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Effect of Processing Conditions and Cooking Methods on Resistant Starch, Dietary Fiber and Glycemic Index of Rice

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ABSTRACT. *The digestibility and Glycemic Index (GI) of rice starch are partly attributable to the inherent properties of starch. In this study, the composition of rice with respect to moisture content, resistant starch (RS), total carbohydrate, dietary fiber, protein content, ash content and glycemic indices of three popular rice varieties, Bg 300, Bg 358 and At 405 were examined under two processing conditions (raw, parboiled) and three cooking methods (rice cooker method, boiling and straining method and conventional cooking method). The RS content of variety At 405 (7.50 ± 0.37 %) was significantly higher ($p<0.05$) than that of the varieties Bg 300 and Bg 358. Parboiling and method of cooking had no effect on protein content and dietary fiber contents of variety Bg 300 and Bg 358.However the parboiling significantly increased ($p<0.05$) the ash content of both variety Bg 300 and Bg 358 Results of this study showed a significant difference ($p<0.05$) in glycemic indices among the three varieties. The GI of varieties Bg 300, Bg 358 and At 405 were 72 ± 2, 70 ± 1 and 68 ± 2, respectively. The mean glycemic indices of parboiled rice varieties Bg 300 and Bg 358, which were 67 ± 1 and 68 ± 1,* respectively, *were significantly lower ($p<0.05$) compared to their raw form. However, the cooking methods had no effect on either the composition or GI of rice.*

Keywords: *Dietary fiber, glycemic index, resistant starch, total carbohydrate*

INTRODUCTION

Rice is known as the 'grain of life'. It is the predominant staple food for 17 countries in Asia and the Pacific, nine countries in north and South Africa and eight countries in America (FAO Report, 2004). Rice provides 20% of the world's dietary energy supply (FAO Report, 2004). The per capita consumption of rice in Sri Lanka is about 108 kg/yr and it contributes to nearly 50% of the energy and 40% of protein in the daily diet (Sartaj and Suraweera, 2005). Rice sector contributes to 30% of the agricultural Gross Domestic Product (GDP) of Sri Lanka (Mendis, 2009).

Digestibility of rice starch is partly attributable to the inherent properties of starch including its crystallinity, granular structure and amylase:amylopectin ratio. The type of crop and variety play an important role in determining the digestibility of starch and it's Glycemic Index (GI). The glycemic index is a measure of the blood glucose response to a 50g carbohydrate in a food as a percentage of the response to an equal weight of glucose by the same subject (Wallace and Monro, 2005).

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Dietary fiber and resistant starch content also have an effect on the glycemic index of a food (Whitney and Rolfes, 1997). Dietary fiber composed of celluloses, hemicelluloses, pectins, lignins and other non–digestible materials in the food which are resistant to the digestible enzymes in human body (Potty, 1996), even though some are digested by bacteria in the gastro intestinal tract (Whitney and Rolfes, 1997). The effectiveness of dietary fiber is governed by its physical properties such as particle size when ingested, water holding capacity, solubility and viscosity in aqueous phase, affinity to bile acid salts, cationic binding/exchange effect, fermentability in the bowel and chemical identity and proportion of various constituents (Potty, 1996). Dietary fiber plays a specific role against cardiovascular disease, obesity, diverticular disease and hypertension (Leveille, 1997, Anderson, *et al*., 2009).

Based on the rate of digestion in human digestive tract, starch can be classified as rapidly digestible starch (RDS), slowly digestible starch (SDS) and resistant starch (RS) (Zhang and Hamaker, 2009). Resistant starch can be defined as the sum of starch and products of starch degradation not absorbed in the small intestine of healthy individuals (Ratnayake, 2005). The RS can be classified under unavailable carbohydrates as it goes through the small intestine without being digested at all. Sometimes is classified and labeled as fiber (Dolson, 2009). When resistant starch reaches the colon, it is fermented by bacteria there, producing short chain fatty acids (SCFAs). The RS is sub-divided into four fractions as RS_1, RS_2, RS_3 and RS_4 andrice contains mainly RS_1 (Sajilata *et al*., 2006). Like fiber and oligosaccharide, resistant starch is also associated with health benefits to human such as prevention of cancer, hypoglycemic effect, prebiotic effect, reduction of gall stone formation and inhibition of fat accumulation and absorption of minerals (Sajilata *et al*., 2006).

