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ORIGINAL ARTICLE

Evaluation of sensory, physicochemical properties and Consumer preference of black rice and their products

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Abstract This study was aimed to evaluate the physicochemical, textural, sensory and antioxidative attributes of various rice products such as boiled rice, beaten rice, popped rice, puffed rice and raw milled rice, prepared from the Indian black rice cultivars *Chakha* (*CH*), *Kalobhat* (*KB*), *Mamihunger* (*MA*) *and Manipuri Black* (*MN*). A popular white rice variety *Swarna Sub-1* (SW) was considered as control. Significant differences in most of the physicochemical and cooking parameters of raw rice were observed across different cultivars. The head rice recovery, amylose content, elongation ratio (ER) and kernel length after cooking of *MA* were most satisfactory among the black rice cultivars and are found to be 50.67%, 17.6%, 1.87 and 10.10 mm respectively, while popped rice of *MA* recorded highest length (10.83 mm) and elongation ratio (ER; 2.01). *MA* showed the highest adhesiveness (11.18 mJ) in boiled rice but hardness (183.53 N) was medium in raw rice. Other textural quality varied differentially according to the various products and cultivars. The highest a* value was obtained from puffed rice of *MA* (6.61) but L value was highest in raw rice of *MN*. Popped and boiled rice of *MA* displayed higher DPPH-antioxidant activity (88.74% and 84.74% respectively) as compared to all other products. The raw rice of *KB* registered higher anthocyanin (57.23 mg/100 g) content while boiled rice of *SW* recorded the least (0.21 mg/100 g). A survey on the consumer preference of these products indicated that boiled rice was usually preferred in lunch and dinner by most of the consumers whiles other products in breakfast. With respect to most of the traits, *MA* showed the good potential for rice Industry as well as for breeding material.

Keywords Black rice · Products · Physicochemical · Texture · Sensory · Preference · Antioxidants · Anthocyanin

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Introduction

Rice (*Oryza sativa* L.), a most popular cereal crop, is consumed as a staple food in the form of boiled, popped, puffed and beaten rice etc. because of its significance in providing basic nutrition. The rice varieties with whitish kernels are very common but India, a reservoir of vast population of rice genotypes, also registers rice varieties and genotypes with a pigmented (black, purple, or red) pericarp and posses medicinal properties (Siva et al. 2010). The pigmented rice cultivars often give white kernels on milling but there are some varieties, which retain their slightly coloured kernels even after milling. Such varieties in which coloured kernel fused with some bran layers are reported to contain several phenolic compounds including anthocyanins, flavonoids, hydroxybenzoic acids and hydroxycinnamic acids. These secondary metabolites are reputed for their protective role against radical-mediated oxidation of cellular constituents and thus act as very good antioxidants. Epidemiological studies with pigmented rice have demonstrated its role in the prevention of several oxygen-linked chronic diseases such as cancer, cardiovascular and nerve diseases (Kehrer 1993). Some red and purple pigmented rice varieties are reported to have much higher total phenol, flavonoids and anthocyanin content resulting enhanced ferric reducing antioxidant property (FRAP) than non-pigmented rice (Mahanta et al. 2012). Thus, pigmented rice owing to its nutritional significance, has received much attention in recent years for inclusion in our diet.

Rice parboiling, a hydrothermal process is responsible to modify the qualitative and processing behaviour of rice (Mahanta et al. 2012) while puffing and popping result in some physical, conformational and structural changes in rice grain due to reorientation of the starch granules leading to altered morphology and texture of the rice grain. The processing involving a hydrothermal change of rice grains into popped, puffed, boiled and beaten rice modifies the concentration of some phytochemicals in kernels. Thus, the bran layers attached with kernels in popped and beaten rice may be a potential source of the compounds of nutritional significance than polished rice products. On the other hand, public acceptance of raw rice or its products is governed by the physico-chemical, cooking and sensory properties of rice grains. For example, grains with higher amylose content (> 20%) are preferred by the Indians because those with low amylose content (< 10%) are generally sticky after cooking. Likewise, length, breadth, processing time, sweetness, aroma content and crunchiness of the rice products are some of the important attributes for evaluation of rice grain quality and consumer preference. While selecting good varieties, milling industry relies on some important parameters such as head rice recovery (HRR), grain colour, hardness, chalkiness, volume expansion and water uptake after cooking (Singh et al. 2005). The degree of whiteness (L), an important attribute of raw and cooked rice varies significantly depending on genotypes and grain processing techniques and the greenness(a*) and yellowness (b*) of many rice varieties decrease by cooking process (Champagne et al. 2010).

In India, boiled rice is consumed in most families and prepared by boiling raw or parboiled rice with water till completion followed by draining of excess water. This process seems to result in removal or conversion of a major part of the nutrients of rice grains to unavailable form. The preparation of other products such as popped and puffed rice, which requires much higher temperature, probably registers differential quantity of nutritional compounds than conventional boiled rice. In view of these considerations and scanty information in the context of pigmented rice, the present research is aimed to examine the effect of different processing methods on textural quality, colour difference, consumer preference, physical properties of rice grains of the black rice cultivars viz. *CH*, *MA*, *MN and KB* (Sanghamitra et al.2017) of eastern India and a very popular white rice variety *SW* as control. In addition, DPPH-antioxidant activity of these products is also reported here. The study will provide valuable information about public preference of different products of black rice cultivars and their suitability for inclusion in our daily diet.

Materials and methods

Samples

The four pigmented rice cultivars (*CH*, *MA*, *MN and KB*) and a popular white rice variety *SW* as control were grown in ICAR-National Rice Research Institute, Cuttack. The soil of this experimental field was *Aeric Endoaquept* with sandy clay loam texture (25.9% clay, 21.6% silt, 52.5% sand). Conventional puddling method with recommended dose of fertilizers ($N_{100}P_{40}K_{40}$) was followed for their cultivation. The mature grains collected after harvesting were sundried for 3–4 days maintaining final moisture content of 12–13%. The grains were then stored at 4 °C in plastic containers.

