Energy conservation in domestic rice cooking

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Abstract

Energy conservation in cooking rice is an important area for scientific investigation. Experiments were conducted to measure the energy consumption during normal and controlled cooking of both unsoaked and presoaked rice using two types of domestic cooking appliance, namely, an electric rice cooker and a pressure cooker. Cooking rice with controlled energy input, under pressure and with presoaking were the three approaches, which resulted in saving of energy. Electric rice cooker was found to be the most energy-efficient among the different combinations of cooking appliance and the types of heat source used in the study. The energy consumption was much less (23–57%) compared to other methods. Prior soaking of rice generally reduced energy consumption as well as cooking time, more prominently during normal cooking. Controlled cooking offered more savings in energy compared to presoaking rice. Considering the energy consumption and cooking time, controlled cooking of presoaked rice was found to be the best among the several approaches investigated. Measurement of water evaporation loss appears to be a good indirect method of assessing the efficiency of heat utilization. Controlled energy input is another useful method that optimizes the energy utilization for cooking, besides presoaking and pressure cooking. Controlled cooking is desirable in all types of rice cooking.

Keywords: Controlled cooking; Cooking time; Domestic cooking appliance; Energy saving; Gelatinization; Presoaking; Pressure cooking; Rice cooking

1. Introduction

Rice is one of the world's major cereal crops next to wheat and maize, and is the staple food for nearly half of the world's population. It is grown in over 100 countries spread in every continent except Antarctica (Juliano, 1985). The production of paddy in India during 2004 was 124 Million tonnes (http://faostat.fao.org) and ranks second in the world next to China. Milled raw and parboiled rice are consumed mainly as cooked rice. The cooking process and the choice of cooked rice texture are different from place to place. Consumers in Western countries prefer long grain, light, fluffy or slightly dry individual kernel of rice having cooked flavour with essentially no gritty or hard uncooked core. Japanese preference is for short grain, which produce rather sticky cooked rice. However, Indian preference is for medium grain with fluffy, light individual kernel of rice with cooked flavour and without hard core.

The two important variables in rice cooking are the amount of water and the control of heating. The water-to-rice ratio is important in keeping the cooked rice from being either too hard or too soft. Controlled heating ensures that the rice is gently heated and gelatinized to the core without getting scorched. The cooking of rice is associated with complete gelatinization of the starch, complex formation, transformation and interactions involving biopolymer by heat treatment in the presence of water. Suzuki, Kubota, Omichi, and Hosaka (1976) reported that cooking rate followed the equation of a first-order chemical reaction.

Electric rice cooker and pressure cooker are commonly used in domestic rice cooking. The electric rice cooker works on the principle of dielectric heating and originated from the military equipment (Juliano & Sakurai, 1985). This method has been improved over the years to make the quality of the cooked rice more acceptable. In the automatic rice cooker, heat is regulated by a thermostat coupled with microswitch, which switches off the heater when the water is completely absorbed and the temperature begins to rise rapidly. The temperature of the rice decreases quickly after the heater is switched off. Therefore, cookers with '*cooking*' and '*keep warm*' modes were introduced which are common in countries like India. In 1938, Alfred Vischler introduced the very first pressure cooker, Flex-Seal Speed Cooker designed for home use (http://missvickie.com). The pressure cooker has seen many developments and is extensively used in many households.

Past research has indicated that presoaking, storage and degree of milling influence the cooking time of whole rice grain. Santos, Guzman, Umali, Mananes, and Abanto (1980) carried out a study on time and fuel conservation in rice cooking. They reported that it is possible to reduce the cooking time of rice with presoaking by 7 and 5 min using electricity and gas (LPG), respectively. Sowbhagya and Ali (1991) also observed reduction of cooking time when rice was presoaked. Since presoaking leads to energy saving, it is included as a vital step in the manufacture of dried rice from pregelatinized starch (Yano, Taniguchi, & Nakanaga, 1988). Kim and Cho (1993) studied changes in water uptake rate, cooking and gelatinization properties during storage of milled rice for 3 months. They reported that rice grain became harder and cooking time was prolonged by 3–8 min as a result of storage. Cheigh, Kim, Pyun, and Kwon (1978) reported that the cooking rate of rice followed the equation of a first-order reaction and the reaction rate constants increased with increasing polishing degree from 50% to 90%. Cooking rate of brown rice was about 50% that of white rice (Kim, Pyun, Choi, Lee, & Kim, 1984). Bhattacharya (1993) carried out a study on energy consumption for cooking raw and parboiled rice using a pressure cooker with LPG stove. He reported that the lowest specific energy consumptions were achieved by cooking large quantity at a time as well as adopting cooking methods of shorter duration.

'Energy saved is twice generated' and rice cooking is a good candidate for a case study since rice is the staple food for nearly half of the Indian population. Presoaking is a simple technique that offers great savings (energy and cooking time) in cooking stored or freshly milled rice. However, cooking rice without presoaking is the general practice in many parts of the world. While presoaking needs to be promoted as an energy conservation measure, there is a necessity to look for further saving in energy. In the present work, attempts have been made to optimize the energy requirements in rice cooking by controlling the cooking conditions in the domestic cooking appliances such as electric rice-cooker and pressure cooker.

