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Influence of hydrothermal processing on physico–chemical qualities of red–pigmented and non–pigmented rice varieties

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ABSTRACT

Four red–pigmented and one non–pigmented paddy rice varieties were subjected to shelling and milling properties and some of their physico–chemical qualities in pre and post hydrothermally processed form have been studied. Alkali score for rice indicated that these varieties were of high Gelatinization Temperature (GT) nature. (EMC) Equilibrium moisture content of raw husked/milled rice was less compared to their respective hydrothermally processed forms. Total amylose Equivalent (AE) was 28–30% in husked rice and 29–31% in milled rice. Hydrothermal processing reduced AE as well as soluble amylose equivalent to different extents. Amylography studies indicated that GT of husked rice of pigmented variety were high (77–81° C). Peak Viscosity (PV) was high for husked rice of IR–64 (1075 BU) compared to that of pigmented varieties (395 to 600 BU). In milled rice of all varieties GT decreased by 4–7° C compared to their respective husked rice, whereas PV increased by 340 to 720 BU in pigmented rice whereas 355 BU in IR–64. By hydrothermal processing, GT increased by 5 to 10° C in both forms of rice. PV decreased by 500 BU in non–pigmented rice and 75–445 BU in pigmented rice varieties. Pigmented rice showed negative break down (BD) inferring that they showed the property of cross linked starch which was not observed in IR-64. Proximate composition in all the raw and parboiled rice varieties indicated that, under given set of conditions, degree of milling in hydrothermally processed rice was always less compared to raw rice.

Key words: *Pigmented rice, husked rice, hydrothermal processing, amylose equivalent*

Rice is the only cereal crop cooked and consumed mainly as whole grains, and quality considerations are much more important compared to any other food crop (Hossain *et al.*, 2009). Quality is not always easy to define as it depends on the consumers and the intended end use of the grain. The grain quality is not solely a varietal characteristic but also depends on the crop production, environment, harvesting, processing and handling systems. Quality desired in rice vary from one geographical region to another and consumer demand certain varieties and favors specific quality traits of milled rice for home cooking (Juliano *et al.*, 1964). Therefore, maintaining good grain quality is the concern of all disciplines such as breeding, agronomy, entomology, chemistry and engineering.

Rice grain quality represents a summary of the physical and chemical characteristics that may be genetic or acquired properties. The genetic properties include: chemical characteristics (gelatinization temperature, apparent amylose content, gel consistency, alkali spreading value and aroma). Physical characteristics (shape, size, color of grain, chalkiness, bulk density, thermal conductivity, equilibrium moisture content and flow ability). The acquired properties or environmental factors are either additional to the normal complement of genetic qualities or are the consequence of certain genetic qualities being lost or modified. The important acquired properties are: moisture content, grain purity, physical and pest damage, cracked grains, presence of immature grains and milling-related characteristics (milling and head rice recoveries, grain dimensions, whiteness, milling degree and chalkiness). The hydrothermal processing is a big share of the global rice processing industry. Generally, the majority of the populations of a developing country consume hydrothermally processed rice. This is especially true on the Indian Sub–continent when it originated a long time ago. It was reported that one–fifth of the world's rice is hydrothermally processed (Bhattacharya, 1985).

Commercially more than two thousand varieties of rice are grown around the world (Deepa *et al.*, 2008). There are red and black paddy rice varieties which have about 38% more protein, about 18% more crude fiber and are richer in lysine, vitamin B_1 and other minerals compared to conventional rice varieties (Chaudhary and Tran, 2001). Colored rice (black and red) consumption is rapidly growing due to their healthy functional food ingredients (Kim *et al.*, 2008). Pigmented red-rice varieties showed higher dietary fiber compared to non-pigmented rice (Savitha and Singh, 2011).

Hydrothermal processing of rice induces many changes including reduction in breakage of rice. The vitamin B content increases, milling quality improves hence head rice recovery will be high. The grain becomes hard and insects attack will be less. Overall nutrition improves in the grain, however the rubbery texture is induced after cooking, which is liked by some sector of population, specially who live near to the coastal lines.

Information on the changes in the physico–chemical properties during hydrothermal treatment of red rice varieties is limited and scanty. Hence the present study was aimed at bridging this gap with an objective to study the effect of varietal difference of rice subjected to hydrothermal processing and their physico–chemical properties in raw and hydrothermally treated form.

MATERIALS AND METHODS

Four red–pigmented paddy rice varieties viz. Jyothi, Aishwarya, Kar bhatha (medium) and Kar bhatha (small) and one non–pigmented variety, IR–64 were procured from the Agricultural Produce Market committee (APMC), Bandipalya, Mysore, Karnataka, India. All these paddy rice varieties were cleaned and stored at 4–6°C until use. All the chemicals used were of analytical grade unless stated otherwise.

A weighed sample (100 g) of paddy rice of each variety was husked using the Laboratory Satake Sheller (Satake Corporation Tokyo, Japan) with rubber rolls adjusted to grain size so as to minimize the breakage. The husked rice and husk were weighed separately for determining the yield of brown rice/husked rice.

The husked rice (150 g) of each variety was subjected to milling using Mc–Gill miller for 2 minutes with a pressure of 2 lbs. It consists of a wire–mesh screen with slotted perforated enclosure in which a shaft rubs the grain against the casing (frictional). The bran is removed from the husked rice which passes through these screens. Then the bran obtained is passed through 18 # sieve, pass through material was weighed and degree of polish (dop) or degree of milling (dom) was calculated.

The paddy rice was hydrothermally processed according to the procedure followed by (Savitha and Singh, 2011). The hydrothermally treated paddy rice was air–dried in the shade (1–2 days) to a safe moisture level. Hydrothermally processed paddy rice obtained was husked and milled under similar conditions as mentioned above.

Ten kernels of brown rice/husked rice and milled rice of each variety, both in raw and hydrothermally treated forms were arranged length and breadth wise for cumulative measurements in millimeter. The value of L/B was determined and mean of 10 replications is reported.

One thousand kernels of brown rice/husked rice and milled rice of each variety both in raw and hydrothermally treated forms were counted in triplicate and weighed separately. Mean of three replications is reported.

Equilibrium moisture content on soaking in water at room temperature (EMC-S at RT). The EMC-S at ambient temperature was determined as per the procedure (Indudharaswamy *et al.,* 1971).

Cooking time was determined by parallel plates method (Bhattacharya and Sowbhagya, 1971) in which 10 grains were pressed between 2 glass plates every two minutes until at least 90% no longer has opaque centre.

