International Food Research Journal 24(3): 1140-1147 (June 2017)
Journal homepage: *http://www.ifrj.upm.edu.my*

Effect of domestic cooking methods on physicochemical, nutritional and sensory properties of different varieties of brown rice from Southern Thailand and Malaysia

[1]Chapagai, M. K., [2]Wan Rosli ,W. I., [2]Wan Manan, W. M., [3]Jalil, R. A., [1]Karrila, T. and [1*]Pinkaew, S.

[1]*Department of Food Science and Nutrition, Faculty of Science and Technology, Prince of Songkla University, Pattani Campus, 94000, Pattani, Thailand*
[2]*School of Health Sciences, Universiti Sains Malaysia, 16150 Kubang Kerian, Kelantan, Malaysia*
[3]*School of Medical Sciences, Universiti Sains Malaysia, 16150 Kubang Kerian, Kelantan, Malaysia*

Article history

Received: 17 April 2016
Received in revised form: 19 May 2016
Accepted: 1 June 2016

Keywords

Brown rice
Pasting properties
Pressure cooker
Rice cooker
Texture

Abstract

Consumption of brown rice is increasing on account of higher nutritional components such as vitamins, minerals, fibres and antioxidants than white rice. However, the effect of domestic cooking methods on nutritional attributes of brown rice is not well-characterized. Hence, this study aimed to investigate the effect of cooking methods; pressure cooker (PC) and rice cooker (RC) on physicochemical, nutritional and sensory properties of brown rice from five different varieties: Sungyod (SY), Chiang (CH), and Lepnok (LP) of Thai and long grain LS_1 and LS_2 of Malaysian origin. Peak viscosity (PV) and final viscosity (FV) among uncooked samples were significantly different except for LS_1 and LS_2. Between cooking methods, protein content (8.17 – 10.14%) was significantly different ($p < 0.05$) except in SY, LS_1 and LS_2 varieties whereas fat (1.74 – 2.71%) and ash content (1.15 – 1.46%) showed significant difference ($p < 0.05$) only in LP and SY varieties. Loss of iron was significantly higher in RC method than PC method but zinc and thiamine was insignificant. The LS_1 and LS_2 cooked in PC was significantly softer ($p < 0.05$) than cooked in RC. Hardness of PC cooked rice was correlated with PV ($r = –0.965$), breakdown viscosity ($r = –0.973$), setback viscosity ($r = –0.944$) at $p < 0.01$ and pasting temperature ($r = 0.89$, $p < 0.05$) of uncooked brown rice flours. Overall, PC was found better over RC in terms of cooking time, textural properties, nutrients and sensory attributes.

Introduction

Brown rice is richer in vitamins, minerals, fibres and antioxidants than white or milled rice and hence consumption of brown rice brings higher potential to prevent malnutrition (Monks *et al.*, 2013) as well as chronic diseases such as diabetes (Greenwood *et al.*, 2013; Kozuka *et al.*, 2013), blood pressure, hyperglycaemia, heart diseases (Hallfrisch *et al.*, 2003; Mirrahimi *et al.*, 2014) and cancer (Nagle *et al.*, 2013). However, longer cooking time and harder texture even after cooking are the major factors attributing to lower consumption of brown rice compared to other forms of rice. Texture of cooked rice is influenced by various factors such as variety, physicochemical properties, degree of milling, moisture and cooking methods (Lyon *et al.*, 2000). Number of researches have been conducted to shorten the cooking time as well as to improve the texture of brown rice. Minimal milling improved the cooking quality, but the loss of vital nutrients as well as integrity of rice bran composition exists (Rosniyana *et al.*, 2006). Only a minimal reduction in cooking time from 39.2 min to 33.0 min has been reported by Cui *et al.* (2010) after ultrasonic treatment of brown rice. Furthermore, germinating brown rice was found to reduce the cooking time but the rice developed off-smell due to fermentation (Patil and Khan, 2011).

Cooking of rice is done to achieve the complete starch gelatinization and to produce a desirable texture. Cooking also increases the bioavailability of nutrients by inactivating the associated antinutritional factors (Ma *et al.*, 2005). The conventional method of rice cooking is boiling method using either limited water or excess water. Pressure cooking is less commonly practiced for rice cooking despite the advantages of faster cooking and less energy consumption than boiling method. In addition, research has shown that pressure cooking enhances starch and protein digestibility (Sagum and Arcot, 2000). Several studies have reported that pressure cooking of legumes led to enhanced nutritional

*Corresponding author.
Email: *siwaporn.p@psu.ac.th*

quality (Grewal and Jood, 2005; Saikia *et al.*, 1999; Güzel and Sayar, 2012). Application of moist heat to save cooking time has also been documented but it produced unsatisfactory textural and eating quality (Cui *et al.*, 2010).

Hence, besides various advance technologies, pressure cooking could be an appropriate technology to be used in daily life as an affordable mean. However, there is scanty literature on pressure cooking method applied to brown rice. Therefore, present study aims to characterize and investigate the effect of cooking methods; pressure cooker (PC) and rice cooker (RC) on physicochemical and nutritional properties of brown rice. The correlations of different properties of uncooked and cooked rice were also explored.

