>Solubility</th>
<th>Swelling power</th>
<th>Water absorption index</th>
<th>Released glucose</th>
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<tbody>
<tr>
<td><strong>White rice flour</strong></td>
<td></td>
<td></td>
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<tr>
<td>Mean size</td>
<td>−0.80</td>
<td>−0.66</td>
<td>0.74</td>
<td>−0.77</td>
<td>−0.63</td>
<td>−0.65</td>
<td>−0.66</td>
</tr>
<tr>
<td>Amylose</td>
<td>−0.68</td>
<td>−0.74</td>
<td>0.79</td>
<td>−0.73</td>
<td>−0.87*</td>
<td>−0.87*</td>
<td>−0.81</td>
</tr>
<tr>
<td>Protein</td>
<td>−0.17</td>
<td>−0.47</td>
<td>0.45</td>
<td>−0.31</td>
<td>−0.53</td>
<td>−0.53</td>
<td>−0.57</td>
</tr>
<tr>
<td>Starch damage</td>
<td>0.92*</td>
<td>0.98**</td>
<td>−0.97**</td>
<td>0.96**</td>
<td>0.99**</td>
<td>0.99**</td>
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<tr>
<td><strong>Brown rice flour</strong></td>
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<tr>
<td>Mean size</td>
<td>−0.77</td>
<td>−0.61</td>
<td>0.71</td>
<td>−0.79</td>
<td>−0.37</td>
<td>−0.26</td>
<td>−0.85*</td>
</tr>
<tr>
<td>Amylose</td>
<td>−0.75</td>
<td>−0.53</td>
<td>0.23</td>
<td>−0.78</td>
<td>−0.15</td>
<td>−0.16</td>
<td>−0.53</td>
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<tr>
<td>Protein</td>
<td>−0.10</td>
<td>−0.38</td>
<td>−0.14</td>
<td>0.01</td>
<td>−0.58</td>
<td>−0.67</td>
<td>−0.02</td>
</tr>
<tr>
<td>Starch damage</td>
<td>0.90*</td>
<td>0.94**</td>
<td>−0.74</td>
<td>0.85*</td>
<td>0.96**</td>
<td>0.92*</td>
<td>0.90*</td>
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*P < 0.05 (n = 6). **P < 0.01 (n = 6). Two tailed.
The coarse jet-milled flours (WJL and BJL) had higher endothermic enthalpy than the finest hammer-milled flours (WHS and BHS; Fig. 6). This difference indicates that the hammer mill caused greater damage to the crystalline structure of the starch granules than the jet mill at a similar mean particle size. The lower endothermic enthalpy values for the finest flours (WJS and BJS) indicate that the crystalline structure was further disrupted with further reduction in size.

Starch damage is an important factor in applications of rice flour. Ultra-fine flour with a mean particle size of <5 μm was far more dispersible and soluble and was more easily hydrolyzed enzymatically. These advantages were due to higher starch damage and lower enthalpy. These findings will allow new applications for rice flour in the food industry.

4. Conclusion

Ultra-fine rice flour with a mean particle size of <5 μm obtained by dry jet-pulverization had much greater dispersibility than coarser flours (15–120 μm). Its fineness and greater degree of starch damage contributed greatly to maintaining dispersibility in suspension. Starch damage had significant positive correlations with hydration properties and a negative correlation with enthalpy. Dry jet-pulverization increased the degree of starch damage to >30% and decreased enthalpy, resulting in different hydration properties, and greater enzymatic hydrolysis than in the coarser flours. Ultra-fine pulverization using a dry jet mill is a novel approach to changing the properties of rice flour, making new applications possible.

5. Acknowledgements

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和文要約

米の超微粉砕：水和特性と酵素加水分解への影響

Md. シェリフ ホッセン 1, 五月女格 1, 竹中真紀子 1, 五十部誠一郎 1, 2, 中崎秀敏 1, 2, 清水直人 2, 3, 岡留博司 4, 5

農研機構 食品総合研究所 1, 北海道大学 2, 北海道大学 3

本研究では食品産業での米粉の新規用途を見出すことを目的とし、ジェットミルでマイクロサイズまで乾式粉砕した米粉の水和特性と酵素加水分解について調査した。その結果、平均粒径5μm以下まで粉砕した超微粉砕米粉（白米および玄米）は粒度の粗い米粉（15～120μm）よりも良好な分散性を示した。分散性は粒径が小さく、損傷質粉の割合が大きいほど増加した。また超微粉砕米粉は溶解性、膨張性、吸水性指標およびグルコース遊離量が最も高かった。平均粒径5μm以下に乾式粉砕した米粉は損傷質粉の割合が30%以上となり、エンタルピの著しい低下を示し、結果的に粒度の粗い米粉とは全く異なる水和特性や酵素加水分解を示した。