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Quality Evaluation of Parboiled Rice with Physical Properties

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This study was undertaken to generate useful information regarding the change of quality of parboiled rice for different processing conditions through the change of physical properties and to search for correlation among the quality indicators. Physical properties, namely, maximum viscosity, hardness of brown rice, hardness and adhesion of cooked rice, volume expansion ratio and solid content were investigated. A first order kinetic model predicted well the effect of processing conditions on the maximum viscosity and hardness of brown rice, indicating the quality index and rate of change of quality with their respective final and reaction rate constant values. The effect of steaming period was found to be greater on the quality indicators of cooked rice, such as adhesion, volume expansion ratio and solid content. Good linear correlation of gelatinization property with the cooking quality and rheological property of parboiled rice was achieved. The positive correlation between adhesion and solid content is assumed to be responsible for producing a less sticky product.

Keywords: quality evaluation, parboiled rice, physical properties, parboiling process

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 was originated a long time ago. It was reported that about one-fifth of the world's rice is parboiled (Bhattacharya, 1985). This production seems to be increasing day by day, because the growth rate of the population in these countries is higher and a major part of the food value comes from rice itself. Parboiling is the hydrothermic treatment given to rough rice. As a result, the physicochemical properties of the rice are changed (Roberts *et al.*, 1954; Kurien *et al.*, 1964; 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; Unnikrishnan & Bhattacharya, 1995), which affects the milling quality, nutritional value and storability of grain. It consists of soaking, steaming and drying. This treatment also leads to the final product of the cooked parboiled rice, having a favourable texture for those who eat it. There is much in the literature available regarding the physicochemical properties, milling, cooking and eating quality of parboiled rice. To better understand the quality it is worth knowing how the physical properties affect the quality of the rice with the change of processing conditions. This study was undertaken to provide useful information to the processors as well as to the consumers of parboiled rice regarding the change of quality for different processing conditions through the change of physical properties and to search for correlation of some quality indicators with others. The objectives of this paper are: i) to study the effect of parboiling on the physical properties of rice such as maximum viscosity and hardness of brown rice; ii) to determine

the physical properties of cooked parboiled rice using a method of evaluating those of cooked rice and the effect of parboiling on these properties such as hardness and adhesion of cooked rice, volume expansion ratio and solid content; iii) to discuss how physical properties affect the qualities of parboiled rice; and iv) to discuss the relationship between the physical properties of parboiled rice and parboiled cooked rice.

Material and Methods

Material One Indica variety of rough rice called 'Belle Patna' was used as raw material in this study, which was harvested in the Japan International Co-operation Agency (JICA) Agricultural Farm in 1996, Tsukuba-shi, Ibaraki-ken. Before conducting the experiment the rough rice was stored in a refrigerator at a wirehouse temperature below 10°C.

Experimental method About 3.6 kg of rough rice was soaked in a bath equipped with a temperature controller, which provided a continuous circulation of water to maintain an almost uniform temperature. First, water was heated to the desired temperature chosen from the scale on the temperature controller, and then the rough rice was poured into the bath. Although the temperature of the bath decreased slightly just after pouring the rough rice, it revived within a short period. The effect of initial temperature fluctuation was offset by using a longer soaking period. Before soaking the rough rice was washed thoroughly and immature grains were removed. Ali and Bhattacharya (1982) proposed a steam pressure range of 1 to 2 kg/cm² to produce parboiled rice of acceptable quality to the consumer. Kimura (1989) also did autoclaving during steaming. In this study steaming was done using an autoclave (TOMY BS-245) at lower steam pressure considering the practical circumstances practiced in different types of parboiling plants. The desired steaming temperature and period were selected from the panel of the autoclave. During insertion of the sample into the autoclave the temperature went

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down to a level adequate to gelatinise the starch, and it took about 5 to 8 min to achieve the desired steaming temperature (Fig.1). The total holding time of sample in the autoclave is reported as the steaming period in this paper. Experimental conditions of this study are given in Table 1. Table 2 shows the steaming period and final moisture content (in percent wet basis) after drying of individual samples. After drying, samples were stored in airtight polyethylene bags for equilibration of moisture content as well as hardness stabilisation (Kimura, 1991). After at least seven days, other tests were conducted.

