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Effect of Temperature Distribution on the Quality of Parboiled Rice Produced by Traditional Parboiling Process

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Laboratory scale studies were conducted to determine temperature distribution in the traditional parboiling process using a rice cooker. A sample holder with a wire-mesh bottom was used to keep the sample from the hot water. The material temperature and the qualities of parboiled rice (hardness, color, lightness and head rice yield) were determined for different layers. The thickness of each layer was about 20 mm. The temperature distribution in this parboiling process (pre-steaming and steaming) was found to be uneven. The change of material temperature was faster for the first (bottom layer; beneath which steam started to penetrate the paddy mass), next was the second (middle) and last was the third (top) layer. The greater the thickness of the material, the lower was the material temperature. The hardness and the head rice yield were found to be the highest for the first, with the second and third layers following in that order; this might be affected by the material temperature. Difference in color intensity and lightness value was insignificant among the layers. The hardness, color intensity and lightness value were about 70 N, 24, and 57, respectively, corresponding to the maximum head rice yield (67%, first layer) which is considered to be the suitable quality of parboiled rice.

Keywords: traditional parboiling, temperature distribution, material temperature, quality of parboiled rice.

Parboiling is the combined effort of soaking, steaming and drying and is widely used in some of the developing countries including Bangladesh, where parboiled rice is the staple food. Parboiled rice has been produced by both traditional and modern methods. Modern methods are energy and capital intensive, and are not suitable for a small-scale operation at the village level (Ali and Ojha, 1976; Bhattacharya, 1990). In Bangladesh, more than 80% of the rice is processed in villages and less than 20% in commercial rice mills (Rahaman *et al.,* 1996). In the modern parboiling processes, the paddy is soaked in hot water for a period of 3 to 6 h at 55 to 70°C (CFTRI, 1969; Tiwary and Ojha, 1981; Kimura, 1989; Islam *et al.,* 2002). For steaming, steam is generated in the boiler and is applied to the soaked paddy in hoppers through connecting pipes. Traditional parboiling processes use either single or double steaming. In single steaming, paddy is soaked in water of room temperature for a period of 36 to 72 h and in double steaming pre-steamed paddy is soaked in unheated water for 24 h. Various methods and devices are being used in the traditional parboiling process and produce parboiled rice of different grades. The device consists of pottery to boilers. The vessel (Fig. 1) is the most commonly used traditional parboiling device in villages (Roy *et al.,* 2003a), where the paddy is subjected to double steaming. It has been reported that 20% of paddy is submerged in water during pre-steaming and steaming. The hot water parboils the submerged paddy and the rest is parboiled by steam generated in the system (Haque *et al.,* 1997); this is considered to be a dual system and results in producing a lower quality parboiled rice.

Many researchers have studied the parboiling process, however, studies on temperature distribution are scarce except for a few examples of the modern parboiling process (Kimura *et al.,* 1976; Kimura, 1989). It has been reported that upward temperature propagation is higher than the other direction and drastically increases in the temperature range above 90°C (Kimura, 1989), which suggests that the density of perforation of the bottom of the sample holder might be responsible for a non-uniform steam flow through the paddy mass. The use of an improved parboiling vessel with a wire-mesh 150 mm above the bottom has also been reported to reduce energy consumption compared to the conventional vessel method (Adhikarinayake and Swarnasiri, 1988), which keeps back the sample from the hot water in the vessel. The temperature distribution in the traditional parboiling process and its effect on the quality of parboiled rice is yet to be explored. Therefore, laboratory scale parboiling studies have been conducted using a sample holder with a wire-mesh bottom to measure the temperature distribution in the traditional parboiling process and its effect on the quality of parboiled rice.

Materials and Methods

Materials The Bellepatana, an *indica* variety of paddy, which was harvested in 2000 at the Japan International

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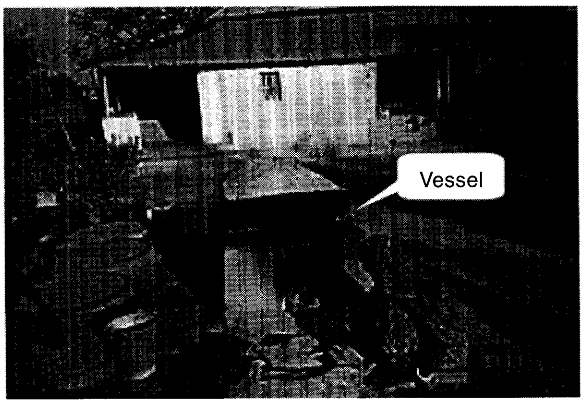

Fig. 1. Commonly used traditional parboiling device (vessel).

