Food Sci. Technol. Res., **8** (2), 106–112, 2002

Effect of Processing Conditions on Physical Properties of Parboiled Rice

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Received June 14, 2001; Accepted December 28, 2002

A laboratory-scale parboiling setup was fabricated to produce parboiled rice at low steaming temperatures for determination of its physical properties, the quality indicators, and to compare those qualities with rice produced at higher temperatures. Parboiled rice was prepared under different steaming conditions using different sample sizes, both of which affected the rice temperature and quality. A sample size of 200 g, which maintained a 10 mm thick layer of rough rice, was found adequate for favorable quality. Better quality of parboiled rice was achieved at lower steaming temperatures (80–100˚C) than that at higher temperatures (110 and 120˚C). The temperature-time combinations of 80˚C-40 min, 90˚C-30 min and 100˚C-20 min were recommended steaming conditions. Parboiled rice produced under these conditions has adequate lightness and color intensity, 4.0 to 7.5% more milling yield having 55 to 80 N hardness values compared with an untreated sample. It is believed the proposed parboiling method would be seen as important by both household and commercial parboiling plants in their production of a good quality product.

Keywords: parboiling setup, processing conditions, parboiled rice, physical properties

The parboiling process is a big share of the global rice processing industry. Generally, the majority of the population of a developing country consumes parboiled rice. This is especially true on the Indian Sub-continent where it originated a long time ago. It was reported that about one-fifth of the world's rice is parboiled (Bhattacharya, 1985). This seems to be increasing day by day, because the growth rate of populations in these countries is higher and a major part of the food value of what they consume comes from rice. Parboiling is a hydrothermic treatment given to rough rice, and consists of soaking, steaming and drying. During the parboiling process, starch gelatinization takes place, a thermochemical reaction between the starch granules and heat energy in the presence of water. This starch gelatinization changes the physicochemical properties of rice (Bhattacharya & Subba Rao, 1966; Bhattacharya & Indudhara Swamy, 1967; Raghavendra Rao & Juliano, 1970; Gariboldi, 1972; Kimura, 1983; Bhattacharya, 1985; Itoh & Kawamura, 1985; Kimura, 1991; Kimura *et al*., 1993; 1995; Islam *et al*., 2001), which affects the other processing operations of storage, milling, cooking and eating quality. Islam *et al*. (2001) evaluated the quality of parboiled rice by its physical properties of maximum viscosity, hardness of brown rice, hardness and adhesion of cooked rice, volume expansion ratio and solid content, utilizing the first-order kinetic model. They identified the rate of change of quality and the quality index of parboiled rice with the reaction rate constant and final values of the quality indicators. The quality of parboiled rice was greatly affected by the severity of the parboiling treatment; severely treated rough rice produces a product of lesser quality. For wider acceptability of parboiled rice, processing equipment and conditions should be developed to produce a better quality product. Parboiling of rough rice at higher temperatures generally produces a dark colored product (Bhattacharya, 1985; Kimura *et al*., 1993). Therefore, parboiling at lower temperatures (80 to 100˚C) is preferable to produce a better quality product for consumer acceptance.

The main aim of this study was to determine the quality of parboiled rice produced at lower temperatures and to compare that with the quality of rice produced at higher temperatures (110 and 120˚C). The specific objectives were: i) to study the effect of parboiling treatment on the physical properties which are the quality indicators of rice, such as hardness, milling yield, lightness and color intensity value; ii) to compare the quality indicators of parboiled rice produced at lower temperatures with those of higher temperatures; and iii) to identify optimal parboiling conditions to produce a good quality product.

Material and Methods

Material 'Belle Patna' was used in this study an *indica* variety of rough rice which was harvested at the Japan International Cooperation Agency (JICA) Agricultural Farm, Tsukuba-shi, Ibaraki-ken, Japan in 1999. Before conducting the experiment, rough rice in a 30 kg nylon bag was stored in a refrigerator at a temperature of 5˚C.

Parboiling setup A laboratory-scale parboiling setup was fabricated to produce parboiled rice at lower temperatures (80 to 100˚C). Figure 1 shows a schematic diagram of the experimental setup. It consists of: an aluminum electric rice cooker (Model SR-W 180, 1.8 dm^3, 100V, 600W, National Electric Co., Osaka); an aluminum sample holder (220 mm id) having a perforated bottom with a cover; a PID (proportional plus integral plus derivative action) temperature controller (TF3-10, Keyence Co. Ltd., Osaka); a relay switch and a data logger (Model 436506-20/H8, Yokogawa Electric Corporation, Tokyo). The outer surfaces of the rice cooker and the sample holder were insulated with a 10 mm thick polyurethane foam to reduce heat loss. During steam-

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ing at 80 and 90°C, temperature of the steam was controlled by the combined action of the PID temperature controller and the relay switch through a thermocouple wire placed in the steam in the cooker between the sample holder and the water surface. The data logger was used to record the rough rice temperature.