Rice is subjected to various processing techniques and cooking methods before consumption which changes its physicochemical properties leading to changes in starch digestibility and glycemic response (Ostegbayo *et al.,* 2001). Hettiarachchi *et al*. (2001) and Pathiraje *et al.* (2004) have already done GI studies on both raw and parboiled form of some Sri Lankan rice varieties, but they have not studied the effects of the method of cooking on the GI. The aim of the present study was to compare the composition of three popular rice varieties with respect to their dietary fiber, total carbohydrate, resistant starch, protein, and ash contents and the Glycemic Indices under two processing techniques (raw or parboiled) and three cooking methods (rice cooker method, boiling and straining method and conventional cooking method).

MATERIALS AND METHODS

Raw materials

Three rice varieties, Bg 358 (*Samba*), Bg 300 (*Nadu*) and At 405 (*Basmathi type*) were obtained from Rice Research and Development Institute, Bathalagoda, Sri Lanka which are popular rice varieties in Sri Lanka. Parboiling and polishing of respective rice varieties were done at the Laboratory of the Department of Food Science & Technology, University of Peradeniya. Both raw and parboiled rice were polished at the rate of 10% on the basis of weight with a paddy husker and rice polisher (PM 500, Japan).

Sample preparation

Rice samples (50 g) were cooked according to the methods shown in Table 1 in triplicates. The variety At 405 was not subjected to parboiling as it is *Basmathi* type rice which is not consumed in parboiled form. Hence, the variety At 405 was subjected to cooking using the rice cooker method only.

Table 1. Cooking methods of rice

Rice Variety	Method of Cooking	Notation
Bg 300	Rice cooker method	A
	Boiling and straining method	B
	Conventional cooking method	C
Bg 358	Rice cooker method	A
	Boiling and straining method	B
	Conventional cooking method	C
At 405	Rice cooker method	A

Rice cooker method (A)

Rice was placed in the rice cooker with different amounts of water for raw rice (50 g rice in 125 mL of water) and parboiled rice (50 g rice in 140 mL of water) and cooked until the amount of added water was fully absorbed.

Boiling and straining method (B)

The rice samples (50 g) were heated to boil with 500 mL of water. When water was boiling, content was stirred and returned to boiling and cooking until rice was tender. Finally the excess water was drained off.

Conventional cooking method (C)

The rice (50 g) was cooked in a gas cooker with different amounts of water:rice for raw (125 ml) and parboiled rice (140 ml). When water was boiling, rice was stirred,returned to medium-boil condition by regulating the flame of gas cooker. Boiling continued until water was fully absorbed and rice became tender.

Determination of moisture content

Moisture content of rice was determined by oven dry method at 130 ^{o}C for 2 hours (AOAC, 2000).

Determination of resistant starch and non resistant starch content

Resistant starch (RS) and non-resistant starch (NRS) contents were determined by Megazyme Assay Kit for Resistant starch and non-resistant starch determination which was based on AOAC (2000) method 2002.02 and AACC (2000) method 32-40. Assay kit was purchased from Megazyme International limited, Ireland (RS TAR 05/2008). The cooked rice was ground into a paste with a mortar and pestle. The rice paste (100 mg) was digested with enzymes, pancreatic α-amylase (3 Ceralpha Units/mg) and amyloglucosidase (3300 Units/mL).

Determination of total carbohydrate content

The total carbohydrate content was determined by AOAC (2000) method 988.12 (Standard Phenol Colorimetric Method). Cooked rice was made into a paste and 5 g from the paste was used for the analysis. Total carbohydrate contents were measured against the D-glucose standard curve.

Determination of dietary fiber content

AOAC (2000) method 985.29 was used for the determination of dietary fiber. Oven dried, cooked samples were used for the analysis. Digestion was done with α-amylase (23-566-6EC), amyloglucosidase (300 U/mL) and protease (≥0.3U/mg)
Determination of protein content

Protein content (%) was determined by Kjeldhal method. Calculation was done using the factor; N x 5.95 (AOAC, 2000).

Determination of ash content

The ash content (%) was determined by igniting the moisture-free cooked rice samples at 550 ^{o}C until white ash was formed (AOAC, 2000).

Determination of glycemic index

Study sample

Ten volunteers (5 males and 5 females) aged between 20-45 years with a normal glucose tolerance test were participated in the study. Subjects were given a brief outline of the study and requested to report at 6.30 am, after fasting for 10 hours on the assigned days.

Testing procedure

After collecting the fasting blood sample each subject was given cooked rice containing 50 g of available carbohydrate with a tea spoonful of chili paste (test food) or 50 g of D-glucose (analytical grade) dissolved in 250 mL of water (standard). Mineral water (200 ml) was given for drinking. Finger-prick blood samples were collected at 15, 30, 45, 60, 90 and 120 minute intervals after completion of the meal (Brouns *et al*., 2005). Capillary blood was collected by finger-prick using sterile lancets. Blood glucose level was determined using a glucometer (ENTRUST™, Bayer Health Care, USA). Rice or glucose was fed at 3-day intervals to the subjects.

