Research Article

Cooking properties of different forms of rice cooked with an automatic induction heating system rice cooker

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Abstract

The cooking process was studied with an automatic rice cooker to determine the cooking properties of different forms of rice (well milled rice: WMR; partially-milled rice: PMR; germinated brown rice: GBR; brown rice: BR). Each form of rice was cooked with three different water-rice ratios using recommended cooking modes and temperature and energy consumption profiles were measured. Physical properties of cooked rice were also measured. Cooking time, temperature and energy consumption profiles differed among rice forms and consumed different amounts of energy. For a certain hardness value of cooked rice, brown rice required the longest cooking time and highest water-rice ratio and attained the highest amount of moisture and consumed the highest amount of energy compared to the other forms of rice. This study revealed that the cooking properties of rice are dependent upon the form, the water-rice ratio and the preset cooking mode.

Keywords: temperature and energy consumption profiles, physical properties, water-rice ratio

Introduction

Rice is the staple food of nearly two-thirds of the world's population. Although consumer preferences vary from region to region, the majority of consumers prefer well-milled or white rice containing little or no bran on the endosperm. For example, the Japanese prefer well-milled sticky rice [1], while Americans favour semi-milled long grain or brown rice and people from the Indian subcontinent like well-milled parboiled rice [2]. In Japan, rice is considered to be the most important crop in domestic agriculture. Japan produced 11.34 million tones of rough rice (paddy) in 2005 [3]. However, rice consumption has been decreasing since the 1960s, which has led to the development of various value-added rice products (germinated brown rice, rice bread etc.) to counter falling rice consumption in Japan. Rice-based food products come in diverse forms, such as partially milled, frozen or aseptically cooked [4, 5]. Per capita rice consumption is estimated to be 61.05 kg/year [6]. As a result of growing health consciousness, consumers have also started to consume partially milled rice or even brown rice [7]. However, some forms of rice (including partially milled and brown rice) are difficult to cook with an ordinary rice cooker, leading to the development of more modern rice cookers.

Cooking is the process of heating food to make it edible and suitable for consumption and a large portion of household energy is attributed to cooking. Thus far, much research has focused on the cooking process of well-milled rice directly transferred to an excess of boiling water or cooked in an ordinary rice cooker, hotplate or microwave oven [8, 9, 10, 11, 12, 13]. However, the cooking of rice (well-milled, partially-milled, brown and germinated brown) in a modern rice cooker by induction heating (IH) has yet to be reported and temperature and energy consumption profiles during the cooking process have not yet been examined. Despite this lack of literature, Panasonic released their steam induction heater rice cooker on to the Japanese market in June 2009 and several studies have been undertaken on the electronics involved in the process. Therefore, this study evaluated various forms of rice cooked with an IH system rice cooker to determine temperature and energy consumption profiles during the cooking process as well as the physical properties of cooked rice.

Materials and Methods

Brown rice (Koshihikari) cultivated in Ryuugasaki, Ibaraki-ken, Japan and harvested in 2006 was obtained from the local market and stored at 15°C was used for this study undertaken during the first half of 2007.

Milling
Brown rice was milled to varying degrees (single pass) by adjusting the duration of milling with a vertical friction-type milling machine (RK30, Hosokawa, Japan). The degree of milling (DOM) is a quantitative measure of the amount of bran that has been removed from kernels during the milling process. The outlet pressure and flow rate in the milling machine were fixed by trial and error before each milling to obtain 10% and 2% DOM. Whole grain was separated from broken grain with a cylinder-type test rice grader (TRG type, Satake Co., Higashihiroshima, Japan). The milled whole grain rice was stored in sealed polyethylene bags at 15°C prior to use for cooking.

Production of germinated brown rice (GBR)
Germinated brown rice was produced with an automatic rice cooker (NP-FT18-XJ, Induction Heating, Zojirushi Corporation, Japan) using the 9 h option in the rice cooker. Seven hundred and fifty grams of brown rice were used for each treatment. Brown rice was washed with distilled water (water temperature 25°C) and put in the rice cooker vessel with adequate amounts of distilled water (2850 ml). GBR was washed twice and transferred to a wire-mesh basket to drain the excess water. The GBR was whipped quickly (about 1 minute) on filter paper to remove the surface water and used to measure the cooking properties.

