EFFECT OF PRE-SOAKING AND GRAIN SHAPE ON COOKING ENERGY OF PARBOILED AND RAW RICE

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ABSTRACT

Rice is the staple food of Sri Lankans and both parboiled and raw rice forms of medium and slender grain types are popular in Sri Lanka. These two shaped grain varieties were selected and the optimum pre-soaking duration was calculated using the Peleg's model. The optimum rice to water ratios were determined for different rice types. A three factor factorial experiment was used to analyse the cooking energy and cooking time, considering the grain shape, rice grain process condition and pre-cooking condition. Soaking durations for 86% rice grain saturation was 10 minutes for both shapes in raw form and the optimum rice: water ratio was 1:2.

Parboiled forms, slender grains and un-soaked rice consumed considerably higher amounts of cooking energy and time than raw rice forms, medium type grains and pre-soaked rice. When considering pre-cooking condition and process condition, highest cooking energy and time is consumed by un-soaked parboiled form of rice. Pre-soaked raw rice requires the least and saved about 40% of energy and time compared to the un-soaked parboiled rice. With respect to process condition and grain type, Parboiled slender grains consume the highest cooking energy and cooking time while cooking Raw medium type grains saves about 40% of those requirements.

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ශ්‍රී ලාංකිකයන්ගේ ප්‍රධාන ආහාරය වන සහල්, කැකුළු සහ තම්බන ලද යන දෙවර්ගයෙන්ම ජනතාව අතර ප්‍රචලිතය. මධ්‍ය සහ සිහින් හැඩති සහල් වර්ග දෙකක් මෙම පර්යේෂණයේදී අධ්‍යනයට තෝරා ගන්නා ලද අතර ඒවාහි ප්‍රශස්ථ පෙඟවීමේ කාල පරාසය ප්ලෙග් දර්ශය මගින් ගණනය කරන ලදී. තවද සහල් පෙඟවීම සඳහා අවශ්‍ය ප්‍රශස්ථ සහල් : ජල අනුපාතයන්ද විවිධ සහල් වර්ග සදහා නිර්ණය කරන ලදී.

සහල් පිසීමේ ශක්ති පරිභෝජනය සහ ගතවන කාලය තුන් සාධක ක්‍රමාරෝපිත සංඛ්‍යාන අධ්‍යනයක් මගින් ඇගයීමට ලක් කරන ලදී . මෙහිදී ප්‍රධාන සාධක ලෙස ධාන්‍ය හැඩය, සැකසුම් තත්වය සහ පෙර පිසීමේ තත්වය යන සාධක තුන භාවිත කරන ලදී. කැකුළු සහල් වල අධ්‍යනය කරන ලද හැඩයන් දෙක සඳහා 86%ක සංතෘප්ත ප්‍රතිශතයක් ලබා ගැනීමට මිනිත්තු 10ක කාලයක් ගත විය. ප්‍රශස්ථ සහල් ජල අනුපාතය 1:2 ලෙස විය.

පිසීමේ ශක්ති පරිභෝජනය සැලකීමේදී තම්බන ලද, සිහින් සහ පෙර නොපෙඟවූ සහල් වල ශක්ති පරිභෝජනය මධ්‍ය හැඩති පෙර පෙඟවූ කැකුළු සහල් වල ශක්ති පරිභෝජනයට වඩා වැඩි විය. පෙර පිසුම් තත්වයන් සහ සැකසුම් තත්වයන් සැලකීමේදී තම්බන ලද පෙර නොපෙඟවූ සහල් වැඩි පිසීමේ ශක්ති ප්‍රමාණයක් සහ කාලයක් පරිභෝජනය කරන ලදී. කලින් පොඟවන ලද කැකුළු සහල් සදහා අවම ශක්ති පරිභෝජනයක් වාර්තා වූ අතර 40% ක ශක්ති හා කාල ඉතුරුවක් තම්බන ලද නොපෙගවූ සහල් වලට සාපේක්ෂව ලබා දෙන ලදී. සැකසුම් තත්ව සහ ධාන්‍ය වල හැඩය සැලකීමට ගැනීමේදී තම්බන ලද සිහින් හැඩති සහල් වැඩිම පිසීමේ ශක්තියක් හා කාලයක් පරිභෝජනය කරන ලද අතර මධ්‍ය හැඩති කැකුළු සහල් එම පරිභෝජනයෙන් 40%ක ඉතිරියක් ලබා දීමට සමත් විය.