All the rice varieties of raw and hydrothermally treated (husked/milled rice) were pulverized in a mixer (Johnson Lady Bird plus) and the flour was then sieved (60–mesh). Defatting of samples was carried out with

85% methanol using a Soxhlet apparatus for 18–24 h. prior to amylose estimation. Amylose was estimated according to the procedure (Singh *et al.*, 2000).

A Brabender Viscoamylograph, Type VSK 4 (Duisburg, Germany) fitted with a 700–cmg sensitivity cartridge was used for determining viscography of rice varieties as per the method of (Bong and Singh, 2009). Experiments were carried out in aqueous medium independently in triplicate.

The alkali test was conducted as suggested by (Bhattacharya and Sowghagya, 1972) with minor modifications. Six whole milled kernels of raw and hydrothermally treated rice were placed in a closed 7–cm diameter petridish, placed on a black Kg card board sheet, immersed in 20 mL of potassium hydroxide solution of different concentrations (1% – dilute, 1.5% – moderate and 2% – concentrated alkali of KOH) and the reaction being observed at (0, 4, 24 and 48 h) time intervals. An improved 9–point single–series scoring scale is described along with other simplifications of the test.

Moisture content of the samples were estimated as per the method AOAC (2000), the micro Kjeldhal method was employed to determine the total nitrogen and the crude protein was calculated (N x 5.95) AOAC (2000). Fat was extracted with petroleum ether (60–80 ºC) for 12–16 h using a Soxhlet apparatus and ash contents (gravimetrically) were determined based on methods outlined in AOAC (2000). The total carbohydrate was calculated by difference method. Total phosphorus was determined spectrophotometrically at 355 nm using KH_2PO_4 as a standard (Singh and Ali, 1987).

Data were analyzed using Minitab 17 statistical software. Each experiment was performed in triplicate and the results were expressed as the mean values ± standard deviation. Results were analyzed and significance level was calculated using Tukey–Kramer multiple comparison test by means of one way ANOVA. Values with $p < 0.05$ were considered statistically significant.

RESULTS AND DISCUSSION

Size and shape are among the grain characteristics that dictate the marketability and commercial viability of rice (Khush *et al.*, 1979). The length (L), breadth (B) and L/B ratio of all the rice varieties are shown in Table 1. This study showed that the rice varieties viz– Jyothi and IR–64 had high mean grain length and low grain breadth, resulting in higher L/B ratio. The opposite was the case for other three rice varieties viz., –Aishwarya and Kar bhatha (medium and small). Jyothi and IR–64 were long grain and the rice varieties viz., –Aishwarya and Kar bhatha (medium and small) were medium grain according to the Codex standards for rice (198-1995). However, two rice varieties – Jyothi and Aishwarya were medium shaped grains, while the other two rice varieties viz., – Kar bhatha (medium and small) were bold shaped. The non–pigmented rice variety, IR–64 was slender shaped. However the hydrothermally treated rice kernel had a shorter length and broader breadth when compared with the raw rice. This is in agreement with the result of (Chitra *et al.*, 2010) that hydrothermally treated rice expanded less in length but more in breadth.

The rice varieties such as Jyothi, 20–23 g, Kar bhatha (medium), 22–25 g and IR-64, 20–23 g had higher Thousand Grain Weights (TGW), compared to other two rice varieties viz., – Aishwarya, 17–20 g and Kar bhatha (small), 16–18 g. Values of TGWs between 20 and 30g are considered good while those less than 20g could be indicative of the presence of immature, damaged and unfilled grain (Adu-Kwarteng *et al.*, 2003). It is also seen that from the Table 1, that dimensions reduce after milling the husked rice to various extents, though they were milled to same timings. Even TGWs reduced in husked rice after hydrothermal processing, except in the case of Kar batha where there was increase by ~ 6%, which may be due to uneven removal of bran while milling or polishing. The TGW reduced after polishing the hydrothermally treated husked rice except in the case of Jyothi, where there was increase in TGW, which may be due to less degree of polish after hydrothermal processing under similar conditions of milling.

There was a small but definite difference in the EMC values among the different rice varieties and difference were also maintained after hydrothermal processing [Fig.1 (A–D)]. Equilibrium moisture content (EMC) of raw husk, in all the rice varieties was high, which ranged from 39 to 44 g/100 g, indicating the capillary action by pores in the hull causing rapid water

Table 1. Grain size and shape classification of pigmented and non-pigmented, rice varieties before and after hydrothermal treatment

	Rice Varieties		Length, L (mm)	Breadth, B (mm)	L/B ratio	Size Classification γ	Shape Classification γ	1000–Grain weight (g)
Husked Rice	Jyothi	R	6.79±0.11C	2.46±0.05B	2.76	Long	Medium	22.68±0.23B
		HT	6.64±0.07D	2.57±0.05A	2.58	Long	Medium	21.99±0.17E
	Aishwarya	R	6.13±0.09F	2.32±0.06CD	2.64	Long	Medium	19.61±0.11E
		HT	6.06±0.13F	2.35±0.07C	2.58	Long	Medium	19.42±0.42F
	Kar Bhatha	R	6.48±0.04E	2.48±0.04B	2.61	Long	Medium	24.44±0.27A
	(Medium)	HT	6.42±0.09E	2.61±0.08A	2.46	Long	Medium	25.26±0.22C
	Kar Bhatha	R	5.78±0.04G	2.47±0.05B	2.34	Medium	Medium	17.71±0.11F
	(Small)	HT	5.58±0.06H	2.54±0.07AB	2.20	Medium	Medium	17.75±0.15G
	IR-64	R	7.21±0.07A	2.24±0.05D	3.22	Extra long	Slender	22.91±0.10B
		HT	6.94±0.05B	2.26±0.05D	3.07	Long	Slender	22.31±0.02D
MilledRice	Jyothi	R	6.46±0.13c	2.34±0.05d	2.76	Long	Medium	19.71±0.21b
		HT	6.22±0.04d	2.39±0.05cd	2.60	Long	Medium	20.75±0.24e
	Aishwarya	R	5.68±0.40f	2.35±0.05d	2.42	Medium	Medium	17.62±0.04e
		HT	5.60±0.06g	2.43±0.05c	2.30	Medium	Medium	17.37±0.05f
	Kar Bhatha	R	5.94±0.21e	2.85±0.05a	2.08	Medium	Medium	21.92±0.10a
	(Medium)	HT	5.55±0.06g	2.87±0.04a	1.93	Medium	Bold	23.18±0.02c
	Kar Bhatha	R	5.26±0.12h	2.57±0.05b	2.05	Medium	Bold	16.71±0.07f
	(Small)	HT	5.04±0.46i	2.63±0.05b	1.92	Medium	Bold	16.54±0.03g
	IR-64	R	6.86±0.82a	2.20±0.04e	3.12	Long	Slender	20.44±0.04b
		HT	6.74±0.08b	2.24±0.05e	3.01	Long	Slender	21.25±0.01d

R: Raw, HT: Hydrothermally treated

(A–J) Husked Rice. (a–j) Milled Rice

Values are mean ± standard deviation of ten determinations (n=10).Values within the same column with different letters are significantly different at $p < 0.05$.

