Performance of the traditional parboiling process

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Abstract

Laboratory scale studies were conducted to investigate temperature distribution and heat utilization efficiency in the traditional parboiling process using a rice cooker under open and covered conditions. A sample holder with a wire-mesh bottom was used to keep the sample above the hot water in the rice cooker. The material temperature and the quality of parboiled rice (measured by hardness and head rice yield) were also determined for different layers. The temperature distribution in the parboiling process (pre-steaming and steaming) was found to be uneven for both conditions. However, the covered method has a propensity to improve it. The change of material temperature was faster for the first, next was the second (middle) and last was the third (top) layer. The higher the thickness of the material, the lower the material temperature. The hardness and the head rice yield were found to be the highest for the first, then the second and third layer, which might be affected by the material temperature. The heat utilization efficiency also varied from 40.5 to 47.9%. The hardness, material temperature and energy consumption were about 70 N, 90 °C, and 1150 to 1290 MJ/t, respectively, corresponding to the maximum head rice yield (67-68%, first layer) which are considered to be the suitable quality of parboiled rice.

Keywords: traditional parboiling, temperature distribution, material temperature, heat utilization efficiency, quality of parboiled rice

Introduction

Parboiled rice is the staple food in some developing countries including Bangladesh. It is produced by both traditional and modern methods. Modern methods are energy and capital intensive, and are not suitable for 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% is processed in commercial rice mills (Rahaman et al., 1996). Generally, in the case of modern parboiling processes, hot soaking is given to the paddy for a period of 3 to 6 h at 55 to 70°C (CFTRI, 1969; Tiwary and Ojha, 1981; Kimura, 1989). For steaming, steam is generated in the boiler and is applied to the soaked paddy in hoppers through the connecting pipes. Single or double steaming process has been used in traditional parboiling processes. In the case of single steaming, paddy is soaked in normal water for a period of 36 to 72 h and in the case of double steaming pre-steamed paddy is soaked in normal water for 24 h. Various methods and devices are used in the traditional parboiling process to produce parboiled rice of different grades. Among the devices, the vessel (Fig. 1) is the most commonly used traditional parboiling device in villages, where no cover is used causing heat loss in the process and greater energy consumption (Roy et al., 2003a). 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), which is considered to be dual system and responsible for lower quality parboiled rice.

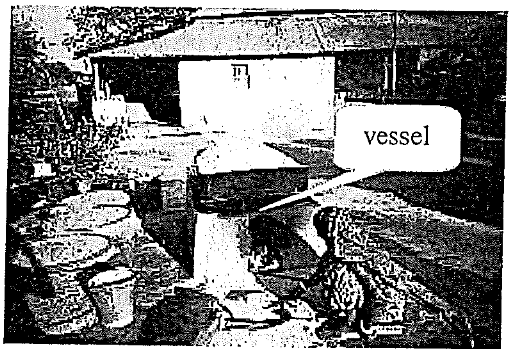

Fig. 1 Commonly used traditional parboiling device (vessel).

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Until now many researchers have studied the parboiling process. However, studies on temperature distribution and heat utilization efficiency are scarce except for a few examples (Kimura, 1989; Roy et al., 2004). It has been reported that upward temperature propagation is higher than the other direction and drastically increases in the temperature range higher than 90°C, which suggests that the density of perforation of the sample holder's bottom might be responsible for non-uniform steam flow through the paddy mass. The use of an improved parboiling vessel with a wire-mesh at a distance of 150 mm from the bottom has also been reported to reduce energy consumption in parboiling process compared with the conventional vessel method (Adhikarinayake and Swarnasiri, 1988), which keeps back the sample from the hot water in the vessel. The temperature distribution, energy consumption and heat utilization efficiency in the traditional parboiling process and its effect on the quality of parboiled rice is yet to be explored. Therefore, laboratory scale parboiling studies were conducted using a sample holder with a wire-mesh bottom.
The objectives of this study were:

i) To measure the temperature distribution
ii) To measure the heat utilization efficiency in traditional parboiling process and
iii) To measure the quality (hardness and head rice yield) of parboiled rice.

