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Assessment of physicochemical, functional and nutritional properties of raw and traditional popped rice

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Popped rice is a common, chip and nutritious breakfast item widely consumed in India. We analyzed functional, physico-chemical and nutritional properties of raw rice (RR) and popped rice (PR) of some Indian rice cultivars (*Kalabhat, Banskathi, JP-73, Kabirajsal, Dehradun Gandheswari*). RR of *Kabirajisal* showed better physical grain quality among all whereas *Banskathi* and *Dehradun gandheswari* was found to be better with respect to physical quality of popped rice. Amylose content (AC), phytic acid content (PA) and total antioxidant capacity were also higher in both RR and PR of *Banskathi*. *In vitro* starch digestibility (IVSD) of RR was higher in *JP-73* followed by *Dehradun gandheswari* while in PR, it was higher in *Kalabhat*. Therefore, *Banskathi, Dehradun gandheswari* and *Kalabhat* are most suitable for popping. This study provides knowledge about different functional, physicochemical and nutritional properties of RR and PR and their relationship.

Keywords: Raw rice, Popped rice, Physicochemical properties, Functional properties, Starch granules

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Among the various value added products of rice, popped rice (PR) is one of the earliest known and highly popular snacks in India. It is generally consumed at the time of sacred ceremony like wedding, worship, etc. It is also a popular breakfast item of India as it is readily digestible and convenient to make several delicious preparations with minimum processing. Many traditional food items are prepared from PR, especially in the eastern part of India, having excellent sensory properties. Besides, PR powder can be used as a substitute of glucose in ORS formulation[1]. Popping of rice is performed by heating the kernel (intact rice grain without removing the hull) in sand at more than 177 ºC. This heat gradually vaporizes the water contained in the kernel which leads to gradual build up of vapor pressure. When the vapour pressure exceeds ~135 psi the kernel ruptures suddenly leading to kernel expansion by 6-8 times its original volume. The expanded state is then fixed by dehydration resulting from rapid diffusion of water vapor out of it. The popped product is to be maintained at about 3% moisture to retain the desired crispness. The popped rice is very porous, and, therefore, becomes very soft in a few seconds of wetting and hence can be consumed with milk or curd. Volume expansion is the most important quality parameter for popped rice. Wide varietal difference in volume expansion during popping of rice has been reported by many authors. Tightness of husk (lemma-palea) interlocking and grain hardness is positively and chalkiness is negatively correlated with popping[2]. Proper moisture content (14%) is known to govern expansion value as it creates the necessary vapour pressure inside the kernels immediately before popping. Moisture loss decreases popping performance, where as excess moisture produces low popped volume[3]. Unfortunately, unlike in maize where several physico-chemical properties of the kernel related to popping are well studied[4], not much is known, except the above mentioned few factors influencing poppability in rice. Generally the specialty rice types are native landraces or folk cultivars of India and PR are prepared from specific specialty rice cultivars. Consequently the objective of this research was (a) to evaluate the functional and physicochemical attributes of RR and PR of 5 Indian cultivars in order to identify the physico-chemical properties related to good poppability and (b) evaluate the nutritional parameters after making PR.

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Materials and methods

The 26 quality rice cultivars, mostly landraces of West Bengal were collected from the farmers and after making popped rice, 5 cultivars (*Kalabhat, Banskathi, JP-73, Kabirajsal and Dehradun Gandheswari*) were selected on the basis of sensory evaluation and their subsequent physicochemical and nutritional analysis was performed as follows. These cultivars were suitable for irrigated low land ecology and commonly cultivated in clay loam soil of *Indo-Gangatic* plain.

Raw rice (RR) and popped rice (PR) preparation

Rice grains were harvested at maturity and sundried naturally for further processing to grain moisture content of 12-13%. The dried grains were stored at 20 °C and <60% RH in a closed chamber for analysis of various physico-chemical qualities. Brown rice samples were prepared from rough rice through rice huller (Satake Corporation, Japan) and subsequently polished rice was prepared by rice miller (Satake Corporation, Japan) with 10% polishing of brown rice. For making popped paddy, rough rice was put into heated sand (>177 ºC) in an iron pan for 40-50 seconds with continuous stirring. Almost all the husk was separated from popped kernel, which was already detached during heating (Fig.1).

Physical characteristics of rice kernels

The rough rice was dehulled and the brown rice, obtained was polished for 60 seconds. Milled rice out-turn was expressed as per cent of milled rice. The digital image analyzer (*Annadarpan*, India) was used for measurement of grain length, breadth, L/B ratio in case of both grain and popped paddy.