Materials and Methods

Sample

Three varieties of brown rice; Sungyod (SY), Chiang (CH) and Lepnok (LP) were obtained from Phatthalung Rice Research Centre (PRRC), Thailand and two varieties of brown rice; long grain specialty (LS_1) and long grain specialty (LS_2) available in commercial packages were purchased from supermarkets in Kota Bharu Kelantan, Malaysia. For sensory tests, jasmine rice (white) was purchased from local supermarket (Big C, Pattani, Thailand). All the samples were vacuum packed and kept at 4°C until further use. Before the experiments, samples were kept at room temperature for 24 hr.

Determination of physical properties of uncooked brown rice

Thousand kernels weight, L/B ratio and bulk density were determined as described by Singh *et al.* (2005). Briefly, one thousand intact brown rice kernels were selected and weighed in triplicates and reported as 1000 kernels weight. Ten kernels of brown rice were measured by vernier calliper (10" manual version, Japan) with accuracy of ± 0.02 mm for length (L) and breadth (B) and from these, L/B ratio was derived. Brown rice was poured into a measuring cylinder for volume and weight was noted for corresponding volume. Bulk density was determined as the ratio of weight and volume.

Determination of pasting properties

Sample was prepared by grinding brown rice using cyclotec sample mill (Foss cyclotecTM1093, Sweden) and passed through 250 µm standard sieves. Three grams of rice flour on dry matter basis (d.b.) was mixed with 25 mL distilled water in a canister. The pasting property was determined

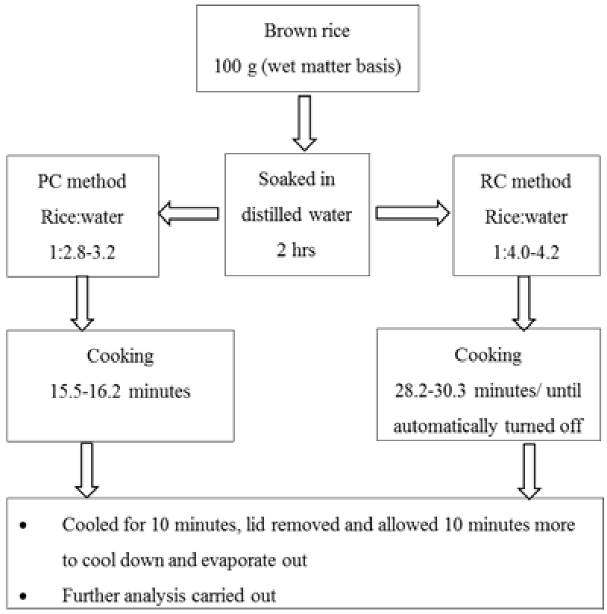

Figure 1. Flow diagram of rice cooking procedure (PC, Pressure cooker; RC, Rice cooker)

in Rapid Visco Analyser, RVA (RVA 4D, Newport Scientific, Australia, Thermocline Software version 2.0). The paddle speed was 960 rpm for 10 sec and then maintained at 160 rpm throughout. The initial temperature was 50°C for 1 min 30 sec and then increased to 95°C (ramp time 3 min 45 sec) where the sample was held for 2 min 30 sec before cooling to 50°C (ramp time 3 min 45 sec) and held at this temperature (1 min 30 sec). Parameters such as peak viscosity, breakdown viscosity, final viscosity, setback viscosity, peak time and peak temperature was measured using the RVA software.

Cooking treatment

Cooking was done following the cooking procedure (Figure 1) using PC (4 L capacity, working pressure 80 kPa, local brand, Thailand) and RC (4 L, National, Japan). Cooking was done to attain complete gelatinization of starch (checked by pressing plate method described by Singh *et al*. (2005)).

Determination of nutrient and antinutrient compositions

Determination of protein content, crude fat and ash content was done according to the standard methods of Association of Official Analytical Chemists (AOAC, 2000). Protein content was calculated by determining nitrogen content by Kjeldahl method (Gerhardt, Germany) and multiplying by a factor of 5.95. Iron (Fe) and zinc (Zn) were determined by using atomic absorption spectrophotometer (AAS-Perkin Elmer 100, Germany) following AOAC (2000). Samples were prepared by dry ashing method. Thiamine (Vitamin B_1) was determined according to method

AOAC (2000).

Phytate in brown rice sample was determined by the slight modifying the method described by Muñoz and Valiente (2003), where inductively coupled plasma optical emission spectroscopy (ICP-OES, Perkin Elmer, Optima 4300 DV) was used. Sample was first filtered through 0.45 µm filter and purified using anion-exchange solid phase extraction method containing AGI-X8 resin. Sample was then eluted with 50 mL of 50 $mmolL^{-1}$ HCl to separate out interfering phosphorous and other matrix components. 2 mL of 2 $molL^{-1}$ HCl was applied to elute phytate from the sample which was collected and diluted.

Determination of textural properties

Textural profile analysis (TPA) of the cooked brown rice was conducted with slight modification of the method described by Mohapatra and Bal (2006). A texture analyser (Stable Micro Systems, TA.XT. Plus, Texture Technologies Corp., UK) with a 50 kg load cell was used with two-cycle compression method. The cooked brown rice (2-3 kernels) still in warm condition were selected and kept on the base of the instrument. A two-cycle compression force versus time program was used to compress the samples till 90% of the total strain, return to the original position and re-compress. A 6 mm diameter probe was used to compress 1 to 2 grains; with pre-test and post-test speeds of 1 mm/sec and test speed of 0.5 mm/sec. Parameters recorded from the test curves were hardness, adhesiveness and cohesiveness. All textural analyses were replicated at least six times.