INTRODUCTION

Energy cost is one of the most important issues in Sri Lanka similar to most of the countries in the world. At present, the highest amount of primary energy in Sri Lanka is provided by the biomass (43%), followed by the petroleum (37%), hydropower (13%) and coal (4%). Electricity remains as the main secondary energy source *(Energy, 2015)*. According to the available statistics in 2014, households, commercial and other sectors accounted for the largest share of energy being 44.7% while the transport and industry sector accounted for 29.4% and 25.9%, respectively *(SLSEA, 2014)*. Another study reveals that 50% of domestic energy use is for cooking purposes *(Wijayatunga, Attalage, 2002)*. In the cooking context, rice is the staple food which is consumed two or three meals a day in almost all households and the per-capita rice consumption is about 105 kg/year *(WorldBank, 2010)*. Therefore, rice cooking accounts for a significant fraction of the cooking energy at each household; a population of 20.8 million cooks approximately 2.18 million tons of rice annually. Energy conservation in rice cooking has a national importance in reducing cost of living and minimizes the national energy crisis while reducing greenhouse gas emissions to the environment.

The basic dimension used for the rice grain classification is size (length of the grain) and the shape (length/width ratio). Both USDA (United States Department of Agriculture) and FAO (Food and Agriculture Organization of the United Nations) classification systems are being used by the scientists. Out of different rice grain types, classified according to shape classification under both systems, slender and medium types are of the prime importance as they are the most popular two grain types consumed by Sri Lankans *(Gunasekara, Dharmasena, 2011).*

A study has been carried out to investigate the effect of soaking on cooking energy conservation of a rice variety (Belleputana) *(Roy, Shimuzu, Kimura, 2004)*. However, in this study only three selected soaking durations were considered instead of moisture saturation percentage and physical characteristics of grains. Two other studies have reported a comparison of energies to cook un-soaked and pre-soaked rice of the variety “Bangara Thigadu” with different cooking appliances *(Das et al, 2006)* and a kinetic analysis has been carried out for cooking at both pre-soaked and un-soaked conditions with different levels of water with the same paddy variety (*Chakkaravarthi et al, 2008)*. The temperature on soaking had a significant effect on chemical composition, glycemic index and starch characteristics of rice *(Kale et al, 2015)*. Effect of thermodynamic properties on pre-soaking was studied in another research and they have used five different temperatures as 35°C, 45°C, 55°C, 65°C and 75°C for soaking. Peleg model was used for curve fitting of the experimental data and the results revealed that the constants of the Peleg model (k_1 and k_2) decreased with increasing temperature, indicating a higher initial absorption rate and higher product water absorption capacity, respectively *(Paulo et al, 2016)*. *(Gunasekara, Dharmasena, 2011)*, the same research group of this study has studied the effect of grain shape and pre-soaking conditions and established a model for soaking pattern for two common polished rice grain types but limited only for parboiled rice.

Therefore, the objective of this study was to extend the model for polished rice grain soaking patterns and to compare the effect of pre-soaking on cooking time and cooking energy of Raw and Parboiled rice as it has a paramount importance at national and global perspective.

MATERIALS AND METHODS

As the consumer preference is mostly governed by the size and the shape of the rice grains, two popular varieties were selected to represent both long grain varieties and medium grain varieties as shown in Table 1 *(Gunasekara, Dharmasena, 2011)*. Like most of the Sri Lankan rice varieties, the selected two varieties are falling into intermediate category (70 -74°C) according to their gelatinization temperature *(Gunasekara, Dharmasena, 2011)*.

Table 1

Classification of BG 360 and BG 94-1 rice varieties according to USDA and FAO classification system

Rice variety	Length (mm)	Width (mm)	Length/Width ratio	Classification according to size (Length)		Classification according to Shape (Length/Width)	
				USDA	**FAO**	**USDA**	**FAO**
BG 94-1	6.58	1.87	3.66	Medium	Long	Slender	Slender
BG 360	4.5	1.72	2.67	Short	Short	Medium	Medium

A two-parameter empirical formula that was proposed by Peleg *(Peleg, 1988)* for milk powder was reported as satisfactory in modeling hydration kinetics in vacuum soaking of paddy (rough rice) *(Bello, Tolaba, Suarez, 2008)*. The same model was used to derive sorption curves for each of the factorial combinations after testing its fitness for sorption of polished rice grains. The Peleg model relates the instantaneous moisture content with the initial moisture content and the soaking time as given in equation (1).