Preparation of the products

The following products were prepared from the grain of these cultivars (Fig. 1): (a) *Raw polished rice*—The grains were husked and milled through rice huller and miller machine (Satake Corporation, Japan) (b) *Popped rice*—The grains were popped as per protocol of Murugesan and Bhattacharya (1991) with some modifications. The rough rice with husk were roasted directly into heated sand (> 177 °C) in an iron pan for 10–15 s with continuous stirring. The entire husk almost detached during heating was separated from popped kernel. (c) *Puffed rice*—The polished double parboiled rice grains, mixed with 10–12% brine solution were roasted over preheated (approx. 220 °C) fine sand with constant stirring for 15–20 s. The puffed product was then separated from the sand by sieving (Hoke et al. 2005). (d) *Beaten rice*—This product was prepared according to the protocol described by Kumar et al. (2016) with some modifications. The graded grains obtained by removing the impurities were soaked overnight in normal water followed by hot water (60 °C) for 1 h. After mild drying, they were roasted in an iron pan to make flakes by the flake making machine. (e) *Boiled rice*—It was prepared through conventional boiling with water followed by draining of water.

Physicochemical properties of raw rice

The brown rice obtained after hulling was polished for 60 s. This polished rice was made to flour using a *Glen* mini grinder (Model 4045G, Glenindia, India). Milled rice out-turn was expressed as percentage basis. The digital image analyzer (Annadarpan, India) was used for

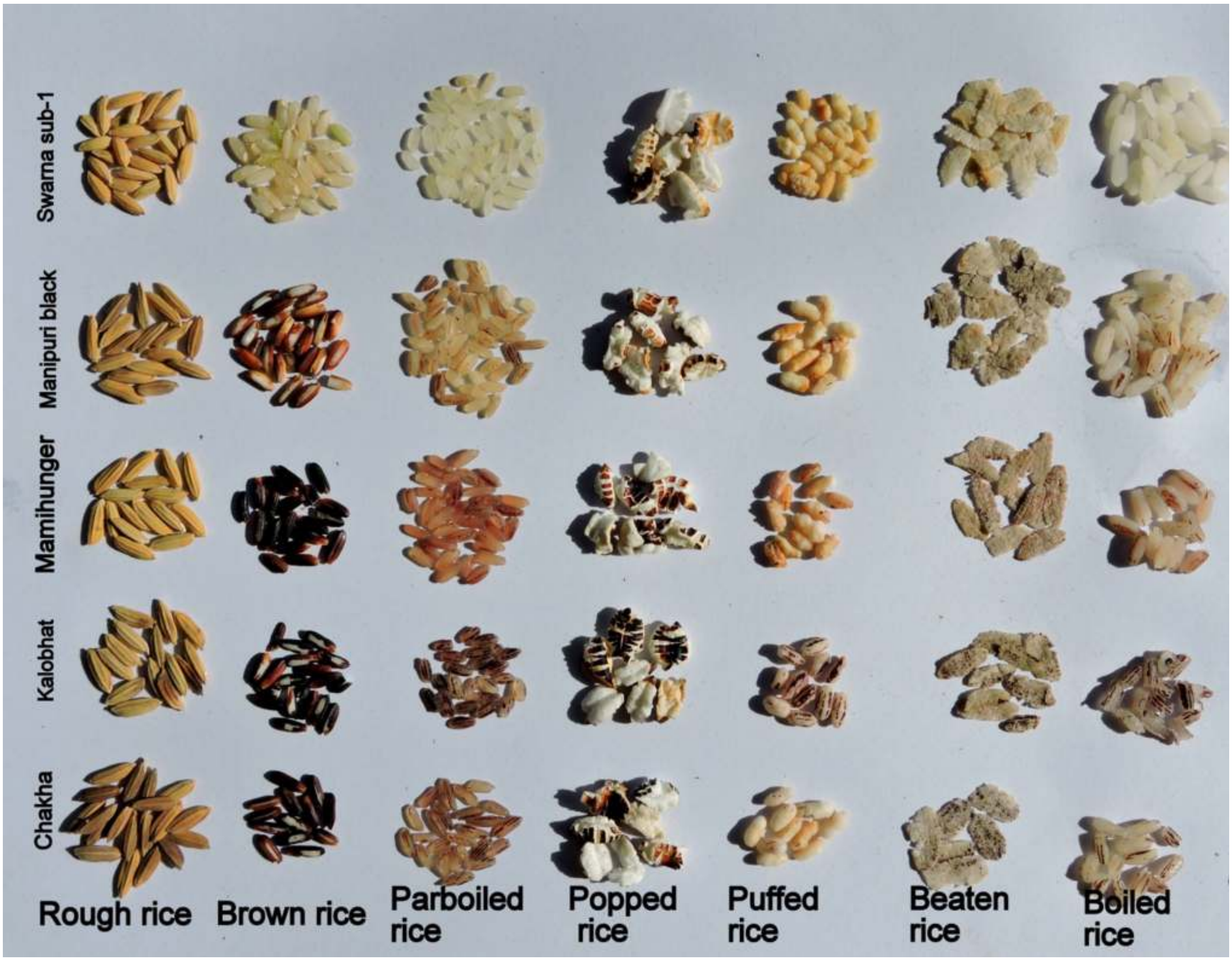

Fig. 1 Different rice products prepared from four black rice and one white rice (control). Popped rice, puffed rice, beaten rice and boiled rice are the eatable form whereas brown rice and parboiled rice have to be cooked before eating

measurement of grain length, breadth and L/B ratio. Volumes of cooked and milled rice were measured by the water displacement method. Briefly, 5 g of milled rice was added to a graduated cylinder containing 50 ml of water and the change in volume was noted. To measure the volume of cooked rice, 5 g of milled rice was cooked and then kept it to the same cylinder to note down the change in volume. Gel consistency (GC), alkali spreading value (ASV) and amylose content (AC) were measured as per protocol described earlier (Juliano 2003).