The amount of cooked rice containing 50 g of available carbohydrate varied from 177 to 188 g within three varieties under different processing conditions and cooking methods. The lowest value was obtained for the variety Bg 300 under parboiled condition, for the cooking method B while the highest value was obtained for the variety At 405, raw form following the cooking method A.

Preparation of chili paste

Chili pieces (50 g), chopped red onions (25 g), and table salt (5 g) were mixed and tempered in heated coconut oil (10 mL) in a nonstick pan. Fresh samples were prepared in each day of study.

Calculation of the glycemic index

The area under the blood glucose curve (AUC) for each subject for each variety and treatment combination was calculated. The AUC was calculated by applying an appropriated mathematical formula (Brouns *et al*., 2005). The glycemic indices of rice varieties according to processing conditions and cooking method for each subject were calculated using the formula shown below, and the mean glycemic index was determined.

$$\text{Glycemic index} = \frac{\text{AUC of test food}}{\text{AUC of glucose}} \times 100$$

Statistical analysis

Data obtained from each variety under different processing conditions and cooking methods were fitted into a factorial completely randomized design (CRD) and subjected to analysis of variance (ANOVA). Mean separation was done using the Duncan's Multiple Range Test to determine the statistical differences among varieties at a significance level of 0.05. Statistical analysis was carried out using SAS (1990) software package.

RESULTS AND DISCUSSION

Effect of variety, parboiling and method of cooking on resistant starch and non-resistant starch content of rice

As shown in Table 2, two Bg varieties had similar RS contents (%) which was significantly lower than that of the variety At 405. According to the NRS content, Bg 358 showed the lowest NRS content (%) compared to the other two rice varieties.. Total Starch (TS) content shown in the Table 2 was derived by adding RS and NRS contents of each variety.

As shown in Table 2 there is no clear effect of parboiling on RS content in the two Bg varieties, although the RS content has been increased significantly after cooking the Bg 300 using the rice cooker method. When consider the NRS content, parboiling significantly reduced the NRS content in the variety Bg 358 under all three cooking methods, but in the variety Bg 300 reduction of NRS during parboiling was evident only in the rice cooker method of cooking.

It is also evident from Table 2 that there is no significant difference in both RS and NRS contents among the three methods of cooking in the rice variety Bg 358. However, in the variety Bg 300, both RS and NRS contents have been reduced, in raw and parboiled forms, when the rice cooker was used for cooking compared to other two methods.

Generally in intermediate gelatinization temperature starches, cooked and cooked-parboiled rice have higher RS content than uncooked, and parboiling was reported to increase the RS content of cooked rice by not more than 1% (Eggum *et al*., 1993). In the presence study Increasement of RS was observed only in the variety Bg 300 under rice cooker method of cooking. Niba (2003) has shown that parboiling could increase the slowly digestible starch level in rice which is a type of starch in rice and the other starchy foods. This may be a reason for low GI of parboiled rice. According to Walter, *et al*. (2005) RS contents in both parboiled and un-parboiled rice were similar when tested with the AOAC method 996.11. In the present study RS content was increased in the variety Bg 300, when parboiled rice was cooked using the rice cooker. According to Mitra, *et al*. (2007) parboiling can alter the physic-chemical characteristics of rice, including the resistant starch content.

Table 2. Resistant starch, non-resistant starch and total starch content of 10% polished rice varieties under different processing conditions and cooking methods

Variety	Processing condition	Cooking method	RS content (Dry basis %)	NRS content (Dry basis %)	Total Starch content (Dry basis %)$^{\$}$
358	Raw	A	^{**B}3.7±0.6^{*c}	^{B}61.4±1.9^{cde}	65.1
		B	4.3±0.4^{c}	63.1±1.9^{bcd}	67.4
		C	5.9±0.6^{c}	63.7±1.9^{bcd}	69.6
	Parboiled	A	4.1±0.2^{c}	56.2±1.5^{f}	60.3
		B	4.3±0.1^{c}	57.2±1.4^{ef}	61.5
		C	4.4±0.1^{c}	57.9±1.1^{ef}	62.2
Bg 300	Raw	A	^{B}4.3±0.9^{c}	^{AB}64.4±1.7^{bc}	68.7
		B	5.8±0.1^{a}	69.1±3.0^{a}	74.9
		C	6.3±0.1^{a}	66.0±1.3^{ab}	72.3
	Parboiled	A	5.1±0.1^{b}	59.4±5.9^{def}	64.5
		B	5.8±0.1^{a}	66.7±1.9^{ab}	72.5
		C	6.0±0.0^{a}	67.3±1.1^{ab}	73.3
At 405	Raw	A	^{A}7.5±0.4	^{A}67.4±1.0	74.9