Maximum viscosity Twenty grams of whole milled rice were ground into fine powder using a cyclone sample mill (UDY). The moisture content of rice powder was determined by drying two grams of sample in an oven at 135°C for one hour and was expressed as the average value of duplicate determinations on a per cent wet basis. A Rapid Visco Analyser-Type 3D (Newport Corporation, Warriewood, Australia), was used to determine the maximum viscosity of parboiled rice flour. A solu-

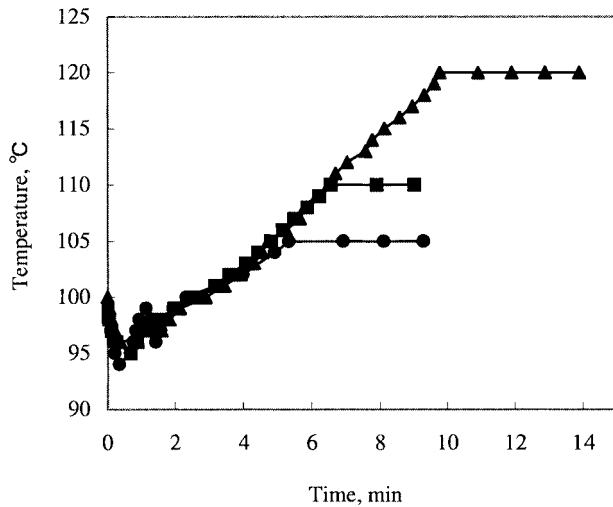


Fig. 1. A typical temperature history during steaming before attaining desired steaming temperature. ●, steaming at 105°C temperature; ■, steaming at 110°C temperature; ▲, steaming at 120°C temperature.

Table 1. Parboiling conditions.

Stage	Temperature/Gage pressure	Period
Soaking	65°C	3 h.
Steaming	105, 110 and 120°C (0.2, 0.4 and 1.0 kg/cm ²)	7–36 min
Drying	Room temperature (28–30°C)	16–24 h
	Final moisture contents 10–13% (w.b.)	

tion of 3.50 g of rice flour (at 14% moisture) and 25 ml of distilled water was used for the measurement. The peak viscosity value, average of duplicate determinations, was treated as the maximum viscosity during the measurement and was expressed in rapid visco analyser (RVA) units. One stir unit is equivalent to 12.6 mPa.s in the SI unit system (Kimura *et al.*, 1995).

Hardness of brown rice More than 25 grains of rough rice were selected randomly from each sample. Hardness of 25 uncracked brown rice grains (husk removed by hand peeling), was measured using a Texture Analyser TA-XT2 (Stable Micro System, Surrey, England). The average bio-yield point value (Mohsenin, 1980) of 25 determinations was expressed as the hardness in newtons (N). A brown rice grain was put on the sample table attached to the load cell and its bio-yield value measured in a flat position (Prasad & Gupta, 1973; Kimura, 1991). A 25 kg load cell, probe of 2 mm diameter and 0.1 mm/s test speed were used.

Cooking method For the measurement of hardness and adhesion of cooked rice, the water and rice ratios used were 1.4, 1.6, 1.8 and 2.0. Cooking was performed according to Shimizu *et al.* (1997). Ten grams of whole milled rice was placed in a 100 ml beaker. After soaking at room temperature with the predetermined amount of water for the duration of 60 min, cooking was done with an electric rice cooker (National Electronic Co., Osaka, SR-3150, 1.5 l) for a period of 14 min. Four beakers were used at a time with 120 ml water in the outer pot. After standing for 14 min after the power switch was turned off, a holding period of 90 min was allowed to cool the sample to room temperature in the airtight sample keeper before measuring the hardness and adhesion of the cooked rice. For the measurement of volume expansion ratio and solid content, the access water cooking method was followed. Ten grams of whole milled rice was placed in a wire-mesh cylinder (78×38 mm). A 300 ml beaker with 180 ml distilled water was boiled in a rice cooker with excess water in the outer pot. The wire-mesh cylinder with sample was placed in the boiling water of the beaker and was cooked for 30 min (Bhattacharya & Subba Rao, 1966).