$$m(t) = m_o + \frac{t}{k_1 + k_2 t} \quad (1)$$

The variation of moisture content is denoted as *m (t)*, in decimal dry basis, with the time *t* and m_o is the initial moisture content (decimal dry basis) while k_1, k_2 being constants. The Mean Relative Deviation Modulus

(P), one of the statistical tools used in assessing the goodness of fit of the Peleg model with data was calculated using the equation (2).

$$P = \left(\frac{100}{n}\right)\sum\left(\frac{|M_a - M_p|}{M_p}\right) \quad (2)$$

Where *P* is the Mean Relative Deviation Modulus, M_a is the actual Experimental Moisture content; M_p is the predicted moisture content; and *n* is the number of observations. *P* value less than 5, between 5-10 and greater than 10 indicates that the model has an extremely good fit, reasonably good fit and poor fit respectively, with the experimental data.

Since the Parboiled and Raw rice forms are popular among the consumers from different parts of the country, four 100 g samples of both BG 94-1 and BG 360 in both Parboiled and Raw rice forms were soaked in 300 mL of distilled water under room temperature (27± 2°C) and at atmospheric pressure. Subsequently the samples were drawn at 15 minutes intervals for 2.5 hours. After the surface moisture was removed from rice kernels, the samples were kept in oven at 120°C for 24 hours *(AOAC, 2000)* and dry weights were obtained and the moisture contents were calculated at each time period.

The model fitting procedure of the previous study *(Gunasekara, Dharmasena, 2011)* was followed for the raw rice as well. According to the Peleg model, the highest moisture content (Equilibrium Moisture Content (EMC)) is achieved when $t \rightarrow \infty$. Even though the Peleg model, gives the highest moisture content or EMC when $t \rightarrow \infty$, prolonged soaking enhances the microbial fermentation resulting in bad odour development. Further, the longer soaking durations are not practical with the present lifestyles. Therefore, the maximum allowable soaking time was limited to 2.5 hours as previously reported by the same research team *(Gunasekara, Dharmasena, 2011)*. In order to provide the equal conditions for both samples of raw and parboiled, the factor combination in which the sorption process is the slowest (parboiled types), was only allowed to hydrate 150 minutes and the moisture content at that particular time and wetted percentage with respect to the EMC was back calculated using the Peleg model. Then the required soaking duration was calculated for the other factor combinations taking the above wetted percentage as a constant.

Four parboiled and raw samples of 250 g each from slender (BG 94-1) and medium grain types (BG 360) were cooked in an electric rice cooker using four different rice to water volume ratios; 1:2, 1:2.5, 1:3 and 1:3.5. After the rice was cooked, few kernels were taken out and pressed between two glass plates. Minimum rice to water ratio which produced cooked rice without having an opaque core when pressed was considered as the optimum rice to water ratio. It was found the 1:2 as the optimum volume ratio for raw rice of both grain types. *(Gunasekara, Dharmasena, 2011)* have already found that 1:2.5 is the optimum ratio for parboiled rice of both grain types (BG 94-1 and BG 360 varieties).

A three factor factorial experiment was conducted considering the pre-cooking condition (un-soaked and soaked conditions as two levels), rice grain process condition (parboiled and raw rice forms as two levels) and the rice grain type/variety (with two levels as BG 94-1 and BG 360) as the considered factors. Four replicates were tested for each of the factor combination. A rice sample of 300 mL was cooked using 750 mL of distilled water for samples containing parboiled rice while the same amount of rice was cooked in 600 mL of distilled water for raw rice. A Mitsubishi electric rice cooker (Model NJ-Z18T) was used to conduct the cooking trials, while an 110V digital watt meter (Model P4400 KILL A WATT™) (Fig. 1) was employed to obtain the data on cooking energy and cooking time. The data were analyzed by General Linear Model (GLM) using Minitab 15® (2006) statistical software.