Materials and Methods

The Bellepatana, an *indica* variety of paddy, which was harvested in 2000 at the Japan International Co-operation Agency (JICA) farm, in Tsukuba, Japan, and stored in a refrigerated warehouse at 5°C, was used in this study. The double steaming process is the most common and widely used process for small-scale household production (Roy et al., 2003a) which was adopted for this study.

Parboiling

A stainless-steel sample holder with a wire-mesh bottom was developed and placed on an electric rice cooker (Model SR-W180, National Electric Co., Osaka, Japan) vessel to hold the sample above the water in the vessel. The peripheral surface of the sample holder and rice cooker was insulated with polyurethane foam sheets to reduce heat loss during parboiling. The steam generated in the vessel penetrates underneath it and parboils the paddy mass. 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 with the temperature controller, which helped to control the steam temperature and the other was connected with 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 process. Three nylon-net bags (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. Figure 3 shows a placement of the thermocouples and the schematic diagram of the experimental setup of this study. In the case of open steaming, the cover was not used on the sample holder.

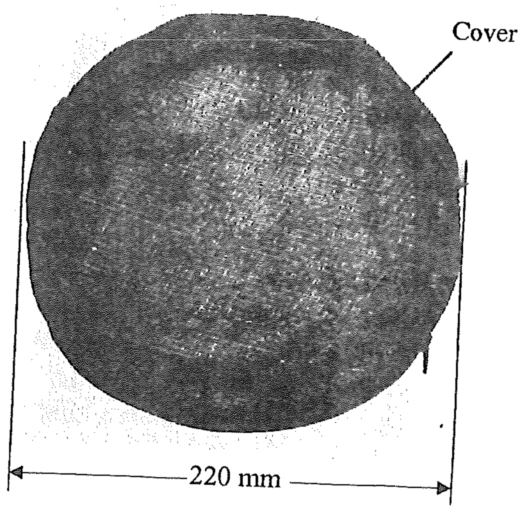

Fig. 2 Nylon-net bag

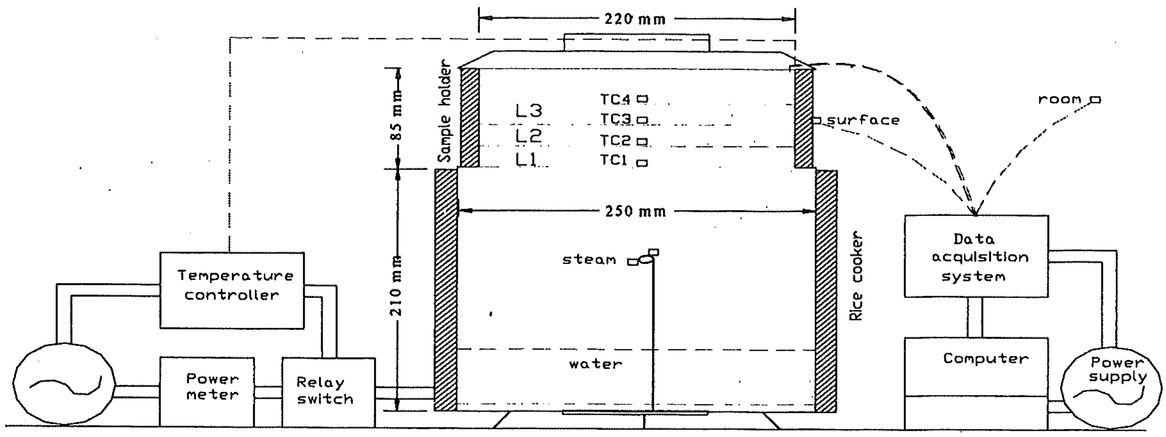

Fig. 3 Schematic diagram of the experimental setup

The paddy was washed with normal water (23.5°C) to remove the foreign matter and put in nylon-net bags after draining the water. 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). The pre-steamed paddy was soaked for 24 h (Haque et al., 1997) in the rice cooker. After draining out the excess soaking water, the soaked paddy was steamed to produce parboiled rice of different grades. Recording of the treatment time (steaming and pre-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 was added in the rice cooker vessel and then the pre-steamed paddy was submerged for soaking. The steamed paddy was then shade-dried at room temperature (25-28°C). It was dried in two stages: first it was dried up to 18-20% (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 (Bhattacharya and Swamy, 1967; Rahaman et al., 1996). Table 1 shows the parboiling conditions of this study.