Determination of sensory properties

Sensory properties of cooked brown rice by both methods were compared with the white jasmine rice cooked by RC, since RC cooked white jasmine rice is common feeding practice in Thailand. Cooked rice samples were hot served by keeping warm and evaluated by 31 semi-trained (by providing lecture and demonstration about the sensory parameters of cooked rice) panellists according to the 9-point hedonic scaling method outlined by Land and Shepherd (1988). The cooked brown rice samples were served in sensory cups with lids coded with 3 digit random numbers. Permutation was applied to the samples before presenting to the panellists. Panellists were asked to evaluate samples for colour, flavour, softness and overall acceptance on a 9 point scale (1 = dislike extremely and 9 = like extremely).

Statistical analysis

All the analyses were done in triplicates (unless mentioned). The results are shown as mean ± SD. The statistical analysis was done using statistical software R and MS-EXCEL 2007. Mean values of different parameters were evaluated by analysis of variance (ANOVA) and significance was differentiated using Tukey's post-hoc test at $p < 0.05$. The Pearson's correlation coefficients for different properties were also calculated.

Table 1. 1000 kernel weight, L/B ratio and bulk density of five varieties of brown rice

Variety	TKW (g)	L (mm)	B (mm)	L/B ratio	BD (g/mL)
SY	14.14 ± 0.02[a]	6.6 ± 0.0[ab]	1.63 ± 0.06[a]	4.02 ± 0.14[dc]	0.85 ± 0.01[c]
CH	18.02 ± 0.02[b]	6.8 ± 0.1[b]	1.75 ± 0.04[a]	3.92 ± 0.11[c]	0.80 ± 0.00[b]
LP	13.86 ± 0.16[c]	6.2 ± 0.2[a]	2.12 ± 0.12[b]	2.94 ± 0.13[a]	0.86 ± 0.01[c]
LS_1	21.35 ± 0.16[d]	7.6 ± 0.1[c]	2.05 ± 0.07[b]	3.69 ± 0.08[bc]	0.75 ± 0.02[a]
LS_2	22.04 ± 0.05[e]	7.6 ± 0.2[c]	2.12 ± 0.04[b]	3.60 ± 0.07[b]	0.84 ± 0.02[c]

[a-e]The different suffix letters of same column represent significant difference ($p < 0.05$); TKW, Thousand kernel weight; BD, Bulk density; L, Length; B, Breadth; L/B, Length/breadth

Results and Discussion

Physical properties of uncooked brown rice

Table 1 shows 1000 kernels weight, L/B ratio and bulk density of brown rice from five different varieties. The 1000 kernels weight was found in the range of 13.86 (LP) to 22.04 (LS2) g and they were significantly different ($p < 0.05$) among varieties. Brown rice having L/B ratio ≤ 2, 2.1 to 3 and ≥ 3.1 are regarded as short, medium and slender, respectively (Bergman *et al*., 2004). SY, CH, LS_1 and LS_2 were classified as long and slender while LP (2.94) as medium grain. Bulk density of LP variety was the highest (0.86 g/mL) while LS1 (0.75 g/mL) was the lowest. Higher bulk density of medium grain in comparison to long grain brown rice was reported by Fan *et al.* (1998) and is in agreement to our results. Bulk density is used for determining the quality and type of packaging material for handling of grains (Falade *et al*., 2014).

Pasting properties of uncooked rice flours

Pasting properties of uncooked rice flour by RVA is shown in Figure 2. Peak viscosity (PV) ranged from 1204 (SY) – 1912 (LS_2) cP. PV is the indication of starch granule swelling and high value

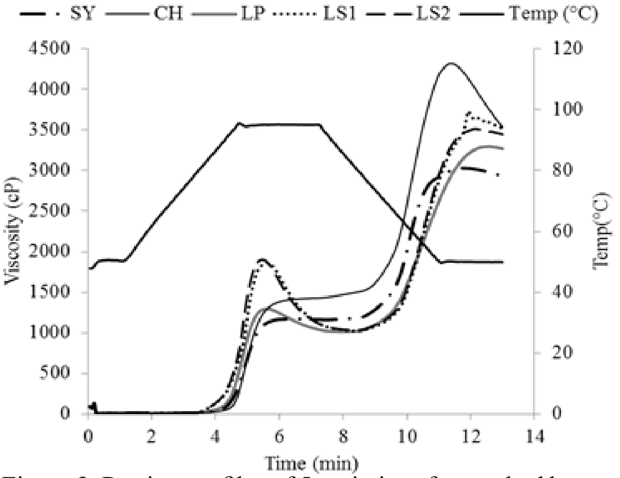

Figure 2. Pasting profiles of 5 varieties of uncooked brown rice flours

(SY, Sungyod; CH, Chiang; LP, Lepnok; LS1, Long grain specialty 1; LS_2, Long grain specialty 2)