Cooperation Agency (JICA) farm in Tsukuba, Japan, and stored in a refrigerated warehouse at 5°C, was used in this study.

Methods Double steaming is the most common and widely used process for small-scale household production (Roy *et al.,* 2003a), and it was adopted for this study.

Parboiling A stainless-steel sample holder with a wire-mesh (mesh: size, 1 mm; thickness, 0.2 mm) bottom was developed and placed on an electric rice cooker vessel (Model SR-W180, 1.8 dm^3, 100 V, 600 W, National Electric Co., Osaka, Japan) to hold the sample above the water in the vessel. The steam generated in the vessel penetrates underneath it and parboils the paddy mass. The peripheral surface of the sample holder and rice cooker were insulated with polyurethane foam sheets to reduce heat loss during the parboiling process. A PID (proportional plus integral plus derivative action) temperature controller (TF3-10, Keyence Co., Ltd., Osaka, Japan) and a relay switch (LY2N, Omron, Tokyo, Japan) were used to control the steam temperature using the auto tuning mode of the PID temperature controller. The temperature controller was set at 100°C. Two thermocouples (TC) were placed inside the rice cooker vessel, one of them was connected to the temperature controller, which helps to control the steam temperature and the other was connected to a personal computer (Aptiva, IBM 2144-26J) through a data acquisition system. The thermocouples connected with the personal computer through the data acquisition system (NR-1000, Keyence Co., Ltd., Osaka, Japan) were used to record the steam temperature and the temperature distribution during pre-steaming and steaming. Three nylon-net bags (mesh: size 1.5 mm; thickness, 0.2 mm; Fig. 2) were used to create three different layers of paddy during pre-steaming and steaming treatment. Two hundred and fifty grams of paddy was used for each layer. The thickness of each layer was about 20 mm. The specific heat and thermal conductivity of paddy are reported to be $C_p = 1.62 + 0.03114\ M_w$, and $k = 0.09999 + 0.01107\ M_w$, respectively, where, C_p is specific heat, kJ/kg *K*; *k* is thermal conductivity, *W/m K* and M_w is moisture content of paddy (%) on a wet basis (Bala *et al.,* 1987; Morita and Singh, 1979). The bulk density of paddy is reported to be about 663 to 682 kg/m^3 (Kunze and Wratten, 1985). Figure

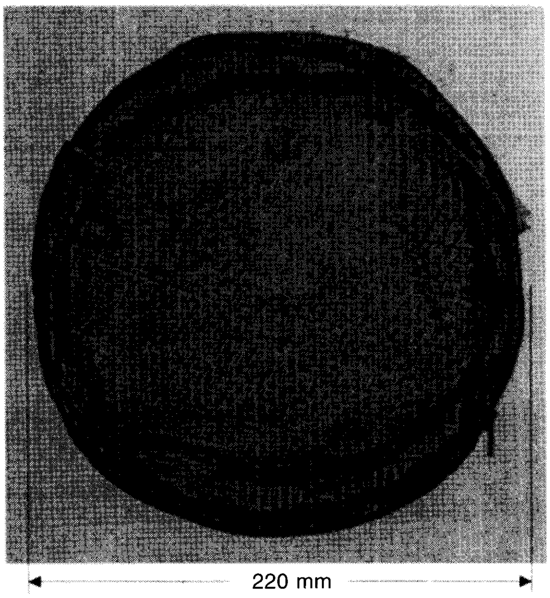

Fig. 2. Nylon-net bag.

3 shows a schematic diagram of the experimental setup and the placement of the thermocouples in this study.