Cooking
Simple/ordinary rice cookers are typically used for the preparation of plain rice (white rice) and turned off at the end of cooking. Modern rice cookers use microprocessors to control the cooking process and incorporate a timer which can be used to set the desired start time of cooking and having different cooking mode to facilitate in cooking of a wide forms of rice (well milled rice, partially milled rice, gruel rice, germinated brown rice, brown rice etc.). Some of the improved modern cookers use an induction heating (IH) system. Rice was cooked in an automatic IH system rice cooker (NP-GA05-XA, Zojirushi Corporation, Osaka, Japan). One hundred and fifty grams of head rice was used for each treatment. Preliminary experiments had been conducted with well milled rice (WMR) and no differences were observed in cooking time (42.65±0.02 min) and energy consumption (0.56±0.03 kWh/kg) for a certain water-rice ratio (1.5). Temperature and energy consumption profiles were also observed to be similar. Therefore, the cooking experiment was not replicated for a certain water-rice ratio and cooking mode (forms of rice). After washing the rice, distilled water at 25°C was added to the desired water-rice ratio by mass (i.e., ratio of the mass of water and mass of rice). The rice cooker was immediately switched on after a 1 h soaking period [9, 13, 14], and the cooking time was recorded. Cooking time was considered to be from the time the rice cooker was switched on to the time it automatically turned off.

Measurement of energy consumption, t*emperature and energy consumption profiles*
Energy consumption during the cooking process was measured with a power meter (WT110E, Yokogawa Electric Corporation, Tokyo, Japan). A fibreoptic thermometer probe (FS100, Anritsu Meter Co. Ltd, Tokyo, Japan) connected to a fibreoptic thermometer (FL 2000, Anritsu Meter Co. Ltd, Tokyo, Japan) was used to measure temperature profiles during cooking. The fibreoptic thermometer and power meter were connected to a data logger (5030A, Thermodac-F, Eto Denki, Tokyo, Japan), which recorded temperature and energy consumption profiles. Figure 1 shows a schematic of the experimental setup used in this study. Thermometer probes were calibrated by measuring the temperatures of ice water and boiling water. One probe was placed inside the rice cooker about 1 cm above the surface and centre of the vessel to measure the temperature profile during cooking, while the other probe was used to measure the room temperature. Figure 2 shows the placement of the thermometer probe within the rice cooker.
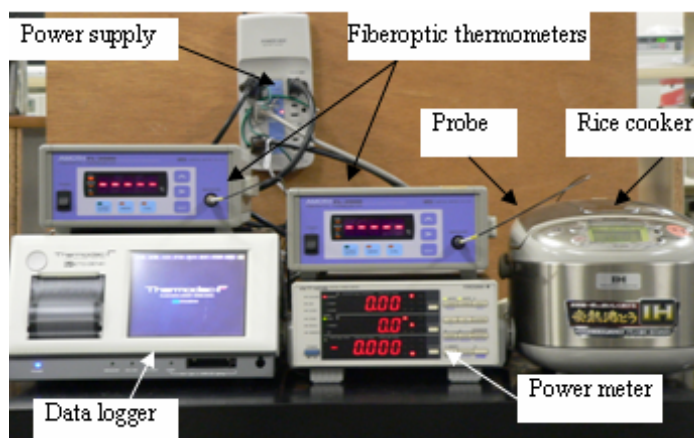
Figure 1. The experimental setup of this study.

Figure 2. Placement of sensor within the rice cooker vessel.

Measurement of physical properties of cooked rice
The upper portion of the cooked rice mass was removed and a sample was taken from the centre. The collected sample was then transferred into a container, covered (airtight) and kept for one hour prior to the measurement of any physical properties of cooked rice.

Moisture content
The moisture content of the cooked rice was measured in duplicate samples using the air oven method at 135°C for 2 h [15]. The average value was expressed as a percentage on a wet basis.

Hardness and adhesion
The hardness and adhesion of the cooked rice was measured with a Texture Analyzer TA-XT2 (Stable Micro System, Surrey, England) on a single rice kernel [16]. A load cell of 49 Newton (N) and a solid cylindrical probe 25 mm in diameter were used. The rice was placed onto a