Parboiling Soaking was done in a water bath shaker (MM-10, Taitec Co., Ltd., Saitama) at 65.0±0.1°C, using tap water. In this study four different sample sizes were considered: 75 to 400 g having a grain layer thickness of 5 to 20 mm. About 300 to 2000 g of rough rice was soaked in different nylon bags according to sample size. Figure 2 shows the hydration behavior of the Belle Patna variety of rough rice at 65°C. Steaming of rough rice requires about 30 to 35% of moisture content on a wet basis (w.b.) (Bhattacharya, 1985; Kimura *et al.*, 1976). A soaking period of about 6 h was needed to attain the moisture content of around 30% (unless otherwise mentioned, moisture contents are expressed on a wet basis); consequently, a soaking period of 6 h was selected in this study. For steaming at 80, 90 and 100°C the fabricated parboiling setup was used, and an autoclave (BS-245, Tomy Engineering Co., Ltd., Tokyo) was used for 110 and 120°C. Parboiling conditions of this study can be seen in Table 1. After drying, samples were stored at room temperature in airtight polyethylene bags for moisture equilibration and hardness stabilization (Kimura, 1991). Other tests were conducted after at least seven days.

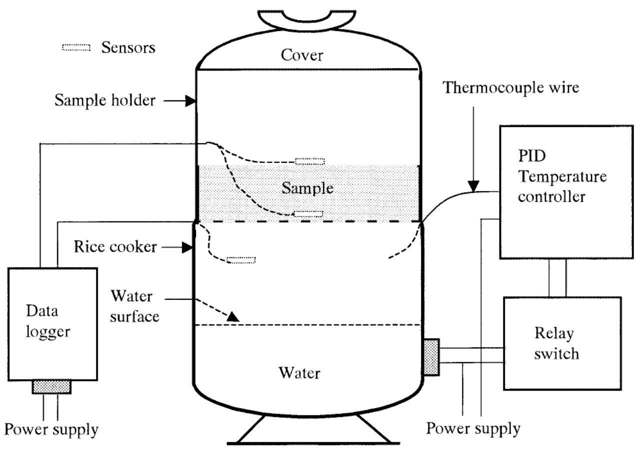

Fig. 1. Schematic diagram of the experimental setup.

Table 1. Parboiling conditions.

Stage	Temperature	Duration
Soaking	65°C	6 h
Steaming	80, 90, 100, 110 and 120°C	10 to 60 min
Drying	At room temperature (26–28°C) to 9.5–13.0% moisture content (w.b.)	1 to 2 days

Measurement of rough rice temperature The change of rough rice temperature was recorded using the data logger. For sample sizes of 200 and 400 g two sensors were used: one was placed at the bottom on layer of single grain thickness and the other on top of the grain. The average value was reported as the rough rice temperature during steaming. For the sample sizes of 75 and 120 g, a sensor was placed on top of the grain. In all cases sensors were placed at the diametric center of the sample holder.

Moisture content To determine the moisture content, triplicate samples of ten grams were dried in an oven at 105°C for 24 h, after which their final weight was recorded. The difference between the initial and final weights of the sample was expressed as percentage of the moisture content of the initial weight of the sample on a wet basis.

Hardness More than 25 grains of rough rice were selected randomly from each sample. Hardness of 20 uncracked brown rice grains (husk removed by hand peeling) was measured using a compressional-elongational rheometer (Texture Analyzer TA-XT2, Stable Micro System, Surrey, England). The average bio-yield point value (Mohsenin, 1980) of the 20 measurements was expressed as the hardness in newtons (N). A typical force-deformation curve of parboiled brown rice is shown in Fig. 3. Brown rice grains were put on the sample table attached to the load cell and their bio-yield point value measured in a flat position (Kimura, 1991; Islam *et al.*, 2001). A 245.2 N load cell, a probe of 2 mm diameter and 0.1 mm/s compression rate were used.

Milling yield Three hundred grams of parboiled rough rice was taken for milling. Husking was done using an impeller husker (FCS type, Otake Co., Oharu, Japan). A friction type milling machine (VP-31T, Yamamoto Co., Tendou, Japan) and a test rice polisher (Pearlest, Kett Electric Laboratory, Tokyo) were used for whitening. Milling was done at 6 to 12% degrees. A cylindrical separator (TRG type, Satake Co., Higashihiroshima,

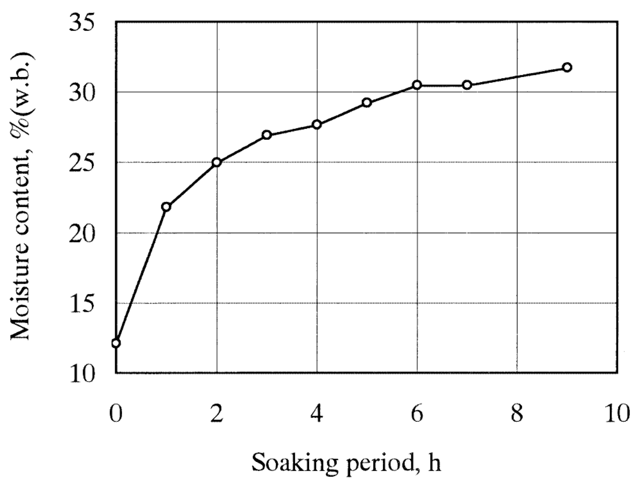

Fig. 2. Hydration behavior of Belle Patna variety rough rice at 65°C.