Preference study of the consumers

The diverse groups of consumers consisting of 79 members from rice consuming states were used for this survey to find out the acceptance of the four primary rice products. The consumers were divided into four overlapping groups based on age, gender, income and time of consumption. The data were collected according to their consent about the consumption of rice products per month basis. In this case, the consumers were pre-informed about the questions to minimize the error. The raw data were statistically analyzed and mean values were presented in Table 3.

Textural qualities of cooked rice samples

The rice grains that were processed into different forms were subjected to the texture profile analysis using "Stable Micro Systems" texture analyzer model TA.XT plus (Stable Micro Systems Ltd, Surrey, UK) as per modified method of Jaiboon et al. (2016). This measurement was performed in three replications by using cylindrical probe (p75) with diameter of 10 cm and the single sample was placed on a metal plate for each test. The probe was controlled to compress the sample to 90% strain for two cycles with the pretest speed of 1 mm/s, test speed and post test speed were 2 mm/s, distance 2 mm (0.5 mm for beaten rice) and trigger force 5 g (0.049 Newton). From the texture profile analysis (TPA) curve, the values of hardness, adhesiveness, cohesiveness, springiness, gumminess and chewiness were determined.

Colour

The colour of the grain samples at different state of processing were determined by CIE colour scales L*, a* and b* using Hunter Lab digital colorimeter (Model D25M, Hunter Associates Laboratory, Reston, VA). Where L* indicates the degree of lightness or darkness of the sample extended from 0 (black) to 100 (white), a* indicates degree of redness (+ a) to greenness (− a) whereas b* indicates the degree of yellowness (+ b) to blueness (− b), respectively (Ahmad et al. 2014).

Physical properties of popped, puffed and beaten rice

The volume of popped, puffed and beaten rice were estimated by sand displacement method whereas that of raw rice and boiled rice by water displacement. Loose and packed bulk densities of the rice samples were determined using the formula D = weight/volume (g/ml), but packed density was measured with additional tapping of the measuring cylinder, containing sample to the work bench and the modified volume was taken (Bagchi et al. 2016). The length and breadth were measured by venire caliper scale (± 0.02 mm accuracy).

Antioxidant capacity

The antioxidant activity of different rice processed products was measured using a stable neutral radical DPPH according to the method adopted by Zhu et al. (2011) with minor modification. Extract was prepared by vortexing 1 g fine ground sample flour in 10 ml ethanol. After centrifugation at 10,000 g for 20 min, the supernatant was collected. To 1 ml of extract, 2 ml ethyl alcohol and 1 ml DPPH (10 µM i.e. 2 mg/50 ml) solution were added. After 30 min at room temperature, the absorbance was measured at 517 nm against a blank. Antioxidant capacity was measured by percent inhibition of absorbance.

$$\text{DPPH scavenging activity}\,(\%) = \frac{(\text{Abs. of control} - \text{Abs. of sample}) \times 100}{\text{Abs. of control}}$$

Anthocyanin content of grains and their products

Anthocyanin content in the samples was determined using the method described by Fuleki and Francis (1968) with some modifications. Briefly, 1 g of sample was homogenized with 5 ml acidified organic solvent (95% methanol: 1.5 N HCl 85:15, v: v; P^H = 1). The sample was extracted twice by keeping it overnight with solvent followed by centrifugation at 10000 rpm for 10 min in a chilling centrifuge. The final volume of supernatant was made to 10 ml and the absorbance was read at 535 nm. Total anthocyanin content of the samples was calculated as mg total anthocyanin per 100 g of sample using an multiplication factor = 16.73 × Absorbance or

$$\begin{aligned}\text{Anthocyanin (mg/100 g)} &= \text{abs} \times \text{Mol. wt} \\ &\quad \times 1000/\text{molar absorptivity (e)} \\ &\quad \times \text{path length (cm)} \\ &= \text{abs} \times 450 \times 1000/26900 \times 1\end{aligned}$$

Statistical analysis

The data obtained in this study were expressed as the mean of three replicates. Tukey's means comparison test was applied at a significance level of 5% to determine differences among treatments. All the data analysis was performed using SAS v 9.3 software and MS Excel.

Results

Physicochemical and cooking properties of raw rice

The physicochemical and cooking characteristics of the grains of black and white rice cultivars are presented in Table 1. Moisture percent, hulling, milling, HRR, kernel length and breadth were significantly ($p < 0.05$) differed amongst the cultivars. The white rice SW registered higher percentage of hulling (79.33), milling (68.00) and HRR (64.33). The black rice cultivars showed lower percent of hulling, milling and HRR values than the white rice, though the HRR values were satisfactory to nearly 50% except *MN* that had lowest HRR (33%). *MA* displayed little higher kernel length (5.40 mm) and breadth (2.16 mm) among the cultivars without significant variation in L/B. The cultivars *MA* and *MN* registered higher KLAC (10.10 mm) and water uptake (273.33 ml/100 g) respectively but with no significant differences in volume expansion ratio after cooking. The elongation ratio ranged between 1.55 and 1.87 with the higher value in *MA*. The *CH* and *MN* ranked distinct first for their alkali spreading value (ASV, 6.0). The amylose content generally