sample table in the centre of the probe in a flat position [17] and compressed to 80% deformation to measure the positive and negative peak force that could be endured by a single kernel; these values were used to represent the hardness and adhesion of the rice, respectively (Fig. 3). Each measurement was repeated twenty times using 20 different rice kernels and the average value was reported.
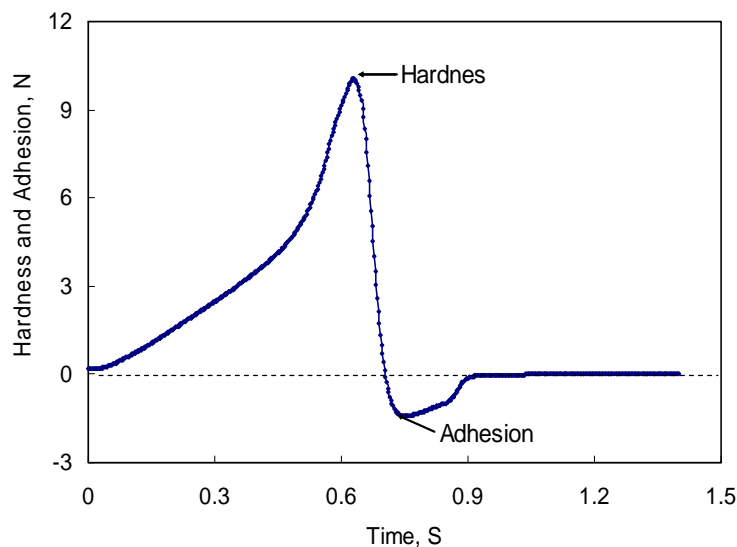

Figure 3. An example of force deformation curve of cooked rice.

Results and Discussion

Temperature and energy consumption profiles during cooking and energy consumption
The cooking properties of rice are largely related to the gelatinization properties of its starch granules [18]. The severity and duration of heat treatment of the food generally depends on the type of food cooked. Similarly, the severity and duration of heat treatment of rice varies greatly depending on the form of rice used. It is reported that gelatinization occurs over a range of temperatures and can commence anywhere between 55 and 79°C depending on the rice variety. Brown rice is noted for requiring longer cooking time compared to milled rice. The differences in the cooking times of brown and milled rice may also be related to differences in their starch gelatinization temperatures and water absorption properties. Rice starch samples with higher gelatinization temperatures have been shown to require longer cooking times than those with lower gelatinization temperatures [19]. Binding of lipids to rice amylose and amylopectin may result in higher gelatinization temperatures [20, 21]. The properties of different forms of rice might lead to the development of different cooking modes on a rice cooker to facilitate the cooking process. It is also reported that the starch granules may break and loosen at around 60°C [22]. Figure 4 lists temperature and energy consumption profiles during the cooking process for different forms of rice cooked in their respective cooking modes. The recommended (reported in the user's manual for the rice cooker) water-rice ratios (WRRs) were 1.5, 1.6, 1.5 and 1.9 for well-milled rice (WMR), partially milled rice (PMR), germinated brown rice (GBR) and brown

rice (BR), respectively [23]. Initially, energy intake for WMR, PMR, GBR and BR was found to be continuous for 0.7, 0.7, 0.9, 1.6 minutes, respectively. Afterwards, power intake was discontinuous until 16.8, 22.5, 25.0 and 16.0 minutes for WMR, PMR, GBR and BR, respectively, and appeared to be influenced by the cooking mode (i. e., form of rice). Again the energy intake was found to be continuous from 16.8 to 22.2, 22.5 to 28.3, 25.0 to 31.0 and 16.0 to 22.5 minutes for WMR, PMR, GBR and BR, respectively. The temperature rose progressively with power intake, reaching about 50°C. This period spanned approximately 18.0, 23.0, 25.0 and 17.0 minutes for WMR, PMR, GBR and BR, respectively. After this period, power intake was continuous and the temperature rose sharply for all forms of rice, reaching about 100°C in 28.0 minutes with the exception of WMR. For WMR, the temperature reached 100°C in 25.0 minutes. Figure 4 also shows that during cooking temperature reached 60°C in about 18.6, 24.1, 26.3 and 17.4 minutes for WMR, PMR, GBR and BR, respectively, which indicates that gelatinization may start early in the case of BR compared to other forms of rice which might have preset based on the properties of rice. The cooking time was found to be 42.6, 49.3, 62.5 and 75.4 minutes for WMR, PMR, GBR and BR, respectively which might be affected by cooking mode, form of rice and WRR.