* :> 7.0: extra long; 6.0-6.99: long; 5.0-5.99: medium; <5.0: short;

γ:> 3.0: slender; 2.1-3.0: medium; 1.1-2.0: bold; <2.0: round.

absorption (Kulkarni and Bal, 1984). Compared to raw husk, the EMC values for hydrothermally treated husk decreased which ranged from 34 to 38 g/100 g, indicating that the hydrothermally treated siliceous husk does not wet easily and resists water absorption, as well as hemicelluloses reduced water absorption after hydrothermal processing. The EMC values were less for raw paddy rice, 26 to 29 g/100 g compared to hydrothermally treated paddy rice, 30 to 33 g/100 g, because hydrothermally treated paddy rice, absorbed water much faster than raw paddy rice due to the slight splitting of its husk (Indudhara Swamy *et al.*, 1971) as well as retrograded starch present in the husked rice of hydrothermally treated paddy. There was relatively little difference between raw husked rice, 28 to 29 g/100 g and raw milled rice, 27 to 28 g/100 g.

Compared to raw rice, the EMC was 5–15% more in hydrothermally treated rice. The hydration values were high for hydrothermally treated milled rice, 35 to 44 g/100 g when compared to hydrothermally treated husked rice, 33 to 41 g/100 g, indicating that the bran layers delays or obstructs hydration to some extent.

The proximate compositions of the pigmented and non-pigmented rice varieties before and after hydrothermal processing are presented in Table 2. The moisture content of all the rice varieties before and after hydrothermal processing ranged from 11 to 13%, which indicated similar agro–climatic conditions and/or the place where the paddy was stored, even method of drying or evaporation while storage may lead to different moisture content range in the different forms of rice.

The carbohydrate content of the hydrothermally treated (husked/milled rice) rice was higher than that of raw rice (husked/milled rice). The range of increase from raw husked rice to hydrothermally treated rice varied from 0.2 to 7%, highest was shown for Aishwarya and least was by Jyothi. The carbohydrate content from raw milled rice to hydrothermally treated milled rice varied from 0.5

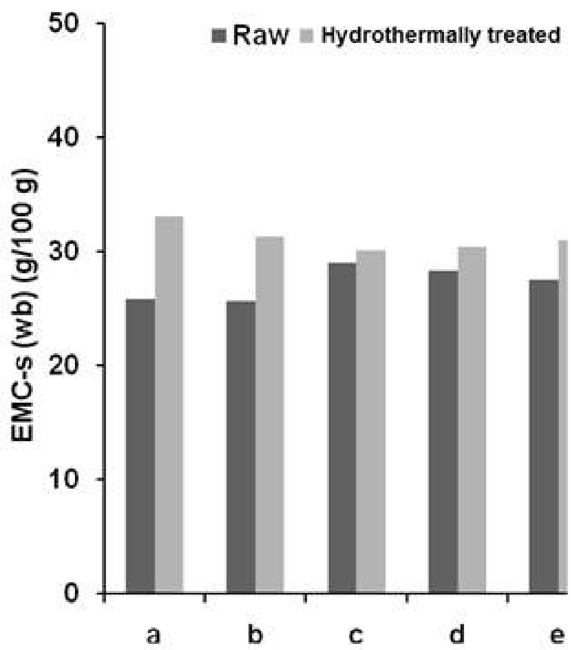

Fig. 1(A). Rice Varieties (Paddy)

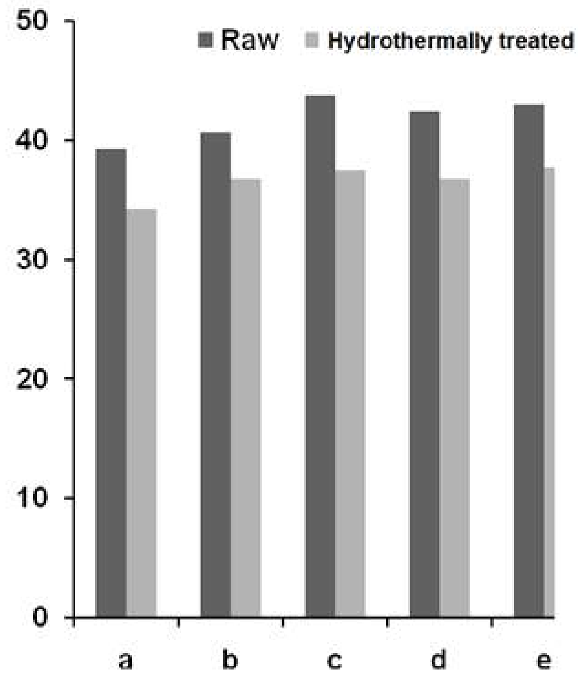

Fig. 1(B). Rice Varieties (Husk)

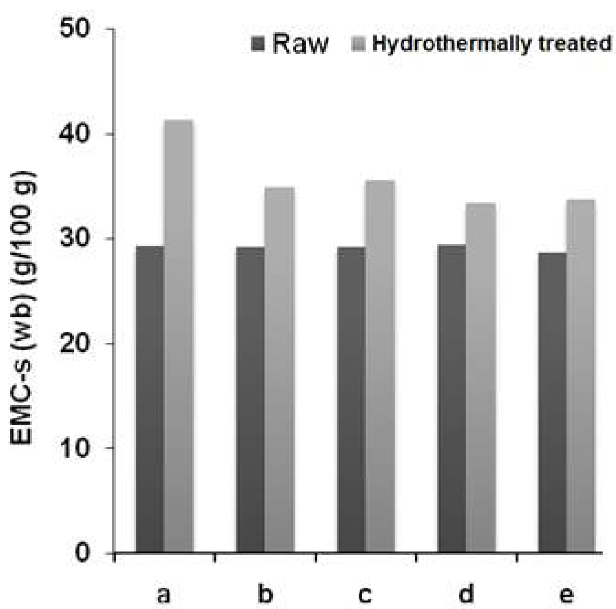

Fig. 1(C). Rice Varieties (Husked rice)