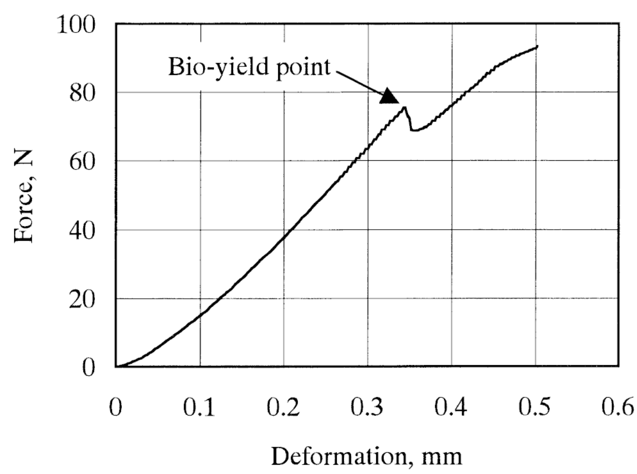

Fig. 3. A typical force-deformation curve of a parboiled brown rice.

Japan) was used to separate the whole kernels. The milling yield was expressed as the weight of the milled rice as a percentage of the weight of rough rice.

Lightness and color intensity value A color meter (CR-200, Minolta Co., Ltd., Tokyo) was used to measure the lightness and saturation of the color intensity value of the whole kernel milled rice utilizing the CIE $L^*a^*b^*$ uniform color space procedure. The value of L^* expresses the psychometric lightness value, and a^* and b^* are factors expressing hue and saturation of the color intensity. The instrument was calibrated with a standard white plate having L^*, a* and b* values of 96.82, 0.04 and 2.23, respectively. Each measurement was replicated five times and the average value was used. The color intensity value (B) of parboiled grain was calculated using the following formula (Kimura *et al*., 1993):

$$B=\sqrt{(a^*)^2+(b^*)^2}. \quad (1)$$

Kinetic analysis A first-order kinetic model, as shown in Eq. 2, was used to perform 'least squares' non-linear regression analyses (Kimura, 1991; Kimura *et al*., 1993) of the experimental data using SigmaPlot (Jandel Corporation, San Rafael, CA). The kinetic parameters were estimated for better understanding the reaction kinetics of the physical properties that occur during the parboiling process:

$$C=C_e+(C_o-C_e)\exp(-K_t), \quad (2)$$

where C is the value at steaming time t, C_e and C_o are the final and initial value of the physical properties, respectively, and K is the kinetic reaction rate constant value.

Results and Discussion

Change of rough rice temperature during steaming Figure 4 shows the change of the rough rice temperature for different steaming conditions and sample sizes. It was mentioned above that the fabricated parboiling setup was used for steaming at 80, 90 and 100°C and this was accomplished using an autoclave for 110 and 120°C. The rough rice temperature rose to about 70, 80 and 99°C in the steaming period of 30, 25 and 7 min, respectively, by steaming at 80, 90 and 100°C (Fig. 4A). In autoclaving, rough rice and steam were considered to have the same temperature, and it took about 7 and 9 min to attain the temperatures of 110 and 120°C, respectively. During steaming at 80 and 90°C, the rough rice temperature rose to about 70 and 82°C, respectively, for the longer steaming period. Comparing the rough rice temperatures for different sample sizes it can be seen that the effect of the size was greater during the initial heating period. If we consider the rough rice temperatures of 70, 80 and 99°C when steaming at 80, 90 and 100°C, then it can be seen that it took about 30, 25 and 7 min for the sample size of 400 g; 11, 11 and 4 min for the sample size of 200 g; 6, 6 and 3 min for the sample size of 120 g and 3 min for the sample size of 75 g, respectively, to attain the rough rice temperature. The change of the rough rice temperature was similar for the sample sizes of 200 and 120 g steaming at 80°C, and for the sample sizes of 200, 120 and 75 g steaming at 90°C for the longer steaming period.

Moisture content after steaming Several researchers reported varying amounts of moisture content (≥ 30%) required for starch gelatinization depending on the soaking conditions. In the literature it was reported that soaked rice having a moisture content of 25–35% can be completely gelatinized by steaming without increase in the moisture content. Bhattacharya (1985) reported that after regular parboiling rough rice has around 35% moisture content. Figure 5 shows the moisture content after steaming for different sample sizes; in most of them, the moisture content had increased. At the steaming temperature of