A similar trend in temperature and energy consumption profiles were observed for a certain forms of rice at different WRRs and those are reported only for the recommended WRRs (in the user's manual of rice cooker). Figure 5 shows the relationship between cooking time and energy consumption of different forms of rice. At this cooking condition energy consumption was found to be 0.540, 0.667, 0.794 and 0.860 kWh/kg for WMR, PMR, GBR and BR, respectively. These results could be due to differences in the WRRs or patterns of power intake and energy consumption and gelatinization properties of rice, which appear to be dependent on the form of rice cooked (i.e., preset cooking mode). The caryopsis coat consists of the pericarp and seed coat, both of which have high wax contents [24]. These layers act as a diffusion barrier for water and retard penetration of the starch granules, thereby delaying the gelatinization process [25, 26]. Removal of these waxy layers eliminates this barrier and allows gelatinization to occur at a lower temperature. It is also reported that larger and thicker grains require longer cooking times [7, 27]. Milling also reduces the kernel size and gelatinization temperature to about 20% DOM [28], possibly leading to decreases in preset cooking times for various forms of rice.
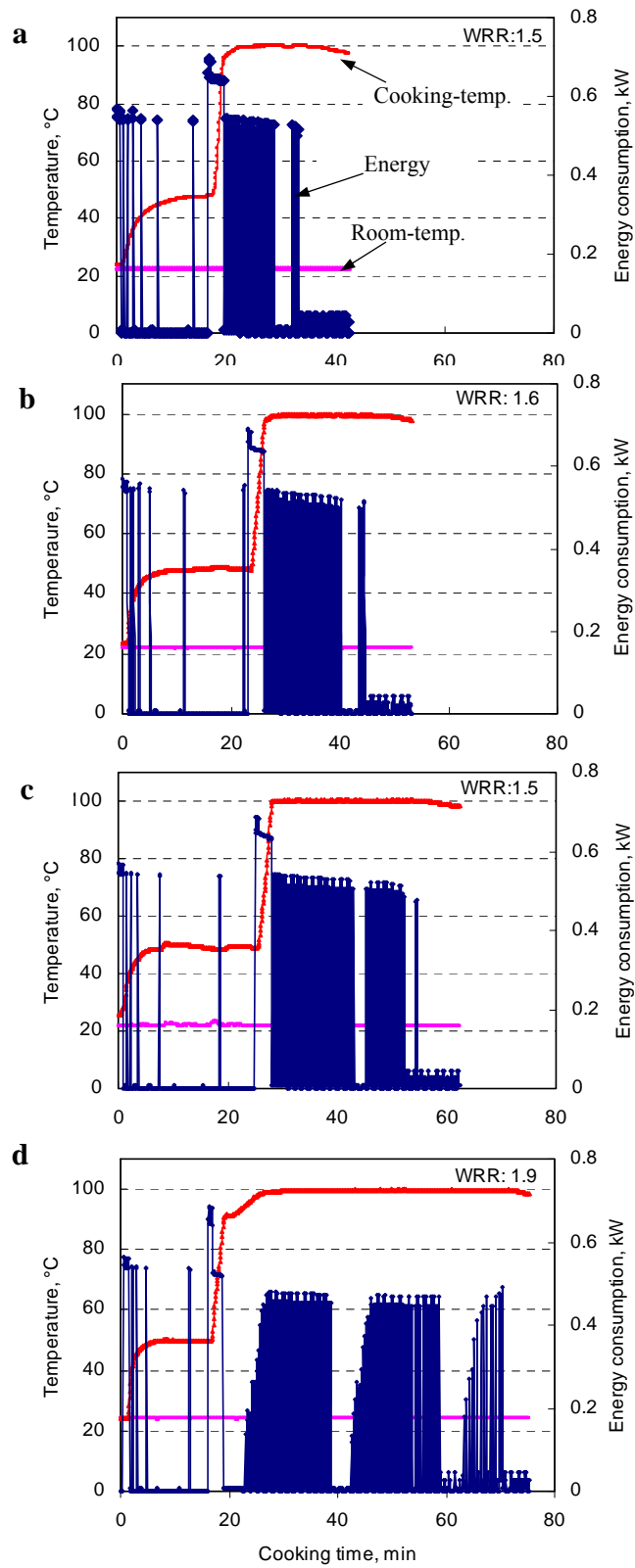
Figure 4. Comparison among different forms of rice (a. WMR; b. PMR; c. GBR; d. BR).
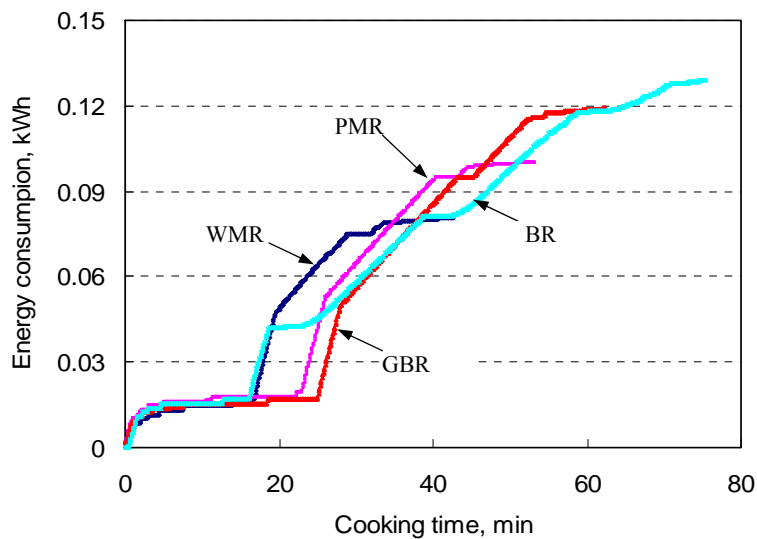
Figure 5. Relationship between cooking time and energy consumption of different forms of rice.