Table 1. Parboiling conditions

Treatment	Paddy MC% (w.b.)	Pre-steaming, min	Steaming, min	Drying
T_1	13.0	7	10	
T_2	13.0	7	20	
T_3	13.0	7	30	To about 14% of moisture content at room temperature
T_4	13.0	7	40	
T_5	13.0	7	50	
T_6	13.0	7	10	
T_7	13.0	7	20	
T_8	13.0	7	30	
T_9	13.0	7	40	
T_{10}	13.0	7	50	

Note: Soaking = 24 h; T_1 to T_5 under open and T_6 to T_{10} under covered condition.

Measurement of Temperature Distribution and Material Temperature

The temperature distribution data was stored in a personal computer during pre-steaming and steaming. 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 bottom and surface of the paddy mass, respectively. The TC_2 was placed between the first and second layers. Similarly, 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. The average room temperature was 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 another week at 25°C and 60% relative humidity to homogenize it for all samples, which helped to avoid any effects of moisture content on de-husking and milling outturns. After de-husking, brown rice was also put in the humidity cabinet under the above conditions to stabilize the hardness and to homogenize the MC of brown rice before the measurement of quality indicators of parboiled rice.

Moisture Content

The MC of replicated samples was determined by the air oven method at 105°C (Roy et al., 2004) for 24h and expressed in percent, 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 brown 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.

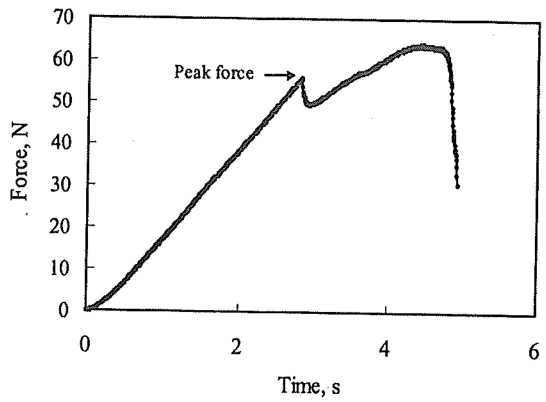

Fig. 4 Force deformation curve of parboiled brown rice

Head Rice Yield

Head rice yield is an estimate of the quantity of rice (whole kernels) which can be produced from a unit of paddy. The dried parboiled paddy was de-husked 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., Tendo, Japan). The degree of milling was restricted to 7-8% for maximum milling recovery (Rahaman et al., 1996) by varying time. 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 of paddy weight and expressed in percentage.

Heat Utilization Efficiency

The heat utilization was calculated for the different steps (pre-steaming and steaming) to calculate overall heat utilization. It was determined with the following equations and expressed it in MJ.

$$H_1 = m_1Cp(t_{pf}-t_{pi}) + m_2C_w(t_{wf}-t_{wi}) \quad \text{. . . . . Eq. 1}$$

$$H_2 = m_1C_p(t_{pf}-t_{pi}) + m_2C_w(t_{wf}-t_{wi}) + m_3C_w(t_{pf}-t_{pi}) + m_4C_w(t_{pf}-t_{pi}) + m_4L \quad \text{. . Eq. 2}$$

$$\text{Overall heat utilization (O.H.U)} = (H_1 + H_2) \quad \text{. . . . Eq. 3}$$