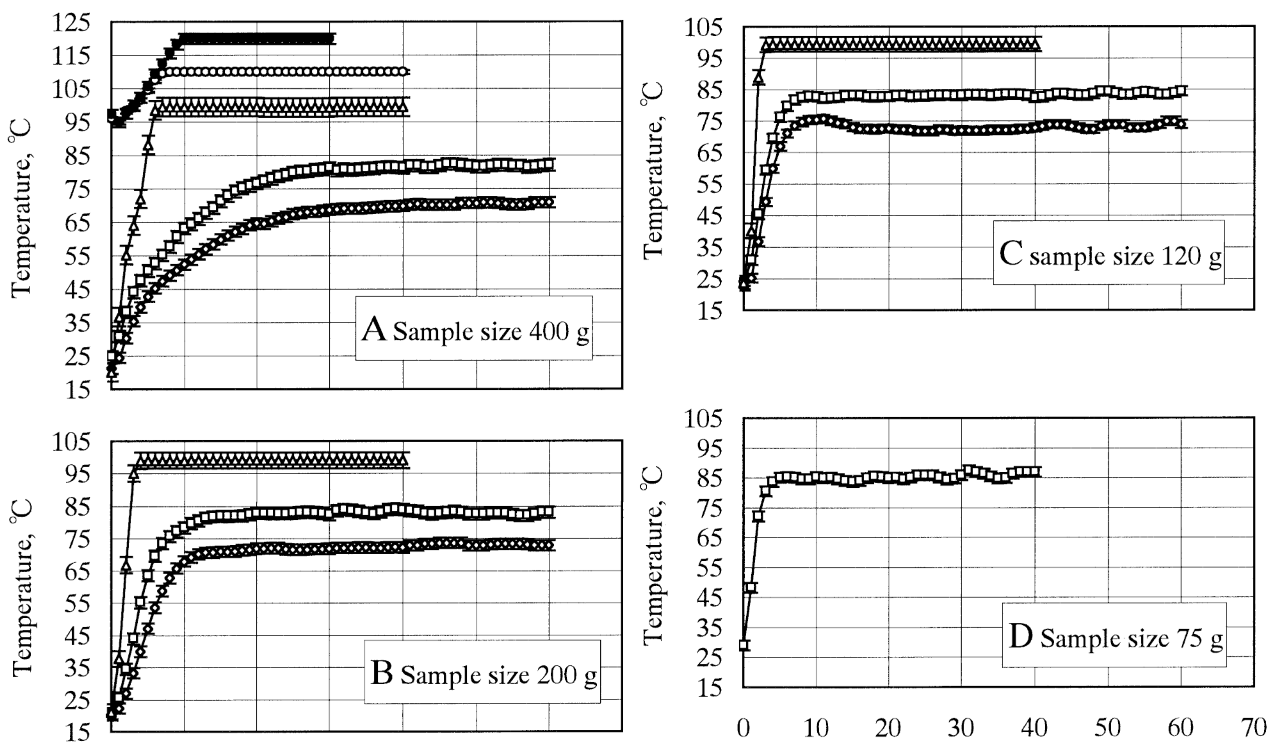

Fig. 4. Change of rough rice temperature during steaming. ◇, 80°C; □, 90°C; △, 100°C; ○, 110°C and ●, 120°C steaming temperature.

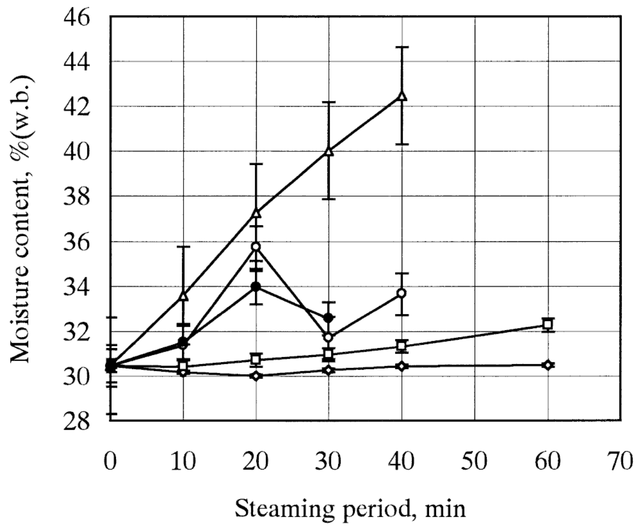

Fig. 5. Moisture content after steaming for different sample sizes. ◇, 80°C; □, 90°C; △, 100°C; ○, 110°C and ●, 120°C steaming temperature.

100°C, the moisture content after steaming rose to above 35%. In this case, samples were steamed for 30 min and splitting of the husk was observed due to excessive expansion of the endosperm; this was severe when a longer steaming period was used. The grains were also noticeably deformed with exuded endosperm. Although following steaming at 110 and 120°C moisture content hardly exceeded 35%, yet for a steaming period of 20 min husk splitting was observed and was severe for a longer period. The lower moisture content in these cases might be due to steaming under pressure and to release of moisture from the steamed rough rice as soon as pressure was released. In samples parboiled at lower temperatures of 80 and 90°C, moisture content after steaming did not exceed 33% and no husk splitting was observed. Excessive husk splitting during parboiling is a disadvantage of the process, because dry matter is lost through leaching and milling yield is reduced due to loss of exuded endosperm. The parboiling condition in which excessive husk splitting occurs also affects the quality of the parboiled rice. Steaming at lower temperature (80 and 90°C) is viewed as advantageous as it offers lower moisture content after steaming compared with that at higher temperature; this saves energy and labor during drying.