Determination of hundred grain weight for RR and PR

A hundred grain weight of randomly selected rice kernels and PR was determined using an automatic grain counter and afterwards the analytical balance.

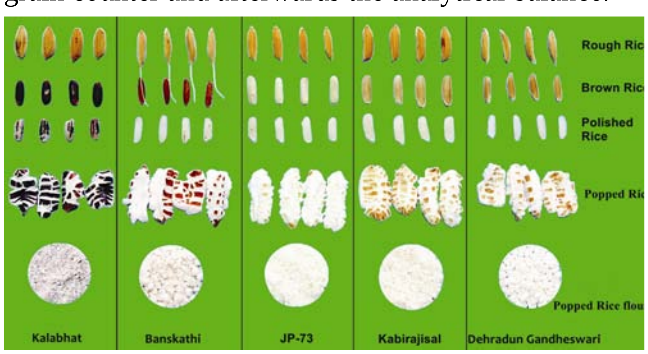

Fig. 1—Morphology of different processed products of five rice cultivars.

Determination of loose and packed bulk densities of PRF

A measuring cylinder (100 mL) was filled with the sample to the 100 mL mark and the weight was obtained with a digital weighing balance. Loose and packed bulk densities of the PR flour were determined, but packed density was with additional tapping (x 50) of the edge of the work bench prior to re-weighing. The densities were calculated as the ratio of the bulk weight to the volume (gm/mL).

Determination of water (WAC) and oil (OAC) absorption capacities of PRF

One gram of sample was suspended in 10 mL distilled water (or refined rice bran oil) in a weighed centrifuge tube. The suspension was vortexed three times and 10 min rest periods were allowed between each mixing. This suspension was centrifuged at 2000x gm for 30 min and the supernatant was decanted, and the tubes were air-dried. The bound water was calculated from the increase in the weight of the samples. Water (or oil) absorption capacity was expressed as percentage of water (or oil) adsorbed by 100 gm of sample.

Determination of swelling power, solubility, foam capacity and foam stability of PRF

PRF-water slurry (0.35 gm in 12.5 mL distilled water) was heated in a water bath at 60 ºC for 30 min with constant agitation. After centrifugation at 3500 x gm for 20 min, the supernatant was decanted in pre weighed evaporating dish and dried at 100 ºC for 20 min. The difference in weight of the evaporating dish was used to calculate the solubility. Swelling power was calculated by weighing the residue after centrifugation and dividing by the original weight of the flour[5]. Foam capacity and foam stability were determined by the standard methods.

Popping percentage of PR

Hundred rough rice grains were popped by the above mentioned method and number of popped grain was measured. The percentage of popping was calculated.

Length and breadth elongation ratio and volume expansion ratio (VER) of PR

Length (L) and breadth (B) of randomly selected 100 unbroken milled rice grains and PRs grain were measured using a manual veneer caliper with accuracy of ±0.02 mm and the average length/breadth (L/B) ratio was calculated. Volume of PR was measured by the following formula: $V_{PR} = \pi r^2 h$ (r= radius of each PR, h= length). Volume of 30 PR for each cultivar was measured and average data was presented here.

Starch granule morphology

The starch was extracted from dehulled rice by alkali extraction with steeping in NaOH solution[6] (0.2%, 2 L). The starch obtained as sediment was dried in an air convection oven at 40 ^{0}C for 48 hrs. The dried starch was pulverized into a smooth flowing powder using the dry mill of the commercial blender. Light microscopy method[7] was used in assessing the morphology of rice starch samples under 20 X magnifications.

Chemical properties of raw grain and popped rice

The moisture content of rough rice was measured through digital moisture meter (Kett moisture meter, Japan).The total protein content was determined by taking ten brown rice sample in three replication and as described in the AOAC methodology (Kjeldahl digestion) using the formula N × 5.95.

Total soluble sugars

The total soluble sugar was measured by anthrone method.

Phytic acid content (PAC)

PAC of brown rice was estimated using wade reagent (0.03% $FeCl_3$, $6H_20$+0.3% Sulpho- salicylic acid)[8]. Standard curve was prepared by sodium phytate so that the blank OD will be 0.453$\pm$ 0.002. PAC can be determined through standard curve.