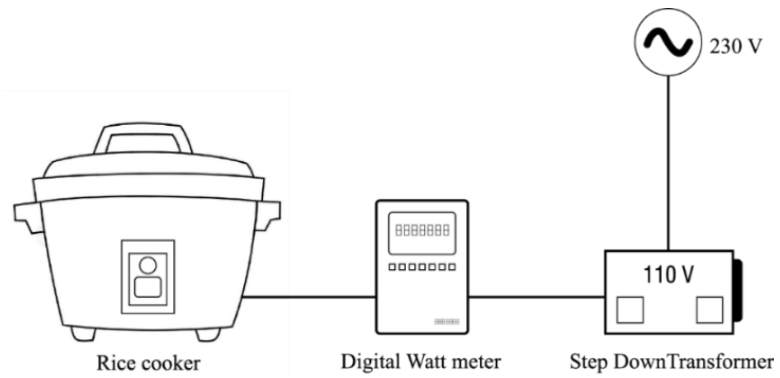

Fig. 1 - Instrumentation setup for the measurement of rice cooking energy

RESULTS

- **Mathematical model fitting for moisture sorption of polished rice grains**

The characteristic hydration curves obtained for raw rice samples of both varieties are shown in Fig. 2. Hydration curves for parboiled rice is extracted from a previous study by the same research team for the comparison purpose of two different forms. The rapid hydration rates shown in the initial phase were diminished to reach a plateau towards the Equilibrium Moisture Contents (saturation) in each of the four cases *(Gunasekara, Dharmasena, 2011)*. According to the hydration curves, the parboiled forms of both rice varieties took much more time to reach the plateau when compared to the raw rice form. The parboiled form of the slender type took the longest time in comparison with all other types. Hydration curves of the raw rice forms of both varieties were more or less similar and almost overlapping with each other. In the parboiled context, there was a huge variation of sorption pattern between two rice types or varieties. Medium grain variety showed higher initial hydration rate compared to the slender grain variety. However, the parboiled medium rice achieved its predetermined moisture content (86% saturation) quickly, in 44 minutes, compared to that of parboiled slender grain variety that took 150 minutes *(Gunasekara, Dharmasena, 2011)*.

In the mathematical model fitting procedure, the corresponding Peleg's coefficients, Residual Sums of Squares (RSS), correlation coefficients (R^2), Mean Relative Deviation Modulus values (P) are given in Table 2.

Table 2

Peleg's model fitting for curves of rice hydration as a function of time

Variety	k_1	k_2	RSS	R^2	P
Slender Grains (BG 94-1)	45.28 ± 7.58	1.485 ± 0.074	0.00514	0.987	2.38
Medium Grains (BG 360)	19.32 ± 3.34	1.973 ± 0.047	0.00166	0.993	1.53
Slender Grains (BG 94-1)	11.69 ± 5.53	4.065 ± 0.107	0.00059	0.988	1.59
Medium Grains (BG 360)	12.15 ± 8.97	4.112 ± 0.173	0.00147	0.972	2.28

Source: (Gunasekara, Dharmasena, 2011)

According to Table 3, BG 94-1 parboiled slender rice saturated 86% with respect to its EMC in water or water saturation within 150 minutes of soaking, while BG 94-1 slender raw rice, BG 360 medium parboiled and BG 360 medium raw rice forms took 10, 44 and 10 minutes, respectively to reach the pre-determined 86% saturation.

Table 3

Comparison of soaking times of different rice types to reach predetermined saturation level and the Peleg's sorption model parameters

Variety	Mo	t	MC(t)	Me	Soaking%
BG94-1 Parboiled	0.138	150	0.698	0.811	86
BG94-1 Raw	0.166	10	0.353	0.409	86
BG360 Parboiled	0.156	44	0.570	0.663	86
BG360 Raw	0.157	10	0.348	0.403	86

Source: (Gunasekara, Dharmasena, 2011)

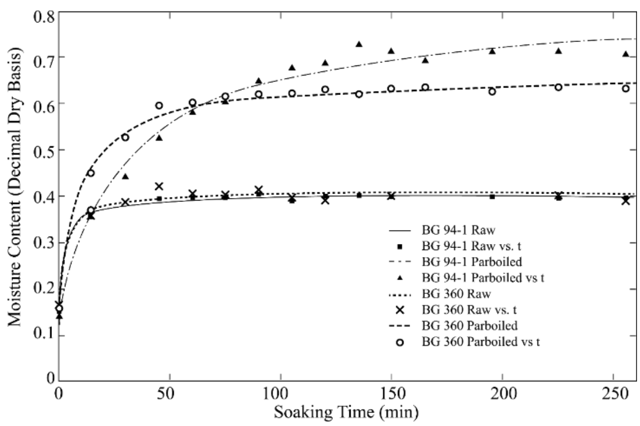

Fig. 2 - Comparison of sorption curves of parboiled and raw rice forms of both slender and medium grain varieties at the room temperature (27 ± 2°C) and at atmospheric pressure.