2. Materials and methods

2.1. Materials

One lot (100 kg) of milled B.T. (Bangara Thigadu) variety rice was procured from the local market and stored in a refrigerator at 4 °C. The required quantity of rice was taken out as and when necessary for the experimental work. The moisture content of the raw rice was 12.8% (w.b.) as determined by oven dry method (105 °C for 24 h) (Swamy, Ali, & Bhattacharya, 1971).

2.2. Methods

A number of preliminary experiments were conducted to standardize the conditions for each set of experiments.

2.2.1. Hydration behaviour at ambient conditions

Rice (150 g) was soaked in excess water at room temperature and samples were drawn at different time periods (at intervals of 15 min up to 2 h, and at intervals of 30 min from 2 h to 5 h) and moisture contents were measured using oven-dry method as suggested by Swamy et al. (1971). A hydration curve was obtained by plotting the moisture content (% w.b.) of rice versus soaking time. Besides, the rate of absorption of water during soaking was obtained from the data.

2.2.2. Identification of end point of cooking

The end point of cooking was identified by using parallel glass plate method as proposed by Desikachar and Subrahmanyan (1961). In this method, the rice samples periodically drawn during cooking were pressed in between two small glass plates and when there was no more white core observed, then the sample was considered to be completely cooked. Sowbhagya and Ali (1991) examined the texture of cooked rice by a sensory method of testing the firmness by pressing the cooked grains between thumb and forefinger. They reported that the moisture content of cooked rice samples was in the range of 72–73% for raw rice. Therefore in all our experiments, method of Desikachar and Subrahmanyan (1961) was used as a quick test and for confirmation;

moisture content of the cooked rice was subsequently measured for parallel samples.

2.2.3. Cooking in excess boiling water

A known quantity of water (300 g) was taken in a beaker and heated over an electrical coil stove. A measured quantity of rice (50 g) was added once the water reached boiling state. The heating was continued till the completion of cooking at the same heating rate and the time was recorded. Samples were drawn out periodically for assessment of cooking stage (5–6 grains) and measurement of moisture (3–5 g) at different (1–3 min) time intervals. Temperature of rice and water was recorded at regular time intervals using a thermocouple at a fixed appropriate location. This experiment was carried out for both unsoaked as well as presoaked rice (soaked for 30 min). The moisture content of completely cooked rice was ~74% (w.b.).

2.2.4. Cooking in domestic appliances

Experiments were conducted with electric rice cooker (SR-810FN, 2.7 L, 450 W, National, Thailand) and pressure cooker (Model: Butterfly, 7.5 L, IS: 2347, Gandhimathi Appliances Ltd., India). The pressure cooker was evaluated using two different heat sources, namely, electrical coil stove (2000 W, Surana, India) and LPG stove (Pentax Pioneer, India). It was operated in two modes, namely, open cooking (without pressure pin) and pressure cooking (with pressure pin). Normal and controlled cooking experiments were carried out for both unsoaked as well as presoaked (30 min) rice. The detailed experimental plan is provided in Table 1.

The normal cooking experiments were performed generally as per the recommended guidelines of the appliance manufacturer and according to the general practice. The controlled cooking experiments were conducted to achieve energy savings by controlling the energy input to closely match the actual energy required for cooking. Temperature was monitored and the heat input was cut off whenever the temperature of the contents (rice and water) reached the boiling temperature (~100 °C) and was resumed whenever the temperature fell below 90 °C. This strategy of controlled heat input was continued till rice got cooked which prevented excessive evaporation of water resulting in energy saving.

2.2.4.1. Cooking in electric rice cooker. Experiments were conducted to standardize the cooking procedure in the electric rice cooker mainly to optimize water evaporation loss. The amount of water evaporation was monitored during experimentation with the help of an electronic balance (Model DS-420, Essa-Digi, India). In the subsequent experiments, the amount of extra water required owing to evaporation loss was added along with the water required for cooking to make the final moisture content of cooked rice to 74% (Table 1). Thermostat coupled with microswitch automatically switched off the cooker at the end of cooking when there was no more free water available in the container.

During controlled cooking experiments, heat input was controlled using the ON–OFF power supply of the electric rice cooker. The temperature of the cooker contents was measured at a fixed location with the help of a thermocouple linked to a display unit. The total duration of cooking as well as power ON–OFF durations were recorded. Energy consumption was measured with an energy meter.

Moisture content of cooked rice at different locations (normal cooking of unsoaked rice)

After cooking was done, the cooker container was covered with the lid and kept undisturbed for 10 min.

Table 1
Experimental plan and standardized conditions for cooking rice using different types of cooking method[a]

S. no.	Type of cooking	Method of heating	Unsoaked		Presoaked	
			Normal	Controlled	Normal	Controlled
		Standardized conditions	Total water[b] (g); No. of whistles	Total water[b] (g); No. of whistles	Total water[b] (g); No. of whistles	Total water[b] (g); No. of whistles
1	Electric rice cooker		830	725	830	723
2	Pressure cooker	Electrical stove				
	(a) Open cooking		706	706	706	706
	(b) Pressure cooking		706; 2	706; Nil	706; 1	706; Nil
3	Pressure cooker	LPG stove				
	(a) Open cooking	(high flame)	706		706	
	(b) Open cooking	(high + low flame)	706	706	706	706
	(c) Pressure cooking	(high flame)	706; 1		706; 1	
	(d) Pressure cooking	(high + low flame)		706; Nil		706; Nil

[a] Quantity of rice used for cooking was 296 g (moisture content 12.8% w.b.); water required to achieve 74% moisture content was 706 g; water used for steam generation in pressure cooker was 500 g.

