**Note**

Gelatinization Properties of Aged Rice and Improvement of Rice Texture by External Layer Removal

Toshihisa Ohno*, Makoto Tomatsu, Kazuki Toeda and Naganori Ohisa

Institute for Food and Brewing, Akita Prefectural Agriculture, Forestry and Fisheries Research Center, 4–26 Aza-sanuki, Arayamachi, Akita 010–1623, Japan

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Textures of cooked rice prepared from aged rice and improvements in cooked rice through removal of its external layer were investigated. Cooked rice prepared from aged rice became hard and stickiness/hardness (S/H) ratios were significantly lowered in comparison to that of new rice. The cooked rice prepared from aged rice with 7% of the external layer removed became soft and no significant differences existed between the S/H ratios of new rice and aged rice. The soaking solution of rice became starchy solution at the time of heating. The amount of the solid of starchy solution was significantly decreased in aged rice compared with new rice, and that of further polished and aged rice was increased. Therefore, we presumed that the starchy solution became a gelatinous paste layer of starch on the rice grain surface after cooking, and that the amount of the solid of starchy solution was related to the textural deterioration of aged rice and the textural improvement by partial removal of the external layer in aged rice. The RVA pasting properties of the flour in aged rice were also different from those of new rice. However, their changes were different from those for cooked rice texture.

Keywords: aged rice, texture of cooked rice, removal of external layer, gelatinization properties, extractable solids

**Introduction**

The taste of cooked rice is well known to be related to textural factors such as hardness and stickiness (Okabe, 1979). Japanese people generally prefer cooked rice that has a soft and highly sticky texture. The texture of cooked rice that has been stored is generally hard and non-sticky. For that reason, cooked rice prepared from aged rice, not only brown rice in storage but also milled rice in storage, is deemed inferior to newly harvested rice (Shibuya et al., 1974; Toyoshima et al., 1998). Therefore, the market price of aged rice is low in comparison with new rice. The removal of these undesirable changes raises the quality and the value of aged rice. Many attempts have been made to improve these changes of cooked rice prepared from aged rice, including: the addition of rice vinegar or fruit juice to the cooking water (Ema and Kainuma, 1991); high-pressure treatment and enzymatic treatment of the rice (Watanabe et al., 1991); enzymatic degradation of the cell wall (Shibuya and Isawa- saki, 1984); and the addition of sodium sulfite to the cooking water (Ohno and Ohsita, 2005). In addition, Kainuma (1979) and the authors’ previous paper (Ohno and Ohsita, 2005) reported textural improvement through removal of the external layer from aged rice that had been in milled rice storage. Furthermore, Inoue and Suzuki (1986) and Fukai and Ishitani (2004) reported textural improvement through removal of the external layer from aged rice that had been in brown rice storage. Nevertheless, the mechanism of that improvement by the removal of the external layer remains unknown. Therefore, we intensively investigated the texture of cooked rice prepared from aged rice and further-polished aged rice, as well as their gelatinization properties.

**Materials and Methods**

Experimental materials and texture measurement A Japonica type rice (Oryza sativa L. japonica, cultivar Akita-komachi) harvested in Akita Prefecture was used for the experiments. After brown rice grains harvested in 2001 were polished to wash-free grade (about 1.5% further polished from normal polished rice grains), they were used as New Rice. During summer, milled rice reveals features of aged rice unless it is consumed within 1 month. Therefore, New Rice, stored for 2 months at 30 °C in a closed aluminum pouch, was used as Aged Rice (milled rice storage). Thereafter, samples were stored below −5°C until use in experiments.

Texture measurement was performed as mentioned in our previous paper (Ohno and Ohsita, 2005). The hardness (H), stickiness (S), and stickiness/hardness (S/H) ratio of the individual cooked rice grains was measured.

Removal of the external layer of polished rice Samples were cooked after the rice was further polished in a mill
(Grain Testing Mill; Satake Co. Ltd., Higashi-hiroshima, Japan). The rates of removal of the external layer of the polished rice were 5% and 7% (w/w). The sample from which no external layer was removed is designated herein as 89% (w/w) polished rice (the moisture of New Rice and Aged Rice was 16.1%); the sample from which 5% of the external layer was removed is denoted as 84% (w/w) polished rice (the moistures of New Rice and Aged Rice were 16.0% and 15.8%, respectively); and the sample from which 7% of the external layer was removed is denoted as 82% (w/w) polished rice (the moistures of New Rice and Aged Rice were 15.8% and 15.7%, respectively). The methods of cooking and measurement of texture were identical to the methods described above.