- **Comparison of optimum rice to water volume ratios for cooking**

Main effects of all the factors: pre-cook condition (pre-soaked or not), process condition (Raw or Parboiled) and the rice grain type (slender or medium) were significant for both cooking energy and cooking time. Even though pre-cook x process condition and process condition x grain shape were significant for cooking energy, the pre-cook condition x grain shape interactions were not significant for the cooking energy ($p > 0.05$). The three way interaction: pre-cook condition x process condition x grain shape was also not significant for the cooking energy ($p > 0.05$) (Table 4). Similarly for cooking times, all the main effects were significant and the two way interaction of pre-cook x process condition and process condition x grain shape were significant ($p \leq 0.05$). However, the two way interaction of pre-cook condition x grain shape and the three way interaction; pre-cook condition x process condition x grain shape were not significant ($p > 0.05$) (Table 5).

Table 4

Analysis of variance for cooking energy, using adjusted sums of squares for tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Pre-cook	1	0.0200	0.0200	0.0200	369.2300	0.000
Process	1	0.0946	0.0946	0.0946	1746.6900	0.000
Grain	1	0.0200	0.0200	0.0200	369.2300	0.000
Pre-cook x Process	1	0.0025	0.0025	0.0025	45.2300	0.000
Pre-cook x Grain	1	0.0000	0.0000	0.0000	0.2300	0.635
Process x Grain	1	0.0032	0.0032	0.0032	59.0800	0.000
Pre-cook x Process x Grain	1	0.0000	0.0000	0.0000	0.2300	0.635
Error	24	0.0013	0.0013	0.0001		
Total	31	0.1416				

Table 5

Analysis of variance for cooking time, using adjusted sums of squares for tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Pre-cook	1	157.530	157.530	157.530	225.720	0.000
Process	1	693.780	693.780	693.780	994.070	0.000
Grain	1	166.530	166.530	166.530	238.610	0.000
Pre-cook x Process	1	19.530	19.530	19.530	27.990	0.000
Pre-cook x Grain	1	2.530	2.530	2.530	3.630	0.069
Process x Grain	1	22.780	22.780	22.780	32.640	0.000
Pre-cook x Process x Grain	1	1.530	1.530	1.530	2.190	0.152
Error	24	16.750	16.750	0.700		
Total	31	1080.970				

- **Effect of pre-soaking on cooking time and cooking energy**

Fig.3 illustrates the cooking time and cooking energy requirements of four main factor combinations: soaked raw and parboiled and un-soaked raw and parboiled types. According to the graph, pre-soaking requires less cooking energy and cooking time for both parboiled and raw rice types. The amount of cooking energy and cooking time conservation with respect to highest energy consuming factor combination considering pre-cook condition and the process condition are illustrated in Table 6. According to Turkey mean comparison test, pair wise comparisons among all the levels of pre-cook condition x process condition interactions were significantly different ($p \leq 0.05$).

Table 6

Mean percentage energy and time saving in cooking Parboiled and Raw rice

	Un-soaked-Parboiled	Un-soaked-Raw	Soaked-Parboiled	Soaked-Raw
% Energy Reduction	0	-32	-17	-40
% Time Reduction	0	-33	-18	-41

Fig. 4 illustrates the cooking time and cooking energy comparisons of slender and medium grain types processed as parboiled or raw. According to the graph, slender grain of both parboiled and raw consume more energy and time than medium grain type. According to data, parboiled slender consumes the highest cooking energy and cooking time and Table 7 provides the percentage energy and time saving for above four rice types with respect to parboiled slender rice type. The pair wise comparisons among all the levels of process condition x grain type interactions were significantly different ($p \le 0.05$) for cooking energy and cooking time.