To determine the effect of cooking mode on the temperature and energy consumption profiles, rice was prepared in cooking modes other than its recommended mode. For example, WMR was cooked in a rice cooker with the PMR, GBR and BR cooking modes. The WRR remained constant at 1.5 for each cooking mode. Temperature and energy consumption profiles of WMR were shown in Figs. 4a and 6. They show that the temperature and energy consumption profiles were similar to those previously observed, although WMR was prepared using different cooking modes. Moreover, the period of continuous energy intake was found to be similar to those observed for different forms of rice cooked in their respective cooking mode (in Fig. 4). These figures revealed that the temperature and energy consumption profiles are dependent on the cooking mode and the form of rice has little or no influence. The effect of WRR on temperature and energy consumption profile for WMR was shown in Figs. 4a and 7. They show that the temperature and energy consumption profiles of WMR cooked with different WRRs were similar for each WRR. In all cases, the temperature increased progressively and was held at 50°C for 18.0 minutes before a sharp rise to 100°C was seen at about 23.0 minutes for each WRR. Although the temperature and energy consumption profiles are similar, the power intakes were found to be spanned slightly longer for greater WRRs. The cooking time was found to be 41.0 to 46.0 minutes and seems to be induced by the WRR.
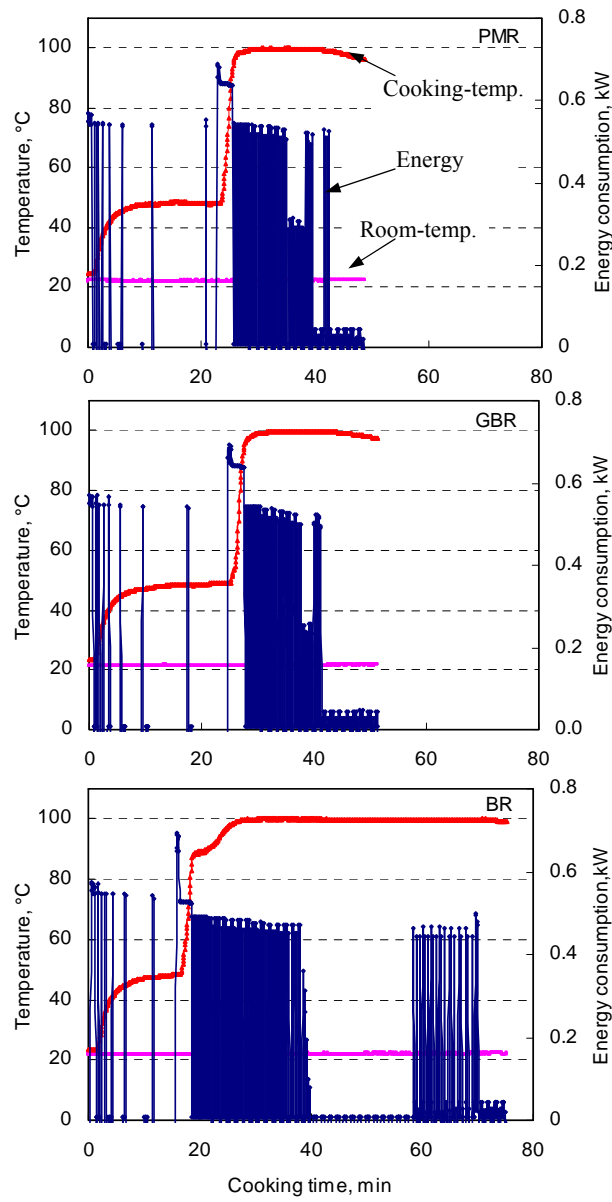
Figure 6. Effect of cooking mode on the temperature and energy consumption profiles for WMR with WRR 1.5.
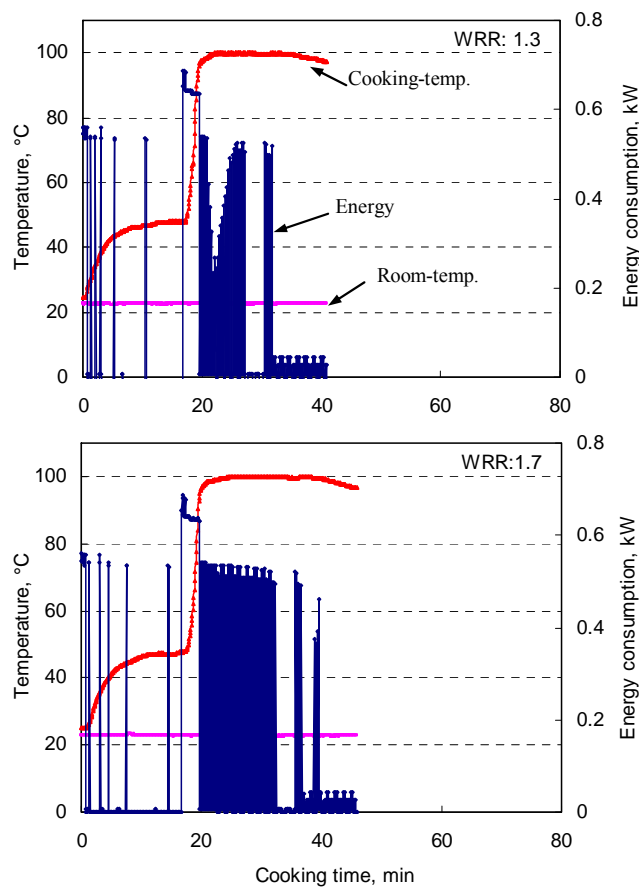
Figure 7. Effect of WRRs (water rice ratio) on temperature and energy consumption profiles for WMR (well milled rice).