The crushed grains were measured by the method of Kitao et al. (1998).

**Measurement of pasting properties**

Pasting properties of rice flour were measured using a Rapid Visco-Analyzer (RVA, 3-D; Newport Scientific Pty. Ltd., Warriewood, NSW, Australia) using Thermocline software. Rice flour (2.6 g, db) milled in a Cyclone Sample Mill (UDY Corp., Fort Collins, CO, USA) was mixed with 25 mL of distilled water or 1 mM copper (II) sulfate in an RVA sample cup. For copper sulfate, before measurement of pasting properties, rice flour was soaked in the copper sulfate solution for 1 h to hold down amylase activity (Shibuya et al., 1983). A programmed heating and cooling cycle was used in which the samples were held at 50°C for 3 min, heated to 95°C in 7.5 min, maintained at 95°C for 7 min, cooled to 30°C in 10.8 min, then maintained at 30°C for 7 min (Takahashi et al., 2005). Peak viscosity (PV), minimum viscosity (MV), final viscosity (FV), breakdown (BD), and setback (SB) were recorded. Viscosity parameters were expressed in rapid viscosity units (RVU). Because the error of three times repetitions in the same sample was within 4 RVU, the measurement was performed once. The pasting properties of the flour derived from further-polished rice were also measured.

**Measurement of extractable solids after heating**

Measurement of extractable solids was performed with the weight ratio of the rice grains to the soaking water as 1:1.6 because this ratio was identical to the ratio of cooking. Unwashed 5 g rice samples were soaked in 8 mL of distilled water for 1 h in an aluminum cup and then placed in a water bath at 80°C for 5 min, shaking occasionally. After adding 10 mL distilled water, the starchy solution was collected and dried at 105°C for 3 h. The amount of solids was then measured as extractable solids. The extractable solids of further-polished rice were also measured.

**Statistical analysis**

Significant differences between data of new rice and those of aged rice were analyzed using Student's t-test. One, two, and three asterisks indicate statistical significance inferred respectively at 5%, 1%, and 0.1% levels.

**Results and Discussion**

**Texture of various types of cooked rice**

Table 1 shows textural parameters of various types of cooked rice. Aged Rice in 89% polished rice became significantly harder and the S/H ratio of Aged Rice became significantly less than that of New Rice. The cooked rice prepared from aged rice generally became hard and non-sticky. However, in the results described above, few differences existed in stickiness between new rice and aged rice. Because we measured the texture using the individual method, stickiness in new rice must have been measured not as stickiness but as softness.

In contrast, in 84% polished rice, the hardness was low in aged rice. Therefore, the difference of hardness between new rice and aged rice decreased, but a significant difference of S/H ratio was still recognized between New Rice and Aged Rice. In 82% polished rice, no significant difference of S/H ratios was found between New Rice and Aged Rice. These phenomena were also recognized in our previous report (Ohno and Ohisa, 2005). Kainuma (1979) reported that the removal of more than 10% of the external layer improved the texture of rice that had been stored at room temperature for 1 year. Results showed that removal of 5-7% of the external layer was effective to improve the texture of cooked rice prepared from aged rice. Because the storage time was short in our conditions, the removal of less than 10% of the external layer was apparently sufficient to improve the texture.

The results of crushed grains were shown in Table 2. The crushed-grains/total-grains of aged rice were increased, especially in 82% polished rice. Therefore, we estimated that the removal of 5% of the external layer was suitable for the improvement of the texture in aged rice.

**Measurement of pasting properties**

Characteristic curves that represent New Rice and Aged Rice are shown in Table 1. Textural parameters of cooked rice in New Rice and Aged Rice are shown in Table 1.