Hardness Hardening is the most important phenomenon in the parboiling process. The hardness of parboiled rice depends on the severity of the parboiling treatment. Many researchers reported hardness is greatly affected by parboiling conditions, moisture content after drying, elapsed time, the balance of starch gelatinization and retrogradation and other factors (Ali & Bhattacharya, 1976; Pillaiyar & Mohandoss, 1981; Bhattacharya, 1985; Itoh & Kawamura, 1985; Kimura, 1991; Islam *et al*., 2001). Figure 6 shows the effect of parboiling treatment on the hardness of brown rice for different steaming conditions and sample sizes. The hardness increased with increase in steaming temperature for all sample sizes, although the effect of sample size and steaming period is not clear from the figure. As mentioned above, in addition to the parboiling treatment there are many factors that affect the hardness of parboiled rice, moisture content after drying being considered the most important. A linear negative relationship can be seen between the moisture content after drying and hardness of parboiled rice in Fig. 7. This figure also shows that at the same moisture content hardness increased due to in-

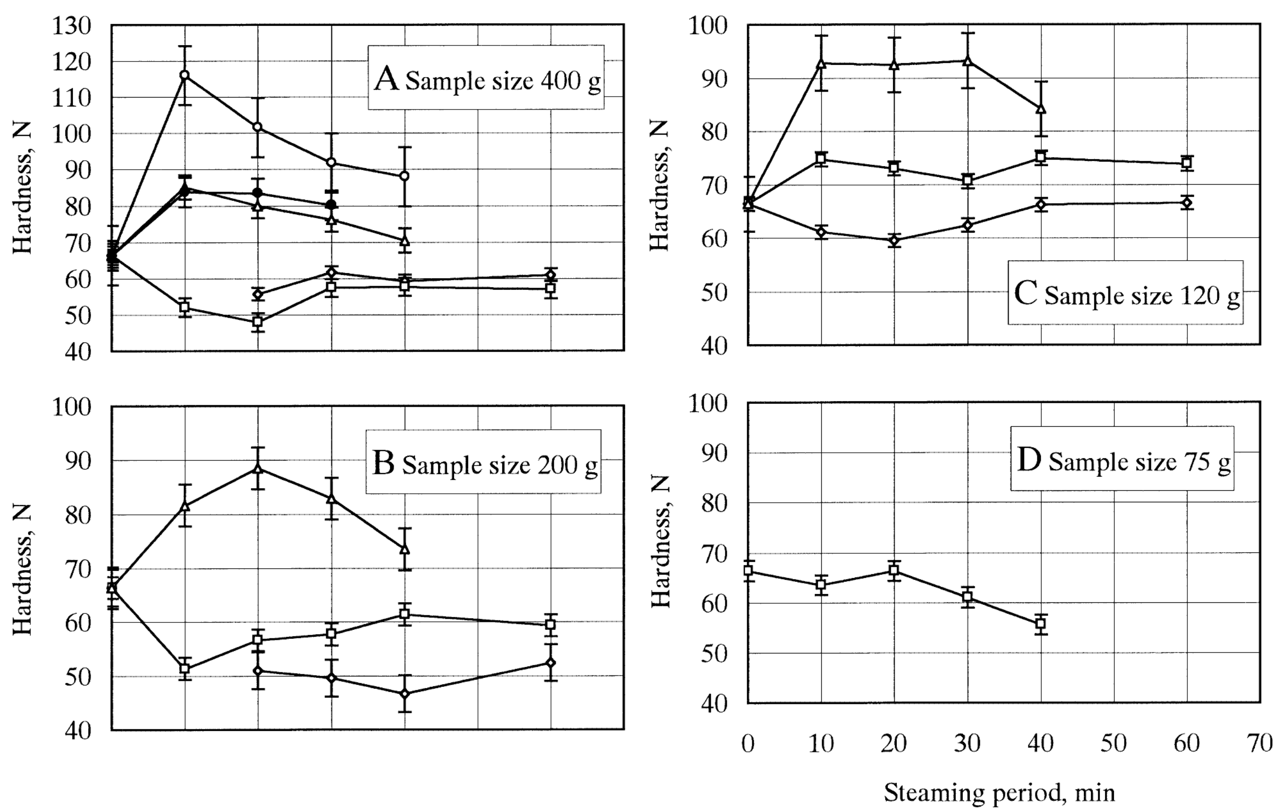

Fig. 6. Effect of parboiling treatment on hardness of brown rice. ◇, 80°C; □, 90°C; △, 100°C; ○, 110°C and ●, 120°C steaming temperature.

crease in steaming temperature, with higher temperature providing lower correlation coefficient (r-value) value. This indicated that there was less effect of factors influencing the hardness of parboiled rice on the milder treated product. Kimura (1991) also reported a linear negative relationship between the moisture content and hardness of parboiled rice.

Milling yield Parboiling treatment brought about a striking improvement in the milling quality of rough rice (Bhattacharya & Subba Rao, 1966). The parboiling imparts hardness to the grains so that they resist breakage during milling, minimizing breakage loss and increasing milling yield (Garibaldi, 1974), especially in long grain varieties of rough rice. This might be the reason the parboiling process originated a long time ago on the ancient Indian Subcontinent where the indica variety of rough rice is generally cultivated. In this study, milling yield was controllable only for the sample size of 400 g; for other smaller sizes it was not controllable. Figure 8 shows the effect of parboiling treatment on the milling yield. It can be seen that at steaming temperatures of 80 and 90°C, on average, about 4.5 and 4.0% more milling yield was obtained in a steaming period of 20 min or more than for the untreated sample. At 100 and 110°C this yield was about 7.5% in the steaming period of 20 and 10 min, respectively, and then decreased rapidly. During parboiling of rough rice at higher temperatures, severe deformation of the grain occurs along with exudation of endosperm due to husk splitting and absorption of excessive moisture content. The deformed grain loses the exuded part of the endosperm during milling. Thus, with parboiling of rough rice at higher temperatures for a longer steaming period milling yield decreases, depending on the processing conditions. Since higher steaming temperature is most favorable for grain deformation, which reduces the milling yield, at lower steaming temperatures of 80 to 100°C the above milling yield can be achieved with a hardness value of about 55 to 80 N (Fig. 6A).