Effect of cooking mode on the physical properties of rice

The main goal of cooking is to improve the moisture content and reduce the hardness of cooked rice. The physicochemical properties, such as MC, hardness and adhesion of cooked rice, affect the eating quality of rice. Several researchers have reported that the MC of cooked rice influences its hardness and adhesion [10, 16, 29]. A wide range of MCs for cooked rice was reported to give an acceptable soft texture (61% to 72% for well-milled untreated and parboiled rice of Indica variety, well-milled, partially milled, and brown rice of Japonica and Indica varieties, [10, 30]) or to be the result from optimal cooking (about 75% for parboiled rice of Indica variety, [27]). Additionally, in order to produce a suitable and acceptable soft rice texture, the hardness of cooked rice should be approximately 10 N [10, 31]. Therefore, each rice sample was cooked with three different WRRs using their recommended cooking modes in the rice cooker. Figure 8 shows the relationship between the WRR and moisture content of cooked rice. The MC of cooked rice increased with an increase in WRR for all forms of rice.
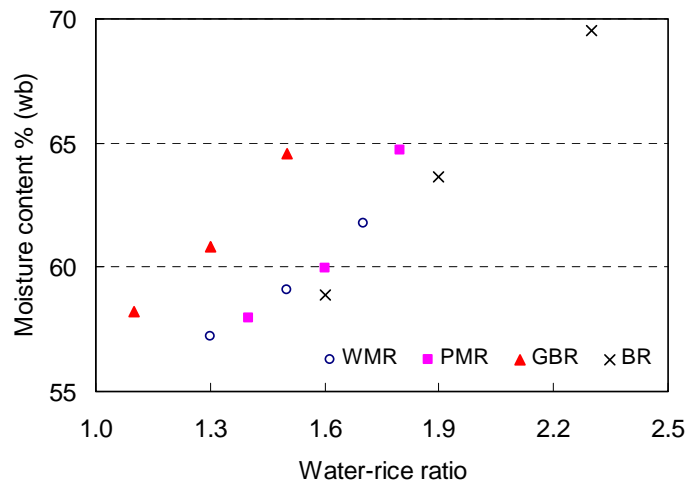
Figure 8. Effect of the WRR on the MC of cooked rice.