Physical properties of cooked rice Hardness and adhesion of a single grain of cooked rice was measured with the texture analyser. A 5 kg load cell, plunger of 25 mm diameter and 3 mm/s test speed were used. The hardness and adhesion of the cooked rice were determined as the maximum and minimum forces, respectively, during the test run (Shimizu *et al.*, 1997) and expressed as the average value of 20 determinations in newtons. The moisture content of cooked rice was determined by drying two grams of sample in an oven at 135°C temperature for two hours and was expressed as the average value of triplicate deter-

Table 2. Steaming period and final moisture content after drying of individual samples.

Steaming temperature					
105°C		110°C		120°C	
Period (min)	Moisture content % (w.b.)	Period (min)	Moisture content % (w.b.)	Period (min)	Moisture content % (w.b.)
10 (5)	12.89	7 (1)	12.47	9 (1)	12.57
16 (10)	12.27	11 (5)	12.66	15 (5)	12.38
20 (15)	12.27	16 (10)	12.30	18 (10)	10.87
26 (20)	11.96	22 (15)	12.04	22 (15)	10.65
36 (30)	11.68	27 (20)	11.54	28 (20)	10.43

The steaming period of samples after achieving desired temperature are mentioned in brackets.

Table 3. Statistical results (*p*-values) for different physical properties of parboiled rice and parboiled cooked rice.

Treatment	Physical properties of parboiled rice and parboiled cooked rice					
	Max.V. (RVA unit)	HNBR (N)	HNCR (N)	ADCR (N)	VER (-)	SC (g)
Steaming period	7.046E-05***	0.0007***	0.5007	0.0008***	0.0194*	0.0010**
Steaming temperature	0.0025**	0.0027**	0.0876	0.1108	0.0750	0.1579

Max. V., maximum viscosity; HNBR, hardness of brown rice; HNCR, hardness of cooked rice; APCR, adhesion of cooked rice; VER, volume expansion ratio; SC, solid content; N, newtons; g, gram; ***, Significant at 0.1% level; **, Significant at 1% level; *, Significant at 5% level.

minations on a per cent wet basis. The volume expansion ratio, average value of triplicate measurements, was determined by measuring the height of raw and cooked rice in the wire-mesh cylinder (Kimura, 1983). The residual cooking liquid was standardized to 200 ml. The solid content was determined by drying 10 ml of residual cooking liquid in an oven at 105°C temperature for 24 h (Kimura, 1983) and was expressed as the average value of triplicate determinations in gram.

Data Analysis Statistical analyses of data were done with analysis of variance using Microsoft Excel 2000 (Microsoft Corporation, USA). A first order kinetic model, as shown in Eq. (1), was used (Kimura, 1991; Kimura *et al.*, 1993) to perform 'least squares' non-linear regression analyses using SigmaPlot (Jandel Corporation, San Rafael, CA). The kinetic parameters were estimated for better understanding of the rate and index of change of quality indicators that occur during the parboiling process through the change of physical properties:

$$C = C_e + (C_o - C_e)\exp(-kt), \quad (1)$$

where *C* is the value at steaming time *t*, *C_e* is the final value and *C_o* is the initial value of quality indicators, respectively; and *k* is the kinetic reaction rate constant value.

Results and Discussion

Statistical results Statistical analysis was done using analysis of variance to know the significance of processing treatment on the physical properties of parboiled rice. Table 3 shows the statistical results for different physical properties of parboiled rice and parboiled cooked rice. This table shows that the effects of steaming period and temperature were highly significant on the maximum viscosity and hardness of brown rice. For the physical properties of cooked rice, no significant effect of parboiling treatment was observed on the hardness of cooked rice. Shimizu *et al.* (1997) reported the relationship between moisture content and hardness of cooked rice. In this study it was assumed that the effect of moisture content rather than the parboiling treatment was greater on the hardness of the cooked rice, but a significant effect of steaming period was observed on the other physical properties, such as adhesion, volume expansion ratio and solid content.