Table 1 Physico-chemical and cooking properties of black raw rice

TR	HULL	MILL	HRR	KL	KB	L/B	KLAC	ASV	ER	GC	VER	WU	MC	AC
CH	76.00^{B}	61.00^{BC}	48.67^{B}	5.55^{A}	2.18^{A}	2.55^{B}	9.30^{C}	6.00^{B}	1.68^{C}	77.33^{A}	3.75^{E}	233.33^{B}	12.22^{B}	6.37^{D}
KB	75.00^{BC}	61.67^{BC}	52.00^{B}	5.23^{C}	2.05^{B}	2.55^{B}	8.10^{E}	5.00^{C}	1.55^{D}	75.33^{B}	3.75^{D}	156.00^{C}	12.11^{C}	5.44^{E}
MA	76.33^{AB}	62.00^{B}	50.67^{B}	5.40^{B}	2.16^{A}	2.50^{B}	10.10^{A}	4.00^{E}	1.87^{A}	66.00^{D}	3.75^{C}	163.33^{C}	13.12^{A}	17.60^{B}
MN	72.47^{C}	60.00^{C}	33.00^{C}	5.60^{A}	2.02^{C}	2.77^{A}	9.50^{B}	6.00^{A}	1.70^{C}	71.33^{C}	4.00^{A}	273.33^{A}	12.25^{B}	10.26^{C}
SW	79.33^{A}	68.00^{A}	64.33^{A}	5.15^{C}	2.04^{BC}	2.53^{B}	9.10^{D}	4.00^{D}	1.77^{B}	56.00^{E}	3.75^{B}	82.00^{D}	12.22^{B}	22.48^{A}
p value	0.0007	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Tukey HSD 5%	3.034	1.708	4.12	0.14	0.029	0.084	0.126	0	0.056	1.784	0	7.928	0.036	0.09

The group letters indicate higher to lower values and significant variation among the values at 5% level. *HULL* hulling (%), *MILL* milling (%), *HRR* head rice recovery (%), *KL* kernel length (mm), *KB* kernel breadth (mm), *L/B* length/breadth ratio, *KLAC* kernel length after cooking(mm), *ASV* Alkali spreading value, *ER* elongation ratio, *GC* gel consistency (mm), *VER* volume expansion ratio, *WU* water uptake (ml/100 g), *MC* moisture content (%), *AC* amylose content (%), *CH* Chakha, *KB* Kalobhat, *MA* Mamihunger, *MN* Manipuri black, *SW* Swarna sub-1

determines the stickiness of boiled rice, cooking time and gelatinization temperature (Juliano 1985). In this study, amylose content of the grain ranged from 5.44 to 22.48% in *KB* and *SW* respectively. So, stickiness property of the boiled rice was more with *KB* and *CH* than others. *SW* was non-sticky in nature, while others were sticky. The gel consistency was varied significantly ($p < 0.05$) among the cultivars with 77.33 mm in *CH* followed by *KB* (75.33 mm).

Consumer preference of the various rice products

The results relating to consumer acceptability as summarized in Table 2, indicated that people of age group from 11 to 20 (98.3%) followed by 21–35 years (97.00%) preferred boiled rice while only 4.2–24.6% within these four age groups preferred popped rice. However, the highest consumption of beaten rice (59.2%) and puffed rice (63.3%) was recorded from the age groups of 21–35 and 36–60 years respectively. Moreover, boiled rice was equally consumed by male (98.3%) and female (97.4%). Interestingly, females almost equally preferred puffed (72.5%) and beaten rice (74.1%) followed by popped rice (12.6%) while the corresponding figure for males were 68.2, 61.1 and 6.4% respectively. People below poverty line mainly consumed puffed (87.8%) and beaten rice (84.9%). However, preference of these products were much higher (74.1–84.7%) for the people of middle class. On the other hand, people of both high and middle class preferred boiled rice. The rich people (3.4%) hardly consumed popped rice. In addition, popped (95.5%), puffed (92.2%) and beaten rice (95.4%) in contrast to boiled rice (36.2%) were mainly consumed in breakfast. Boiled rice was usually consumed in lunch (99.5%) and dinner (82.6%). Popped, puffed and beaten rice were consumed very occasionally in lunch and dinner. Thus, consumer preference varied on the type of rice products, age groups, gender, income group and time of consumption.

Textural properties of different rice products

The textural attributes of rice products (Table 3) showed that the processing methods significantly affected the textural properties of various rice products depending on the type of the rice. The raw rice of *SW* exhibited higher hardness (187.68 N) followed by *MN* (187.19 N) and *MA* (183.53 N) without any significant differences between them. Lower hardness was found to be associated with the boiled rice from *KB* (0.87 N), beaten and popped rice from *MN*. The adhesiveness quality of popped, puffed and beaten rice in contrast to boiled rice was absent. Boiled rice of *MA* showed the higher adhesive property (11.18 mJ). The mean value of cohesiveness was higher

Table 2 Preference percent evaluation among diverse group of people, who consumed these products per day basis

		Popped rice %	Puffed rice %	Beaten rice %	Boiled rice %	Population number
Age group	5–10 years	5.2	10.9	8.6	95.5	15
	11–20	4.2	19.2	25.1	98.3	18
	21–35	18.5	42.4	59.2	97.1	16
	36–60	24.6	63.3	41.4	84.2	30
Gender	Male	6.4	61.1	68.2	98.3	41
	Female	12.6	72.5	74.1	97.4	38
Income group	Poor	26.8	87.8	84.9	76.2	18
	Middle	19.7	84.7	74.1	94.1	36
	Rich	3.4	25.6	24.2	97.3	25
Time of consumption	Breakfast	95.5	92.2	95.4	36.2	18
	Lunch	2.1	5.3	11.2	99.5	36
	Dinner	6.2	10.1	12.1	82.6	25

Table 3 Textural properties of rice products, prepared from black rice and white rice