The paddy was washed with room temperature water (23.5°C) to remove any foreign matter, drained and put in the nylon-net bags. The bags were loaded on the sample holder and the thermocouples were placed in the appropriate position. Then the paddy was pre-steamed for 7 min (Sarker and Faruk, 1989) followed by soaking for 24 h (Haque *et al.,* 1997) in the rice cooker vessel. After draining the excess soaking water, the soaked paddy was steamed to produce parboiled rice of different grades. Recording of the treatment time (pre-steaming and steaming) began when steam temperature reached 100°C. For both the pre-steaming and steaming treatment, 500 mL of water was used in the rice cooker vessel. After pre-steaming, an additional 1000 mL of water (23.5°C) was added to the vessel and then the pre-steamed paddy was submerged for soaking. The pre-steaming treatment raised the paddy temperature which helped to raise the soaking water temperature and reduced soaking time. During the soaking period the water temperature was observed to be about 55 to 24°C. The steamed paddy was dried under shade at room temperature (25 to 28°C) in two stages: first it was dried to up to 18 to 20% (w.b.) of moisture content (MC) and then was heaped overnight for steeping (Haque *et al.,* 1997). Finally, it was dried to about 14% (w.b.) of MC to get better quality and higher milling yield (Rahaman *et al.,* 1996). Table 1 shows the parboiling conditions of this study.

Measurement of temperature distribution and material temperature The temperature distribution data during pre-steaming and steaming was stored in a personal computer. Four thermocouples were used to measure the temperature distribution and another three were used to record the steam, room and surface temperature of the sample holder, respectively. The thermocouples TC_1, and TC_4 were placed at the

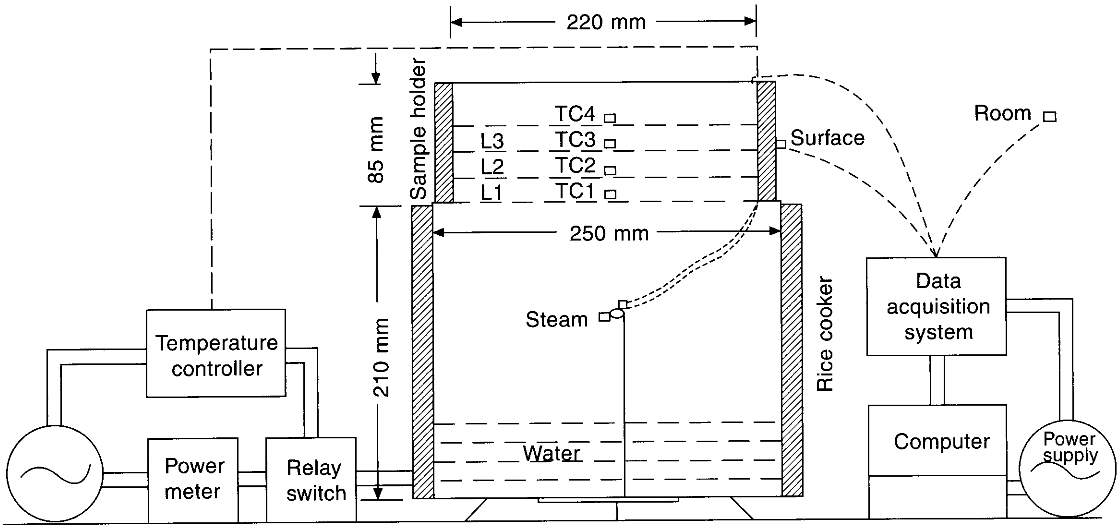

Fig. 3. Schematic diagram of the experimental setup.

Table 1. Parboiling conditions.

Treatment	Paddy MC% (w.b.)	Pre-steaming, min	Steaming, min	Drying
T_1	13.0	7	10	To about 14% of
T_2	13.0	7	20	moisture content
T_3	13.0	7	30	at room
T_4	13.0	7	40	temperature
T_5	13.0	7	50	

Soaking = 24 h, MC = Moisture content.

bottom and surface of the paddy, respectively. The TC_2 was placed between the first and second layers and the TC_3 was placed between the second and third layers. The average temperature of TC_1 and TC_2, TC_2 and TC_3, and TC_3 and TC_4 were considered to be the material temperature for the first (L_1), second (L_2) and the third (L_3) layers of paddy, respectively. Average room temperature is considered to be the material temperature for raw rice.

Measurement of energy consumption The energy consumption in the parboiling process (pre-steaming and steaming) was measured with a power meter (Model W-787Y, Namikoshi Electronics, Hyogo-ken, Japan).

Quality indices of parboiled rice The dried parboiled paddy was kept in a warehouse for one week to stabilize the MC and then put in a humidity cabinet (LHL-113, Tabai Espec Corp., Osaka, Japan) for one week at 25°C and 60% relative humidity to homogenize it for all samples; this helps to avoid any effects of moisture content on dehusking and milling outturns. After dehusking, brown rice was also put in the humidity cabinet under the above conditions to stabilize the hardness and to homogenize its MC (12%) before the quality indicators of parboiled rice at room temperature were measured.