[b] Total water used in the cooker container.

The moisture content of the cooked rice was determined at five different layers from top to bottom at 1 cm apart by oven-dry method. Samples at different layers were collected by obtaining cylindrical portion of cooked rice from three locations (one at the centre and two at the periphery), using an open-ended cylindrical glass tube. The samples were immediately transferred in to the moisture cups for moisture estimation.

2.2.4.2. Cooking in pressure cooker using an electrical coil stove. Experiments were conducted to standardize the cooking procedure in the pressure cooker in two modes (open cooking and pressure cooking) using electrical coil stove and also to standardize the quantity of water required for steam generation (Table 1). The electric rice cooker container was used in these experiments as well. Water evaporation loss during cooking occurred mainly from the water added into the cooker for steam generation that acts as a heat transfer medium and sets the upper limit of temperature inside the cooker. A good material balance between water added for cooking and moisture gained during cooking was observed. Water evaporation loss was obtained by measuring the amount of water inside the cooker (for heat transfer) before and after 10 min (resting time with the lid on) of cooking with the help of an electronic balance. Electrical energy consumption was measured with an energy meter.

Open cooking

During normal cooking, the electrical coil stove was switched OFF after the cooking was completed. In the case of controlled cooking, the temperature was monitored and heat input was controlled using the ON–OFF power supply of the electrical coil stove. The power ON–OFF duration was also recorded.

Pressure cooking

Experiments were conducted to standardize normal cooking procedure in the pressure cooker with pressure pin including the required number of pressure releases (whistles). The electrical coil stove was switched OFF soon after the required number of whistles occurred and the cooker was immediately removed from the stove and kept undisturbed for 10 min (Table 1).

Controlled pressure cooking of unsoaked rice in pressure cooker was performed by controlling the power supply to the electrical coil stove according to temperature (between 100 °C and 90 °C) of the contents as described earlier.

2.2.4.3. Cooking in pressure cooker using a LPG stove. Experiments were conducted to standardize the cooking procedure and the amount water required for steam generation in the pressure cooker in two modes (open cooking and pressure cooking) with LPG stove. The rates of LPG consumption at high flame and low flame positions of the burner were determined. The amounts of LPG consumption for various experiments were obtained with the LPG consumption rate and the duration of burner ON-time. These values were also verified by measuring the weight of the gas cylinder before and after each experimental run. Energy consumption was calculated by multiplying the quantity of LPG consumed with its calorific value, 47 700 kJ/kg (www.lpgforyou.com). The amounts of water used for cooking and measurement of water evaporation loss were as per the procedure described in Section 2.2.4.2.

Open cooking

Normal cooking was done using two methods, (a) keeping the LPG burner at high flame throughout the process [normal (high)], and (b) keeping the burner initially at high flame till the vapours steadily escape through the hole on the lid of the cooker and then maintaining low flame till the rice gets cooked [normal (high + low)].

Controlled cooking was performed by keeping the flame initially high till the contents of the cooker container reached the boiling temperature and then the burner was switched OFF. It was again switched ON at low flame when the temperature fell below 90 °C. The ON–OFF cycle between the above temperature range was continued till the cooking was completed. Energy consumption, temperature, water evaporation loss and total duration of cooking were measured as described earlier.

Pressure cooking

Experiments were conducted to standardize normal cooking procedure in the pressure cooker with pressure pin including the required number of whistles. During pressure cooking, the burner was switched OFF soon after the required number of whistles occurred and the cooker was removed from the stove and left undisturbed for 10 min.

Controlled pressure-cooking performed by controlling the energy input within the specified temperature range as described earlier. Fuel consumption, temperature, water evaporation loss and total duration of cooking as well as burner ON(high and low)–OFF duration were measured as described earlier.

All the experimental runs were carried out in duplicate and practically no difference was observed in the energy measurements (±1%).

3. Results and discussion

3.1. Hydration of rice

The initial moisture content of the raw rice was 12.8 (% w.b.). Hydration curve of rice (Fig. 1) shows that the water absorption during soaking increased rapidly up to 30 min. Thereafter the rate of absorption decreased and

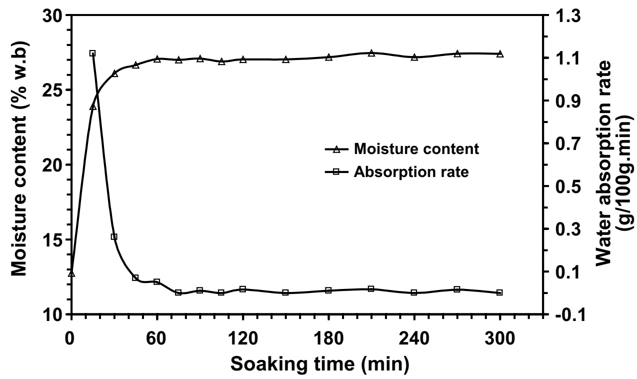

Fig. 1. Hydration curve of rice.

attained an equilibrium (moisture content 27% w.b.) after ~1 h of soaking. The moisture content of rice remained almost the same between 2 and 5 h of soaking and practically, there was no further absorption of water in rice grain (Fig. 1). The hydration behaviour was generally similar to the earlier studies conducted with raw rice of indica variety (Sowbhagya & Ali, 1991; Swamy et al., 1971). By looking at these results on rate of absorption, it was decided to stick to 30 min of soaking for studying the effect of soaking on rice cooking.

