Discoloration Characteristics of Rice during Parboiling (I)
- Effect of Processing Conditions on the Color Intensity of Parboiled Rice -


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ABSTRACT

This study was conducted to develop a new and appropriate technology applicable to the improvement of conventional parboiling methods in the developing countries.

In this report, the discoloration characteristic of rice which is regarded to be one of the most important changes during parboiling treatment was investigated. The classification of respective effects of processing stages, i.e. soaking, steaming, drying and storing on discoloration were determined.

Keywords: discoloration characteristic, parboiling, non-enzymatic browning, color intensity, paddy, parboiled rice

INTRODUCTION

It is said that the dark color is one of the major but negative effects of parboiling process, and that parboiled rice with a dark color is not accepted by consumers in most countries (Bhattacharya 1985). To expand to wider markets and to gain the consumers' acceptance for parboiled rice, it is necessary to alleviate the negative features represented by discoloration.

Roberts et al. (1954) measured the color difference of parboiled rice and reported that the effect of various parboiling conditions on its color was large. Jayanarayanan (1964) reported that soaking condition, water temperature and pH value greatly affected the whiteness of parboiled grain. He concluded that soaking condition was the most important in the discoloration of parboiled rice. Bhattacharya et al. (1966) measured the hue change of rice during parboiling and found that discoloration seemed to be caused by a non-enzymatic browning reaction of the so called Maillard type. Kimura (1978) reported that browning occurred both in soaking and in steaming stages. He assumed that the browning in the former stage was mainly derived from either transfer of color substance or enzymatic reaction, while the browning in the latter stage was due to non-enzymatic reaction.

Figure 1 shows the typical approach to the production of less colored products in modernized parboiling plants. It is roughly divided into two groups; 1) performing of special milling or color-sorting after ordinary parboiling, and 2) adopting special treatments such as pressure-vacuum treatment in soaking or in steaming stage. The former method could be easier than the latter because the capability and the price of recent color sorters have been greatly improved. However the removal of colored grains results in a reduction of substantial yield and the latter also requires more investment and running costs.

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In this respect, a great deal of fundamental study is still needed in the production of less colored products. The main objectives of this report are to determine the relationship between processing conditions and the color intensity of parboiled products, and to classify the respective contributions of soaking, steaming, drying and storage to the color intensity.

**MATERIALS AND METHODS**

1. Materials

Though parboiled rice is produced from indica paddy in most countries, a japonica paddy named Kiyonishiki was used as a raw material for parboiled sample in this study, because sufficient quantity of indica paddy was not available. The paddy was harvested at the Research Farm of Iwate University in 1987.

The initial moisture content was about 24% w.b. and the paddy was stored in the warehouse controlled at 5°C until processing.

2. Parboiling

In this study, a very small scale processing was undertaken to produce samples for color measurement. At first, raw paddy was soaked in a plastic bucket with a thermo-controller. Steaming was done with an autoclave and then the steamed paddy was dried artificially with a ventilated dryer or dried naturally in the shade. The moisture content ranged from 15 to 16% w.b. after drying stage. The details of processing conditions are listed in Table 1.

### Table 1 Parboiling conditions in this study

<table>
<thead>
<tr>
<th>Processing</th>
<th>Temperature</th>
<th>Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soaking</td>
<td>RT*</td>
<td>24 and 48 hr</td>
</tr>
<tr>
<td>Steaming</td>
<td>38°C</td>
<td>36 hr</td>
</tr>
<tr>
<td>Drying</td>
<td>100</td>
<td>5~60 min</td>
</tr>
<tr>
<td></td>
<td>120</td>
<td>5~40 min</td>
</tr>
<tr>
<td></td>
<td>130</td>
<td>5~30 min</td>
</tr>
<tr>
<td></td>
<td>RT* natural</td>
<td>18~24 hr</td>
</tr>
<tr>
<td></td>
<td>30 artificial</td>
<td>5~7 hr</td>
</tr>
<tr>
<td></td>
<td>55 artificial</td>
<td>2~3 hr</td>
</tr>
</tbody>
</table>

*RT* : Room temperature (20~27°C)

3. Measurement

A photoelectric colorimeter (CR-100, Minolta, Japan) was used for color measurement of parboiled samples. Parboiled samples were dehusked by a Test Huller (Satake Mfg., Japan) and ground into uniform particle size (0.1~0.5 mm in diameter) by a coffee mill in order to avoid data fluctuation.