The hardness of cooked rice was found to be inversely proportional to the MC of cooked rice (Fig. 9). At the same MC level, the hardness of cooked BR was the highest and the hardness was lowest for WMR. A linear relationship was established between MC and hardness ($r^2 \geq 0.9$) to determine the MC of cooked rice for an acceptable soft rice texture (10 N). The MC of cooked WMR, PMR, GBR, and BR was found to be about 62%, 66%, 64% and 68%, respectively. The hardness of cooked rice was found to be dependent not only on its capacity to bind water, but also on the form of rice cooked. For an acceptable soft texture, 1 kg of WMR, PMR, GBR and BR produced 2.2, 2.5, 1.8 and 2.7, kg of cooked rice, respectively. The results were found to be consistent with other studies [30, 32].
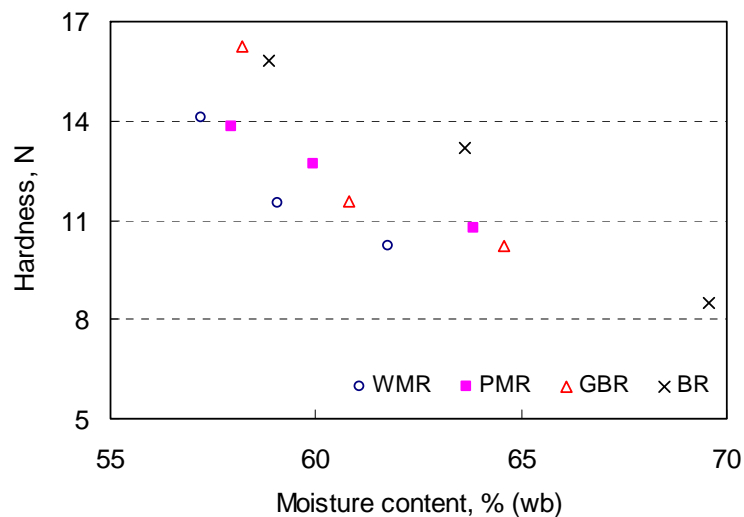

Figure 9. Effect of the MC on the hardness of cooked rice.

Figure 10 represents the effect of MC on the adhesion of cooked rice. The adhesion of cooked rice increased with the increase of moisture content, and then it decreased. The highest adhesion value for WMR, PMR, GBR and BR was found to be 1.9, 1.8, 1.1 and 1.3 N, respectively. It may be because of starch gelatinization after cooking, which improves the stickiness of cooked rice up to a certain MC. With a further increase of moisture content, the stickiness might decrease and affect the adhesion of cooked rice. This result also indicates that the adhesion value of cooked rice is dependent on the form of rice. The presence of bran might negatively affect the adhesion and reduce the stickiness of cooked rice.
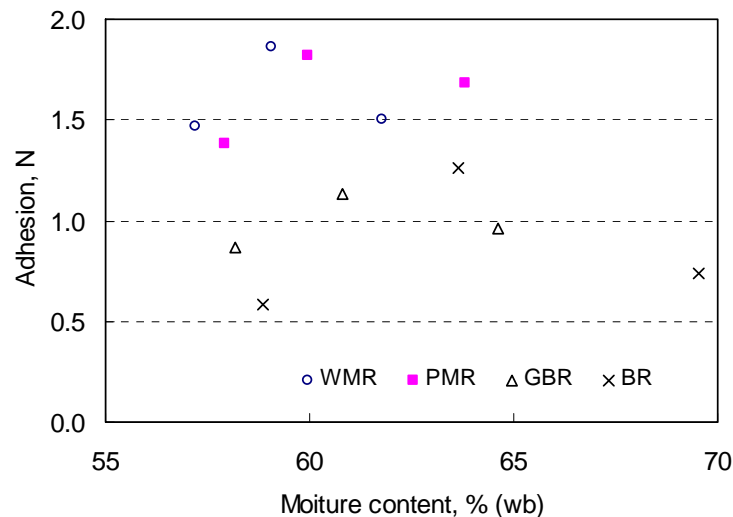

Figure 10. Effect of MC on the adhesion of cooked rice.

