The Relationship between Translucency of Rice Grain 
and Gelatinization of Starch in the Grain 
during Cooking

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Summary The soaked and nonsoaked rice grains were cooked by the excess water method and the steamer method, and subjected to Ranghino's test, X-ray diffraction, and microscopic observation. The starch granules in the nonsoaked rice were gelatinized at the same time as the grains became translucent during cooking. However, when the grains of medium amylose varieties and waxy rice were presoaked, the starch granules were not fully gelatinized in the translucent grains cooked for Ranghino's cooking time. The gelatinization of starch granules proceeded faster in the soaked rice and by the excess water method than that in the nonsoaked rice and by the steamer method. The cooking time and gelatinization time correlated negatively with the water content after soaking, and positively with the amylose content in the rice grains. The japonica rices were gelatinized fully in less than 20 min when the amount of water added for cooking was adequate.

Key Words excess water cooking method, Ranghino's cooking time, X-ray diffraction, crystallinity index, starch gelatinization, amylose content, alkali spreading value, gelatinization temperature (GT)

The eating quality of cooked rice has been proved to be determined by the inheritable characteristics of the rice grain, and affected by the environmental factors during grain development and the storage conditions(1–3). The cooking practice also has an influence on the eating quality(4).

The cooking time is an important marker of the cooking quality of rice, and has been measured by the “Ranghino test” (5). In this test, rice grains are cooked in excess water, and when the cooked grains are pressed between two glass plates and no longer show an opaque center, it is said to be Ranghino's cooking time. Ranghino's cooking time was related to the gelatinization temperature and the surface area of rice grains(6, 7). Ranghino's test has been applied to the studies on
the cooking quality of rice and the texture of cooked rice (8). Soaking rice grains in water before cooking is a popular practice in some countries (9). Whether Ranghino's test is suitable to the determination of cooking time of the soaked rice has not yet been experimentally confirmed. In this study, we observed the translucency of grain and the gelatinization of starch in the grain during cooking and found their relationship in the soaked rice was not the same as in the nonsoaked rice.

MATERIALS AND METHODS

1) Rice sample. White rices of two indica and three japonica varieties were used in this experiment. Of the japonica varieties, Koganemasari is a hard quality, Koshihikari, a soft quality, and Kurenaimochi, a waxy rice. Varieties Aijiaonante, IR43, and Koshihikari were produced in 1983, Koganemasari and Kurenaimochi were produced in 1985. The brown rice was milled to white rice with a milling degree of 91% by Satake grain test mill, then stored under 4°C until use. The amylose content of white rice was determined by a simplified method (10). The testing mixture contained 5mg of rice powder previously defatted with refluxing 85% methanol for 48 h, 2mg iodine and 20mg potassium iodide per 100ml.

The alkali spreading test was conducted by immersing the rice grains in 1.7% potassium hydroxide solution at room temperature for 23 h. The scores were according to the scale standard of the National Institute of Food Research, Japan.

2) Cooking methods. Rice grains were cooked by the excess water method and steamer method. In the excess water method, 200ml deionized water in a 500ml beaker was heated to boiling by a gas burner and about 5g rice were added. The burner was adjusted to keep the water boiling and the temperature was about 97.0°C. The rice grains were either nonsoaked or soaked in deionized water overnight before cooking.

Only the presoaked rice was cooked by the steamer method. The grains were laid as a layer on a piece of wetted gauze in an 8-cm Petri dish, then the dish was put in a boiling steamer and steamed vigorously for a specified time. Temperature in the steamer was 100°C.

The water content of rice grain was obtained by drying the sample in a 105–110°C oven for 24 h. Ranghino’s cooking time was measured by checking the translucency of the cooked rice grains according to Ranghino’s report (5).

3) Microscopic observation. The central portion of the pressed grain that had been checked for translucency was dispersed with water and observed under a light microscope to confirm if the starch granules remained.

4) X-ray study. Samples for X-ray diffraction were prepared from the rice grains cooked for the desired duration. After being tested for translucency, the grains were dehydrated with distilled ethanol three times, treated with acetone, ground to powder in a mortar with a pestle, then stored in a desiccator. The X-ray

diffraction instrument used was the Rigakudenki X-ray diffractometer RAD II. Samples were scanned from $2\theta = 5^\circ$ to $2\theta = 30^\circ$. The operating condition was as follows: CuK$_\alpha$ radiation was excited at voltage 35 kV, current 20 mA and with a Ni filter to eliminate CuK$_\beta$ radiation, scanning speed: 1°/min, scale factor: 4, time constant: 4, divergence slit: 1°, receiving slit: 0.2 mm, and chart speed: 10 mm/min (11).