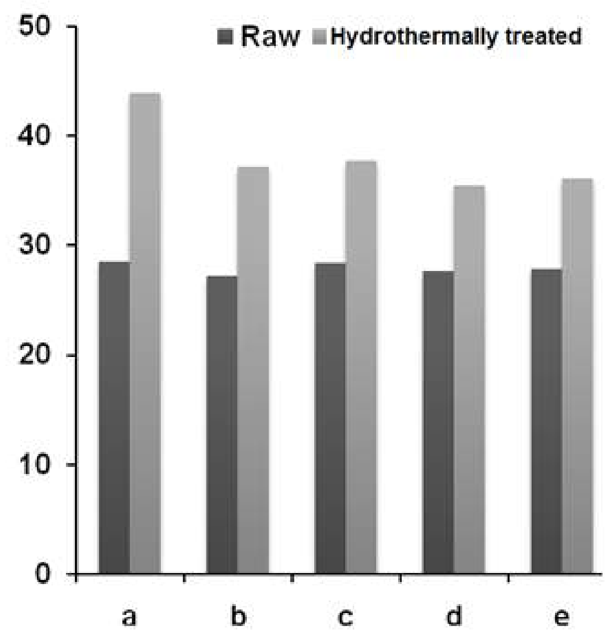

Fig. 1(D). Rice Varieties (Milled rice)

to 5.4% [Kar bhatha (medium) and IR-64]. This marginal increase may be as a result of starch gelatinization, which makes the granules to expand, thus filling up the surrounding air space. Starch reassociation, increases in some carbohydrate components like reducing sugars, changes in molecular size and partial dextrinization of starch which have been known to occur during hydrothermal processing (Rhagavendra and Juliano, 1970).

There was decrease in protein content of the hydrothermally treated husked rice compared to the raw husked rice. The decrease ranged from 3.6 to 9.3% [(Aishwarya, Kar bhatha (medium)]. This may be due to leaching of protein substances during soaking of paddy and denaturation of proteins that occurs in the protein molecules due to steaming/hydrothermal treatment. The hydrothermal processing makes the protein bodies to sink into the compact mass of gelatinized starch granules making it less extractable hence a decrease in the protein content (Otegbayo *et al.*, 2001). Hydrothermal processing slightly increased the protein content of milled rice compared to raw milled rice in all the rice varieties. The increase varied from 5.6 to 15.5% [Kar bhatha (medium), Jyothi]. Under similar conditions of milling, degree of polishing in hydrothermally treated rice is always less compared to raw husked rice on polishing. When degree of polishing is less, bran content in hydrothermally treated rice is high and hence the protein content may be high in milled hydrothermally treated rice. (Houston *et al.*, 1964) found that hydrothermally treated rice grain becomes harder in the presence of the outer layers (polishing, which have a high protein content). These were quite difficult to remove during milling.

The hydrothermally treated husked rice also had lower fat content than the raw husked rice. This may be explained in terms of leaching and rupturing of the oil globules that occur while hydrothermal process (Otegbayo *et al.*, 2001). There was slight increase in fat content in hydrothermally treated milled rice compared to raw milled rice. As informed above the higher fat content may be due to the presence of bran content. This is attributed to the difficulty in the removal of bran layers from hydrothermally treated rice, as it

Table 2. Proximate composition of pigmented and non-pigmented rice varieties before and after hydrothermal treatment

	Rice varieties		Moisture (%)	Carbohydrate* (%)	Protein (%)	Fat (%)	Ash (%)	Phosphorous (mg)
Husked Rice	Jyothi	R	12.66±0.11^{ABC}	74.97±0.58	7.87±0.33^{C}	2.95±0.11^{A}	1.55±0.03^{C}	432.42±4.04^{CD}
		HT	12.44±0.18^{CD}	75.83±0.29	7.36±0.18^{DE}	2.81±0.13^{A}	1.57±0.06^{C}	492.63±8.74^{AB}
	Aishwarya	R	12.43±0.14^{CD}	74.06±0.23	9.71±0.14^{A}	2.20±0.03^{B}	1.60±0.03^{C}	353.98 ±4.28^{EF}
		HT	12.10±0.11^{D}	74.59±0.38	9.36±0.11^{A}	2.05±0.35^{BC}	1.90±0.03^{A}	499.79±40.55^{AB}
	Kar Bhatha (medium)	R	11.55±0.02^{E}	76.38±0.21	8.66±0.24^{B}	2.05±0.35^{BC}	1.37±0.07^{D}	326.01±5.47^{F}
		HT	12.73±0.09^{ABC}	76.06±0.10	7.81±0.29^{CD}	1.80±0.07^{C}	1.61±0.03^{C}	455.69±9.53^{BC}
	Kar Bhatha (small)	R	12.15±0.11^{D}	75.56±0.51	7.82±0.48^{CD}	2.90±0.14^{A}	1.57±0.06^{C}	392.08±39.12^{DE}
		HT	12.84±0.22^{AB}	76.68±0.30	7.14±0.10^{EF}	2.59±0.08^{A}	1.77±0.11^{B}	503.15±18.63^{A}
	IR-64	R	12.91±0.11^{A}	76.56±0.16	7.41±0.13^{CDE}	2.10±0.07^{BC}	1.02±0.07^{E}	223.77±10.54^{G}
		HT	12.53±0.37^{BC}	77.72±0.28	6.75±0.10^{F}	2.00±0.0^{BC}	1.01±0.0^{E}	345.53±38.20^{EF}
Milled Rice	Jyothi	R	11.47±0.24^{e}	80.68±0.25	6.47±0.16^{f}	1.12±0.12^{cd}	0.28±0.04^{d}	140.2±28.85^{ef}
		HT	11.74±0.01^{cde}	78.84±0.07	7.47±0.17^{de}	1.22±0.16^{bcd}	0.74±0.06^{b}	261.60±6.71^{c}
	Aishwarya	R	12.03±0.11^{abc}	77.99±0.29	8.65±0.07^{b}	1.03±0.08^{d}	0.31±0.03^{d}	112.20±12.59^{f}
		HT	11.61±0.06^{de}	77.10±0.31	9.28±0.16^{a}	1.20±0.08^{bcd}	0.81±0.13^{b}	292.94±0.72^{b}
	Kar Bhatha (medium)	R	11.46±0.01^{e}	79.81±0.3	7.13±0.01^{e}	1.23±0.16^{bcd}	0.38±0.12^{cd}	118.75±7.0^{f}
		HT	12.07±0.01^{ab}	78.0±0.02	7.87±0.10^{c}	1.27±0.04^{bcd}	0.80±0.07^{b}	284.83±4.67^{bc}
	Kar Bhatha (small)	R	11.59±0.08^{de}	80.20±0.24	6.68±0.33^{f}	1.25±0.16^{bcd}	0.29±0.0^{d}	160.05±28.07^{e}
		HT	11.85±0.29^{bcd}	78.02±0.01	7.54±0.25^{cd}	1.54±0.04^{a}	1.06±0.0^{a}	347.54±3.61^{a}
	IR-64	R	12.17±0.00^{a}	79.79±0.09	6.48±0.20^{f}	1.30±0.0^{abc}	0.27±0.11^{d}	80.95±15.20^{g}
		HT	12.31±0.18^{a}	78.55±0.16	7.21±0.16^{de}	1.43±0.18^{ab}	0.51±0.0^{c}	191.69±1.53^{d}