of PV indicates high capacity of swelling of starch (Choi *et al*., 2012). This suggests that SY flour would exhibit low shear on pasting. The highest breakdown viscosity (BD) value was observed in LS_2 (849 cP) and the lowest in SY (14). This means SY flour of low BD could give more stable hot paste in comparison to LS_2 flour of high BD (Choi *et al*., 2012). There were no significant differences in BD between CH and SY as well as between LS_1 and LS2. Setback viscosity (SBV) values were observed between 1772 – 2540 cP where the lowest SBV of SY (1772 cP) was significantly different ($p < 0.05$) from the other varieties. SBV is found due to reassociation of gelatinized starch (retrogradation) in the course of reaching its final viscosity, and is an indication of retrogradation properties of starch (Choi *et al*., 2012). SBV of SY was obtained lower than LP, CH, LS_1 and LS_2 in present study, indicated the low capacity of retrogradation of SY. Final viscosity (FV) was observed in between 2962 (SY) – 3602 (LS2) cP. The low amylose rice (SY) flour resulted in the lowest values of PV, BD, SBV and FV in comparison to the other varieties of medium amylose content. Interestingly, although PV, BD, SBV values of CH were significantly different ($p < 0.05$) to LS_1 and LS_2; FV was not different ($p > 0.05$). Peak time (PT) was found in between 5 – 7 min. The PT of CH (7 min) indicated comparatively slow gelatinization of starch granules to reach PV. It was observed that pasting temperature was higher for the brown rice flour which had high PT.

Effects of cooking on nutrient and antinutrient compositions

Protein content of five varieties of brown rice (uncooked) was in the range of 7.25 – 8.76% (Table 2) and is in agreement with the protein content of Oryza sativa varieties reported in the range of 4.5 – 15.2% by Kennedy and Burlingame (2003). Apart from natural variation of protein in different varieties, factors such as fertilization and environment may have influence (Moongngarm and Saetung, 2010). Rice has been considered as an important source of protein in the area where rice is the main staple food (Dipti *et al.*, 2012). In present study, protein content of all five varieties of brown rice was found to be 8.18 – 10.14% and 8.17 – 9.41% after cooking by PC and RC, respectively. There was an average increase in protein content by 12% and 10% in PC and RC method, respectively. Maximum increase in protein after cooking was seen in CH (~ 15%) and minimum in LS_1 (~ 8%) variety. This might be because of the absorption of water through aleurone and pericarp layer during cooking, resulting in swelling and gelatinization of starch granules causing bursting of bran from ventral surface. This leads to leaching of some portion of starchy endosperm in the form of gruel (unrecoverable), a phenomenon also reported by Briffaz *et al.* (2014). This causes decrease of total content of starch, therefore, proportionately increasing the amount of protein of the cooked brown rice. The change in amount of protein due to cooking of brown rice could be considerably important in such areas. According to Khatoon and Prakash (2006), microwave and pressure cooking had no significant effects on protein content of milled Gowri sanna and Jeera rice. Pressure cooking had no significant impact on protein content of milled Doongara and Inga (Sagum and Arcot, 2000). A significant positive correlation was obtained for protein content of brown rice cooked by PC ($r = 0.963$, $p < 0.01$) and RC ($r = 0.897$, $p < 0.05$) with peak time, a pasting property of uncooked flour.

Fat content of uncooked brown rice was observed in a range of 1.44 – 2.48% , and is in agreement with the report by Kennedy and Burlingame (2003). On comparison of uncooked, PC and RC of each variety, fat content did not change significantly ($p > 0.05$) in 4 rice varieties except in LS_2 by both PC and RC method. Normally, brown rice is a good source of high quality fat present on the bran layer as well as germ. Various studies has reported that germ oil contains vitamin E and γ-oryzanol with potential to hypercholesterolemic, anti-inflammatory and antioxidant activities (Pascual *et al*., 2013).

Ash content analysis showed presence of 1.14 – 1.50, 1.15 – 1.50, and 1.18 – 1.45% of ash in uncooked, PC and RC cooked rice respectively. Significant reduction ($p < 0.05$) of ash content due to cooking was seen in CH alone. Comparatively CH variety having higher amylose content after cooking