Lightness value To produce whiter parboiled rice is the overall goal. Parboiling treatment discolors grain and decreases the lightness value. Several researchers measured various kinds of lightness value (Jayanarayanan, 1964; Bhattacharya & Subba Rao, 1966; Kawamura *et al.*, 1982; Kimura *et al.*, 1993). Jayanarayanan (1964) reported that whiteness of parboiled rice was affected by soaking conditions, water temperature and pH value. Others reported that lightness (or whiteness) of parboiled rice was mainly affected by the temperature and period of steaming (Bhattacharya & Subba Rao, 1966; Kimura *et al.*, 1993; Bhattacharya, 1996). Figure 9 shows the effect of parboiling treatment on the lightness value under different steaming conditions and sample sizes. The lightness value decreased with increase in steaming temperature and period; the decrease tendency was severe at higher temperatures (Fig. 9A). This indicated that lower steaming temperatures were favorable to produce a better quality of parboiled rice. Experimental data were fitted to a first-order kinetic model (Eq. 2) to calculate the kinetic parameters. Table 2 shows the kinetic parameters of lightness value for different temperatures and sample sizes. From this table it can generally be seen that the K-value increased and the final lightness value decreased with increasing steaming temperature. With respect to the sample size, K-value increased with decrease in sample size, indicating that smaller sample sizes will achieve better parboiling treatment. Better rise in rough rice temperature was also achieved for smaller sample sizes (Fig. 4), although the effect of sample size on the final lightness value was not significant at different temperatures. Visually it was observed that lightness value for sample sizes of 400 and 200 g was similar, especially at lower steaming temperatures. But better rough rice temperature was achieved for the sample size of 200 g (Fig. 4B), which was not too dissimilar from the sample sizes of 120 (Fig. 4C) and 75 g (Fig. 4D). From the above consideration, a sample size of 200 g may be considered adequate to produce a better quality product of parboiled rice. Comparing the experimental data (Fig. 9B) and corresponding calculated values (Table 2), the quantitative lightness values of 63.5 to 57.5 can be seen as an index of a good quality product of parboiled rice produced at the temperature-time combinations of 80°C-40 min, 90°C-30 min and 100°C-20 min, respectively.

Color intensity value Discoloration of rice due to parboiling treatment is another important quality indicator. This is a negative effect of the parboiling process, because dark colored parboiled rice loses market value and lowers consumer acceptability in most countries (Bhattacharya, 1985). Many researchers measured the color intensity value following parboiling treatment (Jayanarayanan, 1964; Bhattacharya & Subba Rao, 1966; Pillai-

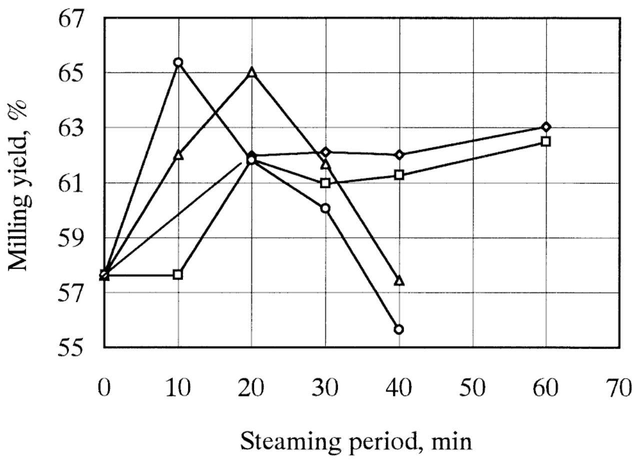

Fig. 8. Effect of parboiling treatment on milling yield. ◇, 80°C; □, 90°C; △, 100°C and ○, 110°C steaming temperature.

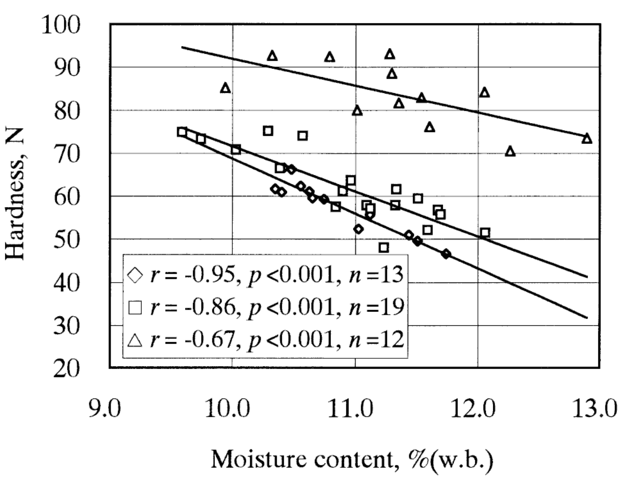

Fig. 7. Relationship between moisture content and hardness of parboiled rice. ◇, 80°C; □, 90°C and △, 100°C steaming temperature.