Effect of parboiling on the maximum viscosity Parboiling is the process of starch gelatinisation, which depends on the severity of the parboiling process. As a result, the gelatinisation properties of parboiled rice are changed. Figure 2A shows the effect of steaming on the maximum viscosity. It can be seen that the gelatinisation property of parboiled rice of maximum viscosity decreased due to increase in steaming temperature and period. This decreasing pattern agrees well with other researchers in case of RVA parameter (Kimura *et al.*, 1995), as well as, amylograph

viscosity (Raghavendra Rao & Juliano, 1970; Priestley, 1976; Ali & Bhattacharya, 1980c). In this study the maximum viscosity value range was from 40 to 305 RVA units for different steaming temperatures and periods and was 412 RVA units for the raw sample. The temperature-time combination selected in this study was within the range used in different types of parboiling plants. Therefore, the maximum viscosity to the palatability of parboiled rice is assumed to be within the above range. The change in quality of parboiled rice with respect to maximum viscosity due to parboiling treatment can be understood from the least squares analysis using the first order kinetic model. It was found that the final value of maximum viscosity was lowest for the higher steaming temperature of 120°C (33.92 RVA units) compared with 105 (43.39 RVA units) and 110°C (78.24 RVA units) temperature, and that of reaction rate constant value was highest at the higher steaming temperature, in the order of 0.0452, 0.0880 and 0.1618. The final maximum viscosity and reaction rate constant value indicates the quality index and the rate of change of quality for the respective steaming temperature.

Effect of parboiling on hardness of brown rice Among the physical properties of parboiled rice hardness is the most important one because it reduces breakage during milling. The hardness depends on the severity of the parboiling treatment. Many researchers reported that it is greatly affected by parboiling conditions, moisture content after drying, balance of starch gelatinisation and retrogradation and other factors (Ali & Bhattacharya, 1976; Pillaiyar & Mohandoss, 1981; Bhattacharya, 1985; Itoh & Kawamura, 1985; Kimura, 1991). Figure 2B shows the effect of steaming on the hardness of brown rice. It can be seen that the hardness was increased with increasing of both the steaming temperature and period. The quality of parboiled rice depends on the hardness of brown rice, because head rice yield, the important indicator of the milling quality of parboiled rice, which also influences the market value and consumer acceptability, is greatly affected by this factor. The quality change of parboiled rice with respect to the hardness of brown rice due to parboiling can be understood from the least squares analysis using the first order kinetic model. It was found that final hardness value for the steaming temperature of 105 and 110°C (0.2 and 0.4 kg/cm² gage pressure) was almost the same (94.72 and 94.26 N); this might be due to a lower temperatures difference, but higher final hardness value (106.21 N) was obtained for the higher temperature (120°C). Although the reaction rate constant values for different steaming temperatures did not show a distinct pattern, this might be due to lack of data for the transient points; higher final hardness value for the higher steaming temperature, however, reconfirms the general understanding, supported by other researchers, that the hardness of parboiled rice increases with the

severity of the parboiling process (Raghavendra Rao & Juliano, 1970; Pillaiyar & Mohandoss, 1981; Kimura, 1991). The final hardness and reaction rate constant value can also be treated as the index of quality and the rate of change of quality for the respective steaming temperature.