Table 2. Nutrient compositions of uncooked and cooked brown rice

Parameters		CH	SY	LP	LS_1	LS_2
Protein	Uncooked	8.76 ± 0.03^{a}	8.63 ± 0.02^{a}	7.53 ± 0.11^{a}	8.0 ± 0.08^{a}	7.25 ± 0.28^{a}
	PC	10.14 ± 0.07^{c}	9.50 ± 0.50^{b}	8.21 ± 0.12^{b}	8.91 ± 0.03^{c}	8.18 ± 0.04^{b}
	RC	9.60 ± 0.08^{b}	9.41 ± 0.03^{b}	8.26 ± 0.04^{b}	8.63 ± 0.08^{b}	8.17 ± 0.11^{b}
Fat	Uncooked	2.38 ± 0.06^{a}	2.48 ± 0.08^{a}	2.37 ± 0.02^{a}	1.78 ± 0.09^{a}	1.44 ± 0.12^{a}
	PC	2.40 ± 0.14^{a}	2.53 ± 0.03^{a}	2.37 ± 0.05^{a}	1.77 ± 0.11^{a}	1.74 ± 0.07^{b}
	RC	2.51 ± 0.10^{a}	2.71 ± 0.06^{a}	2.52 ± 0.06^{b}	1.86 ± 0.07^{a}	1.88 ± 0.06^{b}
Ash	Uncooked	1.46 ± 0.01^{b}	1.50 ± 0.02^{ab}	1.42 ± 0.02^{a}	1.14 ± 0.02^{a}	1.17 ± 0.05^{a}
	PC	1.32 ± 0.03^{a}	1.50 ± 0.00^{b}	1.40 ± 0.02^{a}	1.15 ± 0.02^{a}	1.31 ± 0.04^{b}
	RC	1.34 ± 0.03^{a}	1.45 ± 0.03^{a}	1.46 ± 0.05^{a}	1.18 ± 0.02^{a}	1.26 ± 0.02^{ab}
Fe	Uncooked	1.16 ± 0.03^{c}	0.85 ± 0.02^{b}	1.23 ± 0.10^{b}	1.17 ± 0.10^{b}	1.08 ± 0.01^{c}
	PC	0.93 ± 0.05^{b}	0.70 ± 0.06^{a}	1.11 ± 0.10^{b}	0.72 ± 0.07^{a}	0.83 ± 0.04^{b}
	RC	0.55 ± 0.06^{a}	0.99 ± 0.01^{c}	0.76 ± 0.08^{a}	0.72 ± 0.04^{a}	0.76 ± 0.02^{a}
Zn	Uncooked	1.90 ± 0.02^{ab}	2.20 ± 0.10^{b}	2.18 ± 0.08^{a}	1.35 ± 0.02^{a}	1.46 ± 0.12^{b}
	PC	2.04 ± 0.10^{b}	2.19 ± 0.10^{b}	2.29 ± 0.08^{ab}	1.71 ± 0.11^{b}	1.23 ± 0.03^{a}
	RC	1.75 ± 0.05^{a}	1.86 ± 0.08^{a}	2.43 ± 0.01^{b}	1.21 ± 0.03^{a}	1.15 ± 0.03^{a}

Values are mean ± SD, $^{a-c}$small case superscripts letters of same column for each parameter indicates significant difference at $p < 0.05$.

exhibited dry and flaky kernels as the bran layer disintegrated through ventral surface. This suggested that wider the opening of outer layer, leaching may be higher resulting in considerable loss of mineral.

Fe content ranged from 0.85 – 1.23 mg/100 g (d.b.) in uncooked brown rice. The cooking loss of Fe was detected in the range of 10 – 38% (PC) and 29 – 53% (RC). Maximum retention of Fe (~ 90%) in LP by PC method and minimum retention (~ 48%) in CH by RC method were observed. Boiling of the rice kernels during cooking caused leaching of micro and macro molecules resulting in the loss of minerals such as Fe. There was significant reduction ($p < 0.05$) of Fe in CH, LS_1 and LS_2 by both cooking methods compared to uncooked. Overall comparison of Fe content of five varieties by both cooking methods showed a significant decrease in Fe content due to cooking. Fe content in 95 different varieties were reported in the range of 0.70 – 6.35 mg/100 g (Kennedy and Burlingame, 2003), which is similar to our results. Ma *et al.* (2005) has reported reduction of minerals such as Fe and Zn due to cooking methods such as steaming, pressure cooking or boiling in agreement with the current study. Reduction of Fe content in rice cooked by pressure and microwave methods resulted in 38 – 50% (Khatoon and Prakash, 2006).

Zn content ranged from 1.35 – 2.20 mg/100 g, 1.23 – 2.29 and 1.15 – 2.43 mg/100 g for uncooked, PC and RC cooked brown rice respectively. Effect of cooking on Zn content of brown rice showed mixed results. However, overall evaluation of five varieties showed no significant changes ($p > 0.05$) in Zn content due to either of the cooking methods.

Phytate content ranged from 220 – 308, 231 – 364, 217 – 278 mg/100 g (d.b.) for uncooked, PC and RC cooked brown rice, respectively. There was no significant change ($p > 0.05$) in phytate content due to cooking methods compared to uncooked rice. A high percentage of reduction in phytate content was reported due to boiling with removing excess cooking water compared to pressure cooking or boiling without removing excess water (Ma *et al.*, 2005). In the present study, brown rice was cooked without washing and not removing the excess water in both methods. Almana (2000) reported that discarding cooking water reduced phytate of rice up to 65% while only 12% when cooked without discarding excess cooking water. Phytate is the important factor for the evaluation of availability of bivalent minerals such as Fe and Zn especially where people rely on non-haeme Fe. In the context of Fe and Zn deficiency, prevailing in rice consuming societies (Dipti *et al.*, 2012), brown rice could be potential source to fight against such deficiency. However, higher molar ratio of such mineral with phytate reflects less bioavailability. There was no significant difference ($p > 0.05$) in the molar ratio of phytate/Zn before and after cooking by both methods. The molar ratio of phytate/Fe of PC cooked rice was significantly higher to that of uncooked, but not significant with RC. Our study showed that the molar ratio of phytate/Fe ranged 15.9 – 22.9, 27.2 – 43.8, 23.8 – 34.6 for uncooked, PC and RC cooked brown rice. Similarly, phytate/Zn ranged 13.0 – 19.9, 13.4 – 24.8, 12.3 – 20.5 for uncooked, PC and RC respectively. The molar proportion of phytate/Fe when exceeds more than 1 and that of phytate/Zn exceeds 15, it is predicted as low bioavailability for Fe and Zn from that food respectively (Ma *et al.*, 2005).