	Cultivar	Adh	Chw	Coh	Gum	Hrd	Spg
Boiled rice	CH	5.00^{B}	44.76^{ABCDE}	1.75^{C}	25.01^{BCDE}	1.43^{C}	1.79^{ABC}
	KB	4.36^{B}	86.35^{ABCD}	5.21^{A}	47.24^{ABCD}	0.87^{C}	1.83^{AB}
	MA	11.18^{A}	90.11^{ABC}	0.58^{CD}	51.52^{ABC}	9.06^{C}	1.75^{ABC}
	MN	4.94^{B}	103.83^{AB}	3.45^{B}	55.93^{AB}	1.57^{C}	1.84^{A}
	SW	3.23^{BC}	122.43^{A}	0.57^{CD}	70.69^{A}	12.31^{C}	1.73^{ABCD}
Beaten rice	CH	0.02^{C}	16.15^{CDE}	0.01^{D}	13.77^{CDE}	87.32^{ABC}	1.17^{DE}
	KB	0.01^{C}	9.04^{DE}	0.01^{D}	6.72^{DE}	36.70^{C}	1.25^{BCDE}
	MA	0.00^{C}	6.05^{E}	0.01^{D}	5.64^{DE}	45.79^{C}	1.04^{E}
	MN	0.00^{C}	0.55^{E}	0.01^{D}	0.53^{E}	4.54^{C}	1.05^{E}
	SW	0.02^{C}	16.32^{CDE}	0.02^{D}	13.32^{CDE}	68.69^{BC}	1.22^{CDE}
Popped rice	CH	-0.00^{C}	3.29^{E}	0.01^{D}	1.89^{E}	19.67^{C}	1.80^{ABC}
	KB	-0.00^{C}	3.17^{E}	0.01^{D}	1.79^{E}	16.99^{C}	1.77^{ABC}
	MA	-0.00^{C}	4.17^{E}	0.01^{D}	2.39^{E}	20.01^{C}	1.73^{ABCD}
	MN	-0.00^{C}	6.32^{E}	0.03^{D}	3.22^{E}	12.46^{C}	1.96^{A}
	SW	-0.00^{C}	24.36^{CDE}	0.03^{D}	12.45^{CDE}	46.02^{C}	1.98^{A}
Puffed rice	CH	-0.00^{C}	11.66^{CDE}	0.03^{D}	7.07^{DE}	23.61^{C}	1.65^{ABCD}
	KB	-0.00^{C}	11.39^{CDE}	0.03^{D}	7.02^{DE}	22.14^{C}	1.61^{ABCDE}
	MA	-0.00^{C}	18.57^{CDE}	0.04^{D}	10.94^{CDE}	24.67^{C}	1.70^{ABCD}
	MN	-0.00^{C}	31.67^{BCDE}	0.09^{D}	17.86^{BCDE}	28.86^{C}	1.76^{ABC}
	SW	-0.00^{C}	9.62^{DE}	0.02^{D}	6.19^{DE}	27.86^{C}	1.55^{ABCDE}
Raw rice	CH	0.11^{C}	47.49^{ABCDE}	0.02^{D}	32.58^{ABCDE}	163.95^{AB}	1.46^{ABCDE}
	KB	0.04^{C}	48.28^{ABCDE}	0.02^{D}	33.49^{ABCDE}	181.71^{AB}	1.44^{ABCDE}
	MA	-0.00^{C}	36.16^{BCDE}	0.01^{D}	21.66^{BCDE}	183.53^{A}	1.68^{ABCD}
	MN	-0.00^{C}	49.67^{ABCDE}	0.02^{D}	30.56^{ABCDE}	187.19^{A}	1.51^{ABCDE}
	SW	-0.00^{C}	43.37^{ABCDE}	0.02^{D}	27.97^{BCDE}	187.68^{A}	1.49^{ABCDE}
p value		< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Tukey HSD at 5%		3.3296	79.402	1.47	42.059	113.25	0.5811

The group letters indicate higher to lower values and significant variation among the values at 5% level. *Adh* adhesiveness (mJ), *Chw* chewiness (N), *Coh* cohesiveness, *Gum* gumminess (N), *Hrd* hardness (N), *Spg* springiness, *CH* chakha, *KB* Kalobhat, *MA* Mamihunger, *MN* Manipuri black, *SW* Swarna sub-1 with boiled rice (2.31) than other products and *KB* registered maximum score (5.22). The cohesiveness of popped, puffed, beaten and raw rice ranging from 0.02 to 0.03 was negligible. Different products did not vary significantly in their springiness. The mean value for springiness was higher in popped rice (1.83) and comparable with boiled rice of *MN* (1.84).The values were similar for popped rice of *SW* (1.98) and *MN* (1.96) as well as for beaten rice of *MA* (1.04) and *MN* (1.05). The mean values for gumminess of the products regardless of the cultivars varied between 56.49 N in boiled rice and 5.54 N in popped rice. However, of all the products irrespective of cultivar, popped rice of *KB* showed lowest gumminess value (1.80 N). The values for chewiness were higher (99.64 N) with boiled rice followed by raw rice (42.6 N).The boiled rice of *SW* with a value of 122.44 N ranked first while popped rice of *KB* registered least (3.17 N).

Colour properties

The colour and other sensory properties of different black rice products were presented in Table 4. Among all the rice products, highest L value was observed in raw rice of *MN* (71.97) and lowest in boiled rice of *CH* (26.08). The highest a* value was obtained from puffed rice of *MA* (6.61) followed by puffed rice of *CH* (5.33), whereas lowest a* value was found in boiled rice of *MN* (0.01).The b* value of all the rice products ranged between 4.89 and 24.4 while the highest and lowest b* values were found in puffed rice of *SW* and boiled rice of *CH* respectively. Overall the mean b* value was higher in puffed rice and lower in boiled rice. The highest "total colour difference" (ΔE) value was obtained in raw rice of *MN* (73.22) and lowest from boiled rice of *CH* (26.78).

Antioxidative capacity and anthocyanin content

The anthocyanin content and DPPH radical scavenging activity of black rice and popular white rice cultivar with their different processed products was summarized in Table 4. It was evident that black rice and their products contain higher antioxidant capacity than white rice. The popped and boiled rice in contrast to raw rice of *MA* exhibited higher antioxidant activity as compared to other products. Considering the black rice, antioxidant capacity of popped rice and boiled rice increased whereas that of puffed rice and beaten rice decreased. Thus, it was evident that antioxidant capacity of beaten rice was poor as compared to all other products. Anthocyanin content of raw rice was higher than other products and *KB* showed the highest anthocyanin content (57.23 mg/100 g). In general, anthocyanin content was lowest in boiled rice where white rice *SW* registered the lowest (0.21 mg/100 g).