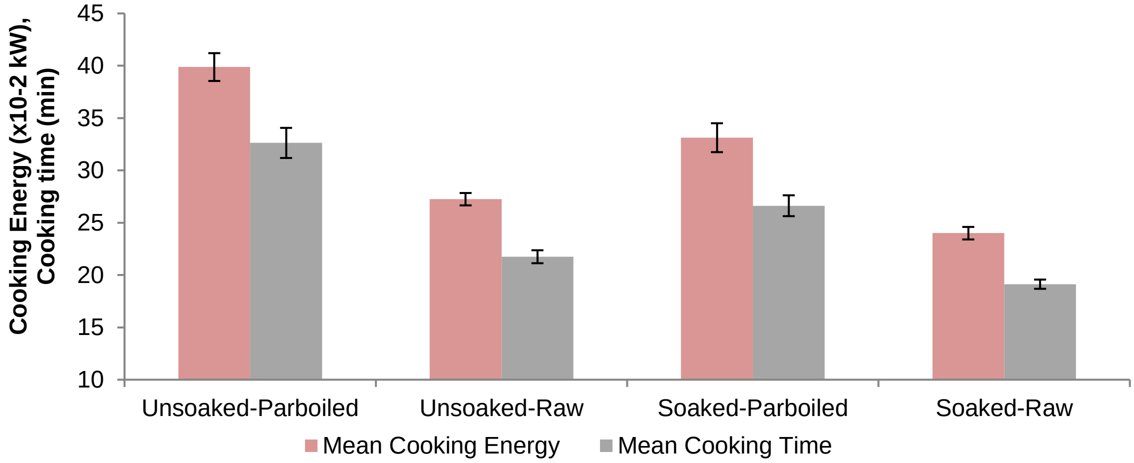

Fig. 3 - Mean cooking energy and cooking times for Parboiled and Raw rice types in both un-soaked and pre-soaked conditions.

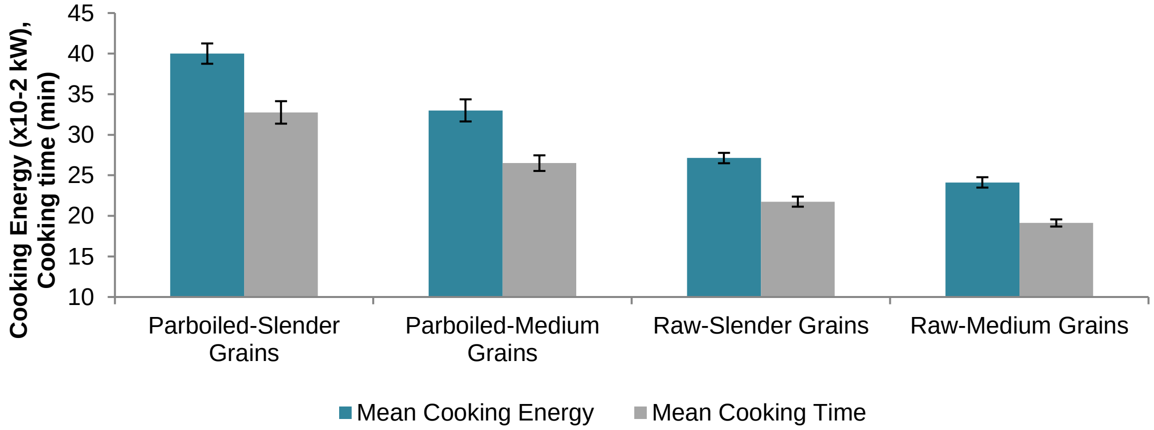

Fig. 4 - Mean cooking energy cooking times for Parboiled and Raw rice of both slender and medium types

Table 7

Mean percentage energy and time saving in cooking different types of rice

	Parboiled-Slender	Parboiled-Medium	Raw-Slender	Raw-Medium
% Energy Reduction	0	-18	-32	-40
% Time Reduction	0	-19	-34	-42

- **Discussion**

Establishment of a mathematical model for moisture sorption for polished rice soaking in water is very important for predicting sorption related unknown parameters. The same research team has reported that the Peleg's model fits well for the sorption of parboiled rice. In the evaluation of the acceptability of Peleg's mathematical model, very low RSS values, very high R^2 values (0.97 to 0.98) and Mean Relative Deviation Modulus (P) value less than five (5) confirms that the Peleg model fits extremely well with the all four types of polished rice grain sorption data. Therefore, the Peleg model can be used to accurately estimate instantaneous moisture content of polished raw rice as well as the parboiled rice when soaking in water at room temperature and atmospheric pressure.