The mean thiamine content of brown rice was found in the range of 0.20 – 0.04 mg/100 g (d.b.), and is in agreement with the report of Kennedy and Burlingame (2003). Thiamine content decreased to 0.19 ± 0.04 and 0.17 ± 0.03 mg/100 g (d.b.) by PC and RC, respectively. However, this reduction was not significant ($p > 0.05$). Thus, brown rice is considerably good source of thiamine even after cooking by both PC and RC methods.

Effect of cooking on texture

Textural properties such as degree of hardness,

Table 3. Textural properties of cooked brown rice

Parameters		Brown rice				
		CH	SY	LP	LS_1	LS_2
Hardness (N)	PC	10.96 ± 2.64^{bc}	13.47 ± 2.96^{c}	10.08 ± 2.95^{b}	5.36 ± 2.42^{*a}	4.92 ± 2.13^{*a}
	RC	13.66 ± 4.5^{b}	13.60 ± 2.5^{b}	11.0 ± 3.58^{a}	8.44 ± 2.28^{ab}	11.40 ± 4.74^{ab}
Cohesiveness	PC	0.14 ± 0.02^{*ab}	0.12 ± 0.01^{a}	0.15 ± 0.04^{b}	0.12 ± 0.02^{ab}	0.12 ± 0.03^{*ab}
	RC	0.20 ± 0.05^{b}	0.12 ± 0.03^{a}	0.14 ± 0.05^{a}	0.15 ± 0.05^{ab}	0.15 ± 0.03^{ab}
Adhesiveness (N. Sec)	PC	-0.11 ± 0.06^{b}	-0.28 ± 0.21^{a}	-0.16 ± 0.09^{ab}	-0.27 ± 0.14^{ab}	-0.27 ± 0.16^{ab}
	RC	-0.05 ± 0.07^{b}	-0.22 ± 0.08^{a}	-0.19 ± 0.16^{a}	-0.23 ± 0.09^{a}	-0.27 ± 0.09^{a}

Values are mean ± SD, $^{a-c}$ superscript letters of row indicate significant difference, * indicates significant difference between PC and RC ($p < 0.05$).

cohesiveness and adhesiveness of cooked brown rice are presented in Table 3. Hardness of cooked rice ranged from 4.96 to 13.66 N where the lowest value was achieved for LS_2 (PC) and the highest for CH (RC). Hardness of LS_1 and LS_2 by PC was significantly lower compared to RC method. Between two cooking methods, there was difference in cooking time, temperature and pressure. However, not all varieties of brown rice behaved differently in terms of hardness. Hardness is one major constraint for brown rice consumption. From the above results, PC tends to reduce the hardness of brown rice. A number of studies have shown variation of hardness due to varieties of rice (Mir *et al*., 2016), amylose content (Singh *et al*., 2005), starch size granules (Singh *et al*., 2003; Mir and Bosco, 2014), and presence of pericarp, aleurone layer and cuticle layer (Briffaz *et al*., 2014; Wu *et al*., 2014). A significant correlation was obtained for hardness of cooked brown rice by PC with pasting properties of uncooked flour such as PV ($r = –0.965$, $p < 0.01$), BV ($r = –0.973$, $p < 0.01$), SBV ($r = –0.944$, $p < 0.01$) and pasting temperature ($r = 0.89$, $p < 0.05$). Limpisut and Jindal (2002) has reported correlation of hardness of cooked milled rice with pasting properties such as pasting temperature ($r = 0.024$, $p < 0.05$), PV ($r = –0.575$, $p < 0.01$) in agreement to the present study.

Cohesiveness ranged from 0.12 – 0.15 and 0.12 – 0.20 for PC and RC, respectively (Table 3). Cohesiveness of only CH and LS_2 was found significantly different ($p < 0.05$) between PC and RC. Cohesiveness is a property of cooked rice to regain the shape after deformation. In general, high amylose rice is found dry, flaky after cooking with cohesiveness in nature. On the other hand, SY with low amylose content, upon cooking was normally found moist and resulted in low cohesiveness. Similar results were observed with a study in Pusa Basmati rice which had high cohesiveness and high amylose content compared to other with low amylose variety even at different degree of milling (Mohapatra and Bal, 2006).

Adhesiveness of PC and RC cooked brown rice ranged from – 0.11 to – 0.28 N. Sec and – 0.05 to – 0.27 N. Sec, respectively and no significant difference were found between the two cooking methods. However, there was significant difference ($p < 0.05$) of adhesiveness of CH (high amylose) and SY (low amylose). A previous study has also reported low level of adhesiveness in the varieties having higher amylose content (Mir *et al.*, 2016). Adhesiveness is an attribute of cooked rice which is distinct and obvious for milled rice, however, lower values are obtained for the brown rice. Wu *et al*. (2014) has reported the effect of aleurone layer, pericarp and seed coat on adhesiveness of brown rice. CH variety with higher amylose content showed low adhesiveness compared to others (Mohapatra and Bal, 2006; Mir *et al*., 2016). Adhesiveness of cooked rice by RC was positively correlated with peak time ($r = 0.922$, $p < 0.05$).