<table>
<thead>
<tr>
<th>Hardness (N)</th>
<th>Stickiness (N)</th>
<th>S/H ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>89% polished rice</td>
<td>New Aged</td>
<td>28.07±4.33 35.06±5.49***</td>
</tr>
<tr>
<td>84% polished rice</td>
<td>New Aged</td>
<td>28.35±3.79 29.70±4.57</td>
</tr>
<tr>
<td>82% polished rice</td>
<td>New Aged</td>
<td>28.36±3.00 28.50±3.68</td>
</tr>
</tbody>
</table>

New Rice was used as a reference for statistical analysis of Aged Rice.

**Results and Discussion**

Table 1. Textural parameters of cooked rice in New Rice and Aged Rice.

<table>
<thead>
<tr>
<th>Crushed grains (%)</th>
<th>89% polished rice</th>
<th>84% polished rice</th>
<th>82% polished rice</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Aged</td>
<td>0.4</td>
<td>1.5</td>
<td>2.6</td>
</tr>
<tr>
<td>Aged</td>
<td>0.4</td>
<td>1.8</td>
<td>6.4</td>
</tr>
</tbody>
</table>

The crushed grains/total grains was expressed (w/w).
in Fig. 1. The PV, MV and FV values of aged rice were different from those for new rice, although the gelatinization temperature of new rice was almost equal to that of aged rice. We recorded the values of PV, MV, FV, BD and SB. Pasting properties of rice flour from various polished rice samples, measured with distilled water, are shown in Table 3. Comparison of aged rice with new rice showed that PV and BD were higher in aged rice.

Shibuya *et al.* (1974), Villareal *et al.* (1976), and Kainuma (1979) also reported that PV or BD measured with amylograms increased in aged rice. In contrast, Zhou *et al.* (2003) reported that PV and BD measured with RVA decreased in aged rice. Villareal *et al.* (1976) and Shibuya *et al.* (1974) used rice stored for from 50 days to 6 months at about 30°C, and Kainuma (1979) used rice stored for 1 year at room temperature. Zhou *et al.* (2003) used rice stored for at least 4 months at 37°C. Indudhara Swamy *et al.* (1978) reported that paste viscosity increased initially, then decreased steadily with storage length. Yamamoto *et al.* (1997) also reported that BD increased initially, then decreased with storage length. The latter condition was harsher than the former conditions; therefore PV and BD of the latter condition decreased in aged rice. Because our conditions were not severe, PV and BD were as high in aged rice as in the former conditions. As shown in Table 1, the textural change in aged rice occurred distinctly in these mild conditions as well as in harsh conditions.

Subsequently, the rice grain surfaces were further polished. PV and BD of further polished rice increased, but MV, FV and SB were almost unchanged. The differences of PV and BD between new rice and aged rice were still recognizable for 82% polished rice, but no significant difference of S/H ratios was found between new rice and aged rice in 82% polished rice. This result might have occurred because of the decreased of amylase activity (Chikubu *et al.*, 1965). For that reason, we measured pasting properties with copper sulfate, which suppressed amylase activity. The result is shown in Table 4. The values of PV and BD in aged rice increased similarly as measured with distilled water in comparison with new rice. The increased PV and BD in aged rice were not attributable to the decreased amylase activity. Although the significant difference in the S/H ratio between new rice and aged rice was not found after removal of 7% of the external layer, a distinct difference was apparent in PV and BD between new rice and aged rice. These phenomena were also recognized in other samples (data not shown).

From the data obtained above, the increase of PV and BD in aged rice was the observation that indicated aged rice. However, the changes of PV and BD in further polished rice were different from changes of the texture in further polished rice. The RVA parameters are values representing the features of rice flour, but the texture parameters of cooked rice are values that represent the rice grain features. Therefore, we presumed that RVA parameters were unsuitable for determining the cause of textural changes of cooked rice prepared from aged rice. The increase of PV and BD might be unrelated to the textural changes of cooked and aged rice, or the relation between the texture and PV or BD might be decreased by the external layer removal.