3.2. Cooking in excess water (unsoaked and presoaked rice)

Preliminary experiments revealed that the moisture content of rice cooked in excess boiling water was ~74% (w.b.). Unsoaked rice took 15 min for cooking and during the process the moisture content increased from 12.8% to 73.2% (w.b.). Presoaked rice took only 9 min for cooking under similar conditions and the moisture content rose from the initial value of 27.1% to 74.4%. Moisture content of rice was plotted against cooking time (Fig. 2). The water absorption was gradual for both unsoaked and presoaked rice, but more rapid in

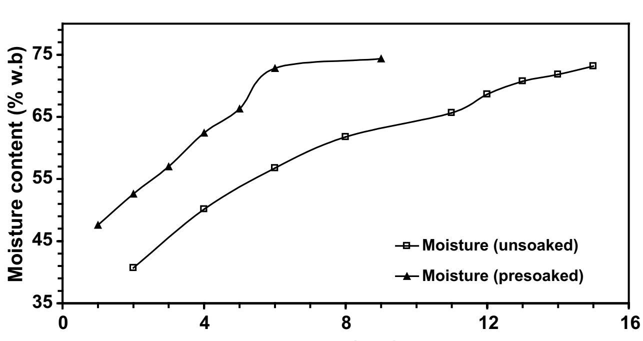

Fig. 2. Changes in moisture content of unsoaked and presoaked rice during cooking in excess boiling water.

the case of presoaked rice. Gelatinization, marked by swelling of starch granules and increase in viscosity of the starch-water slurry occurred gradually over a range of temperature often above 55 °C (Halick & Kelly, 1959). The initial rate of absorption in presoaked rice was very high, which may be due to the fact that presoaked rice had already attained near equilibrium moisture content that facilitated rapid cooking of the grain in the initial stages. Presoaking also leads to fissures on the grain surface facilitating easy access of additional water required for further cooking.

Many researchers have observed that presoaking of rice before cooking reduces the cooking time. Presoaking results in homogenous gelatinization of starch and a tasty rice with a soft texture (Matsumoto, 1970). While unsoaked grain becomes coated with a gelatinized layer, which probably reduces the heat and mass transfer into the grain, resulting in half-boiled rice with the cores neither swollen nor completely gelatinized. Santos et al. (1980) reported that a mean saving of 7 min was obtained for two different rice-water proportions (1:1 1/2 and 1:1 1/3) using electricity, and an average saving of 5 min was obtained with LPG by soaking the rice for an hour. Sowbhagya and Ali (1991) reported that presoaking at room temperature for 15 min for raw rice and 2–3 h for parboiled rice reduced the cooking time by 50% for raw rice and 25–40% for parboiled rice compared to unsoaked rice. Hirannaiah, Bhashyam, and Ali (2001) reported that presoaking of Basmati rice reduced the cooking time from 20 to 10 min, when cooked in excess water.

The reduction in total cooking time of presoaked rice could be due to the swelling of the rice grains (Santos et al., 1980). Swelling upon hydration is a characteristic property common to starches and proteins. A solid swells when it takes up a liquid and at the same time (a) it does not lose its apparent (microscopic) homogeneity, (b) its dimensions are enlarged, (c) its cohesion is diminished, and (d) it becomes soft and flexible (Katz, 1933). Rice, whose nitrogen-free extract is mostly starch, therefore, has the ability to imbibe water. Moreover, if starch granules are soaked for some time before heating, gelatinization begins at a lower temperature (Santos et al., 1980).

Results showed that presoaked rice cooked in less time (9 min) compared to unsoaked rice (15 min). Therefore, parallel experiments were conducted with soaking as a pretreatment step throughout this study, along with experiments of unsoaked rice.

3.3. Cooking in electric rice cooker

Data on energy consumption, water evaporation loss, total duration and power-ON time during normal and controlled cooking of unsoaked and presoaked rice are presented in Tables 2 and 3, respectively.

Table 2
Energy consumption during normal and controlled cooking of unsoaked rice using different types of cooking method

S. no.	Type of cooking	Normal				Controlled			
		Energy (kJ)	Duration		Water evaporation loss (g)	Energy (kJ)	Duration		Water evaporation loss (g)
			On time (min)	Total (min)			On time (min)	Total (min)	
1	Electric rice cooker	675	25	25	125	405	15	36	20
2	Pressure cooker-Electrical								
	(a) Open cooking	2880	29	29	412	1440	15.5	33	72
	(b) Pressure cooking	1620	16.5	26.5	53	1260	12	30.5	27
3	Pressure cooker-LPG								
	(a) Open cooking (high flame)	2098	24	24	298				
	(b) Open cooking (high + low flame)	1510	10 + 16	26	102	1216	10.5 + 7.5	33	63
	(c) Pressure cooking (high flame)	1180	13.5	23.5	80				
	(d) Pressure cooking (high + low flame)					1137	10.5 + 5.5	32.5	30

Table 3
Energy consumption during normal and controlled cooking of presoaked rice using different types of cooking method