where, H_1 = *heat utilization in pre-steaming process*
H_2 = *heat utilization in steaming process*
m_1 = *weight of paddy, kg*
C_p = *specific heat of paddy kJ/kg (at 13% moisture content; Bala et al., 1987)*
t_{pf} = *final temperature of paddy, °C*
t_{pi} = *initial temperature of paddy, °C*
m_2 = *weight of water, kg*
C_w = *specific heat of water, MJ/kg*
t_{wf} = *final temperature of water, °C*
t_{wi} = *initial temperature of water, °C*
m_3 = *water absorbed during soaking, kg*
m_4 = *water absorbed during steaming, kg*
L = *latent heat of water, MJ/kg (considered only in the case of steaming)*

The overall heat utilization efficiency (O.H.U.E.) was calculated from the ratio of heat utilized in the process (pre-steaming+steaming) to the energy input in the process and expressed in 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 to improve the material temperature. The pre-steaming temperature rose to about 98, 75, 34 and 25°C for the open and 98, 75, 37 and 40°C for the covered conditions at the position of TC_1, TC_2, TC_3 and TC_4, respectively. Interestingly, in the case of covered conditions the temperature is found to be greater at TC_4 compared to the TC_3 because of the steam conservation which may come through paddy mass and through the peripheral surface of the paddy mass and helps to improve the temperature at the position TC_4. During pre-steaming a similar trend of temperature distribution was observed in all treatments of this study. Figure 5 shows an example of temperature distribution during the pre-steaming process.

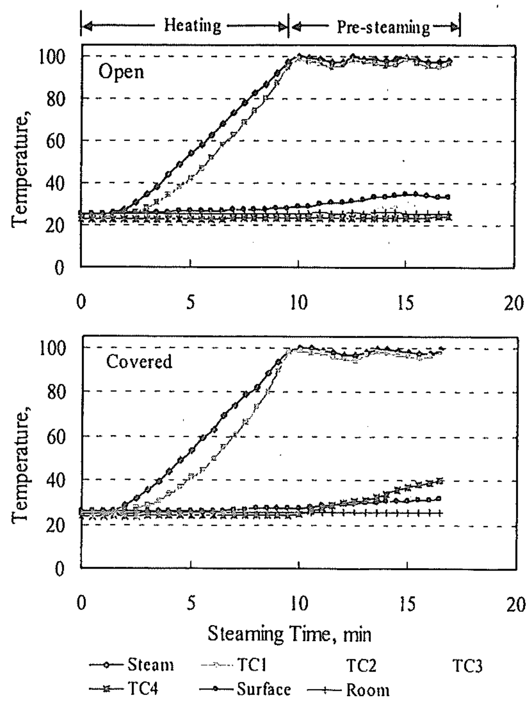

Fig. 5 Temperature distribution during pre steaming

Figure 6 shows the temperature distribution during the steaming process under open and covered conditions. The steam temperature reached 100°C in about 10 minutes of heating for both the pre-steaming and steaming treatment and for both conditions. The temperature rose to 100°C only at the position of TC_1 and it was gradually lower at the position of TC_2, TC_3 and TC_4 for both conditions. The covered condition produced higher temperature at the position of TC_2, TC_3 and TC_4 compared to the open condition even though the steam temperature was controlled at 100°C for both conditions. In the case of covered method after 40 minutes of steaming the temperature became closer to the steam temperature at all positions (92 to 99°C) but it never became closer in case of open method (50 to 99°C), which supports the earlier statement that the covered condition conserves steam and reduces heat losses in the parboiling process, hence produced higher temperature. Like the pre-steaming process, covered method improves the temperature distribution in the steaming process. Figure 5 and 6 also show the room and the surface temperature of the sample holder during pre-steaming and steaming treatments, respectively. In the parboiling process, heat is transferred through convection and conduction. The heat conduction with condensation plays a major role in the heat transfer during steaming. But in the high temperature the steam convection seems to expand its effect (Kimura, 1989). However, in this study it seems that the conduction plays the major role when power intake stops, i.e., steam generation is stopped.