* Means ± SD (n=3). Means bearing the same simple letters in a column are not significantly different at p =0.05
**Means ± SD (n=3). Means bearing the same capital letters in a column are not significantly different at p =0.05
$^{\$}$Mean separation was not done for the total starch content as it is derived from RS and NRS contents

Effect of variety, parboiling and method of cooking on total carbohydrate content of rice

Table 3 illustrates the total carbohydrate content of the three varieties under different processing and cooking methods. The total carbohydrate content in cooked rice varies with the variety. The rice variety At 405 had the highest total carbohydrate content (76.5 ± 0.2%) followed by Bg 300 (74.0 ± 0.5%) and Bg 358 (73.9 ± 0.6%). Parboiling had no effect on total carbohydrate content of the two Bg varieties (Table 3).

Table 3. Total carbohydrate content in rice varieties under different processingconditions and cooking methods (dry basis %)

Variety	Processing condition	Total carbohydrate content under different cooking methods		
		A	B	C
Bg 300	Raw	$^{**B}74.0\pm0.5^{abcde}$	74.0 ± 0.6^{abcd}	74.8 ± 0.3^{a}
	Parboiled	74.5 ± 0.4^{ab}	74.6 ± 0.3^{a}	74.7 ± 0.1^{a}
Bg 358	Raw	$^{B}73.9\pm0.6^{abcdef}$	74.4 ± 0.4^{ab}	74.4 ± 0.6^{ab}
	Parboiled	74.2 ± 0.4^{abc}	75.1 ± 0.1^{a}	73.8 ± 0.7^{abcdefg}
At 405	Raw	$^{A}76.5\pm0.2$	-	-

*Means ± SD (n=3). Means bearing the same simple letters in a row or column are not significantly different at p=0.05

**Means ± SD (n=3). Means bearing the same capital letters in column A are not significantly different at p=0.05

As shown in Table 3 the method of cooking has no significant effect on total carbohydrate content in the two varieties, Bg 358 and Bg 300.

Effect of variety, parboiling and method of cooking on dietary fiber, protein and ash content of rice

As shown in Table 4 dietary fiber content, protein content and ash content are similar between Bg 300 and Bg 358 varieties. However, the variety At 405 had significantly higher protein and ash contents and a lower dietary fiber content compared to the two Bg varieties.

Parboiling and method of cooking had no effect on dietary fiber and protein contents of both Bg 300 and Bg 358 varieties. Parboiling had significantly increased ($p<0.05$) the ash content of both Bg 300 and Bg 358 cooked under all three methods.

Protein content of rice can range from 6-15% (FAO Report, 1993). Protein plays an important role in cooked rice texture due to formation of a complex with starch that impairs the swelling of starch granule. Starch granule swelling affects both viscosity intensity and the rate of starch gelatinization. Protein content can vary with the degree of milling (Suwannaporn, 2007). Parboiling can increase the ash content of rice by increasing the contents of potassium and phosphorus while reducing the contents of manganese, calcium and zinc (Heinemann *et al*., 2004). According to the literature cooking can decrease the nutritional quality of rice such as protein, thiamin, fat, total ash, iron, phosphorus, calcium etc., but cooking has no effect on total dietary fiber content. Whereas it can increase the protein and starch digestibility in rice (Khatoon, 2006).

Table 4. Composition of 10% polished rice varieties under different processing conditions and cooking methods

Variety	Processing condition	Cooking method	Moisture content (%)	Available Carbohydrate (Wet basis %)	Portion size (g)$^{\$}$	Dietary fiber (Dry basis %)	Protein content (Dry basis %)	Ash content (Dry basis %)
Bg 300	Raw	A	62±2	27.8*	180	$^{**A}0.44^{ab}$	$^{B}10.0^{a}$	$^{B}0.24^{d}$
		B	62±1	27.9	179	0.47^{a}	10.0^{a}	0.26^{cd}
		C	62±3	28.0	178	0.41^{b}	10.06^{a}	0.26^{cd}
	Parboiled	A	62±2	27.9	179	$0.44a^{b}$	9.9^{a}	0.34^{a}
		B	62±2	28.3	177	0.41^{b}	9.8^{a}	0.35^{a}
		C	62±3	27.9	179	0.45^{ab}	9.9^{b}	0.31^{b}
Bg 358	Raw	A	63±4	27.1	185	$^{A}0.48^{a}$	$^{B}10.01^{a}$	$^{B}0.25^{cd}$
		B	63±1	27.1	184	0.44^{ab}	10.03^{a}	0.27^{c}
		C	63±1	27.4	182	0.43^{ab}	10.06^{a}	0.27^{c}
	Parboiled	A	63±2	27.3	183	0.43^{ab}	10.00^{a}	0.33^{ab}
		B	63±2	27.3	183	0.44^{ab}	10.01^{a}	0.33^{ab}
		C	63±3	27.4	183	0.44^{ab}	10.02^{a}	0.33^{ab}
At 405	Raw	A	65±3	26.56	188	$^{B}0.39$	$^{A}10.36$	$^{A}0.42$