S. no.	Type of cooking	Normal				Controlled			
		Energy (kJ)	Duration		Water evaporation loss (g)	Energy (kJ)	Duration		Water evaporation loss (g)
			On time (min)	Total (min)			On time (min)	Total (min)	
1	Electric rice cooker	621	23	23	125	405	15	26	17
2	Pressure cooker-Electrical								
	(a) Open cooking	2340	25	25	321	1260	13	30	62
	(b) Pressure cooking	1440	14	24	34	1080	11	30	25
3	Pressure cooker-LPG								
	(a) Open cooking (high flame)	1749	20	20	259				
	(b) Open cooking (high + low flame)	1391	10 + 13	23	90	1132	10 + 6.5	32	39
	(c) Pressure cooking (high flame)	1180	13.5	23.5	79				
	(d) Pressure cooking (high + low flame)					1137	10.5 + 5.5	32	19

3.3.1. Cooking of unsoaked rice

Normal cooking

The time and energy required for cooking 296 g of unsoaked rice under normal condition were 25 min and 675 kJ (Table 2). The contents of the cooker (rice and water) reached boiling temperature in 12–13 min, when evaporation of water could be observed. It continued steadily for the rest of the cooking period. There was 10 g of water loss by evaporation even after the power was switched OFF. The total water evaporation loss during cooking under normal condition was 125 g. The maximum water loss occurred during the time period between 14 and 25 min when the contents were in the boiling state.

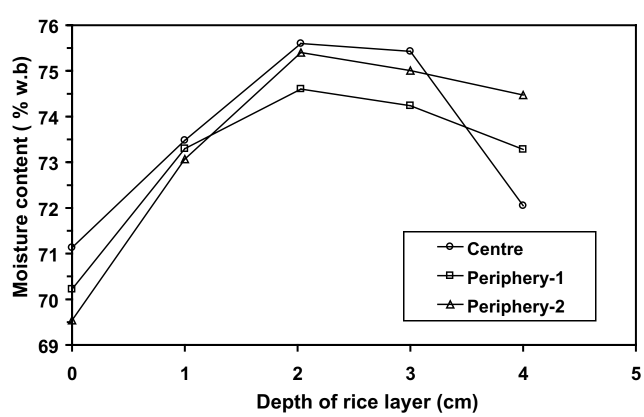

Fig. 3. Moisture content of cooked rice at various locations (normal cooking—unsoaked) in ERC.

The variations in moisture content of cooked rice in different layers and at different locations in the cooker container are shown in Fig. 3. Moisture content of rice at the top layer was the lowest apparently due to surface evaporation. The moisture content increased up to the middle layer reaching the highest value and then decreased in the subsequent layers towards the bottom of the container. The heat is transmitted from the bottom, so also the moisture is driven out from bottom to top. Surface evaporation at the top and location of heat source at the bottom explains the above observation. The moisture contents in different layers at two locations in the periphery are expected to be identical. But they were found not to be so, which may be due to the non-uniform arrangement of heat source in the cooker leading to non-uniformity of heat distribution.

Controlled cooking

During controlled cooking, power was switched OFF whenever the temperature of the contents reached the boiling point and was switched ON whenever the temperature fell below 90 °C. By adopting this strategy, the power-ON time could be brought down to 15 min (savings of 10 min of power-ON time) for cooking unsoaked rice. This strategy was aimed at reducing the water evaporation loss and thereby achieving savings in power consumption. The water evaporation loss during controlled cooking was 20 g, which was much less than that for normal cooking (125 g) (Table 2). This method of controlled cooking resulted in saving of 270 kJ of electrical energy (Table 2). But, the total duration of cooking increased to 36 min as against 25 min for normal cooking. However, saving in energy to the extent of 40% in controlled cooking is very significant and an attractive proposition.

3.3.2. Cooking of presoaked rice

Normal cooking

The time and energy required for cooking presoaked rice under normal condition were 23 min and 621 kJ (Table 3). As in the case of normal cooking of unsoaked rice, evaporation of water was steady once the cooker contents reached the boiling stage. Presoaking reduced the cooking time by 2 min and energy consumption by 54 kJ (Tables 2 and 3). However, the total amount of water lost due to evaporation remained the same as that of unsoaked rice (125 g).

Controlled cooking

Energy requirement for cooking presoaked rice reduced by ~35% during controlled cooking compared to normal cooking. But there was no difference in the energy consumption between controlled cooking of presoaked and unsoaked rice. However, presoaking reduced the total cooking time from 36 to 26 min that was close to the time taken (23–25 min) for normal cooking. The water evaporation loss for controlled cooking of presoaked rice was 17 g, which appears to be close to the near ideal condition (Tables 2 and 3). Controlled cooking of presoaked rice in electric rice cooker appears, therefore, to be the best option among the four different approaches studied (Fig. 4).

Mori (1983) reported that a microcomputer–controlled rice cooker offers higher thermal efficiency by holding down evaporation to a minimum. Thermal efficiency improved by 19% when rice was cooked in a microcomputer-controlled cooker compared to ordinary type electric rice cooker. Present studies revealed that it is possible to achieve substantial savings in energy (40%) by incorporating a fine temperature controlled ON–OFF system in the cooker.

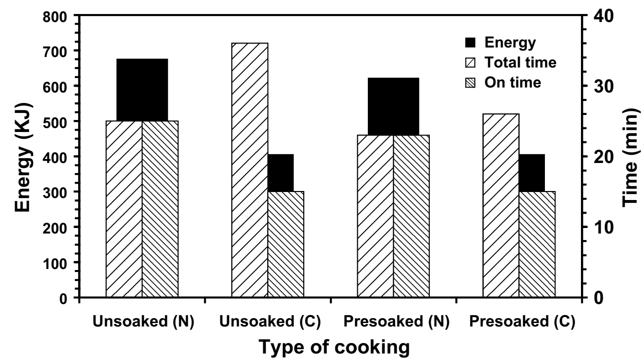

Fig. 4. Energy consumption and time taken during normal and controlled cooking of unsoaked and presoaked rice in ERC.