Sensory properties

The sensory scores in terms of colour and flavour of all varieties cooked by both PC and RC were significantly low ($p < 0.05$) compared to jasmine (white rice) except of LS_2 variety. In present study, the effects of cooking on softness of cooked brown rice varied according to rice varieties. The softness of SY and LS_2 by PC and softness of LS_1 by both PC and RC were comparable to white Jasmine rice. The sensory scores in terms of overall acceptability of LS_2 variety by both methods were found similar to that of jasmine white rice.

Conclusion

The effects of domestic cooking methods (pressure cooker and rice cooker) on physicochemical, nutritional and sensory properties of brown rice were investigated. Brown rice sample was soaked for two hours without washing and cooked in limited water. Both the cooking methods affected the physicochemical properties such as texture. PC method was effective to reduce hardness of certain varieties. Nutritional properties such as protein, fat and Fe was affected by both cooking methods but Zn and thiamine were not affected as compared to uncooked brown rice. Cooked brown rice were not good sources of Fe, Zn since both PC and RC methods did not reduce phytate as well as molar ratio of phytate/Fe and phytate/Zn. Sensory comparison of cooked brown rice with white jasmine rice showed comparable softness and overall acceptability in certain varieties. From the present study, the prediction of hardness of brown rice cooked by PC can be done from RVA properties. Overall, PC cooked in short time, hardness comparatively reduced, significant increase in protein and considerably well retention of thiamine presenting potential of healthfulness of brown rice of these areas even after cooking. It is recommended for further comprehensive study of PC method to investigate the effects of cooking on antioxidant properties of brown rice in future.

Acknowledgements

This study was supported by SAT-ASEAN research grant, Faculty of Science and Technology, Prince of Songkla University, Pattani Campus, Thailand as well as university research grant, Graduate School, Prince of Songkla University, Thailand.

References

Almana, H. A. 2000. Extent of phytate degradation in breads and various foods consumed in Saudi Arabia. Food Chemistry 70: 451–456.

AOAC. 2000. Official Methods of Analysis. 17th edn. Maryland, USA: Association of Official Analytical Chemists.

Bergman, C. J., Bhattacharya, K. R. and Ohtsubo, K. 2004. Rice end-use quality analysis. In Champagne, E.T. (Ed). Rice Chemistry and Technology, p. 415–460. Minnesota: American Association of Cereal Chemists.

Briffaz, A., Bohuon, P., Méot, J. M., Pons, B., Matencio, F., Dornier, M. and Mestres, C. 2014. Modelling of brown rice and limited-water cooking modes and its potential use for texture prediction. Journal of Food Engineering 141: 99–106.

Choi, I., Han, O., Chun, J., Kang, C., Kim, K., Kim, Y., Cheong, Y., Park, T., Choi, J. and Kim, K. 2012. Hydration and pasting properties of oat (*Avena sativa*) flour. Preventive Nutrition and Food Science 17: 87–91.

Cui, L., Pan, Z., Yuem T., Atungulu, G. G. and Berrios, J. 2010. Effect of ultrasonic treatment of brown rice at different temperatures on cooking properties and quality. Cereal Chemistry 87: 403–408.

Dipti, S. S., Bergman, C., Indrasari, S. D., Herath, T., Hall, R., Lee, H., Habibi, F., Bassinello, P. Z., Graterol, E., Ferraz, J. P. and Fitzgerald, M. 2012. The potential of rice to offer solutions for malnutrition and chronic diseases. Rice 5: 1-18.

Falade, K. O., Semon ,M., Fadairo, O. S., Oladunjoye, A. O. and Orou, K. K. 2014. Functional and physico-chemical properties of flours and starches of African rice cultivars. Food Hydrocolloids 39: 41–50.

Fan, J., Siebenmorgen, T. J., Gartman, T. R. and Gardisser, D. R. 1998. Bulk density of long-and medium-grain rice varieties as affected by harvest and conditioned moisture contents. Cereal Chemistry 75: 254–258.

Greenwood, D. C., Threapleton, D. E., Evans, C. E. L., Cleghorn, C. L., Nykjaer, C., Woodhead, C. and Burley, V. J. 2013. Glycemic index, glycemic load, carbohydrates, and type 2 diabetes: systematic review and dose-response meta-analysis of prospective studies. Diabetes Care 36: 4166–4171.

Grewal, A. and Jood, S. 2005. Effect of processing treatments on nutritional and antinutritional contents of green gram. Journal of Food Biochemistry 30: 535–546.

Güzel, D. and Sayar, S. 2012. Effect of cooking methods on selected physicochemical and nutritional properties of barlotto bean, chickpea, faba bean, and white kidney bean. Journal of Food Science and Technology 49: 89–95.

Hallfrisch, J., Scholfield, D. J. and Behall, K. M. 2003. Blood pressure reduced by whole grain diet containing barley or whole wheat and brown rice in moderately hypercholesterolemic men. Nutrition Research 23: 1631–1642.

Kennedy, G. and Burlingame, B. 2003. Analysis of food composition data on rice from a plant genetic resources perspective. Food Chemistry 80: 589–596.

Khatoon, N. and Prakash, J. 2006. Nutritional quality of microwave and pressure cooked rice *(Oryza sativa)* varieties. Food Science and Technology International 12: 297–305.