Effect of parboiling on the physical properties of cooked rice Figures 2C to 2E show the effect of steaming on the other physical properties of cooked rice: adhesion, volume expansion ratio and solid content of residual cooking liquid. A first order

kinetic model was used to predict the kinetic parameters. Although from these figures it can be seen that adhesion, volume expansion ratio and solid content decrease with increase in the steaming period, which is in agreement with other researchers (Kurien *et al.*, 1964; Raghavendra Rao & Juliano, 1970; Kaur *et al.*, 1991), the final and reaction rate constant values did not show a steady pattern. Hwang *et al.* (1999) reported the change of thermal properties of comstarch, which depends on the extent of preheating treatment. Parboiling is the preheating treatment

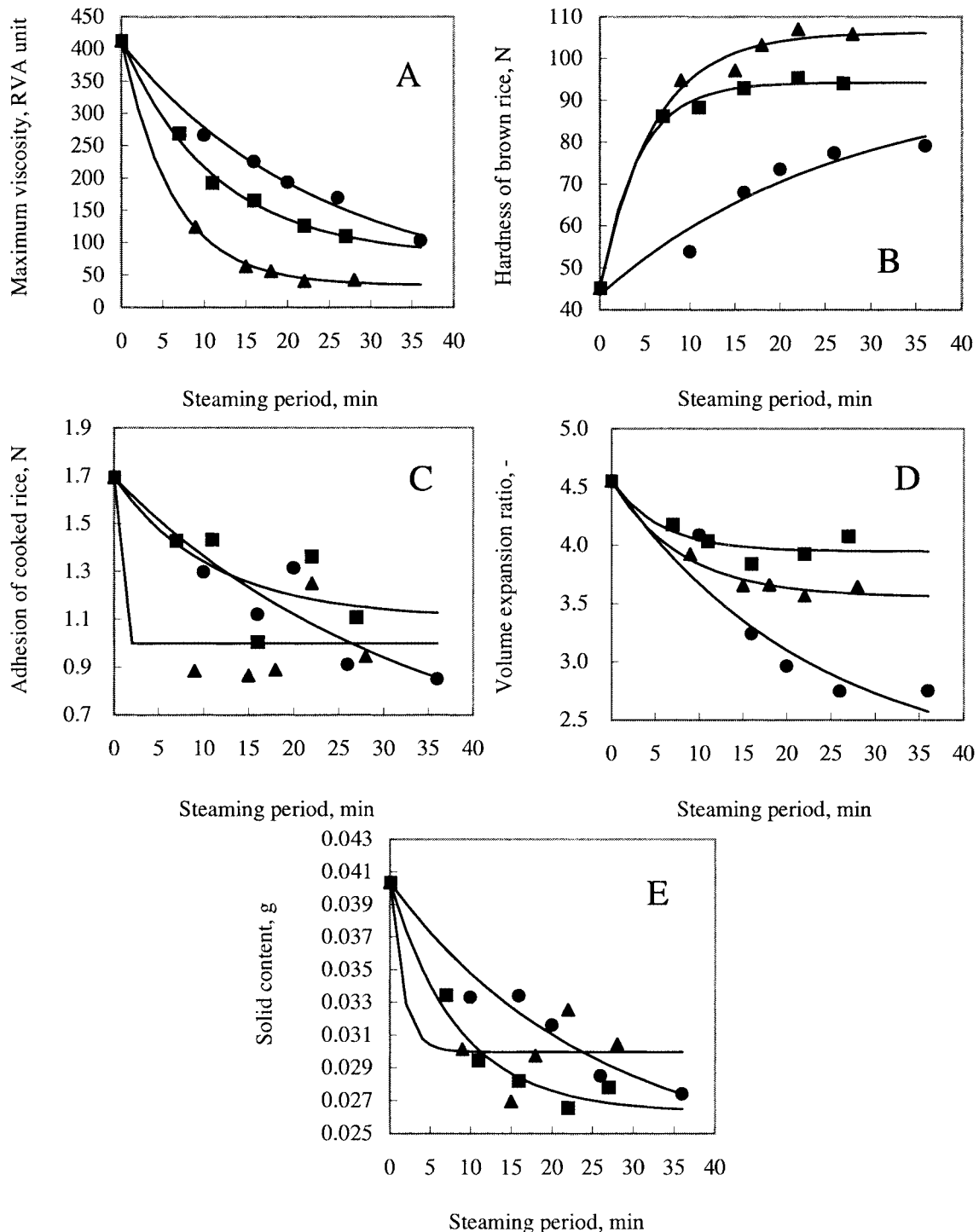


Fig. 2. Effect of steaming on the quality indicators of parboiled rice and parboiled cooked rice. ●, experimental value steaming at 105°C temperature; ■, experimental value steaming at 110°C temperature; ▲, experimental value steaming at 120°C temperature; —, calculated value.