yar & Mohandoss, 1981; Kimura *et al.*, 1993; Bhattacharya, 1996), and reported that discoloration was mainly caused by the Maillard type of non-enzymatic browning reaction, and that the processing conditions determine the intensity of color during parboiling. Figure 10 shows the effect of parboiling treatment on the color intensity value for different steaming conditions and sample sizes. This value increased with increase in steaming temperature and period, and increase pattern was severe at higher temperatures. The color intensity value also increased with decrease in sample size at 80 and 90°C. To understand the reaction kinetics of color intensity, experimental data were fitted to a first-order kinetic model (Eq. 2) to calculate the kinetic parameters. Table 3

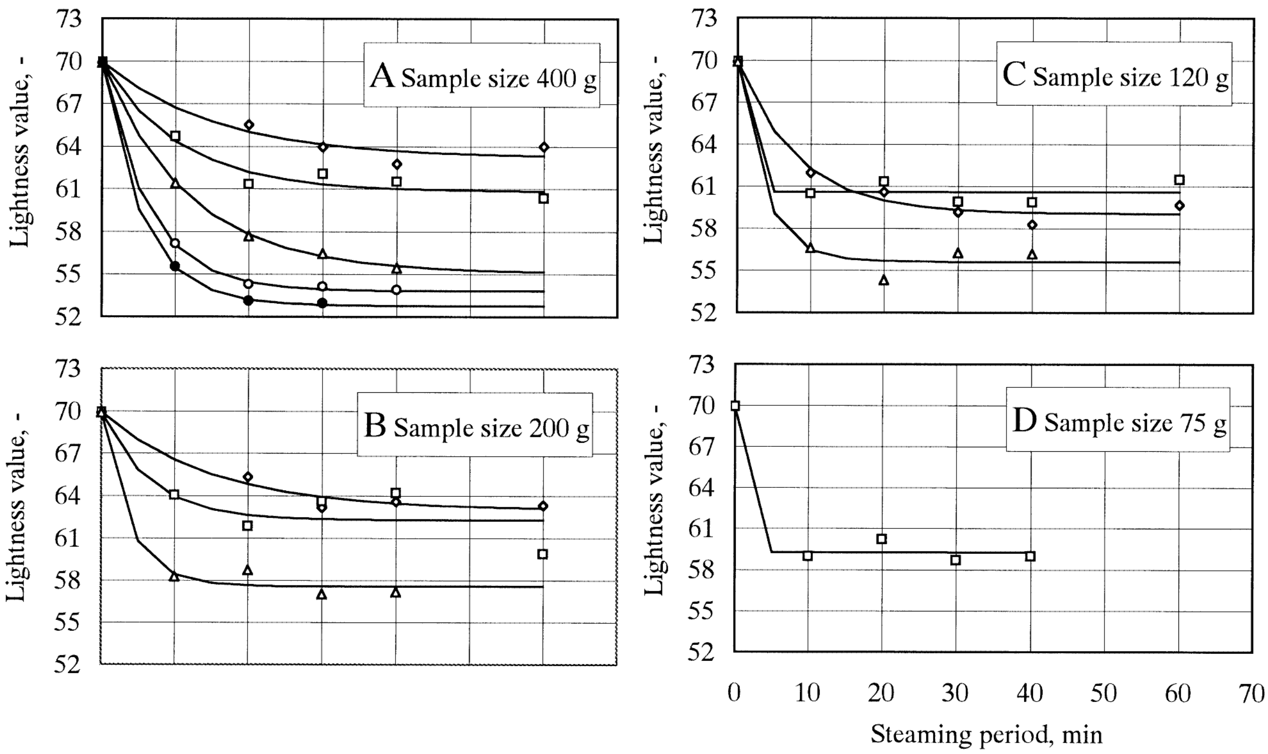

Fig. 9. Effect of parboiling treatment on lightness value. ◇, 80°C; □, 90°C; △, 100°C; ○, 110°C and ●, 120°C steaming temperature.