Kozuka, C., Yabikum K., Takayama, C., Matsushita, M. and Shimabukuro, M. 2013. Natural food science based novel approach toward prevention and treatment of obesity and type 2 diabetes : recent studies on brown rice and γ-oryzanol. Obesity Research and Clinical Practice 7: e165–e172.

Land, D. G. and Shepherd, R. 1988. Scaling and ranking methods. In Piggot, J. R. (Ed). Sensory Analysis of Foods, p. 141–177. London: Elsevier Applied Science Publishers Ltd.

Limpisut, P. and Jindal, V. K. 2002. Comparison of rice flour pasting properties using brabender viscoamylograph and rapid visco analyser for evaluating cooked rice texture research paper. Starch - Stärke 54: 350–357.

Lyon, B. G., Champagne, E. T., Vinyard, B. T. and Windham, W. R. 2000. Sensory and instrumental relationships of texture of cooked rice from selected cultivars and postharvest handling practices. Cereal Chemistry 77: 64–69.

Ma, G., Jin, Y., Piao, J., Kok, F., Guusje, B. and Jacobsen, E. 2005. Phytate, calcium, iron, and zinc contents and their molar ratios in foods commonly consumed in China. Journal of Agricultural and Food Chemistry 53: 10285–10290.

Mir, S. A. and Bosco, S. J. D. 2014. Cultivar difference in physicochemical properties of starches and flours from temperate rice of Indian Himalayas. Food Chemistry

157: 448–456.

Mir, S. A., Bosco, S. J. D., Shah, M. A., Mir, M. M. and Sunooj, K. V. 2016. Variety difference in quality characteristics, antioxidant properties and mineral composition of brown rice. Journal of Food Measurement and Characterization 10: 177–184.

Mirrahimi, A., Chiavaroli, L., Srichaikul, K., Augustin, L. S. A., Sievenpiper, J. L., Kendall, C.W. and Jenkins, D. J. 2014. The role of glycemic Index and glycemic load in cardiovascular disease and its risk factors : a review of the recent literature. Current Atherosclerosis Report 16: 381–391.

Mohapatra, D. and Bal, S. 2006. Cooking quality and instrumental textural attributes of cooked rice for different milling fractions. Journal of Food Engineering 73: 253–259.

Monks, J .L .F. , Vanier, N. L., Casaril, J., Berto, R.M., de Oliveira, M., Gomes, C. B., de Carvalho, M. P., Dias, A. R. G. and Elias, M. C. 2013. Effects of milling on proximate composition, folic acid, fatty acids and technological properties of rice. Journal of Food Composition and Analysis 30: 73–79.

Moongngarm, A. and Saetung, N. 2010. Comparison of chemical compositions and bioactive compounds of germinated rough rice and brown rice. Food Chemistry 122: 782–788.

Muñoz, J. A. and Valiente, M. 2003. Determination of phytic acid in urine by inductively coupled plasma mass spectrometry. Analytical Chemistry 75: 6374–6378.

Nagle, C. M., Olsen, C. M., Ibiebele, T. I., Spurdle, A. B. and Webb, P. M. 2013. Glycemic index , glycemic load and endometrial cancer risk : results from the Australian National Endometrial Cancer study and an updated systematic review and meta-analysis. European Journal of Nutrition 52: 705–715.

Pascual, C. D. S. C. I., Massaretto, I. L., Kawassaki, F., Barros, R.M.C., Noldin, J. A. and Marquez, U. M. L. 2013. Effects of parboiling, storage and cooking on the levels of tocopherols, tocotrienols and γ-oryzanol in brown rice (*Oryza sativa* L.). Food Research International 50: 676–681.

Patil, S. B. and Khan, M. K. 2011. Germinated brown rice as a value added rice product: A review. Journal of Food Science and Technology 48: 661–667.

Rosniyana, A., Rukunudin, I. H. and Norin, S. A. S. 2006. Effects of milling degree on the chemical composition, physico- chemical properties and cooking characteristics of brown rice (kesan darjah pengilangan terhadap kandungan kimia, ciri fiziki-kimia dan sifat memasak beras perang). Journal of Tropical Agriculture and Food Science 34: 37–44.

Sagum, R. and Arcot, J. 2000. Effect of domestic processing methods on the starch, non-starch polysaccharides and in vitro starch and protein digestibility of three varieties of rice with varying levels of amylose. Food Chemistry 70: 107–111.

Saikia, P., Sarkar, C. R. and Borua, I. 1999. Chemical composition , antinutritional factors and effect of cooking on nutritional quality of rice bean [Vigna umbellata (Thunb ; Ohwi and Ohashi)]. Food Chemistry 67: 347–352.

Singh, N., Kaur, L., Singh, S. N. and Singh, S. K. 2005. Physicochemical, cooking and textural properties of milled rice from different Indian rice cultivars. Food Chemistry 89: 253–259.

Singh, N., Sodhi, N. S., Kaur, M. and Saxena, S. K. 2003. Physico-chemical, morphological, thermal, cooking and textural properties of chalky and translucent rice kernels. Food Chemistry 82: 433–439.

Wu, J., Chen, J., Liu, W., Liu, C., Zhong, Y., Luo, D., Li, Z. and Guo, X. 2014. Effects of aleurone layer on rice cooking: A histological investigation. Food Chemistry 191: 28-35.