**Measurement of extractable solids after heating** The results of measurements of extractable solids are shown in Fig. 2. In 89% polished rice, the amounts of extractable solids were small, especially in aged rice. Differences between new rice and aged rice were found to be significant at 0.1%. Villareal *et al.* (1976) and Zhou *et al.* (2002) also recognized these phenomena in aged rice. In 84% polished rice, the amounts of extractable solids increased, so the amount of extractable solids in aged rice was larger than that of 89% polished new rice. In 82%

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**Table 3. Pasting properties of New Rice and Aged Rice with distilled water.**

<table>
<thead>
<tr>
<th></th>
<th>PV (RVU)</th>
<th>MV (RVU)</th>
<th>FV (RVU)</th>
<th>BD (RVU)</th>
<th>SB (RVU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Rice</td>
<td>215</td>
<td>66</td>
<td>155</td>
<td>149</td>
<td>89</td>
</tr>
<tr>
<td>89% polished rice</td>
<td>221</td>
<td>68</td>
<td>157</td>
<td>153</td>
<td>89</td>
</tr>
<tr>
<td>84% polished rice</td>
<td>231</td>
<td>69</td>
<td>160</td>
<td>162</td>
<td>91</td>
</tr>
<tr>
<td>82% polished rice</td>
<td>263</td>
<td>82</td>
<td>174</td>
<td>181</td>
<td>92</td>
</tr>
<tr>
<td>Aged Rice</td>
<td>278</td>
<td>84</td>
<td>177</td>
<td>194</td>
<td>93</td>
</tr>
<tr>
<td>89% polished rice</td>
<td>280</td>
<td>83</td>
<td>177</td>
<td>197</td>
<td>94</td>
</tr>
</tbody>
</table>

Rice flour (2.5 g, db) milled in a Cyclone Sample Mill was mixed with 25 mL of distilled water.

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**Table 4. Pasting properties of New Rice and Aged Rice with copper sulfate.**

<table>
<thead>
<tr>
<th></th>
<th>PV (RVU)</th>
<th>MV (RVU)</th>
<th>FV (RVU)</th>
<th>BD (RVU)</th>
<th>SB (RVU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Rice</td>
<td>226</td>
<td>67</td>
<td>161</td>
<td>159</td>
<td>94</td>
</tr>
<tr>
<td>89% polished rice</td>
<td>232</td>
<td>67</td>
<td>163</td>
<td>165</td>
<td>96</td>
</tr>
<tr>
<td>84% polished rice</td>
<td>244</td>
<td>71</td>
<td>167</td>
<td>173</td>
<td>96</td>
</tr>
<tr>
<td>82% polished rice</td>
<td>269</td>
<td>80</td>
<td>185</td>
<td>189</td>
<td>105</td>
</tr>
<tr>
<td>Aged Rice</td>
<td>286</td>
<td>84</td>
<td>187</td>
<td>202</td>
<td>103</td>
</tr>
<tr>
<td>89% polished rice</td>
<td>289</td>
<td>83</td>
<td>187</td>
<td>206</td>
<td>104</td>
</tr>
</tbody>
</table>

Rice flour (2.5 g, db) milled in a Cyclone Sample Mill was mixed with 25 mL of 1 mM copper (II) sulfate. Before measurement of pasting properties, rice flour was soaked in the copper sulfate solution for 1 h.
polished rice, the amounts of extractable solids increased more than those of 84% polished rice, to about 6 g. Destruction of the rice grain structure by removal of the external layer might increase the extractable solids. These phenomena were also recognized in other samples (data not shown). During cooking, the soaking solution of rice became starchy by heating, and was then concentrated. Next, many bubbles formed above the rice grains; these bubbles were not observed after cooking. Therefore, we presumed that this starchy solution eventually formed a gelatinized paste layer at the surface of rice grains after cooking, and that the increase of extractable solids made the gelatinous paste layer thick and the cooked rice soft. The amount of extractable solids in 89% polished aged rice was small in comparison with 89% polished new rice. The amounts of extractable solids in 84% and 82% polished aged rice were large in comparison to that of 88% polished new rice. Therefore, we presumed that the textural deterioration of 89% polished aged rice and the textural improvement by the removal of the external layer were related to the amount of extractable solids by heating.

Further study is required to clarify the relationship between cooked rice texture and extractable solids. We will continue to investigate the mechanisms of rice aging. The pasting properties of the flour prepared from aged rice also showed altered RVA, but their changes were different from those of the cooked rice texture.

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References