Physical properties

The physical properties of the products when compared with raw polished rice (Tables 1, 5) indicated that popped rice displayed higher VER. Popped and beaten rice from *SW* recorded maximum (18.61) and minimum (0.72)VER value, which ranged between 3.12 and 4.2 in puffed rice. Thus, the length, breadth and ER of popped rice were generally higher as compared to other products. Popped rice of *MA* and beaten rice of *KB* registered highest ER (2.01) and lowest in puffed rice of *SW*(1.03). Beaten rice of *CH* (10.85 mm) and popped rice of *MA* recorded highest length (10.83 mm) and the breadth was highest (8.57 mm) in popped and lowest (2.58 mm) in puffed rice of *SW*. The cylindrical shape of boiled, puffed and popped rice made it difficult to measure their thickness and that for beaten rice it was lowest in *KB* and highest in *SW*. The loose and packed bulk density were highest (0.44 and 0.46 g/ml) and lowest (0.07 and 0.08 g/ml) with puffed and popped rice of *SW* respectively. The mean loose and packed bulk density was higher in beaten rice as compared to other products.

Discussion

Among the various rice products available in India and other Asian countries, popped, puffed, beaten and boiled rice form the basic products, from which other products are derived through suitable preparation method. In general, puffed rice owing to its crispiness and attractive colour, forms a very popular diet in breakfast in South East Asian countries and has also been introduced as breakfast food (Brokington 1967) in US. Popped rice, on the other hand, is not as popular as puffed rice in breakfast due to its reduced crispiness and lack of information about its nutritional values but generally consumed during sacred ceremony viz. worship, wedding etc. (Bagchi et al. 2016). Beaten rice, though very popular among economically disadvantageous classes of people of India, but several types of crispy foods of beaten rice can be prepared in combination with fried groundnut and pulses. Boiled rice, the most popular edible form of rice than other products, is mainly preferred in lunch and dinner as a staple. It is prepared from polished rice, parboiled rice or brown rice through boiling with water followed by draining of excess water, pressure cooker or ohmic heating method. Recently, black rice has received much attention to the consumers due to its higher fibre, mineral, amino acid, vitamin content and antioxidant capacity as compared to white rice (Bordiga et al. 2014). Thus, physico-chemical and cooking properties of black rice and their different products were examined in the present study.

Table 4 Colour differentiation and antioxidant capacity of black rice products

		L	a*	b*	ΔE	DPPH (% inhibition)	Anthocyanin content (mg/100 g)
Boiled rice	CH	26.08^U	3.68^E	4.89^S	26.78^V	70.77^E	1.31^R
	KB	40.12^T	0.14^N	6.85^Q	40.71^U	81.49^C	3.93^M
	MA	48.36^N	1.55^I	8.49^MN	49.13^O	84.74^B	0.84^ST
	MN	53.32^L	0.01^O	6.58^R	53.78^M	72.07^D	3.35^N
	SW	55.76^I	0.12^N	7.74^O	56.41^L	50.32^H	0.21^V
Beaten rice	CH	43.98^R	1.12^K	8.65^M	44.84^S	21.73^N	33.09^C
	KB	43.78^R	1.58^I	11.00^J	45.19^S	12.08^P	31.67^E
	MA	56.11^H	2.69^G	13.36^G	57.72^J	66.47^F	16.72^I
	MN	42.99^S	1.08^KL	10.65^KL	44.22^T	22.32^N	22.78^G
	SW	50.17^M	1.46^J	15.25^E	52.45^N	11.59^P	2.74^O
Popped rice	CH	61.45^E	0.03^O	11.23^I	62.76^F	52.32^G	16.01^J
	KB	67.66^B	0.15^N	15.27^E	69.26^C	42.38^J	31.93^D
	MA	58.16^G	0.11^N	10.55^L	59.12^H	88.74^A	4.30^L
	MN	45.44^Q	0.18^N	10.81^K	46.80^R	32.45^L	5.83^K
	SW	66.53^C	0.02^O	10.82^K	67.40^D	27.24^M	1.63^Q
Puffed rice	CH	54.06^J	5.33^B	16.83^D	56.87^K	47.91^I	1.00^S
	KB	46.00^P	3.68^E	11.42^H	47.55^PQ	50.12^H	17.62^H
	MA	53.76^K	6.61^A	19.53^C	57.58^J	41.03^JK	1.91^P
	MN	60.22^F	4.33^D	22.89^B	64.57^E	42.50^J	0.44^U
	SW	64.81^D	4.55^C	24.44^A	69.77^B	37.34^K	0.41^U
Raw rice	CH	57.95^G	0.46^M	8.44^N	58.52^I	38.78^K	23.18^F
	KB	46.85^O	1.01^L	6.53^R	47.26^Q	51.37^H	57.23^A
	MA	47.05^O	2.79^F	7.13^P	47.69^P	90.53^A	34.27^B
	MN	71.97^A	1.68^H	13.36^G	73.22^A	20.81^N	3.50^N
	SW	58.24^G	0.13^N	13.96^F	59.92^G	15.61^O	0.82^T
p value		< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Tukey HSD at 5%		0.2991	0.0766	0.1774	0.4221	0.3145	0.1734

The group letters indicate higher to lower values and significant variation among the values at 5% level. *CH* Chakha, *KB* Kalobhat, *MA* Mamihunger, *MN* Manipuri black, *SW* Swarna sub-1

L is the measure of brightness from black (0) to white (100); a* indicates red to green color with positive a* values i.e. redness and negative a* values i.e. greenness; b* indicates yellow to blue colour with positive b* values yellowness and negative b* values blueness