Moisture content The MC of replicated samples was determined by the air oven method at 105°C for 24 h and expressed in per cent, on a wet basis.

Hardness The hardness of brown rice was measured with a Texture Analyzer TA-XT2 (Stable Micro System, Surrey, England), using a solid cylindrical probe. The probe diameter and the load cell were 2 mm and 245 N, respectively. The brown rice was put on the sample table at the center of the probe in a flat position (Kimura, 1991) and compressed to 80% deformation to measure the peak force in Newton (N) for a single kernel, which is considered to be the hardness of this rice (Fig. 4). The test speed of the probe was 0.1 m/s. It was replicated twenty times for each sample (each layer and treatment) using 20 different rice kernels, and the average value is reported.

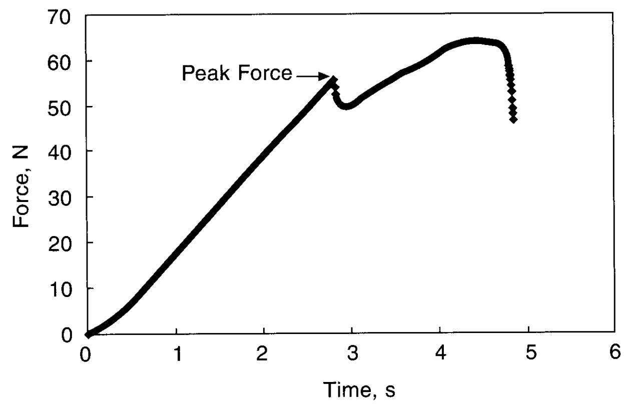

Fig. 4. Force deformation curve of parboiled rice.

Color intensity and lightness The $L^*a^*b^*$ color space of CIE Lab was adopted and measured with a photoelectric color meter (CR-200, Minolta Co., Ltd., Tokyo, Japan), where L^* indicates lightness and a^* and b^* are the chromaticity coordinates. The color intensity of brown rice was worked out using the following equation (Kimura, 1989).

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

where, B = Color intensity

Head rice yield Head rice yield is an estimate of the quantity of head rice which can be produced from a unit of paddy. The dried parboiled paddy was dehusked with a Satake rice machine (THU type, Satake Engineering Co., Ltd., Higashihiroshima, Japan). The brown rice was milled with a vertical friction-type milling machine (VP-31T, Yamamoto Co., Tendu, Japan). The degree of milling was restricted to 7-8% for maximum milling recovery (Rahaman *et al.*, 1996) by varying the time. The milling yield is an estimate of the quantity of milled rice which can be produced from a unit of paddy. A cylinder-type test rice grader (TRG type, Satake Co., Higashihiroshima, Japan) was used to separate the broken grain from whole grain (head rice). The head rice yield was calculated in respect to paddy weight and expressed as a percentage.

Results and Discussion

Temperature distribution The pre-steaming treatment improves the material temperature, which increases the soaking water temperature and helps to reduce the soaking time (Bhattacharya, 1985; Sarker and Faruk, 1989). The temperature distribution plays a key role in improving the material temperature. The pre-steaming temperature rose to about 97, 75, 34 and 25°C at the position of TC_1, TC_2, TC_3 and TC_4, respectively. During pre-steaming, a similar temperature distribution was observed in all treatments (T_1 to T_5) of this study. Figure 5 shows an example of temperature distribution during the pre-steaming process.

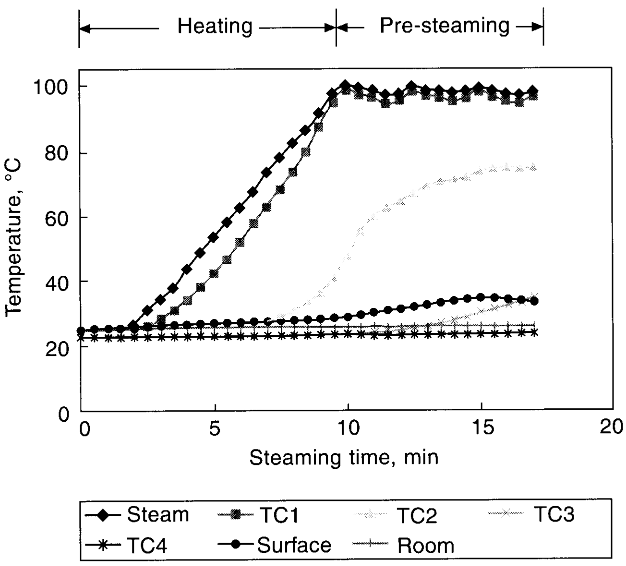

Fig. 5. Temperature distribution during pre-steaming.