The MC of cooked rice was reported to be dependent upon the energy consumed during the cooking process [10]. The MC of cooked rice increased with an increase in energy consumption for all forms of rice (Fig. 11). Energy consumption was found to be the highest for BR and lowest for WMR. A linear relationship between energy consumption and MC of cooked rice was established ($r^2 \geq 0.9$) to calculate the energy consumption for an acceptable soft rice texture. For a fixed hardness value of 10 N (MC of cooked WMR, PMR, GBR, and BR was 62%, 66%, 64% and 68%, respectively), energy consumptions for WMR, PMR, GBR and BR were estimated to be 0.608, 0.692, 0.783 and 0.923 kWh/kg rice, respectively. The acceptable WRRs were also determine from the relationship between WRR and MC and found to be 1.7, 1.8, 1.4 and 2.2 for WMR, PMR, GBR and BR, respectively, for acceptable soft rice texture (10 N).
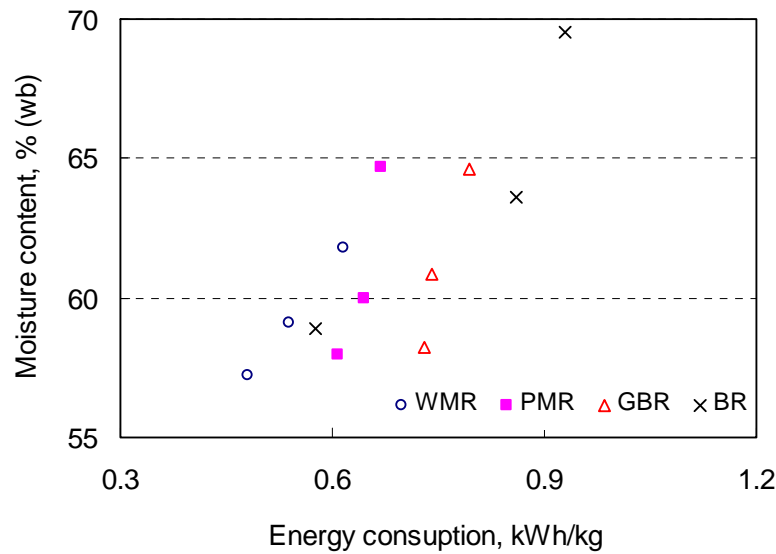
Figure 11. Relationship between the MC of cooked rice and energy consumption.

The effect of cooking mode was also evaluated for WMR. Table 1 shows the cooking conditions and physical properties of WMR. The difference in the hardness of cooked rice (cooking mode: GBR and BR) was found to be 0.0 to 2.6% compared to the hardness of rice cooked with WMR cooking mode, but the difference was 20.8% in the case of PMR cooking mode. The difference in MC was observed to be 0.5% to 3.0%. However, the differences in cooking time and energy consumption were found to be 14.6 to 76.6% and 12.6 to 43.2%, respectively. The BR option required a longer cooking time than either the PMR or GBR due to the preset cooking mode, which may be programmed according to the cooking properties of each rice form. Other forms of rice were cooked with different cooking modes which also indicated that rice had no influence on the cooking time and energy consumption, whereas the cooking mode did (results are not included). This study revealed that the temperature and energy consumption profiles, cooking times and energy consumption were influenced not only by the rice form or the WRR, but also by the preset cooking mode, which may be differentially programmed based upon the properties of various forms of rice.

Table 1. Effect of cooking mode on the cooking properties of rice.

Forms of rice	Water-rice ratio (WRR)	Cooking mode	Cooking time, min	MC% (w.b.)	Hardness, N	Energy consumption, kWh/kg
WMR	1.5	WMR	42.6	59.1	11.5	0.539
		PMR	48.8	59.4	9.1	0.607
		GBR	51.4	60.3	11.8	0.626
		BR	75.3	60.9	11.5	0.772

Conclusions

This study revealed that the temperature and energy consumption profiles as well as cooking times are influenced by the cooking mode of the rice cooker, which may be differentially programmed based on the form of rice used. BR required the longest cooking time, while WMR had the shortest among different forms of rice (WMR, PMR, GBR and BR). For an acceptable hardness (10 N) of the tested rice forms, BR consumes the greatest amount of energy during cooking, followed by GBR, PMR and WMR.

Acknowledgement

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