In vitro starch digestibility (IVSD)

It was measured with some modifications of previous one[9]. About 0.1 gm of ground sample (100 mesh sheaving) was weighted and mixed with 10 ml KCl-HCl buffer (*p*H 1.5) and incubate for 10 min. After adding 0.1 ml pepsin solution (1% W/V in KCl- HCl buffer) it was shaken at 40 °C for one hour. After cooling at room temperature, 9 ml phosphate buffer (*p*H 6.9) was added. 1ml porcine α-amylase (Sigma A3176 Type VI-B) solution (4%) was also added in it and it was shaken for one hour at 37 °C. Then after centrifugation (4000 rpm), supernatant was kept separately and 10ml 2M HCL solution was added to the remaining digesta. 4 ml amyloglucosidase (Sigma) solution (0.833 µL in 4 ml Na-acetate buffer *p*H 4.75) was added with it and left for 45 min at 60 °C with shaking (100 rpm). After centrifugation, supernatant was separated and both the supernatants were tested for a total soluble sugar (TSS) by previously described anthrone method and result was expressed as mg TSS/gm sample.

Antioxidant capacity by ABTS

ABTS radical scavenging assay was performed through modified protocol of the previous[10]. The antioxidant capacity was expressed as ascorbic acid equivalent/gm.

Statistical analysis

All the analysis was performed using SAS 9.3 Software and MS-Excel. The data were presented as mean of three replications. Pearson's correlation coefficient (PROC CORR of SAS) was used to measure strength and direction of the linear relationship between any two quantitative variables.

Results and discussion

Physical properties of RR and PR

In order to understand the influence of different physical properties of RR in popping we studied parameters like hulling, milling, HRR, Kernel length, breadth, 100-kernel weight and length-breadth (L/B) ratio of the milled RR obtained from various cultivars. The varieties under study differed from each other significantly in all the parameters (Table 1). For example, *Kabirajisal* showed the highest Hulling, milling and HRR (76.5%, 65% and 60% respectively) while *JP-73* had the lowest (72%, 60% and 40%). Grain weight is a very important parameter in case of cereal crops from the evolutionary perspective. Large grain type was preferentially selected during early domestication[11]. Among the different cultivars, 100 RR grain wt of *Kabirajisal* was observed to be highest (2.49 gm), followed by *Kalabhat* (1.95 gm) and *JP-73* (1.94 gm), whereas *Banskathi* had the lowest (1.56 gm). L/B ratio was observed to be highest for *Dehradun Gandheswari* (4.36) and categorized as long slender (LS) type but highest length and breadth was observed in *Kabirajisal* (7.99 mm and 2.19 mm). Moisture content of rough rice is an important factor which should be maintained at 12-14% to obtain optimum HRR and for good popping[12]. Moisture content of raw paddy was highest (12.71%) in *Dehradun Gandheswari* and lowest (12.01%) in *JP-73*. All the cultivars showed better results with respect to hulling, milling, HRR, length and breadth as compared to previous

Table 1— Physical properties of Raw Rice (RR) and Popped Rice (PR). All the values are means of three replications. All the grains are long slender type (LS) except *kalabhat* (i.e. short slender type).

Cultivers		Hulling (%)	Milling (%)	HRR (%)	Moisture (%)	Length /mm	Breadth /mm	L/B	100 kernel Wt (g)	Loose BD (g/ml	Packed BD (g/ml	Popping %
Kalabhat	RR	73.67^{B}	63.67^{B}	53.33^{B}	12.25^{C}	6.75^{B}	2.21^{A}	3.06^{D}	1.95^{B}	0.67^{C}	0.81^{A}	ND
Banskathi	RR	74.67^{B}	62.00^{C}	54.00^{B}	12.31^{B}	7.06A^{B}	1.67^{BC}	4.22^{AB}	1.56^{C}	0.72^{A}	0.77^{B}	ND
JP-73	RR	72.00^{C}	60.00^{D}	40.00^{D}	12.01^{E}	7.02^{B}	1.90^{B}	3.70^{BC}	1.94^{B}	0.69^{B}	0.74^{C}	ND
Kabirajisal	RR	76.50^{A}	65.00^{A}	60.50^{A}	12.07^{D}	7.99^{A}	2.19^{A}	3.65^{C}	2.49^{A}	0.67^{CD}	0.69^{D}	ND
Dehradun Gandheswari	RR	74.50^{B}	60.50^{D}	46.50^{C}	12.71^{A}	6.80^{B}	1.53^{C}	4.36^{A}	1.63^{BC}	0.67^{D}	0.74^{C}	ND
p-Value		<.0001	<.0001	<.0001	<.0001	0.008	0.0001	0.0003	0.0002	<.0001	<.0001	ND
Tukey HSD$_{.05}$		1.0925	0.7283	0.7283	0	0.942	0.252	0.564		0.0065	0.0025	
Kalabhat	PR	ND	ND	ND	12.12^{C}	10.80^{D}	6.40^{BC}	1.63^{D}	1.87^{B}	0.06^{A}	0.24^{A}	98.37^{A}
Banskathi	PR	ND	ND	ND	12.21^{B}	12.07^{B}	7.33^{A}	1.64^{C}	1.48^{C}	0.04^{B}	0.12^{BC}	97.50^{A}
JP-73	PR	ND	ND	ND	11.94^{E}	13.03^{A}	6.00^{C}	2.15^{A}	1.92^{B}	0.03^{B}	0.10^{CD}	99.33^{A}
Kabirajisal	PR	ND	ND	ND	12.01^{D}	11.40^{C}	6.80^{B}	1.67^{CD}	2.45^{A}	0.03^{B}	0.13^{B}	99.53^{A}
Dehradun Gandheswari	PR	ND	ND	ND	12.60^{A}	12.50^{B}	6.47^{B}	1.94^{B}	1.53^{C}	0.03^{B}	0.09^{D}	97.70^{A}
p-Value		ND	ND	ND	<.0001	<.0001	<.0001	<.0001	<.0001	0.0002	<.0001	0.0267
Tukey HSD 5%		ND	ND	ND	0.0638	0.502	0.4055	0.0415	0.1005	0.0107	0.0189	2.0347