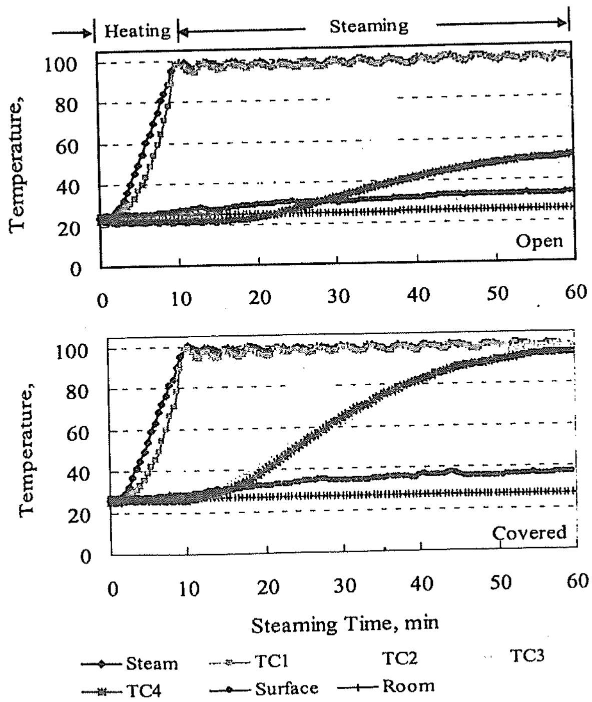

Fig. 6 Temperature distribution during steaming

Change of Material Temperature

The material temperature increased with the increase of energy consumption. The highest material temperature was observed for the first layer, next was the second and the last was the third layer (Fig. 7). Although the steam temperature was controlled to 100°C, the maximum material temperature was found to be 94, 81 and 63°C for the first, second and the third layers, respectively under the open condition after 50 minutes of steaming. Under the covered condition, the maximum material temperature was 98, 98 and 97°C for the first, second and the third layers, respectively after 50 min of steaming. The heat conduction and convection plays a major role to transfer heat in the parboiling process. However, in this study it seems that conduction with condensation plays a major role when power intake stops, i.e., steam generation is stopped. The cover helps to condensate the vapor pass through the paddy mass and its peripheral surface, which plays a major role to improve the third layer's temperature. A faster rise in material temperature for the first layer was observed compared to the second and third layers under both conditions. The difference in material temperature reveals that the traditional parboiling process is responsible for uneven steam distribution throughout the paddy mass, which affects the uniformity of parboiling. In the case of covered method the temperature distribution is found to be improved compared with the open method.

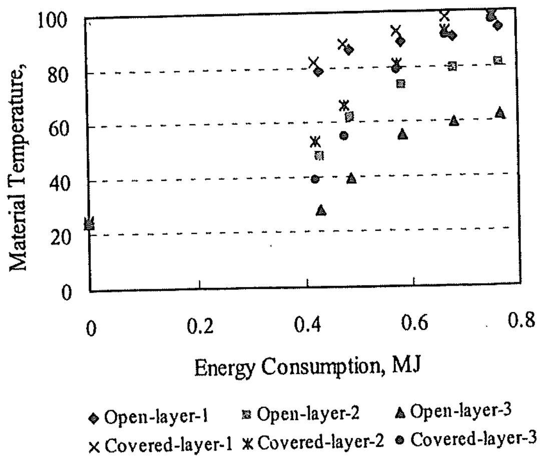

Fig. 7 Relationship between energy consumption and material temperature during steaming

Effect of Material Temperature on the Quality of Parboiled Rice

Hardness of parboiled rice is closely affected by the cooking conditions and the gelatinization of rice starch and dependent on the severity of parboiling. Higher temperature and duration of parboiling produce harder parboiled rice (Pillaiyar and Mohandoss, 1981; Kimura, 1989). The hardness of parboiled brown rice increased with the increase of material temperature for each layer (Fig. 8), which indicates that the higher material temperature during the parboiling process is responsible for higher hardness (Roy et al., 2003a, Roy et al., 2004). It also shows that the hardness was increased even though the material temperature was not increased might be because of the duration of steaming. Higher hardness, which is an indicator of a higher degree of parboiling, was observed for the first layer compared to the others for a certain steaming time under both conditions. The maximum hardness values were found to be 72, 56 and 48 N for the first, second and third layers, respectively under open condition as against 75, 68 and 61 N for the first, second and third layers, respectively under covered condition.