3.4. Cooking in pressure cooker with electrical coil stove

Data on energy consumption, water evaporation loss, total duration and power-ON time during both open and pressure (normal and controlled) cooking of unsoaked and presoaked rice are presented in Tables 2 and 3, respectively.

3.4.1. Open cooking

Normal and controlled cooking of unsoaked rice

The amount of electrical energy required for normal cooking of 296 g of unsoaked rice was 2880 kJ. The temperature gradually increased to reach the boiling condition and remained in that condition until the cooking was complete. The water evaporation loss during cooking was very high (412 g) compared to other methods (Tables 2 and 3).

During controlled cooking, the total power-ON time of the electrical stove for cooking the same amount of unsoaked rice was reduced to 15.5 min, thereby energy consumption reduced to 1440 kJ that amounts to ~50% saving in electrical energy over normal cooking. The water evaporation loss also significantly reduced to the extent of 82.5% but the total cooking time increased by 4 min.

Normal and controlled cooking of presoaked rice

The energy and time required for normal open cooking of presoaked rice were 2340 kJ and 25 min (Table 3). Evaporation of water was steady once the cooker contents (rice and water) reached the boiling stage. The water evaporation loss was 321 g that was 91 g (22%) lower than the corresponding value for unsoaked rice. Soaking reduced energy consumption by 540 kJ (19%) and the cooking time by 4 min (Tables 2 and 3).

The total electrical energy required for controlled open cooking was 1260 kJ (Table 3), down (~46%) from 2340 kJ for normal cooking. The water evaporation loss reduced to 62 g. Although the power-ON time reduced from 25 to 13 min, the total cooking time increased to 30 min.

Presoaking the rice reduced the total cooking time from 33 to 30 min in controlled open cooking that was close to the time taken (29 min) for normal open cooking of unsoaked rice in the pressure cooker. Energy consumption was further reduced with controlled cooking of presoaked rice (1260 kJ) compared to unsoaked rice (1440 kJ). This was also reflected in the amount of water lost due to evaporation during cooking. Controlled open cooking of presoaked rice in pressure cooker appears to be the best among the four different approaches studied (Tables 2 and 3). Presoaking followed by controlled cooking reduced the electrical energy by ~56% compared to normal cooking of unsoaked rice.

3.4.2. Pressure cooking

Normal and controlled cooking of unsoaked rice.

Pressure cooking reduces the cooking time as the cooking is carried out at an elevated temperature corresponding to the higher pressure maintained inside the cooker. This also leads to lot of savings in energy as it is operated as a closed system minimizing the water evaporation loss. During cooking unsoaked rice, the total power-ON time of the electrical stove reduced to 16.5 min, which resulted in the reduction of energy requirement to 1620 kJ, i.e. ~44% saving compared to open cooking. Cooking under pressure reduced the power-ON time by 12.5 min and cooking time by 2.5 min. During cooking the temperature of rice and water gradually increased to the maximum (122 °C) and reduced to 116 °C during pressure release (whistling) and again rose with time and the cycle repeated. The water evaporation loss during normal cooking reduced from 412 g (open cooking) to 53 g (87% reduction) by pressure cooking (Table 2).

The water evaporation loss during pressure cooking reduced from 53 g (normal cooking) to 27 g by controlled cooking (Table 2). Controlled pressure-cooking reduced the energy requirement from 1620 to 1260 kJ (~22.2% saving), saved 4.5 min of power-ON time while increasing the total cooking time by nearly the same duration (4 min). The water evaporation loss during controlled pressure cooking reduced by 45 g under otherwise similar conditions during open cooking.

Normal and controlled cooking of presoaked rice

Presoaking reduced the electrical energy in normal pressure cooking to 1440 kJ, that is ~11% saving compared with cooking unsoaked rice under otherwise similar conditions (Tables 2 and 3). Presoaking also resulted in the reduction of water evaporation loss from 53 g to 34 g and the total time of cooking from 26.5 min to 24 min. Both power-ON time of the electrical stove and cooking time reduced by 2.5 min.

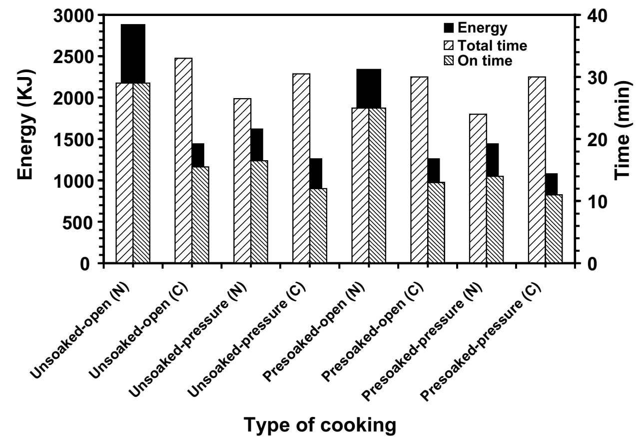

Fig. 5. Energy consumption and time taken during normal and controlled (open and pressure) cooking of unsoaked and presoaked rice in pressure cooker (electrical).