R: Raw, HT: Hydrothermally treated

$^{(A–J)}$ Husked Rice. $^{(a–j)}$ Milled Rice

* Carbohydrate is by difference method.

Values are mean ± standard deviation of three determinations (n=3).

Values within the same column with different letters are significantly different at $p < 0.05$.

becomes hard in nature while hydrothermal processing and drying process. The ash content in raw husked rice varied from 1.02% (IR-64) to 1.57% (Aishwarya), whereas in hydrothermally treated husked rice it varied from 1.01% (IR-64) to 1.90% (Aishwarya). After hydrothermal processing, highest increase (~19%) was observed in Aishwarya and lowest increase in Jyothi variety, remained almost same in IR-64. After milling of husked rice (raw) the ash content reduces by about 77%. On the other hand polishing of hydrothermally treated husked rice, the content reduces by about 50%. In other words the ash content in milled hydrothermally treated rice was quite high which ranged from 89 to 265% compared to milled raw rice. This also indicates that under similar conditions of polish the DOM was less in hydrothermally treated rice, as retainment or retension of bran was high and hence high ash content.

The phosphorous content in raw husked rice ranged from 326 to 432 mg/100 g among pigmented varieties and it was ~224 mg/100 g in non-pigmented (IR-64) variety. In hydrothermally treated husked rice the phosphorous content varied from 455 to 503 mg/100 g among pigmented, whereas in IR-64 it was 345 mg/100 g. Thus pigmented raw as well as hydrothermally treated husked rice had higher content of phosphorus compared to non-pigmented. Milled raw rice showed a phosphorous content of 112 to 160 mg/100 g among pigmented varieties. Whereas in non-pigmented (IR-64) it was ~80 mg/100 g. Thus retainment in raw milled rice of pigmented varieties was high. In hydrothermally treated milled rice the phosphorous content ranged from 262 to 348 mg/100 g among pigmented varieties and 192 mg % in IR-64. The retainment of phosphorous was high in hydrothermally treated milled rice which ranged from 87 to 155% among pigmented varieties and in IR-64 it was 137%. This is another indication that the bran retainment was high in milled hydrothermally treated rice and hence DOM was less in hydrothermally treated rice compared to that of raw rice under similar conditions of milling.

Rice are grouped on their amylose equivalent into waxy (0–2%), very low (3–9%), intermediate (20–25%) and high (>25%) (Cruz and Khush, 2000; Bhattacharya et al 1985) The total amylose content in different rice varieties ranged from 28 to 30% in raw husked rice (Table 3), the contents reduced in hydrothermally treated husked rice in all the varieties which ranged from 23 to 24%. This result indicates that all the rice varieties have high amylose equivalent and therefore, cook dry, fluffy, less tender and becomes harder upon cooling.

There was decrease in amylose equivalent (Table 3) of the hydrothermally treated (husked/milled) rice compared with the raw (husked/milled) rice. After milling of husked rice the amylose equivalent ranged between 29 and 31%. After hydrothermal processing the milled hydrothermally treated rice showed less amylose equivalent which was about 3 to 4% compared to that of milled raw rice. This is because of starch solubilization and leaching of the linear molecule into the surrounding water during soaking and subsequent steaming during hydrothermal processing (Otegbayo *et al.,* 2001).

More than 14% insoluble amylose equivalent was observed in each of raw husked rice as well as raw milled rice, indicating that these pigmented varieties belong to I group of rice classification (Bhattacharya *et al.,* 1982).

The cooking time was generally higher in raw husked rice, 32–40 minutes, compared to raw milled rice, 18–24 minutes, because of a thick aleurone layers and a pericarp which delay water penetration into the grain during cooking (Deepa *et al.,* 2008). The longer cooking time of the hydrothermally treated (husked/milled) rice compared to raw (husked/milled) rice may be due to the strong cohesion between the endosperm cells which are tightly packed. This makes the starch granules to hydrate at a slower rate, which leads to a decrease in water penetration into the grains, hence a longer cooking time (Otegbayo *et al.,* 2001).

Alkali spreading scores indicating the pattern of rice–kernel degradation in dilute alkali differed among the varieties, and the extent of degradation in non–pigmented variety (IR 64) was high compared to red–pigmented varieties. Data in (Table 3) shows the lower alkali spreading values in hydrothermally treated rice compared to raw rice. The resistance of hydrothermally treated rice to dispersion in the alkali test might be related to the hardness of the grain as a result of the retrogradation of gelatinized starch Damir (1985). Raghavendra and Juliano (1970) have reported that, hydrothermal processing made the rice more resistant to disintegrate, reflecting its greater resistance to burst

Table 3. Chemical composition of pigmented and non-pigmented rice varieties before and after hydrothermal treatment