given to rough rice. It can be assumed that parboiling treatment also affects the thermal properties of rice. Thus it can be stated that changes of thermal properties of rice due to parboiling influence the quality of cooked rice. Although in this study fluctuating data were obtained about the quality of cooked parboiled rice, a study on the change of thermal properties of rice due to preheating can provide more reliable information about these qualities. It is generally understood that cooked parboiled rice is harder and less sticky than raw cooked rice. The tenderness of cooked

parboiled rice, determined by extrusion value (Mohandoss & Pillaiyar, 1980) or pressing device value (Pillaiyar & Mohandoss, 1981) was increased due to the severity of heat treatment during parboiling. Kato *et al.* (1983) reported that hardness and cohesiveness of cooked parboiled rice is increased. In this study no significant effect of parboiling treatment was observed on the hardness of cooked rice (Table 3). Biswas and Juliano (1988) reported that parboiling did not increase the hardness of rice cooked at different steaming temperatures. Biliaderis *et al.*

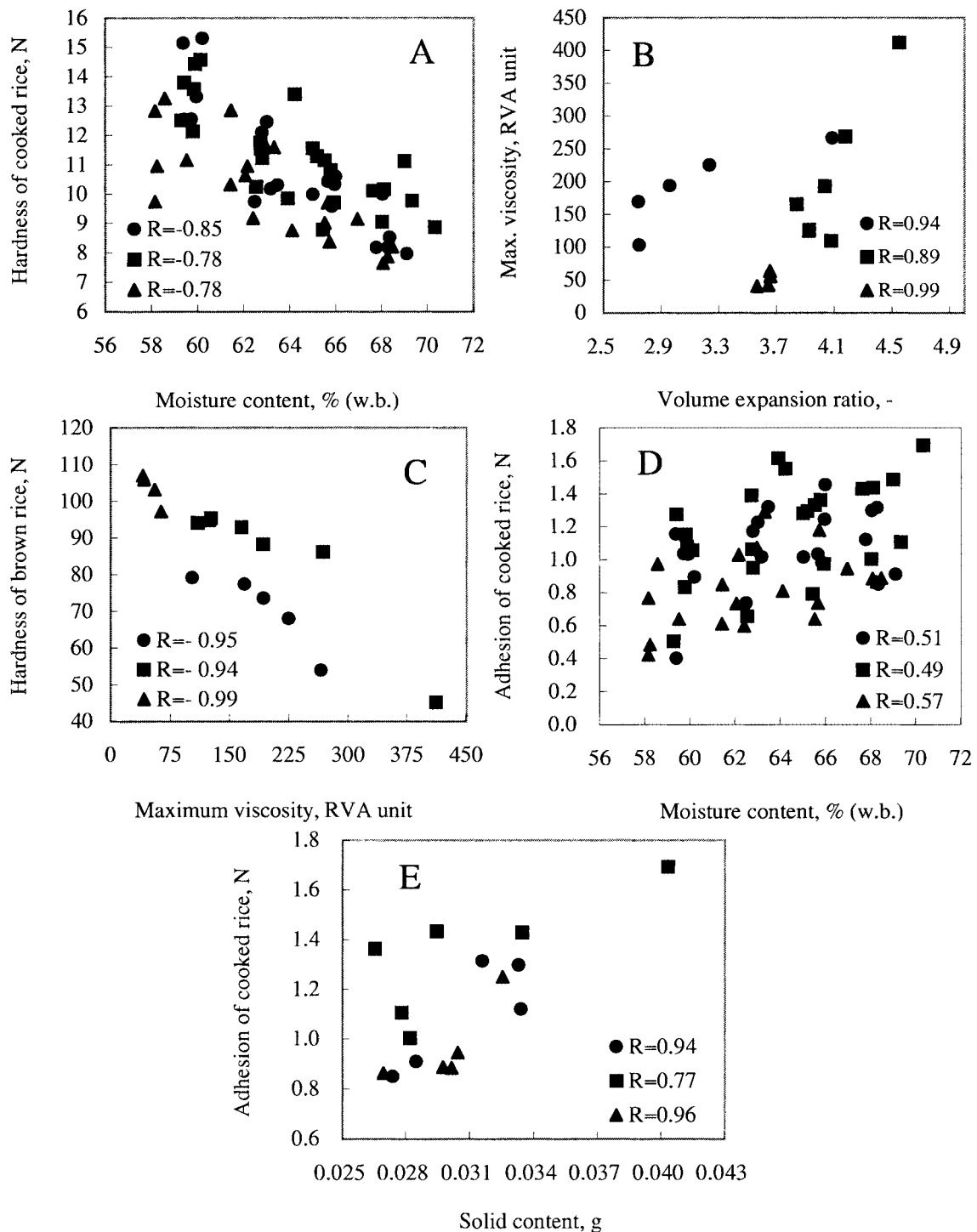


Fig. 3. Relationship among the quality indicators of parboiled rice and parboiled cooked rice. ●, experimental value steaming at 105°C temperature; ■, experimental value steaming at 110°C temperature; ▲, experimental value steaming at 120°C temperature.

(1993) compared the hardness of cooked raw and parboiled rice for different varieties utilising the extrusion method. They reported that hardness of cooked rice was not significantly affected by parboiling for some specific varieties. Therefore, varietal differences, amylose content and moisture content after cooking might be more influential factors on cooked rice hardness than the parboiling treatment. It was reported that the moisture content after cooking influences the hardness of cooked rice (Juliano & Perez, 1983; Shimizu *et al.*, 1997). Figure 3A shows the relationship between moisture content and hardness of cooked parboiled rice. In this figure a negative correlation ($R = -0.85$, -0.78 and -0.78 for the steaming temperatures of 105, 110 and 120°C, respectively) between moisture content and hardness of cooked parboiled rice can be observed. From this fact it can be assumed that the effect of moisture content on the hardness of cooked parboiled rice is greater than the processing conditions.