The correlation crystallinity index ($Cc$) was calculated according to the formula (12):

$$(Iu - Ia) = Cc(Ic - Ia) + b$$

where the $Iu$, $Ic$, and $Ia$ were the diffraction intensity of the samples tested, crystalline standard, and amorphous standard at every $2\theta = 0.4^\circ$, respectively, and $b$ was the intercept of the linear regression equation. In this experiment, the powder of the raw rice grains of each variety was used as the crystalline standard, in which the crystallinity index was supposed to be 1 and the gelatinization degree, 0; the rice grains cooked fully by both methods were used as the amorphous standard, which was supposed to be gelatinized completely; and the crystallinity index was 0.

RESULTS

Some properties of the tested varieties are listed in Table 1. The 100-grain weight of white rice did not vary widely (1.92–2.07 g), except IR43 which is a slender-type grain variety (1.75 g). The alkali spreading value is negatively related to the gelatinization temperature (GT) of rice, which was considered as an indicator of reactivity of rice to cooking (9). Only Aijiaonante showed a value below 3, and thus had a high GT. The values of other varieties were above 5, indicating that the GTs were low. The tested varieties included a wide range of amylose content that was highest in indica Aijiaonante (26.4%) and lowest in waxy Kurenaimochi (1.5%); the other three were the medium amylose varieties (17.1–20.0%). The water content of white rice increased after being soaked in water overnight and differentiated

<table>
<thead>
<tr>
<th>Variety</th>
<th>Type</th>
<th>Weight of 100 grains (g)</th>
<th>Alkali spreading value</th>
<th>Amylose content (%)</th>
<th>Water content (white rice)</th>
<th>Water content (soaked rice)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aijiaonante</td>
<td>ind.nw.</td>
<td>1.93</td>
<td>2.5</td>
<td>26.4</td>
<td>15.3</td>
<td>27.2</td>
</tr>
<tr>
<td>IR43</td>
<td>ind.nw.</td>
<td>1.75</td>
<td>5.0</td>
<td>17.1</td>
<td>15.5</td>
<td>30.8</td>
</tr>
<tr>
<td>Koganemasari</td>
<td>jap.nw.</td>
<td>1.94</td>
<td>5.7</td>
<td>20.0</td>
<td>15.0</td>
<td>30.4</td>
</tr>
<tr>
<td>Koshihikari</td>
<td>jap.nw.</td>
<td>2.07</td>
<td>6.0</td>
<td>18.2</td>
<td>15.5</td>
<td>30.3</td>
</tr>
<tr>
<td>Kurenaimochi</td>
<td>jap.w.</td>
<td>1.92</td>
<td>5.5</td>
<td>1.5</td>
<td>14.3</td>
<td>36.3</td>
</tr>
</tbody>
</table>

*ind.nw., indica nonwaxy rice; jap.nw., japonica nonwaxy rice; jap.w., japonica waxy rice.

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among varieties. The correlation coefficient shows that the water content of soaked rice correlated significantly with the amylose content \( r = -0.9943 \), significant at 99% confidence level, but not with the 100-grain weight and alkali spreading value.

The translucency of cooked rice was checked by Ranghino's test. The opaque center could be clearly seen in undercooked grains of the nonsoaked rice, as described by Ranghino (5). However, some of the cooked grains of soaked rice showed the white crack other than the opaque center before becoming translucent, which was more evident in the steamed grains. We called it "Ranghino's cooking time" when the cooked grains showed no opaque center or white crack and became translucent. The translucent cooked rice grains are shown in Fig. 1, a and b, and those with a small part of the white crack still remaining are shown in Fig. 1c.

Ranghino's cooking times of five varieties determined by this method are shown in Table 2. The cooking time of nonsoaked rice was longest for Aijiaonante (23.3 min) and shortest for IR43 (16.3 min); this might be attributed to the high GT of the former and the low 100-grain weight of the latter, according to Juliano and Bhattacharya (6,7). Ranghino's cooking time of rice by the excess water method was shortened by presoaking, and the effect of presoaking was most distinct in the waxy rice, Kurenaimochi. Ranghino's cooking times of the tested varieties by both methods correlated negatively with the water content in the soaked grains, and thus positively with the amylose content. The gelatinization temperature and the 100-grain weight had little influence on Ranghino's cooking time as compared with the water content. Furthermore, the cooking methods showed an obvious effect on the time necessary for the grains to become translucent. The rice grains became translucent faster in boiling water than in the steamer despite the higher temperature in the latter.