	Rice Varieties		Total Amylose (%)	Soluble Amylose (%)	Insoluble Amylose (%)	Amylose Classification	Cooking Time (min)	Alkali Spreading Score*
Husked Rice	Jyothi	R	28.20 ± 0.22^B	08.52 ± 0.68^C	19.68 ± 0.47	High	32 ± 0.76^E	3
		HT	23.16 ± 0.07^CD	07.23 ± 0.09^D	NA	NA	35 ± 0.29^D	1
	Aishwarya	R	28.41 ± 0.32^B	10.88 ± 0.13^B	17.53 ± 0.46	High	35 ± 0.29^D	3
		HT	24.12 ± 0.46^C	08.57 ± 0.20^C	NA	NA	38 ± 0.76^BC	1
	Kar Bhatha (medium)	R	29.60 ± 0.02^A	10.72 ± 0.20^B	18.88 ± 0.23	High	40 ± 0.50^B	2
		HT	23.26 ± 0.19^CD	07.90 ± 0.02^CD	NA	NA	44 ± 1.15^A	1
	Kar Bhatha (small)	R	30.37 ± 0.20^A	13.44 ± 0.22^A	16.93 ± 0.42	High	36 ± 1.00^CD	3
		HT	22.96 ± 0.45^D	10.95 ± 0.03^B	NA	NA	39 ± 0.29^B	2
	IR-64	R	28.59 ± 0.62^B	13.85 ± 0.37^A	14.74 ± 0.99	High	34 ± 1.15^DE	4
		HT	24.08 ± 0.25^C	10.16 ± 0.71^B	NA	NA	39 ± 0.76^B	2
Milled Rice	Jyothi	R	29.84 ± 0.71^b	12.45 ± 0.35^d	17.39 ± 1.05	High	21 ± 0.50^cd	4
		HT	26.67 ± 0.28^e	08.25 ± 0.08^f	NA	NA	25 ± 0.29^b	1
	Aishwarya	R	30.46 ± 0.05^b	15.00 ± 0.20^b	15.46 ± 0.15	High	23 ± 0.76^bc	4
		HT	26.55 ± 0.01^e	09.58 ± 0.19^e	NA	NA	28 ± 0.76^a	2
	Kar Bhatha (medium)	R	30.07 ± 0.04^b	13.25 ± 0.09^c	16.82 ± 0.12	High	24 ± 1.15^b	3
		HT	26.78 ± 0.01^e	08.49 ± 0.07^f	NA	NA	29 ± 0.29^a	1
	Kar Bhatha (small)	R	31.34 ± 0.07^a	16.07 ± 0.01^a	15.27 ± 0.08	High	20 ± 0.50^de	4
		HT	28.53 ± 0.40^c	12.67 ± 0.16_d	NA	NA	24 ± 1.15^b	2
	IR-64	R	29.83 ± 0.13^b	16.17 ± 0.00^a	13.66 ± 0.13	High	18 ± 0.76^e	4
		HT	27.70 ± 0.05^d	12.60 ± 0.13^d	NA	NA	21 ± 0.50^cd	2

R: Raw, HT: Hydrothermally treated ^(A–J) Husked Rice. ^(a–j) Milled Rice. NA: Not Applicable.
Values are mean ± standard deviation of three determinations (n=3).
Values within the same column with different letters are significantly different at $p < 0.05$.
*: Alkali reaction score for the kernels is as follows: 0–Unattacked or one or two minute cracks in one edge, 1–Unattacked or minute cracks in one edge. Whole chalky, 2–Noticeably cracked and/or slightly opened and/or slightly corroded. Nearly whole chalky, 3–Substantially cracked and/or opened; inner matter partly corroded or turning cottony; ¾ of original kernel chalky, 4–Similar; sometimes split into two pieces; but ½ of original kernel chalky, 5–Similar, but ¼ of original kernel chalky, 6–Nil or trace chalky, cottony; or partly cottony, partly gel. Enlarged, loose or compact, one or more pieces, 7–Compact, enlarged, uniform gel, in one or more pieces and 8–Irregular-shaped lump of gel.

during cooking. On an average, the alkali spreading scores (1–2) placed the rice samples in the high gelatinization temperature category.

The pasting profiles of the raw and hydrothermal treated rice flour samples are presented in Table 4. Gelatinization temperature (GT), a physical property of starch, is the temperature at which 90% of rice starch granules swell irreversibly in hot water with loss of crystalline structure and birefringence. The GT of raw husked rice varied from 73 to 78º C with highest being shown by Kar bhatha – medium and lowest by Jyothi. Raw milled rice of coloured varieties showed a GT of 67.5 to 75º C with lowest shown by Aishwarya and highest by Kar bhatha-medium and that of non-coloured rice was 73º C. Generally hydrothermal treatment increase the GT (Ali and Battacharya 1980). Hydrothermally processed husked rice showed a GT range from ~ 77 to 85.5º C among the coloured rice, with highest by Kar bhatha (medium) and lowest by Kar bhatha (small). Husked hydrothermal treated rice of IR-64 showed a GT of 75º C. Milled hydrothermal treated rice showed a GT of 77º C to 84º C among coloured rice, highest being by Kar bhatha-medium and lowest by Kar-bhatha, small. Non-pigmented rice showed least GT, 75º C. The higher GT for the parboiled rice might be largely due to the reduced swelling ability of starch granules (Damir, 1985).

The peak viscosity (PV), indicating the amount of swelling of starch granules was apparently lower in the raw husked rice (395–1075 BU), compared to raw milled rice (625–1405 BU). A markedly lower PV was noted in the hydrothermally processed samples (husked/

Table 4. Pasting parameters of pigmented and non-pigmented rice varieties before and after hydrothermal treatment