Analysis of color was made in accordance with CIE L*a*b* color space system (1976) based on the tristimulus value. The definitions for each of the components, L*, a* and b*, are as follows.

\[
L^* = 116 \left( \frac{Y}{Y_0} \right)^{1/3} - 16 \quad (\frac{Y}{Y_0} > 0.008856) \quad (1)
\]

\[
a^* = 500 \left( \frac{X}{X_0} \right)^{1/3} - \left( \frac{Y}{Y_0} \right)^{1/3} \quad (2)
\]

\[
b^* = 200 \left( \frac{Y}{Y_0} \right)^{1/3} - \left( \frac{Z}{Z_0} \right)^{1/3} \quad (3)
\]

where, L*: Psychometric lightness [-]

a*, b*: Factors expressing hue and saturation of color [-]

X, Y, Z: Stimulus values for each primary color, Red, Green and Blue [-]

Xo, Yo, Zo: Tristimulus values for standard white [-]

The value of L* expresses psychometric lightness compared with standard white. If the value becomes larger, the color of the sample becomes lighter. The value can be considered to be closely related with so-called whiteness (Kawamura et al. 1982).

The values of a* and b* express hue and saturation on the CIE L*a*b* color coordination system. A positive value of a* shows the magnitude of reddish component, while a negative value shows that of greenish component. A positive value of b* shows yel-
lowish component, while a negative value shows bluish component. The distance from the origin expresses the degree of color saturation.

In this study, the authors assumed it as an indicator of the color intensity and used the values for the evaluation of discoloration by parboiling.

\[ B = \sqrt{(a^*)^2 + (b^*)^2} \]  \hspace{1cm} \text{... (4)}

\( B \) : Degree of color intensity \([-\] \]

The sampling procedure for color measurement and the definition of color intensity derived from each processing stage are illustrated in Fig. 2. Five grams of sample flour was packed in a sample cell made of Teflon plastic and 5 measurements were made for each sample.

\[ \text{PADDY} \rightarrow \text{SOAKING} \rightarrow \text{STEAMING} \rightarrow \text{DRYING} \rightarrow \text{COLOR MEASUREMENT} \]

Color derived from soaking = \( B_1 - B_0 \)
Color derived from steaming = \( B_2 - B_1 \)
Color derived from drying = \( B_3 - B_2 \)

RESULTS AND DISCUSSION

1. Lightness change during steaming

As mentioned above, several researchers have measured various kinds of lightness up to now because the lightness is the easiest indicator of discoloration (Roberts et al. 1954, Jayanarayanan 1964, Bhattacharya et al. 1966, Kimura 1978, Kawamura et al. 1982). Some of them reported that lightness (or whiteness) of parboiled rice was mainly affected by the temperature and the time of steaming (Roberts et al. 1954, Bhattacharya et al. 1966). As shown in Fig. 3, result of this study also indicated the same tendency, i.e. the higher the steaming temperature or the longer the time, the lower were the lightness values. Especially, in the high temperature treatment such as at 130°C, the lightness decreased extremely and rapidly even in a short time. In this context, it can be said that steaming at the temperatures ranging from 100 to 120°C is controllable but steaming at a temperature exceeding 130°C produces only dark color. Bhattacharya et al. (1986) also pointed out that the pressure parboiling method which steamed at the temperature from 130 to 170°C produces dark colored products.