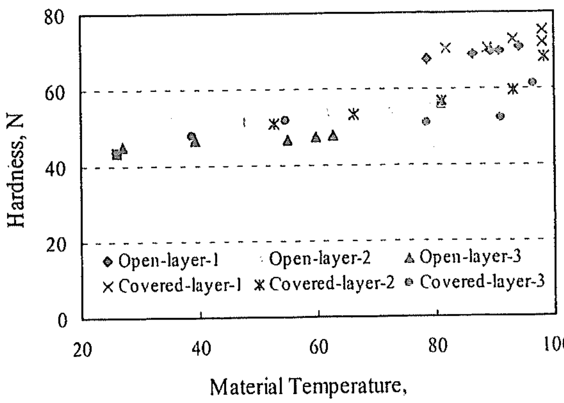

Fig. 8 Effect of material temperature on the hardness of parboiled brown rice

Parboiling treatments gelatinize the rice starch, improve the hardness of parboiled rice, and minimize the breakage loss, which consequently increases head rice yield (Gariboldi, 1974; Kimura et al., 1995). 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 the traditional parboiling (Fig. 9). A further increase of material temperature had a negative impact on the 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 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). The head rice yield varies from 60 to 68%. Twenty and 30 minutes of steaming time provides maximum head rice yield for the first layer under covered and open conditions, respectively and a further increase of steaming time has a negative impact for this layer, however it is positive for the second and third layers, which indicates incomplete parboiling for the second and third layers. The parboiling treatment improved the head rice yield of about 7, 4 and 2% for the first, second and third layers, respectively under open condition at different steaming time. The improvement of head rice yield is about 8, 8 and 7% for the first, second and third layers, respectively under covered condition. This study reveals that the maximum head rice yield would be achieved at the material temperature of about 90°C in 20 minutes of steaming with a uniform temperature distribution. This study also indicates that the parboiling treatment should be given at or above the gelatinization temperature of the paddy, which would reduce the steaming time and energy consumption in the traditional parboiling process. Considering the maximum head rice yield, which is the universal goal of parboiling treatment, the hardness and material temperature were found to be about 70 N and 90°C, respectively, for the suitable quality of parboiled brown rice.