Correlation among the physical properties of parboiled rice The maximum viscosity of rice flour depends on the swelling ability of the starch granules. It was also reported that the lower maximum viscosity value due to parboiling is a reflection of the decreased swelling ability of gelatinised starch (Priestley, 1976; Ali & Bhattacharya, 1980). In this study volume expansion ratio of cooked parboiled rice was evaluated, which might be considered as the index of softness of cooked rice. As mentioned earlier, the palatability of cooked parboiled rice is assumed to be within a certain range of maximum viscosity, therefore within that range the volume expansion ratio of cooked parboiled rice can be predicted utilising the correlation between volume expansion ratio and maximum viscosity. Figure 3B shows the relationship between volume expansion ratio and maximum viscosity. It is seen that maximum viscosity correlates positively ($R = 0.94$, 0.89 and 0.99 for the steaming temperatures of 105, 110 and 120°C, respectively) with the volume expansion ratio. The higher values of correlation coefficient clearly indicate that the maximum viscosity value can be used to predict the volume expansion ratio of cooked parboiled rice for better palatability.

Practically it is difficult to find any correlation between maximum viscosity and hardness of brown rice, because apparently there is no practical evidence to evaluate the correlation between these two parameters except evidence of the effect of processing conditions. In the literature it was reported that information regarding the relationship between rheological property and RVA could be obtained (Kimura *et al.*, 1995). This reported supposition could be utilised to find the relationship between maximum viscosity and hardness of brown rice. It was reported that hardening of parboiled rice is due to swelling and gelatinisation of rice starch (Raghavendra Rao & Juliano, 1970; Ali & Pandya, 1974; Kimura, 1978). On the other hand, starch swelling and gelatinisation also affect the maximum viscosity. For the above reason, it might be possible to find the relationship between maximum viscosity and hardness of parboiled rice; Figure 3C shows this relationship in brown rice and shows that the hardness correlates negatively ($R = -0.95$, -0.94 and -0.99 for the steaming temperatures of 105, 110 and 120°C, respectively) with the maximum viscosity. This correlation implies that gelatinisation property can be used to predict the rheological property of parboiled rice. Based on the above (Fig.3B and 3C) the gelatinisation property of maximum viscosity can be utilised to obtain information about cooking quality and physical property of par-

boiled rice, such as volume expansion ratio and hardness, respectively.