\[ \text{Fig. 3 Effects of steaming temperature and time on the lightness of parboiled grain} \]

2. Characteristics of color intensity during parboiling

In order to analyze the kinetics of discoloration reaction, the following simple kinetic model was introduced. It was based on an assumption that the reaction followed the first order kinetic reaction against time.

\[ C = C_0 - A \left( C_e - C_0 \right) \exp \left( -K \cdot \theta \right) \]  \hspace{1cm} \text{... (5)}

where, \( C \): Value of color intensity \( (=B \text{ in eq (4)}) \)[\(-\)]
\( C_0 \): Initial color intensity \([-\] \]
\( C_e \): Final value of color intensity \([-\] \]
\( A \): Constant \([-\] \]
\( K \): Reaction rate constant \([1/\text{min}]\)
\( \theta \): Time of processing, soaking, steaming and drying \([\text{min}]\)

In eq (5), parameters, \( C_0 \) and \( K \) describe the detailed characteristics of discoloration reaction.

Figure 4 shows the change of color intensity in brown rice flour obtained from parboiled paddy which was soaked at the temperatures of 20, 38 and 55°C. The highest soaking temperature was limited to 55°C in this study because the gelatinization tem-
temperatures of most japonica varieties are usually lower than those of indica varieties by 10 to 15°C (Juliano 1982). It is roughly understood from this figure that the higher soaking temperatures bring higher rates of discoloration to paddy. The higher temperatures also gave paddy higher values of final color intensity. The discoloration of the paddy soaked at a higher temperature reached the equilibrium state in a shorter period. The calculated values of parameters in eq (5) which were listed in Table 2 also supported the hypothesis, where the higher values of Ce and K were provided by the higher temperature soaking. These facts definitely proved that the higher soaking temperature raised the final value of color intensity and the velocity of discoloration reaction during soaking.

Figure 5 shows the effect of steaming on color intensity of soaked grain. In this measurement, the sample paddy soaked under the same condition of 20°C temperature for a 24 hours period were steamed at 100, 120 and 130°C respectively. The steaming temperatures of 120 and 130°C were equivalent to 1-2 kg/cm² gauge pressure in a parboiling tank. These were considered to be representative temperatures for the pressure cooking method (Bhattacharya et al. 1986). The result showed in general that the higher temperature and longer period tended to increase color intensity. Pressure cooking at 2 kg/cm² provided very strong discoloration to rice grain even if it was only done for 5 minutes as shown by the result of lightness change. This fact may be the reason for the very low popularity of pressure cooking in India and other countries as Bhattacharya (1985) mentioned.

When the initial value of color intensity was 11.22 after soaking stage, values of parameters determined by the least squares method for each steaming temperature are shown in Table 2. It can be seen that the higher steaming temperature resulted in larger value of final color intensity and higher rate of discoloration reaction. The discoloration reaction during steaming was likely to be stronger and faster than that during soaking.

The effect of drying stage on the discoloration is shown in Fig. 6 when paddy was soaked and steamed under the same conditions, 20°C/24 h for soaking and 100°C/20 min for steaming respectively. It is understood from the figure that a comparatively large discoloration was observed during drying stage. The trend of color intensity during drying showed a higher rate and a larger final value at higher drying temperatures as well as those of soaking and steaming. The magnitude of color intensity during drying seemed to be larger than that during soaking. This result reveals that the color intensity during drying can not be negligible for controlling the color of parboiled rice. Most of the previous researchers did not mention the importance of drying in the discoloration of parboiled rice.