Figure 2 shows the starch granules in the cooked rice grains. The starch granules could not be observed in the translucent grains of the nonsoaked rice of the tested varieties and in that of the soaked rice of Aijiaonante which contained less water than the other soaked rice (Fig. 2a). However, when the rice grains of the medium amylose and waxy varieties were presoaked then cooked for Ranghino's
Fig. 1. The presoaked and cooked rice grains tested for translucency (1.5×).

(a) Kurenai-mochi, steamed for 1 min.
(b) Koganemasari, steamed for 7 min.
(c) Koganemasari, cooked for 1.5 min.
Fig. 2. Starch granules in the translucent cooked rice grains (150 x).

a) Koganemasari, cooked for 18 min.
b) Kurenaimochi, soaked and steamed for 1 min.
c) Koganemasari, soaked and steamed for 10 min.
cooking time, some starch granules still remained in the center of the grains (Fig. 2, b and c). This observation suggested that some of the starch granules did not gelatinize fully in those grains.

The raw starch granules of rice showed a crystallinity degree about 38% by X-ray diffraction method (13), and that is lost after gelatinization. Therefore, the loss of crystallinity can be used as an acute indicator of the gelatinization of starch. Matsunaga proved that the gelatinization degree indicated by the X-ray diffraction pattern was more sensitive than those by other methods (14). In this experiment, the cooked rice of Koganemasari and Kurenaimochi were sampled for the X-ray diffraction study. The typical diffraction patterns are shown in Fig. 3. The diffraction patterns of the partially gelatinized grains can be easily distinguished from those of the fully gelatinized grains. In the presoaked waxy rice, the diffraction peaks 3b(2θ = 15.0°), 4a(2θ = 17.0°), 4b(2θ = 17.9°), and 6a(2θ = 22.9°) were still
Fig. 4. Gelatinization degree of soaked rice under different cooking conditions.

<table>
<thead>
<tr>
<th>Variety</th>
<th>Cooking method</th>
<th>Cooking time</th>
<th>Gelatinization degree(%)&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>20</td>
</tr>
<tr>
<td>Kogane-masari</td>
<td>Excess water</td>
<td>4 min</td>
<td></td>
</tr>
<tr>
<td></td>
<td>method</td>
<td>7 min</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Steamer</td>
<td>7 min</td>
<td></td>
</tr>
<tr>
<td></td>
<td>method</td>
<td>10 min</td>
<td></td>
</tr>
<tr>
<td>Kurenaimochi</td>
<td>Excess water</td>
<td>10 sec</td>
<td></td>
</tr>
<tr>
<td></td>
<td>method</td>
<td>1 min</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Steamer</td>
<td>1 min</td>
<td></td>
</tr>
<tr>
<td></td>
<td>method</td>
<td>2 min</td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup>Gelatinization degree=(1-Cc)×100%.

dominant in the translucent grains that had been cooked for Ranghino’s cooking time. The gelatinized grains of nonwaxy rice, Koganemasari, showed two peaks at 2θ=13° and 2θ=20°, which resulted from the amylose-lipid complex (15). These two peaks did not appear, but the diffraction peaks 3b, 4a, 4b, and 6a remained, in the patterns of the translucent grains that were boiled for 4 min or steamed for 7 min. That not all the crystallinity was lost suggests that the starch granules were partially gelatinized in the soaked grains of Koganemasari and Kurenaimochi which were cooked for Ranghino’s cooking time.

The crystallinity index can semi-quantitatively represent the crystallinity degree of the samples, that is a relative value with reference to the amorphous and crystalline standards. The gelatinization degree was calculated from the crystallinity index, and the values of the soaked grains of Koganemasari and Kurenaimochi that were cooked for different durations are shown in Fig. 4. The gelatinization degrees were 46–74% in the grains cooked for Ranghino’s cooking time, which means about 26–54% of the crystallinity remained. The steamed waxy rice showed a much lower gelatinization degree in the time when the grains became translucent.