Figure 6 shows the temperature distribution during the steaming process. The steam temperature reached 100°C in about 10 min of heating for both the pre-steaming and steaming treatment. The temperature rose to 100°C only at the position of TC_1 and lowered gradually at the positions of TC_2, TC_3 and TC_4, i.e., the higher the thickness of paddy mass on the sample holder the lower the temperature. In the parboiling process, the heat is transferred through convection and conduction. The heat conduction with condensation plays a major role in the heat transfer during steaming. But at high temperature the steam convection seems to have an expanded effect (Kimura, 1989). In this study, it seemed that the conduction played the major role when power intake stopped, i.e., steam generation stopped. Figures 5 and 6 also show the room and the surface temperature of the sample holder during pre-steaming and steaming treatment, respectively.

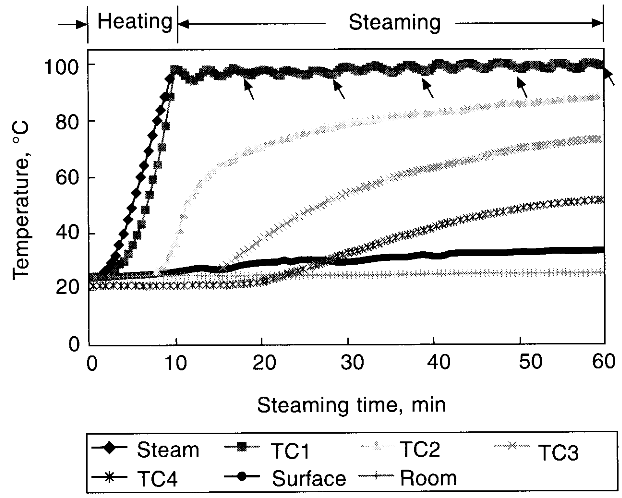

Fig. 6. Temperature distribution during steaming (↖ show the sampling points).

Energy consumption A slight difference in energy consumption was observed among different treatments, although the steaming time varied. The auto tuning process of the temperature controller controlled the power intake through a relay switch to maintain the steam temperature. The power intake was found to be continuous until the steam temperature reached 100°C, then at this temperature the power intake stopped and held the steam at the desired temperature for a certain period. If the steam temperature dropped below the desired temperature level, the power intake started again. The energy consumption in this study was found to be 1080.0 to 1545.6 MJ/t for different treatments (Table 2). The energy consumption in a vessel, small-boiler and medium-boiler process were reported to be 2583, 2758 and 1659 MJ/t, respectively, which are commonly used traditional parboiling processes in a rural area (Roy *et al.*, 2003b), where biomass energy (rice husk) is used. In these parboiling processes, the paddy is treated by double steaming, which is similar to this study. In the vessel method, part of the paddy mass is submerged in the water during pre-steaming and steaming. The submerged paddy is parboiled by the hot water and the rest is parboiled by steam generated in the system. In boiler methods, steam is gen-

Table 2 Energy consumption in the parboiling process.

Treatment	Energy Consumption	
	kWh	MJ/t
T_1	0.225	1080.0
T_2	0.248	1190.4
T_3	0.269	1291.2
T_4	0.296	1420.8
T_5	0.322	1545.6

750 g of paddy was used for each treatment.

erated in the boilers and applied to the paddy in the hopper. In this study, the energy consumption was found to be lower than the reported energy consumption in traditional parboiling processes, perhaps because of the type of energy and equipment. The energy consumption in the conventional vessel and in this study (improved vessel) indicates that the improved vessel method would be useful to reduce energy consumption in the parboiling process.

Change of material temperature The material temperature plays a major role in the parboiling process and affects the quality of parboiled rice. The material temperature was increased with the increase of energy consumption. The highest material temperature was observed for the first layer, then the second and finally the third layer. Figure 7 shows the change of material temperature during pre-steaming and steaming treatment. Although the steam temperature was controlled to about 100°C, the maximum material temperature during pre-steaming was found to be about 86, 57 and 30°C for the first, second and the third layers, respectively. During steaming it was found to be 94, 81 and 63°C for the first, second and the third layers, respectively, which indicated a faster rise in material temperature for the first layer compared to the second and third layers. The difference in material temperature reveals that this parboiling process is responsible for uneven material temperature throughout the paddy mass, which affects the uniformity of parboiling.