The energy required during controlled pressure cooking of presoaked rice reduced to 1080 kJ, i.e. 25% savings in energy compared to normal pressure cooking (Table 3). The power-ON time reduced by 3 min. However, total cooking time increased to 30 min, which was nearly equal to the cooking time of unsoaked rice during normal open cooking in pressure cooker (29 min). The water evaporation loss during controlled pressure-cooking of presoaked rice was the least (25 g) among the eight different approaches attempted with pressure cooker (electrical) (Tables 2 and 3).

Presoaking reduced the energy consumption by 180 kJ, i.e., ~14% reduction compared to the energy required for controlled pressure cooking of unsoaked rice under similar conditions (Tables 2 and 3). This also reflected in the reduction of water evaporation loss (~2 g) during cooking. There was no appreciable saving in total cooking time (0.5 min) with soaking. Controlled pressure cooking of presoaked rice appears to be the best among the eight different approaches studied (Fig. 5).

3.5. Cooking in pressure cooker with LPG burner

Data on energy consumption, water evaporation loss, total duration and burner-ON time during both open and pressure (normal and controlled) cooking of unsoaked and presoaked rice are presented in Tables 2 and 3, respectively. The rate of consumption of LPG at high and low flame positions in the burner were estimated as 1.833 g (87.43 kJ/min) and 0.833 g (39.73 kJ/min), respectively.

3.5.1. Open cooking

Normal (high flame and high plus low flame) and controlled cooking of unsoaked rice.

The amount of energy required for normal open cooking of unsoaked rice at high plus low flame combination (1510 kJ) was lower by ~28% than cooking at high flame (2098 kJ). The water evaporation loss during normal cooking at high plus low flame combination was 102 g as against 298 g at high flame. Although the cooking time increased by 2 min, the energy saved was considerable and hence it is desirable to switch over from high to low flame in the gas stove once the vapour builds up in the cooker during normal cooking. This procedure, in fact, is probably being practiced in many households.

The energy required for controlled open cooking of rice was 1216 kJ, resulting in a saving of ~19% compared with normal cooking at high plus low flame combination and ~42% compared with normal cooking at high flame. The amount of water evaporated was reduced by 39 g compared with normal cooking at high plus low flame combination and 235 g compared with normal cooking at high flame. However, cooking time during controlled open cooking increased compared with normal cooking by 9 min at high flame and 7 min at high plus low flame.

Normal (high flame and high plus low flame) and controlled cooking presoaked rice

The energy required for normal (at high flame) open cooking of presoaked rice reduced to 1749 kJ, ~17% saving compared to unsoaked rice. The water evaporation loss and the burner-ON time were also reduced during normal cooking at high flame (Tables 2 and 3). Presoaking reduced energy requirement, water evaporation loss and duration of cooking during normal open cooking at high plus low flame combination, however, the quantum of reduction was much lower compared to normal cooking at high flame (Tables 2 and 3). Cooking at high flame leads to huge loss in energy in any type of cooking.

The water evaporation loss reduced by controlled cooking method. Controlled open cooking of presoaked rice reduced the energy consumption by ~35% compared with normal cooking at high flame and by ~19% compared with normal cooking at high plus low flame. However, controlled cooking of presoaked rice increased the cooking time to 32 min, much higher than for the normal cooking. During controlled cooking of presoaked rice the energy consumption reduced by 84 kJ and water evaporation loss by 24 g compared to the controlled cooking of unsoaked rice. However, there was no appreciable difference in the cooking time due to prior soaking.

3.5.2. Pressure cooking

Normal and controlled cooking of unsoaked rice

Pressure-cooking reduced the cooking time and energy requirement as explained earlier. The rice and water inside the cooker during cooking attained a maximum temperature of 122 °C. During normal pressure cooking, the energy required for cooking the same quantity of rice was reduced compared with normal open cooking by ~44% at high flame, and by ~22% at high plus low flame (Table 2). The water evaporation loss reduced to 80 g and cooking time to 23.5 min during pressure cooking of unsoaked rice (Table 2).

Controlled pressure cooking reduced energy requirements from 1180 to 1137 kJ (~4% saving) due to controlled cooking under otherwise similar conditions. The water evaporation loss reduced by 50 g, but the cooking time increased by 9 min during controlled pressure cooking (Table 2).

Normal and controlled cooking of presoaked rice

There was no change in LPG consumption and cooking time during normal pressure cooking of presoaked rice compared to unsoaked rice under otherwise similar conditions (Tables 2 and 3). The water evaporation loss was also nearly the same.

Controlled pressure cooking saved 43 kJ of energy compared to the normal pressure cooking of presoaked rice (Table 3). The water evaporation loss reduced to very low levels (19 g) during controlled pressure cooking of presoaked rice. However, the cooking time increased by 8.5 min over normal pressure cooking. It was observed that presoaking did not contribute to energy saving either in normal or controlled pressure cooking using LPG burner (Tables 2 and 3). Controlled cooking of unsoaked and presoaked rice gave more or less similar values of energy consumption and cooking time for both open and pressure cooking (Fig. 6). In normal

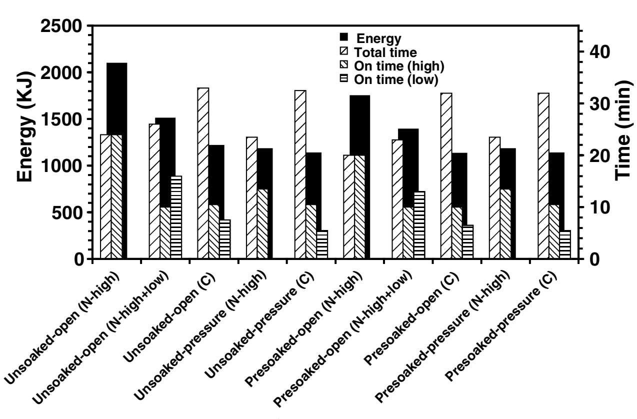

Fig. 6. Energy consumption and time taken during normal and controlled (open and pressure) cooking of unsoaked and presoaked rice in pressure cooker (LPG).

pressure cooking also, energy consumption and cooking time values were similar for both presoaked and unsoaked rice (Tables 2 and 3).