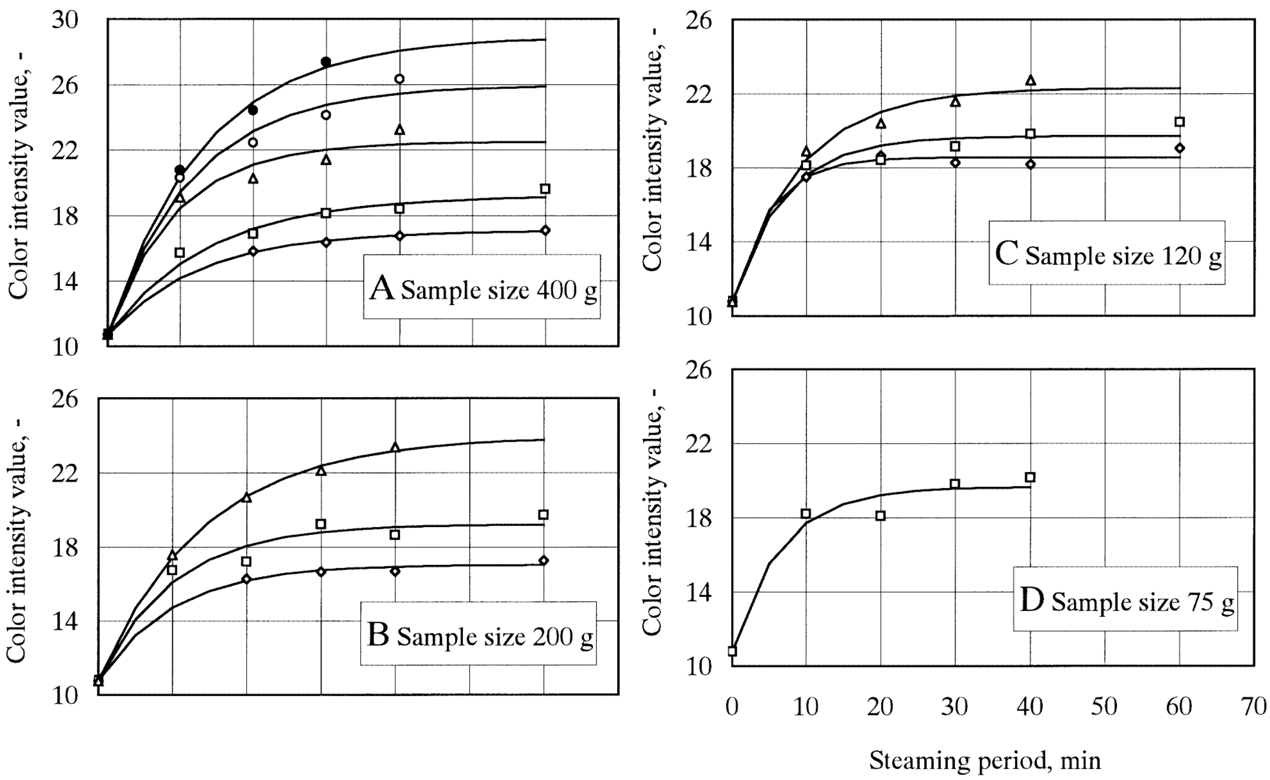

Fig. 10. Effect of parboiling treatment on color intensity value. ◇, 80°C; □, 90°C; △, 100°C; ○, 110°C and ●, 120°C steaming temperature.

Table 2. Kinetic parameters of lightness value.

Sample size (g)	Steaming temperature (°C)	*K*-value (min^{-1})	Final value (–)
400	120	0.19	52.82
	110	0.16	53.84
	100	0.09	55.13
	90	0.09	60.84
	80	0.07	63.22
200	100	0.27	57.60
	90	0.15	62.29
	80	0.07	63.02
120	100	0.28	55.65
	90	6.46	60.61
	80	0.12	59.08
75	90	7.00	59.30

Table 3. Kinetic parameters of color intensity value.

Sample size (g)	Steaming temperature (°C)	*K*-value (min^{-1})	Final value (–)
400	120	0.08	28.97
	110	0.09	25.98
	100	0.11	22.53
	90	0.07	19.25
	80	0.08	17.12
200	100	0.07	23.98
	90	0.10	19.25
	80	0.10	17.06
120	100	0.11	22.33
	90	0.15	19.71
	80	0.20	18.58
75	90	0.15	19.66

shows the kinetic parameters of color intensity value for different temperatures and sample sizes. The final color intensity value increased with increase in steaming temperature, but *K*-value showed no distinct pattern except for the sample size of 120 g. The effect of sample size was not found on the final color intensity value, but *K*-value increased due to decrease in sample size for 80 and 90°C. These results indicated that the effect of parboiling treatment was greater on the lightness value; therefore, this value can be seen to be a more important quality indicator than color intensity value. The change in final color intensity value was found to be greater for higher temperatures of 110 and 120°C. To produce a less colored product, steaming temperature should be selected between 80 to 100°C. It was also reported that color intensity due to parboiling treatment was controllable at lower temperature (Bhattacharya, 1985; Kimura, *et al*., 1993). Considering the visual observations and the change of the rough rice temperature in this case, a sample size of 200 g is considered adequate to produce a good quality product. Compared with the lightness values, the quantitative color intensity values of 17.0 to 21.0 are viewed as an indicator of a good quality product of parboiled rice produced at the temperature-time combinations of 80°C-40 min, 90°C-30 min and 100°C-20 min, respectively (Fig. 10B).

Conclusions

The fabricated laboratory-scale parboiling setup described can be used to produce a better quality product of parboiled rice. A sample size of 200 g, which maintain a 10 mm thick layer of rough rice was found optimal for favorable quality. The temperature-time combinations of 80°C-40 min, 90°C-30 min and 100°C-20 min were recommended steaming conditions that can provide reasonable lightness and color intensity value, 4.0 to 7.5% more milling yield with 55 to 80 N hardness value compared with an untreated sample. Drying time of parboiled rough rice produced at lower temperatures is less because of the lower moisture content after steaming. The proposed parboiling method will be important to both household and commercial parboiling plants to produce a good quality product.

Acknowledgement The authors acknowledge the Japan International Cooperation Agency, Tsukuba-shi, Ibaraki-ken, Japan for supplying the rough rice.

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