<table>
<thead>
<tr>
<th>stage</th>
<th>temp. [°C]</th>
<th>C_o[-]</th>
<th>C_e[-]</th>
<th>K[1/min]</th>
<th>A[-]</th>
</tr>
</thead>
<tbody>
<tr>
<td>soaking</td>
<td>20</td>
<td>10.51</td>
<td>11.39</td>
<td>9.4×10⁻⁴</td>
<td>0.87</td>
</tr>
<tr>
<td></td>
<td>38</td>
<td>10.51</td>
<td>11.63</td>
<td>7.2×10⁻³</td>
<td>1.26</td>
</tr>
<tr>
<td></td>
<td>55</td>
<td>10.51</td>
<td>11.96</td>
<td>1.3×10⁻²</td>
<td>0.98</td>
</tr>
<tr>
<td>steaming</td>
<td>100</td>
<td>11.22</td>
<td>14.92</td>
<td>5.3×10⁻²</td>
<td>0.85</td>
</tr>
<tr>
<td></td>
<td>120</td>
<td>11.22</td>
<td>17.44</td>
<td>6.4×10⁻²</td>
<td>1.09</td>
</tr>
<tr>
<td></td>
<td>130</td>
<td>11.22</td>
<td>17.76</td>
<td>9.6×10⁻²</td>
<td>0.39</td>
</tr>
<tr>
<td>drying</td>
<td>30</td>
<td>13.61</td>
<td>15.44</td>
<td>9.3×10⁻³</td>
<td>1.11</td>
</tr>
<tr>
<td></td>
<td>55</td>
<td>13.61</td>
<td>16.79</td>
<td>1.14×10⁻²</td>
<td>0.72</td>
</tr>
</tbody>
</table>

Fig. 4 Effects of soaking temperature and time on the color intensity

Fig. 5 shows the effect of steaming on color intensity of soaked grain.
Through these results, it is confirmed that not only the steaming but the soaking and the drying provide considerable discoloration to paddy. The results showed in general that the higher temperatures provided the higher rate and the higher final value of the discoloration reaction to rice grain in any processing stage. It is not clear whether the major reason of the discoloration during soaking is different from that during steaming since there was no significant differences in the temperature dependence of rates during soaking, steaming and drying as shown by Fig. 7.

3. Quantitative contribution of respective stage to overall color intensity

Respective and quantitative contributions of soaking, steaming and drying to overall discoloration of final products have scarcely been known up to now (Bhattacharya 1985). But it is very important to consider them if improvements in production method are to be made for developing countries.

Figure 8 summarizes the magnitude of the effect of each processing stage. The samples were obtained from the procedure already described in Fig. 2. As mentioned earlier, it is likely that the steaming had the largest effect and the soaking had the least among the three processing stages. As for the overall color intensity, the experimental results showed that the final products obtained from cold soaking were darker than that from hot soaking.

Fig. 5 Effects of steaming temperature and time on the color intensity after soaking

Fig. 6 Effects of drying temperature and time on the color intensity after steaming

Fig. 7 Temperature dependence of the discoloration rate constant

Fig. 8 Contribution of each processing stage to the color intensity of parboiled rice
This tendency seemed to be opposite from the cases of previous reports that more serious processing, i.e. higher temperatures and longer period resulted in darker color of the paddy. The result in this study agrees with the traditional belief that the conventional cold-soaking usually provides higher color intensity to rice grain (Ali et al, 1974). This fact suggests the existence of the large but indirect effect of soaking stage on the discoloration of parboiled grains. It is because the lukewarm temperature and long period of 2 or 3 days in the cold soaking enzymatically produce much more reducing sugar, an important substrate in the browning reactions, than that produced in the hot soaking. The analytical data by Ali et al. (1980) who investigated the change in sugar and in amino acid during parboiling supports the possibility of this phenomenon.

It is concluded from these results that the role of soaking in the discoloration is indirectly larger than that previously speculated. The final color of parboiled products is a result of the total amount of the discoloration generated in each processing stage. It can be said that not only the role of steaming but also the roles of soaking and drying are important in the improvement of color of final products. The excessive cold-soaking should be avoided, and the introduction of cooling process immediately after the steaming can be recommended to obtain less colored products.