ΔE signifies total colour difference

Physicochemical properties of black rice and their products

HRR of a cultivar, which depends on genotype, stage of harvesting, orientation of the starch granules, physical quality, storage and moisture content of the grains, is directly related to profitability and considered a major factor for acceptance to the farmers. In the present study, the observed reduced HRR associated with black rice over white rice was in well agreement with the observation of Sanghamitra et al. (2017). Kernel length and breadth of black rice were very similar to popular white rice variety *SW*, while cooking quality of *MA* was better than *SW*. However, black rice cultivars are generally sticky after cooking for their lower amylose content (below 20%). Accordingly, they are referred as waxy rice (Juliano 1985) and not usually preferred in lunch and dinner amongst the people of South East Asian Countries. Thus black rice, similar to waxy rice, can find its use for making some special type of sweet dishes. However, among the black rice cultivars tested in the present study, higher hulling (76.33%), HRR (50.67%), AC (17.6%), KLAC (10.10 mm) and ER (1.87) and lower GC(66.00 mm) of *MA* were comparable with the report of Sanghamitra et al. (2018). Mahanta et al. (2012) reported the lower AC (2.2 to 2.9%), very soft GC (144 mm and 119 mm) and higher ER (3.3 and 4.3) for the pigmented rice *Poreiton chakhao* and *Chak-hao-amubi*. Thus, *MA* seems to possess almost all the

Table 5 Physical properties of black rice products (SW as a control)

	Cultivar	VER	ER	L (mm)	B (mm)	T (mm)	Loose BD	Packed BD
	CH	14.21 ± 0.15	1.81 ± 0.18	10.05 ± 0.09	5.69 ± 0.59	ND	0.09 ± 0.21	0.09 ± 0.14
Popped rice	KB	17.82 ± 0.20	1.93 ± 0.22	10.12 ± 0.23	5.21 ± 0.72	ND	0.10 ± 0.23	0.11 ± 0.17
	MA	16.88 ± 0.12	2.01 ± 0.18	10.83 ± 0.23	4.88 ± 0.59	ND	0.08 ± 0.24	0.09 ± 0.14
	MN	14.02 ± 0.05	1.84 ± 0.28	10.5 ± 0.10	5.59 ± 0.12	ND	0.11 ± 0.14	0.12 ± 0.08
	SW	18.61 ± 0.19	1.91 ± 0.03	9.86 ± 0.82	8.57 ± 0.45	ND	0.07 ± 0.15	0.08 ± 0.09
	CH	3.12 ± 0.05	1.37 ± 0.14	7.61 ± 0.52	2.85 ± 0.06	ND	0.26 ± 0.09	0.27 ± 0.14
Puffed rice	KB	3.28 ± 0.08	1.23 ± 0.04	6.42 ± 0.06	2.95 ± 0.21	ND	0.23 ± 0.06	0.24 ± 0.09
	MA	4.22 ± 0.10	1.22 ± 0.06	6.61 ± 0.08	2.95 ± 0.02	ND	0.38 ± 0.14	0.39 ± 0.20
	MN	3.85 ± 0.09	1.09 ± 0.12	6.26 ± 0.06	2.67 ± 0.30	ND	0.35 ± 0.12	0.36 ± 0.12
	SW	3.53 ± 0.12	1.03 ± 0.17	5.29 ± 0.37	2.58 ± 0.11	ND	0.44 ± 0.08	0.46 ± 0.15
	CH	0.89 ± 0.12	1.95 ± 0.15	10.85 ± 0.21	5.60 ± 0.25	0.71 ± 0.06	0.33 ± 0.14	0.35 ± 0.12
Beaten rice	KB	0.84 ± 0.24	2.01 ± 0.16	10.50 ± 0.10	5.56 ± 0.52	0.59 ± 0.04	0.38 ± 0.16	0.40 ± 0.12
	MA	0.92 ± 0.16	1.99 ± 0.14	10.73 ± 0.09	4.81 ± 0.41	0.66 ± 0.04	0.36 ± 0.13	0.40 ± 0.08
	MN	0.76 ± 0.13	1.79 ± 0.05	10.23 ± 0.15	6.29 ± 1.55	0.76 ± 0.22	0.29 ± 0.21	0.34 ± 0.14
	SW	0.72 ± 0.23	1.79 ± 0.08	9.23 ± 0.06	4.45 ± 0.28	0.78 ± 0.08	0.39 ± 0.14	0.42 ± 0.05

ER elongation ratio, *VER* volume expansion ratio, *L* length (mm), *B* breadth (mm), *T* thickness (mm), *Loose BD* loose bulk density, *Packed BD* packed bulk density; *ND* not detected

desirable traits of a good rice cultivar with respect to physical, chemical and sensory qualities of the grain.

Preference study of rice products among diverse groups of people

Many snack foods, which includes popcorn, popped and puffed rice, popped sorghum and wheat, roasted and puffed legumes, though very popular worldwide (Jaybhaye et al. 2014),but boiled rice is usually consumed among all the groups of people while popped rice is least acceptable due to its bulkiness and lesser crispiness. Indian teenagers and people of old age occasionally prefer to consume the dry rice products such as popped, puffed and beaten rice. The middle and poor class Indian female usually consume these dry rice products better than male because of their engagement in domestic work and have enough leisure to consume it at breakfast. The people of eastern part of India, particularly, Odisha favours rice at every meal. Cold rice, puffed rice (*mudhi*), or various types of rice cake (*pitha*) are eaten with molasses or salt, and tea (Oriya 2018) in breakfast. The females of Eastern India are usually involved in the preparation of different delicious products from these primary products. During winter season, the people of Bengal are experienced with a special aromatic sweet known as 'Joynagar er moa' prepared from popped rice, which in turn, derived from the folk rice cultivar *Kanakchur* grown in South 24 Parganas, West Bengal, India (De 2014). However, the rich people prefer these products occasionally.