Rice Varieties			GT	PV	HPV	CPV	BD	SB	SB_t
Husked Rice	Jyothi	R	73.5	535 ± 15	420 ± 0	1115 ± 5	115 ± 15	580 ± 10	695 ± 5
		HT	80	285 ± 25	355 ± 25	890 ± 70	-70 ± 00	605 ± 45	535 ± 45
	Aishwarya	R	75	600 ± 0	405 ± 5	1310 ± 50	195 ± 5	710 ± 50	905 ± 45
		HT	79.5	305 ± 50	340 ± 0	960 ± 00	-35 ± 50	655 ± 50	620 ± 0
	Kar Bhatha	R	78	395 ± 25	420 ± 20	1110 ± 90	-25 ± 5	715 ± 65	690 ± 70
	(medium)	HT	85.5	175 ± 50	240 ± 0	515 ± 50	-65 ± 50	340 ± 0	275 ± 50
	Kar Bhatha	R	75	415 ± 15	385 ± 5	915 ± 5	30 ± 10	500 ± 10	530 ± 0
	(small)	HT	77	325 ± 15	340 ± 20	955 ± 75	-15 ± 50	630 ± 60	615 ± 55
	IR-64	R	73	1075 ± 15	565 ± 5	1470 ± 0	510 ± 10	395 ± 15	905 ± 5
		HT	75	605 ± 50	620 ± 10	1725 ± 5	-15 ± 50	1120 ± 0	1105 ± 5
MilledRice	Jyothi	R	70	735 ± 65	630 ± 30	1590 ± 70	105 ± 35	855 ± 5	960 ± 40
		HT	79.5	430 ± 10	560 ± 20	1420 ± 80	-130 ± 10	990 ± 70	860 ± 60
	Aishwarya	R	67.5	1080 ± 20	730 ± 0	1810 ± 40	350 ± 20	730 ± 20	1080 ± 40
		HT	79	425 ± 25	515 ± 15	1455 ± 5	-90 ± 10	1030 ± 20	940 ± 10
	Kar Bhatha	R	75	625 ± 15	710 ± 10	1965 ± 5	-85 ± 5	1340 ± 20	1255 ± 15
	(medium)	HT	84	195 ± 15	300 ± 10	670 ± 20	-105 ± 5	475 ± 50	370 ± 10
	Kar Bhatha	R	71	1140 ± 20	220 ± 0	1400 ± 80	920 ± 20	260 ± 60	1180 ± 80
	(small)	HT	77	395 ± 50	445 ± 50	1225 ± 5	-50 ± 00	830 ± 0	780 ± 0
	IR-64	R	73	1405 ± 25	440 ± 150	1375 ± 175	965 ± 125	-30 ± 150	935 ± 25
		HT	75	860 ± 15	820 ± 20	1170± 20	40 ± 00	310 ± 00	350 ± 0

R: Raw, HT: Hydrothermally treated
(A–J) Husked Rice. (a–j) Milled Rice
Values are mean ± standard deviation of three determinations (n=3).
Values within the same column with different letters are significantly different at $p < 0.05$.
GT (°C): Gelatinization Temperature; PV (BU) : Peak Viscosity; HPV (BU) : Hot Paste Viscosity; CPV (BU) : Cold Paste Viscosity; Break Down: BD = [PV–HPV]; Set Back: SB = [CPV – PV]; Total Set Back: SBt = [CPV – HPV].

milled), compared to raw samples. The drop in amylograph peak viscosity resulting from hydrothermal treatment was ascribed by (Kamal *et al.,* 1963; Ali and Bhattacharya, 1980). Interestingly peak viscosities of raw husked rice among coloured ones were less (395 to 600 BU) compared to raw husked rice of IR-64 (1075 BU). Similarly milled raw rice of coloured varieties showed less PV (625 – 1140 BU) compared to raw milled rice of IR-64 (1405 BU). This data indicates that the starch granules in coloured rice swells less compared to that in non-coloured rice. Hydrothermal treatment reduces the PV in coloured as well as non-coloured rice. The degree of reduction (reducing) for hydrothermally treated husked rice was in the range of 22 to 56% for coloured rice, whereas in non-coloured it was 44% (compared to native PV) indicating substantial difference between two categories of rice will not exist. Hydrothermal treatment reduces PV in husked rice but after milling the PV of hydrothermal treated milled rice increases indicating bran was hindering swelling of starch granules. The increase ranged from 11 to 51% among coloured rice and 42% in the case of non-coloured rice. Thus we find there were larger variations in PV among coloured rices. Similarly we find differences between raw milled rice and hydrothermally treated milled rice. Conditions during the steaming phase of hydrothermal treatment were severe enough to inactivate any amylases present. Thus the greater extent of retrogradation in the parboiled rice might help to explain its low and delayed peak viscosity, reflecting greater resistance to breakdown.

Hot paste viscosity (HPV) is the viscosity where, on heating, the maximum swollen starch granules do not have space to swell more in the given volume, but the swollen granules bombard each other and break down and hence viscosity decreases (comes down) from peak viscosity. HPV was high in raw milled rice in three varieties and low in two varieties, compared to that of raw husked rice. In hydrothermally treated husked rice, HPV decrease from 12 to 44%, however in hydrothermally treated milled rice, it decreases from 11 to 37% in two varieties and in other two varieties it increases from 102 to 186%, indicating the phenomenon that these rice behave like cross linked starches.

Cold paste viscosity (CPV) was high in raw milled rice (1375–1965 BU) compared to raw husked rice (915–1470 BU). CPV of raw husked rice varied from 915 to 1310 BU among coloured rice and that of IR-64 was 1470 indicating the non-coloured rice starch swells to a greater extent while cooling the sol formed during heating phase. In the case of raw milled rice the CPV of coloured rice varied from 1400 to 1965 BU compared to 1375 in the case of IR-64, indicating the fact that retrogradation phenomenon is high in coloured rice or precipitation of linear polymers is high in coloured rice. After hydrothermal treatment, in coloured husked rices the cold paste viscosity decreases and it varies from 890 to 955 BU. Interestingly the value increased in the case of non-coloured rice indicating the precipitation of linear polymers in the case of non-coloured rice while cooling the sol was high. The CPV of hydrothermally treated milled rice increased compared to that of hydrothermally treated husked rice in the case of coloured rice inferring bran portion was hindering for precipitation of linear polymers. A large increase in viscosity during the cooling stage shows higher retrogradation where linear polymers attempts to precipitate while cooling the sol. (Lii *et al.*, 1995).

Starch breakdown (BD) differed significantly ($p<0.05$) among rice varieties. BD in raw milled rice was high compared to raw husked rice and the extent was quite high in coloured rice especially in Kar bhatha (medium). Breakdown viscosity measures the tendency of swollen starch granules to rupture when held at high temperature and continuous shearing and is indicative of the stability of the starch granules on heating (Patindol *et al.,* 2005). In hydrothermally treated rice (husked/milled), the BD values were negative, indicating that they behave like cross linked starches, which was not observed in non – coloured rice.

The set back (SB) values are indicative of the retrogradation tendency of starch. Since the initial gel network development is dominated by amylose gelation (Miles *et al.,* 1985), set back is more likely related to the retrogradation tendency of amylose. The SB values were higher in the parboiled rice, than in raw rice. SB_t (total set back) decreases in general after hydrothermal treatment except in raw husked rice of IR-64, indicating the enmass retrogradation phenomenon is different in husked rice of IR-64 after hydrothermal treatment.