3.6. Effect of presoaking rice

Experiments of cooking in excess boiling water showed that presoaked rice cooked in less time compared to unsoaked rice and the cooking time typically reduced from 15 to 9 min. In electric rice cooker, there was some reduction in the energy consumption (8%), however, there was only little reduction in cooking time (2 min) during normal cooking. Although there was no change in energy consumption during controlled cooking, the cooking time reduced by 10 min.

In the case of pressure cooker with electrical coil stove, prior soaking of rice generally reduced the energy consumption and cooking time. Controlled pressure cooking of presoaked rice consumed the least power, while normal open and pressure cooking of presoaked rice took the least time.

In open cooking in pressure cooker with LPG stove, presoaking reduced the energy consumption and cooking time. However, presoaking did not affect the energy consumption and cooking time both in normal and controlled pressure-cooking. Controlled open and pressure cooking of presoaked rice consumed the least fuel. Normal open cooking of presoaked rice at continuous high flame took the least time for cooking (20 min).

3.7. Controlled cooking

Controlled cooking reduced the energy consumption, but prolonged cooking time for all the different approaches used for cooking rice. In electric rice cooker, controlled cooking resulted in large saving in energy for both unsoaked and presoaked rice (40% and 35%, respectively). Controlled cooking in electric rice cooker was found to be the most energy efficient among all the different methods used in the study.

Controlled open cooking in pressure cooker with electrical coil stove, for both unsoaked and presoaked rice resulted in large energy savings (50% and 46%, respectively). Among the different approaches made with electrical coil stove, controlled pressure-cooking of presoaked rice consumed the least amount of energy.

As in the case of electrical coil stove, controlled open cooking of unsoaked as well as presoaked rice resulted in large energy savings in pressure cooker with LPG stove. Controlled open and pressure cooking of presoaked rice consumed the least amount of energy.

3.8. Pressure cooking

Pressure cooking generally consumed lower energy compared to open cooking under otherwise similar conditions. The savings were much more pronounced in the case of normal pressure cooking of presoaked as well as unsoaked rice. In the case of controlled cooking, the energy consumption during open cooking could be nearly brought down to the level of pressure cooking; more so with LPG as source of heat.

4. Conclusions

Controlled energy input, cooking under pressure and soaking of rice prior to cooking are the three approaches, which resulted in energy saving. The type of cooking appliance and heat source also are important factors that decide energy requirements for cooking. Electric rice cooker was found to be the most energy-efficient implement among the different combinations of cooking appliance and types of heat source used in this study (Fig. 7). Its energy consumption was much less (23–57%) compared to pressure cooker (open and pressure cooking) with either electrical or LPG stove. Open cooking in pressure cooker with continuous high flame (LPG burner) leads to high energy consumption due to increased losses.

Prior soaking of rice generally reduced energy consumption as well as cooking time, more prominently during normal cooking. Controlled heat input could generally lead to substantial energy savings but generally prolonged the cooking time. Energy consumption in controlled cooking of unsoaked rice was even lower than the normal cooking of presoaked rice in electric rice cooker and pressure cooker. In the case of controlled cooking in electric rice cooker, energy consumption did not reduce with presoaking but there was substantial reduction in cooking time. Considering the energy consumption and cooking time, controlled cooking of presoaked rice appears to be the best among the several approaches investigated in the present study.

Presoaking of rice and cooking under elevated pressure have been reported to offer energy savings;

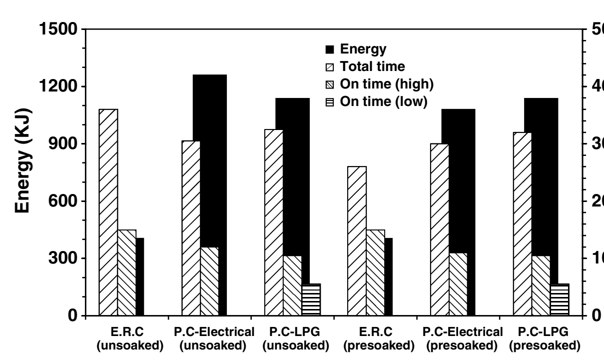

Fig. 7. Comparison of energy consumption and time taken during controlled cooking of unsoaked and presoaked rice in ERC and PC (pressure cooking).

controlled energy input is another useful method that optimizes the energy utilization in cooking. Controlled cooking is desirable to apply in all types of rice cooking.

Measurement of water evaporation loss appears to be a good indirect method of assessing the efficiency of energy utilization. Assessment of the quality of cooked rice would help in deciding the best method of cooking from sensory point of view. There is also ample scope to extend this type of study to the processing of other types of grains.

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