Since the starch granules did not gelatinize fully by cooking the soaked rice grains for Ranghino’s cooking time, we used the X-ray diffraction test and microscopic observation to determine the time in which the starch granules in the rice grains gelatinized fully, and these gelatinization times are shown in Table 3. The gelatinization time and Ranghino’s cooking time were the same in the high amylose
Table 3. Gelatinization time of rice grain (min).

<table>
<thead>
<tr>
<th>Variety</th>
<th>Excess water method</th>
<th>Steaming method</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Nonsoaked</td>
<td>Soaked</td>
</tr>
<tr>
<td>Aijiaonante</td>
<td>23.3</td>
<td>15.6</td>
</tr>
<tr>
<td>Koganemasari</td>
<td>17.8</td>
<td>8.0</td>
</tr>
<tr>
<td>Kurenaimochi</td>
<td>17.7</td>
<td>1.0</td>
</tr>
</tbody>
</table>

variety, Aijiaonante. When the grain became translucent during cooking, the starch granules in it were also completely gelatinized. For the two japonica rices, the gelatinization time was the same as Ranghino's cooking time in the nonsoaked grains, but was longer than Ranghino's cooking time in the soaked ones. Like the cooking time, the gelatinization times also related to the water content in grains and the cooking methods. The correlation coefficient between the gelatinization time and the water content was -0.9088 (significant at 99% confidence level) in the excess water method, and -0.9973 (significant at 99% confidence level) in the steamer method. The water content in the rice grains appeared to be a more important determinant for the gelatinization time than the grain size and the gelatinization temperature of the rice. A longer time was needed to gelatinize the starch granules in rice grains by the steamer method than by the excess water method. The importance of water to the gelatinization of rice grains was clearly demonstrated.

DISCUSSION

Determination of the cooking time is important because the texture of cooked rice depends on the cooking degree and because the time for the grains to attain the best cooking degree is characteristic of variety; therefore it differs among varieties. Ranghino developed a simple method for determining the cooking time of a rice which was cooked in excess water without presoaking. This method has been widely applied and is perfect for the nonsoaked rice, as is also demonstrated by the present experiment. However, for the soaked grains of the medium amylose and waxy rice, which contained more than 30% of water after soaking, this method seemed inapplicable. At the time the grains became translucent, not all of the starch granules gelatinized fully; 26–54% of the crystallinity still remained in those grains. The cooking practice is to gelatinize starch and make it more digestible for humans. From this point of view, the cooking time determined by the translucency of cooked rice is inadequate for the purpose of cooking of the presoaked rice. We tried to apply Ranghino's test to the soaked rice with a modification of adding water to the pressed cooked-grains. In variety Koganemasari, the central portion, which was translucent but not gelatinized fully, turned to white in a minute after water was added.
Fig. 5. X-ray diffraction pattern of the central portion in rice grains soaken and cooked for 3.5 min.

added. When this portion was tested for X-ray diffraction, the pattern was as in Fig. 5 and the crystallinity index was 51%, much higher than that of whole grain (26%). However, the modification failed in waxy rice, because no white center appeared after adding water.

Ranghino's cooking time was proved to be correlated with GT and the surface area of the grains and not with the amylose content in nonsoaked rice (6, 7). When rice was presoaked, the relationship changed. Since the rice grains that contained more water after presoaking became translucent and gelatinized earlier during cooking, and the water content after presoaking increased inversely to the amylose content, the cooking time and gelatinization time correlated significantly with the amylose content. The temperature in the steamer was higher than that in the excess water, but both the cooking time and gelatinization time were longer by the steamer method. The GT of rice starch varies from 55 to 79°C; the minimum amount of water for starch gelatinization was proved to be 0.45–0.47 g water/g starch in wheat and maize (16, 17). Since the temperature is above the GT during cooking, the gelatinization of starch granules in rice is limited mainly by the water entering into the center of the grain and reaching the minimum level. This can explain why the gelatinization proceeded faster in the soaked rice and by the excess water method.

The longest gelatinization time by the excess water method was 23 min for the nonsoaked rice grain of Aijiaonante, a variety with high amylose content and high GT. It was less than 20 min for two japonica rice. Sakurada cooked nonsoaked milled rice with a small amount of water and considered that the cooking for 25–30 min at 98°C was necessary for rice to be gelatinized (18). According to the result in the present experiment, 20 min is sufficient for cooking a common japonica rice, provided water is adequate, from the standpoint of the gelatinization of starch, and not the deliciousness of the cooked rice.

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