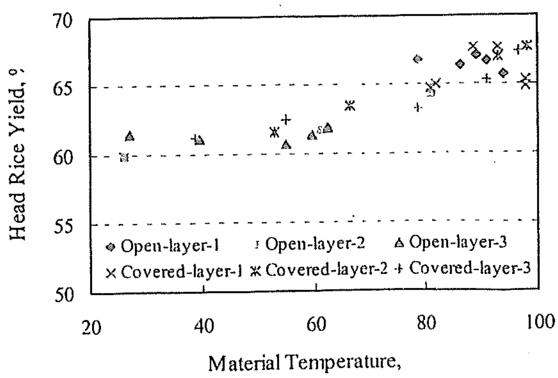

Fig. 9 Effect of material temperature on the head rice yield

Energy Consumption and heat utilization efficiency

The energy consumption in the parboiling process increases with the steaming time. In this study, a slight difference in energy consumption was observed among the 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. In this study, the energy consumption was found to be 1070.0 to 1545.6 MJ/t for different treatments (Table 2). The energy consumption in the commonly used traditional parboiling processes (vessel, small-boiler and medium-boiler) was reported to be 2583, 2758 and 1659 MJ/t, respectively (Roy et al., 2003b), where biomass energy (rice husk) was used and the average steaming time was 16 to 17 min. In the case of boilerless parboiling where hot soaking was given to the paddy and considered to be a modern method, it consumed 30 kg of rice husk to parboil 100 kg of paddy (4200 MJ/t) (Tiwary and Ojha, 1981). The energy consumption in this study was found to be lower than the reported energy consumption might be because of processing methods, type of energy and equipments and the use of the auto-tuning mode of the temperature controller. The use of the auto-tuning mode of the temperature controller indicates that the energy consumption in the traditional parboiling processes can be reduced by holding the material temperature (above gelatinization temperature, preferably at 90°C) after a certain period of steaming instead of continuous steaming. The energy consumption is found to be about 1150 to 1290 MJ/t corresponding to the maximum head rice yield, which is the main goal of parboiling.

Table 2. Energy consumption in the parboiling process

Treatment	Energy consumption, MJ/t
T_1	1080.0
T_2	1190.4
T_3	1291.2
T_4	1420.8
T_5	1545.6
T_6	1070.4
T_7	1142.4
T_8	1281.6
T_9	1396.8
T_{10}	1521.6

Note: 750 g of paddy was used for each treatment;
T_1 to T_5 under open and T_6 to T_{10} under covered condition.

This study reveals that the material temperature plays the most important role in the parboiling process. The difference in material temperature among the layers is responsible for the difference in the physical properties of parboiled rice. Although, there is no significant difference in the energy consumption between the open and covered methods but covered method produced higher temperature compared to the open method (Fig. 10), which may help to improve the traditional parboiling process with less amount of energy. This figure shows that the average temperature rose above the gelatinization temperature (70°C) of paddy after 20 and 30 minutes of steaming under covered and open methods, respectively and consumed 0.475 to 0.583 MJ of energy for 0.75 kg of paddy. Hence, an energy conservation measure can be achieved by adopting the covered method to produce better quality parboiled rice. The overall heat utilization efficiency was found to be 40.5 and 47.9% for open and covered methods, respectively, which also supports the earlier statement that covered method conserves heat and steam in the parboiling process and improved the overall heat utilization efficiency to about 7.4% compared to the open method. The improvement of overall heat utilization also indicates that the covered method appears to be technically feasible over the open method to produce better quality parboiled rice that consumes less energy.

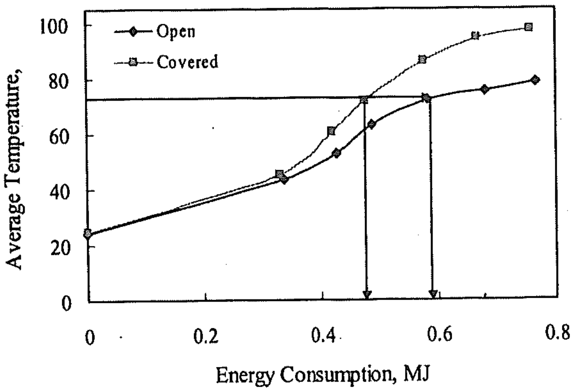

Fig.10 Relationship between energy consumption and average temperature during steaming

Conclusions

The temperature distribution in the traditional parboiling process is found to be uneven, but covered method has a propensity to improve it. A faster rise of material temperature was observed for the first layer compared with the second and third layers under both conditions. The first layer (L_1) tended to have the highest hardness than the second and the third layer for a certain steaming time. In this study, the head rice yield improves about 7, 4 and 2% under open method and it is about 8, 8, and 7% under covered method for the first, second and third layers, respectively at different steaming intervals. The test results reveal that the material temperature has a profound effect on the quality of parboiled rice and the traditional parboiling process is responsible for non-uniform parboiling. Considering the maximum head rice yield, the hardness, material temperature and energy consumption were found to be about 70 N, 90°C and 1150 to 1290 MJ/t, respectively. A uniform temperature distribution would be very important to improve the traditional parboiling process and to produce better quality parboiled rice. The covered method is found to be effective to improve material temperature, overall heat utilization efficiency and to reduce energy consumption.

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