Hydrothermal processing as a means of rice processing affects both the physical and chemical properties of the grain. Under similar conditions of milling, always hydrothermally treated rice shows lesser degree of polish, which is also confirmed by the Phosphorus content data. This process reduced the fat, protein and amylose equivalent of the rice, while the ash and phosphorous content in husked/milled hydrothermally treated rice were high, cooking time and water absorption were also high. Varietal differences were also existed among the rice varieties. EMC-S of husk of hydrothermally treated one was less indicating the constituents of husk absorbs less moisture. Total and insoluble amylose equivalents indicated that these rice belongs to I group of World rice classification. GT was high in coloured husked rice compared to non-coloured one. PV values indicated that coloured rice swells less in raw condition, after hydrothermal treatment the PV values decreased in both types of rice. In non-coloured rice, HPV was high, indicating they behave like cross linked starch. Precipitation of linear polymers were high in coloured rice, but it decreased after hydrothermal treatment.

Today, consumers prefer to have husked rice (brown rice) and red pigmented rice, because of the nutrient values in their bran. The advantage of using red rice varieties, overcomes current physiological effect in the human health due to the presence of high fiber and anthocyanins in these varieties. These components have been recognized as health–promoting functional food ingredients due to the antioxidant activity. Thus, these properties could be responsible for its usage as a vehicle, to facilitate the need of the targeted population. Finally, the need to improve quality of locally grown red rice varieties, to make it more competitive with imported/hybrid rice should be more emphasized.

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REFERENCES

Adu-Kwarteng E, Ellis WO, Oduro I, Manful JT 2003. Rice grain quality: A comparison of local varieties under study in Ghana. Food control 14, 507-514.

Ali SZ and Bhattacharya KR, 1980. Pasting behaviour of parboiled rice. J Texture Stud., 1, 239.

AOAC 2000. Official methods of analysis (17th ed.). Washington, DC: Association of Official Analytical Chemists.

Bhattacharya KR 1985. Parboiling of rice. In "Rice chemistry and technology". ed. by B.O. Juliano. American Association of Cereal Chemists. Inc., St. Paul.Minnesota. 289-348.

Bhattacharya KR and Sowbhagya CM 1971. Water uptake of rice during cooking.Cereal Science Today 16, 420-424.

Bhattacharya KR, Sowbhagya CM 1972. An improved alkali reaction test for rice quality. Journal of Food Technology 7, 323-331.

Bhattacharya KR, Sowbhagya CM, Indudhara Swamy YM 1982. Quality profile of rice. A tentative scheme for classification. J. Food Sci 47, 564-569.

Bong Kyung Koh, Singh V, 2009. Cooking behaviour of rice and blackgram in the preparation of idli, a traditional fermented product of Indian origin, by Viscography. J Texture Stud 40, 36-50.

Chaudhary RC and Tran DV 2001. Specialty rices of the world, breeding production and marketing. Oxford & IBH Publishing Co. Pvt. Ltd. New Delhi.

Chitra M, Singh V and Ali SZ 2010. Effect of processing paddy on digestibility of rice starch by in vitro studies. J Food Sci Technol 47(4), 414-419. Codex standard for rice, 198-1995.

Cruz ND, Khush GS 2000. Rice grain quality evaluation procedures. In: R. K. Singh, U.S. Singh & G.S. Khush (Eds). Aromatic rice. 15-28. Oxford & IBH publishing Co Pvt. Ltd., New Delhi.

Damir AA 1985. Comparative studies on the physicochemical properties and microstructure of raw and parboiled rice. Food Chemistry 16, 1-14.

Deepa G, Singh V, Akhilender Naidu K 2008. Nutrient composition and physicochemical properties of Indian medicinal rice – Njavara. Food Chemistry 106 (1), 165-171.

Hossain MS, Singh AK, Fasih-uz-Zaman 2009. Cooking and eating characteristics of some newly identified inter sub-specific (*indica/japonica*) rice hybrids. Science Asia 35, 320-325.

Houston DF, Mohammad A, Wasserman T and Kester EB 1964. High-protein rice flours. Cereal Chemistry 41 (6), 514-23.

Indudhara Swamy YM, Zakiuddin Ali S and Bhattacharya KR 1971. Hydration of raw and parboiled rice and paddy at room temperature. Journal of Food Science & Technology 8, 20-22.

Juliano BO, Bautista GM, Lugay JC, Reyes AC 1964. Studies on the physicochemical properties of rice. Journal of Agricultural Food Chemistry 12, 131-138.

Kamal MA, Refai FY, Tawfik MA 1963. Effect of cooking upon the biochemical constituents of rice (in Arabic). Congress for Rice Agricultural Research, Egypt 24-26 Jan., 1970. Ministry of Agriculture, Cairo.

Khush GS, Paule CM, De la Cruz NM 1979. Rice grain quality evaluation and improvement at IRRI. Proceedings of the Workshop on Chemical Aspects of Rice Grain Quality, Manila, Philippines: IRRI: 21-31.

Kim MK, Kim HA, Koh K, Kim HS, Lee YS and Kim YH 2008. Identification and quantification of anthocyanin pigments in coloured rice. Nutrition Research and Practice 2, 46-49.

Kulkarni SD, Bal S 1984. On the influence of evacuation on liquid water absorption by paddy grains, Journal of Food Science & Technology 21, 318-320.

Lii CY, Shao YY and Tseng KH 1995. Gelation mechanism and rheological properties of rice starch. Cereal chemistry 72 (4), 393-400.

Miles MJ, Morris VJ, Orford PD and Ring SG 1985. The roles of amylose and amylopectin in the gelation and retrogradation of starch. Carbohydrate Research 135, 271-278.

Otegbayo BO, Osamuel F, Fashakin JB 2001. Effect of parboiling on physico-chemical qualities of two local rice varieties in Nigeria. The Journal of Food Technology in Africa 6 (4), 130-132.

Patindol J, Wang Y and Jane J 2005. Structure–functionality changes in starch following rough rice storage. Starch/Stärke 57, 197-207.

Raghavendra Rao SN and Juliano BO 1970. Effect of parboiling on some physico-chemical properties of rice. Journal of Agricultural Food Chemistry 18, 289-294.

Savitha YS, Singh V 2011. Status of dietary fiber contents in pigmented and non-pigmented rice varieties before and after parboiling. LWT–Food Science and Technology 44 (10), 2180-2184.

Singh V, Ali SZ 1987. Estimation of phosphorous in native and modified starches. Improvement in the molybdovanado phosphoric acid method. Starch/ Stärke 39, 277-279.

Singh V, Hiroshi Okadome, Hi dechika Toyoshima, Seiichiro Isobe, Kenichi Ohtsubo 2000. Thermal and physico–chemical properties of rice grain, flour and starch. Journal of Agricultural and Food Chemistry 48, 2639-2647.