Textural parameters

Textural properties of the rice products varied significantly according to the genotypes and processing techniques. Yu et al. (2009) pointed out that amylose content determines the hardness of cooked rice. The rice grains with higher amylose content are normally less sticky after cooking and hard on cooling (Mutters and Thompson 2009). Thus, boiled rice of *KB*, which contains low amylose, was very soft. The hardness of beaten rice that results from pressing the partially gelatinised paddy with consequent compression of the starch chain is greater than popped and puffed rice. Kumar and Prasad (2018) reported that hardness arises from different arrangement of starch granules in different products, as evident from SEM micrograph and is lower with flaked/beaten rice (213.27 N) than with brown and roasted rice (273.07 N). Moreover, lower hardness of flaked rice (also known as beaten rice) than raw rice results from breakdown of protein-starch matrix (Corre et al. 2007) that arises during flaking process. The boiled rice in contrast to all other products showed greater adhesiveness due to its gelatinization of starch, mediated by hydrothermal process. This finding was in accordance with an earlier report (Singh et al. 2014). On the other hand, cohesiveness that results from the strength of internal bonds in the samples was higher with boiled rice than others due to its gelatinization properties. In a study, cohesiveness of cooked rice of 23 Indian rice cultivars was reported to vary from 40 to 220 N (Singh et al. 2005). The present study demonstrated relatively lower values of cohesiveness that appears to be related to genotypes. Springiness, that defines the ability of deformed sample to return to its original size and shape, was higher with popped rice as compared to boiled white rice of *KDML105* (0.245) and *Sao Hai*I (0.314; Jittanit et al. 2017). Thus, it appears that starch granules, that has been disrupted due to thermal degradation leading to deformed shape and bulky volume in popped rice reorient themselves to their native form. Chewiness, a measure of the energy needed to chew a solid food until ready for swallowing, varied widely and significantly between 0.55 and 22.43 N while the corresponding value in boiled rice ranged from 5.99 to 11.65 N (Jittanit et al. 2017). It was noticed that, boiled white rice *SW* with higher amylose content showed higher value of chewiness.

Evaluation of black rice products through colour parameters

In popped rice, the starch granules, which are blown up into a film generally have a honeycomb structure because of the expansion not only of endosperm but also of aleurone layer and germ (Bhattacharya and Murugesan 1989). Therefore, the average whiteness value of popped rice was greater than that of other products and it was varied significantly depending on the cultivars and their products. The similar results were obtained by the earlier researchers (Singh et al. 2014; Kaur et al. 2018) who observed the L value of milled rice ranged from 68.0 to 76.2 in different genotypes. The puffed rice with reddish brown coloured external layer had higher positive a* and b* values for redness and yellowness respectively. The total colour difference (ΔE) was higher in raw rice than other products and results from hydrothermal transformation/translocation of the pigment molecules, primarily anthocyanin at the time of product preparation (Hua et al. 2016). The higher L values were reported for expanded rice by Ahmad et al. (2014). The colour parameters L* and b* were positively and a* was negatively related to antioxidant capacity (Bao et al. 2009). Thus, here the popped and boiled rice with their lower a* values displayed higher antioxidant capacity.

DPPH radical scavenging activity and anthocyanin content

Antioxidant capacity of a product depends on presence and contents of a diverse array of hydrophilic or hydrophobic compounds including phenolic acids, γ-oryzanol, vitamin-E, anthocyanin and flavonoid in the grains. Shen et al. (2009) reported that the mean flavonoid content of black rice (240 mg RE/100 g) was higher than red rice (147.2 mg RE/100 g) and white rice (131.6 mg RE/100 g). However, flavonoids, owing to its heat instability, were destroyed due to thermal treatment during the puffing process, which was in accordance with the report of Gujral et al. (2011) who observed a 49.9% decrease in total flavonoids in oat during roasting. It was reported that, nutritional value of pigmented rice was greater than conventional white rice because of its enhanced level of antioxidants (Mahanta et al. 2012). In our study, higher antioxidant capacity was also observed in boiled and popped rice of black rice cultivars. Antioxidant activity of phenolics, ascorbate, tocopherol etc., in general, is related to their ability to donate hydrogen atom to stable DPPH radical. The higher antioxidant activity of popped rice appears to be associated with enhanced surface area and greater exposure of antioxidants to DPPH radicals. The higher DPPH activity of boiled rice resulted from release of a large number of antioxidative compounds via hydrothermal process. Interestingly, boiled pigmented rice contained lower anthocyanin because of washing of pigments during draining of excess water. Zaupa et al. (2015) pointed out that total anthocyanin content of pigmented rice was reduced by 64.2% in boiled rice as compared to raw rice. Therefore, the higher antioxidative property associated with boiled rice seems to result from antioxidative compounds other than anthocyanin components. The higher anthocyanin content in milled raw rice was related to existence of little bran layers to the endosperm.

Physical nature of rice products

The storage, handling and packing of the products are important parameters for food industry and depend on physical properties of the rice products. Popped rice registers a very higher VER as compared to other products. Bagchi et al. (2016) observed that the VER of popped rice ranged between 8.97 and 23.34 depending on the genotypes. Popped and beaten rice have higher KER than puffed rice due to their higher length and breadth after processing. Loose and packed bulk density of beaten rice were higher because of their negative correlation with VER.

Conclusion

The nutritional, brightness (L*) and textural (lower adhesiveness, cohesiveness and chewiness) properties of popped black rice were comparable to boiled black rice and greater than white rice. The anthocyanin content was highest with raw black rice followed by beaten rice and least in boiled rice. Moreover, people prefer to consume boiled rice rather than other products. However, black rice *MA* with appreciable HRR (50.67%), AC (17.6%) and KLAC (10.10 mm) appears to be promising with respect to nutritional, physicochemical and product making quality.

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