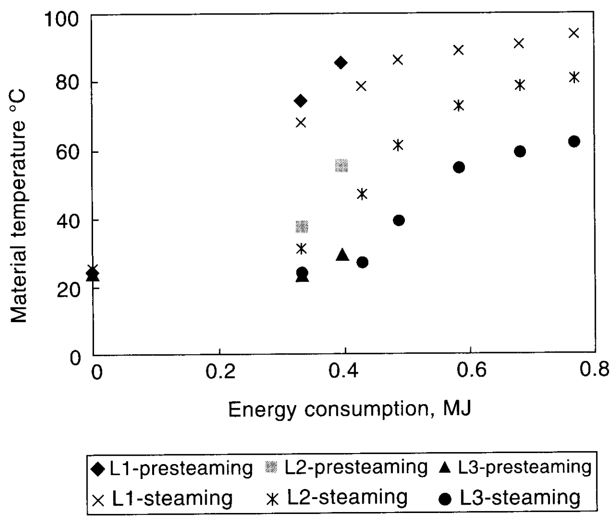

Fig. 7. Relationship between energy consumption and material temperature during pre-steaming and steaming.

Effect of material temperature on the quality of parboiled rice

Hardness Hardness of parboiled rice is closely affected by the cooking conditions and the gelatinization of rice starch. Higher temperature and longer duration of parboiling produce harder rice (Kimura, 1989). The hardness of parboiled brown rice was increased with the increase of material temperature for each layer (Fig. 8a). Higher hardness, which is an indicator of a higher degree of parboiling, was observed for the first layer compared to the other layers even though the duration of steaming and energy consumption were the same. Therefore, it seems that higher material temperature during the parboiling process is responsible for the higher hardness (Roy *et al.*, 2003a). The maximum hardness value was found to be 72, 56 and 48 N for the first, second and third layers, respectively.

Color intensity and lightness The color intensity of parboiled rice has a negative impact on consumer acceptability and causes loss of market value (Bhattacharya, 1985). Treatment conditions affect the color and lightness value of parboiled rice: a higher temperature and a longer period of soaking and steaming increase the color intensity (Bhattacharya and Rao, 1966; Kimura, 1989). In this study, color intensity was increased with an increase of material temperature during steaming (Fig. 8b). This figure also shows that the color intensity was increased sharply even though the material temperature was not. This may be because of the combined effect of the higher material temperature and the duration of steaming.

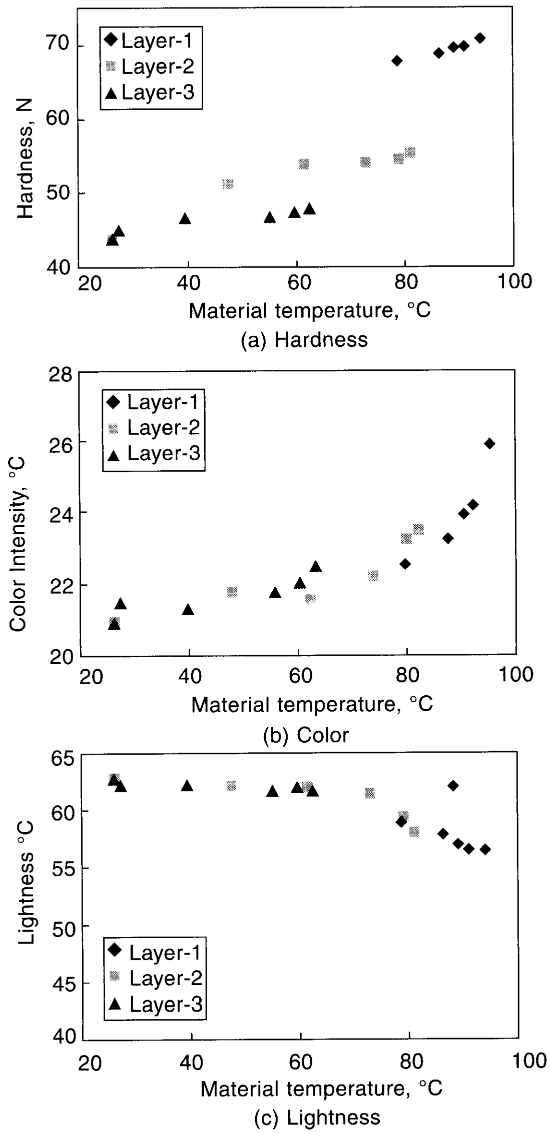

Fig. 8. Effect of material temperature on the hardness, color intensity and lightness of parboiled brown rice.