Kato *et al.* (1983) and Biswas and Juliano (1988) reported that the stickiness of cooked rice is decreased due to parboiling treatment. In this study a significant effect of steaming period on the adhesion of cooked rice was determined (Table 3). Shimizu *et al.* (1997) reported the highest change of adhesion value at a moisture content of 62% for raw cooked rice. In this study no such phenomenon was observed. The adhesion of cooked rice depended on the surface stickiness. On the other hand, stickiness was influenced by the moisture content and adhering solid content on the cooked rice. Therefore the effect of moisture content after cooking and solid content of cooking gruel needs to be investigated to understand the quality of cooked parboiled rice. Figure 3D shows the relationship between moisture content and adhesion of cooked parboiled rice. The adhesion of cooked rice correlates positively with moisture content after cooking with smaller values of correlation coefficient. From this fact it can be assumed that not moisture content but solid content of cooking gruel might be more influential on the adhesion of cooked parboiled rice. Figure 3E shows the relationship between solid content and adhesion of cooked rice, and a positive correlation ($R = 0.94$, 0.77 and 0.96 for the steaming temperatures of 105, 110 and 120°C, respectively) between solid content and adhesion of cooked rice is seen. The coefficient of correlation for the steaming temperature of 110°C was smaller compared with the other two values. The discrepancy of R -value for 110°C arising from the greater data fluctuation in some samples might be due to poor response to the heat and mass transfer in the grain for those samples during cooking. Generally parboiled rice eaters like to consume less sticky rice. The parboiling treatment reduces the solid content in the cooking gruel (Fig.2E; Kurien *et al.*, 1964; Kimura, 1983) because parboiling is known to produce a more compact arrangement of starch in the kernel and greater cohesion between starch granules and protein bodies (Raghavendra Rao & Juliano, 1970; Kato *et al.*, 1983). Batcher *et al.* (1957) also observed a highly significant negative correlation between total solid and cohesiveness scores of cooked rice. The reduced solid content of parboiled rice is responsible for the cooking qualities of adhesion, stickiness and cohesiveness of cooked parboiled rice. Therefore, lower adhesion value of cooked parboiled rice leads to a less sticky final product, cooked rice, a favourable texture to those eating it. From the above discussion it is understood clearly that the two important physical properties of cooked parboiled rice hardness and adhesion largely depend on the moisture content after cooking and solid content of cooking gruel, respectively.

Conclusions

Parboiling is the hydrothermic treatment given to rough rice. The trend of change of physical properties or, in other words, quality indicators for both parboiled rice and cooked parboiled rice depends on the extent of heat and mass transfer during processing operations. In this study, especially in the case of physical properties of cooked rice, discrepancies of data were observed from those in the literature. The reason might be different responses to the heat and mass transfer for different samples during cooking of parboiled rice. It can be concluded that parboiling treatment changes the physical properties, which affect the qual-

ity of the parboiled rice. The first order kinetic model predicted well the quality indicators of parboiled rice of maximum viscosity and hardness of brown rice. The reaction rate constant value indicates the rate of change of quality, and whether the final value indicates the index of quality. The effect of processing period on the quality indicators of cooked parboiled rice was greater than the temperature. The positive correlation between adhesion of cooked parboiled rice and solid content of cooking gruel is assumed to be responsible for production of a less sticky product, a favourable texture to the eaters of parboiled rice.

To better understand the change of quality indicators due to parboiling treatment knowledge of heat and mass transfer in the grains during parboiling and cooking is of utmost importance.

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