4. Color intensity during storage

Although there has been no information of the discoloration during storage of parboiled rice, some producers of parboiled rice have been pointing out that the color of parboiled products sometimes becomes darker during storage. According to the field investigations conducted by the authors in 1986 and 1988, this phenomenon existed in Pakistan, India and Thailand (Kimura et al. 1988). In this connection, the authors conducted an experiment to investigate the change in color intensity of parboiled grain under different storage conditions.

In this experiment, sample and storage conditions are as follows; the samples for storage were parboiled under the conditions of 55°C/2 hours for soaking and 100°C/30 min for steaming. Milling of parboiled samples were performed with Satake Test Mill (abrasive type) after natural drying and dehusking. Three storage temperatures of 1, 20 and 40°C were maintained, considering typical temperature conditions in cold storage and natural storage. All the samples were packed in PVC plastic bags (0.3 mm thickness, 200 g capacity). Added to these, one sample exposed to air was stored at 40°C in order to investigate the effect of fresh air on the browning reaction.

It was confirmed from Fig. 9 that the discoloration of parboiled grain progressed during storage but the degree of increase in color intensity determined by eq (4) were from 0.5 to 1.5 points after one month storage. They were very small, compared with the increases in color intensity during soaking, steaming or drying. The temperature played a major role in the discoloration during storage as well as during soaking, steaming or drying. Darker grain was obtained from the storage at a higher temperature.

Figure 9 also showed an interesting result that the sample exposed to air during storage had a slightly higher value of color intensity than that stored in a plastic bag. The exposed condition seemed to lead to a slightly darker color since the existence of oxygen supplied from the air induces the non-enzymatic browning reactions.

![Fig. 9 Effects of storage on the color intensity of milled parboiled rice](image-url)
Therefore, it is concluded that the possibility of slight change in color intensity is quite high when the rice grains are stored at high temperatures and exposed to air. This condition is very common in most tropical countries. In this context, cold storage can be recommended for producing less colored products in a practical production. Also, the packed storage with deoxidation agent will be very effective in controlling the color intensity of parboiled products.

**CONCLUSIONS**

In this study, the discoloration characteristics regarded as one of the most important factors in the quality of parboiled rice were investigated to produce less colored products which would be preferred by most consumers.

The experimental results showed that not only steaming but also soaking and drying increased the color intensity of parboiled grain. Furthermore, parboiled rice increased in the color intensity even during storage. In general, higher temperatures provided a higher rate and a higher intensity at the equilibrium state to parboiled grain.

The respective and quantitative contributions of soaking, steaming and drying to the overall color intensity of the products were determined. The magnitude of each effect on the apparent color intensity was the largest in steaming and the smallest in soaking. But soaking was likely to have a substantial effect on the discoloration, since the enzymatical production of sugar as a major substrate for browning reaction was affected by soaking temperature and period.

The color intensity of stored products (milled rice) slightly progressed under high temperature and exposed condition to air. From this result, cold storage or packed storage in a plastic bag with deoxidation agent can be recommended for obtaining less colored products in the practical production of parboiled rice.

**ACKNOWLEDGMENT**

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パポイリングによる米の着色特性（Ⅰ）
— パポイル米の着色に及ぼす加工条件の影響 —

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要 旨

本研究は、多くの発展途上国で実施されているパポイリング法を改善し、それらの国の技術レベルに適した新方法を開発する目的の下で実施された。

本研究では、パポイリング加工中に生ずる各種の変化のうち、最も重要なもののひとつである着色特性について調査した。本報では、パポイル米の明度および着色指標に対する浸漬、蒸煮、乾燥の 3 工程の影響を分類することに成功し、各々の影響の大きさを明らかにした。その結果、浸漬工程の影響が後続 2 工程にまで及び、興味深さ役割をしていることが分かった。

キーワード：着色特性、パポイリング、非酵素的褐変、着色指標、もみ、パポイル米