It has been previously reported that prior soaking reduces the energy consumption and cooking time during normal cooking, while the pre-soaking does not contribute to the energy conservation in the case of controlled cooking in electric rice cooker *(Das et al, 2006)*. Soaking rice prior to cooking, an established energy saving practice, resulted in energy savings to the extent of 5–11% in normal cooking and 3–18% in controlled cooking and also pre-soaking shows only a marginal reduction *(Lakshmi et al, 2007)*.

However, according to another study *(Roy, Shimuzu, Kimura, 2004)* cooking of milled raw and parboiled rice by adopting the pre-soaking method for 60 minutes with an electric rice cooker reduces the cooking energy of cooked rice (66% moist) by 4% and 6 to 11% respectively. However, information on grain type, gelatinization temperature and the grain saturation level are not considered in all above studies.

According the results of this experiment, 40% of cooking energy and 41% of cooking time reduction is evident by cooking raw rice after being soaked for 10 minutes (86% saturation), 32% energy and 33% cooking time for un-soaked-Raw rice, and 17% energy and 18% cooking time for soaked Parboiled rice compared to cooking of un-soaked parboiled rice. Therefore, it is clearly evident that significant amount of energy and cooking time could be conserved by switching to soaked raw rice instead of un-soaked parboiled rice. Further, pre-soaking has reduced about 17% energy for parboiled type and about 8% for raw rice type. The percentage energy saving for raw rice is observed as twice as the value reported in a previous study *(Roy, Shimuzu, Kimura, 2004)* and the percentage cooking energy saving for Parboiled rice is also considerably higher than their reported range. This may be due to the differences in physicochemical properties of the grain varieties used in Sri Lanka, optimization of water requirement and the degree of pre-soaking of the rice grains.

In addition, cooking of Raw-Medium shape grain type has shown a 40% reduction in energy and 42% reduction in cooking time compared to Parboiled-Slender shape grain type. The cooking energy and cooking time reduction of Parboiled-Medium shape grain type was 18 and 19%, and Raw-Slender shape grain type was 32 and 34% respectively, compared to that of the Parboiled-Slender grains. Therefore, it is evident that the process condition; raw or parboiled as well as pre-cook condition; pre-soaked or un-soaked have influenced on the reduction of cooking energy and cooking time requirement. The cooking energy reduction in pre-soaked rice may be due to the uniformity of heat and mass transfer during cooking in the pre-soaked rice grains**.** Rice cooking is a process governed by two mechanisms; [1] moisture diffusion from surface to core and [2] physicochemical reactions of grain components. According to kinetics, rice cooking is similar to a first order chemical reaction. In the case of un-soaked rice cooking, there are two falling rate periods similar to drying of hygroscopic foods with two corresponding rate constants. This is due to the initial formation of an outer cooked impervious layer which acts as a barrier for moisture diffusion to the reaction site at the core of the rice grain. Therefore, the initial reaction rate is dropped down after about 80% of gelatinization and enters into a second reaction phase. However, in cooking pre-soaked rice, there is only one reaction rate as the grain is adequately hydrated for gelatinization. This is the main reason for cooking energy and cooking time conservation in pre-soaked rice *(Chakkaravarthi et al, 2008)*.

According to results of the experiment, both slender and medium types of parboiled rice consumed significantly higher cooking energy and time than raw types. A previous study carried out using μ-CT and MRI technologies to identify the grain microstructure's effect on cooking behaviour and reported that the increasing porosity within the grain reduces the cooking time *(Mohoric et al, 2009)*. During parboiling the starch crystals are being gelatinized and become amorphous molecules resulting less porous within the rice grains. Therefore, the hydration time during the cooking process is prolonged for parboiled rice resulting higher cooking time, leading to higher cooking energy than raw milled rice *(Otegbayo, Osamuel and Fashakin, 2001)*.

CONCLUSIONS

The Peleg's mathematical model fits well with the moisture sorption data of polished raw rice. The optimum rice to water ratios for cooking raw rice is 1:2. Parboiled forms, slender grain types and un-soaked rice require considerably higher amounts of cooking energy and time than raw rice forms, medium type grains and at least 86% pre-soaked rice. When considering pre-cook condition and process condition, highest cooking energy and cooking time is consumed by un-soaked Parboiled form of rice. Pre-soaked raw rice requires the least and could be saved about 40% of energy and time required for un-soaked parboiled rice. With respect to process condition and grain type, parboiled slender grains consumes the highest cooking energy and time while cooking raw medium type grains save about 40% of those requirements.

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