* Means ± SD (n=3). Means bearing the same simple letters in a column are not significantly different at p =0.05
**Means ± SD (n=3). Means bearing the same capital letters in a column are not significantly different at p =0.05
Mean separation was not done for the available carbohydrate content as it is derived from the total carbohydrate content and dietary fibre content
$^{\$}$Portion size contains 50 g of available carbohydrate

Effect of variety, parboiling and method of cooking on glycemic indices of rice

There was a significant difference in GI values among the three rice varieties Bg 300 (72 ± 2), Bg 358 (70 ± 1) At 405 (68 ± 2). The variety At 405 had a significantly lower GI value compared to the two Bg varieties (Table 5). The higher resistant starch content of variety At 405 could be contributing to the lower GI value observed in this study.

As shown in Table 5 parboiling has a lowering effect on GI values of both Bg 300 and Bg 358 varieties. The mean GI value (cooked under methods A, B and C) of raw rice of variety Bg 300 and Bg 358, was 71 and the mean GI values of parboiled rice of variety Bg 300 and Bg 358 were 67 and 68, respectively.

There was no significant difference in GI values among the three methods of cooking when the varieties Bg 300 and Bg 358 were compared. The variety At 405 was not subjected to different methods of cooking.

Foods can be categorized as low GI, medium GI and high GI considering the glycemic index. The glycemic index ≤ 55 is considered as low GI, 56-69 as medium GI and ≥ 70 as high GI. According to Hettiarachchi *et al*. (2001), the GI values of 5 white rice varieties (Bg and Bw varieties under raw and parboiled forms) ranged from 62 to 68. Pathiraje, *et al*. (2010) observed that the glycemic indices of un-parboiled variety Bg 300 and Bg 358 were 61 ± 3 and 67 ± 3, respectively, while the glycemic index of parboiled form of variety Bg 358 was 62 ± 2. Pathiraje *et al*. (2010). The GI of rice has been established as low as 59 to as high as 109 (Miller *et al*., 2004). According to Hettiarachchi, *et a.l* (2001), GI values ranged from 55 to 73 in some Sri Lankan commercial rice varieties and the majority can be categorized as medium GI rice. In this study GI ranged from 67-72 when raw and parboiled forms of rice pooled together and they can be considered as either medium or high GI.

Table 5. Glycemic index of 10% polished rice under different processing conditions and cooking methods

Variety	Processing condition	Cooking method	Glycemic index
Bg 300	Raw	A	$^{**A}72\pm2^{a}$
		B	71 ± 2^{a}
		C	71 ± 2^{a}
	Parboiled	A	67 ± 1^{b}
		B	68 ± 1^{b}
		C	67 ± 1^{b}
Bg358	Raw	A	$^{B}70\pm1^{a}$
		B	71 ± 1^{a}
		C	71 ± 1^{a}
	Parboiled	A	68 ± 2^{b}
		B	68 ± 2^{b}
		C	68 ± 1^{b}
At 405	Raw	A	$^{C}68\pm2$

* Means ± SD (n=10). Means bearing the same simple letters in the column are not significantly different at p =0.05
**Means± SD (n=10). Means bearing the same capital letters in the column are not significantly different at p =0.05

CONCLUSIONS

Resistant starch content of variety At 405 (7.5 ± 0.4%) is significantly higher than the resistant starch content of variety Bg 300 (4.3 ± 0.9%) and Bg 358 (3.7 ± 0.6%). Dietary fiber content of At 405 is significantly lower (0.39%) than Bg 300 (0.44%) and Bg 358 (0.48%). Parboiling and method of cooking had no effect on resistant starch, dietary fiberand protein contents in tested Bg varieties, but parboiling significantly increased the ash content in both variety Bg 300 and Bg 358. Variety At 405 can be categorized as medium GI rice and other two Bg varieties, Bg 300 and Bg 358 can be categorized as high GI rice.

Parboiling can lower the glycemic index of rice but the method of cooking had no effect on glycemic index of rice.

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