Production of lighter parboiled rice is very important for higher customer acceptance and market value. The lightness of parboiled rice is affected by the steaming time and temperature (Bhattacharya and Rao, 1966; Kimura *et al.*, 1993). In this study, the lightness value was decreased with an increase in steaming time and material temperature for each layer (Fig. 8c). Although the difference in the color intensity and the lightness value among the layers is insignificant, it seems that the first layer of paddy has the higher degree of parboiling, then the second and, finally, the third, this could be because of the difference in material temperature during steaming.

Head rice yield Parboiling treatments gelatinize the rice starch, improve the hardness of parboiled rice, and minimize the breakage loss during milling, which consequently increases head rice yield (Kimura *et al.*, 1995; Islam *et al.*, 2002). The head rice yield was increased with an increase of material temperature for all layers up to a certain level (90°C), which is considered to be the optimum material temperature for traditional parboiling. A further increase of material temperature had a negative impact on head rice yield, due to excessive parboiling. This resulted in over-opening of husk components followed by bulging out of the endosperm, which initiates surface scouring during milling and the resultant ground particle is lost into bran. On the other hand, incomplete or non-uniform parboiling produces white-bellied rice, which easily breaks during milling and reduces head rice yield (Sarker and Faruk, 1989). In this study, the head rice yield was decreased beyond 90°C of material temperature for the first layer (Fig. 9), which indicates that this layer has been parboiled too long. However, the second and third layers were incompletely parboiled, where the maximum material temperature was found to be about 81 and 63°C, respectively, and provided lower head rice yield. The head rice yield varied from 60 to 67%. The parboiling treatment increases the head rice yield of about 7, 4 and 2% for the first, second and third layers, respectively.

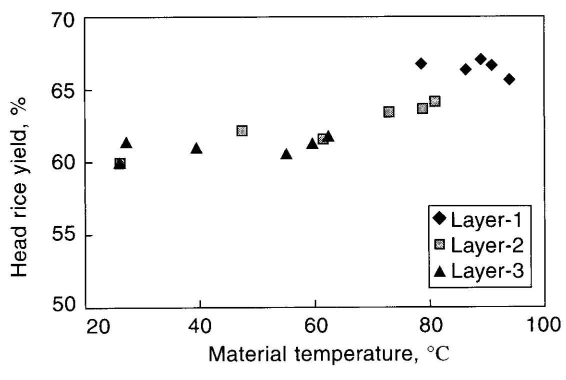

Fig. 9. Effect of material temperature on the head rice yield.

This study indicated that the material temperature plays the major role in the parboiling process. This process is responsible for uneven material temperature and can result in non-uniform parboiling, which produces lower quality parboiled rice. The maximum head rice yield could be achieved at the material temperature of about 90°C in 30 min of steaming with a uniform temperature distribution. Also indicated that the parboiling treatment should take place at or above the gelatinization temperature (67 to 73°C for Indian varieties, source: GFRI, 1969) of the paddy, which would reduce the steaming time and energy consumption in the traditional parboiling process. For the maximum head rice yield, which is the universal goal of the parboiling treatment, the hardness, color intensity, lightness and material temperature were found to be about 70 N, 24, 57 and 90°C, respectively, for the suitable quality of parboiled brown rice.

Conclusion

Parboiling treatment is given to the paddy to increase the head rice yield. In this study, the head rice yield increased about 7, 4 and 2% for the first, second and third layers, respectively. The temperature distribution was found to be uneven. A faster rise of material temperature was observed for the first layer compared to the second and third layers. The first layer (L_1) tended to have the highest hardness and color intensity and the lowest lightness value, then the second and, finally, the third layer, although the treatment time was the same; this could have been the result of the material temperature. The test results reveal that the material temperature has a profound effect on the quality of parboiled rice, and this parboiling process is responsible for non-uniform parboiling. Hence, development of a device for uniform parboiling is desired. A uniform temperature distribution during pre-steaming and steaming would be very important to improve the parboiling process and to produce better quality parboiled rice.

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