*L/B= Length breadth ratio; HRR= Head rice recovery; *Popping % of RR is not possible as popping is related with rough rice (paddy).BD= Bulk Density. *Hulling, Milling and HRR are not possible for PP.

workers[13]. The highest LBD (0.72 gm/ml) of RR was observed from *Banskathi* but highest PBD (0.81gm/ml) was found from *Kalabhat*. Falade *et al*., (2015) reported the LBD of two African cultivars was varied between 0.23 gm/mL to 0.32 gm/ mL and the packed bulk density was 0.41 gm/mL to 0.33 gm/mL, respectively.

In case of PR, significant difference was observed in terms of length, breadth, L/B ratio, 100 kernel weight, loose BD packed BD and popping percentage (Table 1). The moisture content of PR was little lower than RR and varied between 11.94 to 12.6%, which suggest release of some water from raw rice during popping. This might be because of the escape of water contained inside the rice kernel which is transformed into vapor due to heating and get released by rupturing the kernel during popping. Highest length (13.03 mm) of PR was observed from *JP-73* followed by *Dehradun Gandheswari* (12.50 mm) whereas highest (7.33 mm) breadth was found in *Banskathi*. LBD and PBD of the PR from different cultivars were found to range between 0.003 to 0.006 gm/ml and 0.10 to 0.24 gm/ml, respectively. *JP-73* showed the lowest loose and packed BD (0.03 and 0.10 gm/ml, respectively), whereas *Kalabhat* had the highest (0.06 and 0.24 gm/ml, respectively). The highest PBD of *Kalabhat* could be due to its lowest L/B ratio (1.63); the more round the grain, less the porosity and higher compactness represented by the PBD. Consequently, *JP-73* and *Dehradun Gandheswari* with the lower packed bulk density would require larger storage space and invariably more storage costs per weight than *Kalabhat*. In this study, LBD and PBD of PR were lower as compared to others because of reorientation of the starch granules of endosperm. In case of PR, mechanical extrusion of heated starch takes place due to escaping steam leads to disruption (i.e. gelatinization) of starch granules. Thermal degradation of starch has also been shown to occur during popping. Therefore, LBD and PBD of PR flour are lower as compared to RR starch. However, bulk density is an essential requirement in determining packaging and material handling in the food industry. The better popping quality of rice is positively correlated with lower BD of popped rice though other factors are also important[14]. The 100 PR weight was varied between 1.48 - 2.45 gm and *Kabirajisal* showed the highest whereas *Banskathi* showed the lowest. The popping % did not vary significantly and ranged from 97.5 - 99.53%.

Functional properties of RR and PR

Oil absorption capacities (OAC), Water absorption capacities (WAC), Solubility, Swelling power, VER, ASV, Foam capacity, Foam Stability and Popping % of PR were considered as functional properties and presented in Table 2. VER of PR from the different cultivars significantly varied from 8.97 to 23.34

Table 2—Functional Properties of Popped Rice (PR). All the values are means of three replications. VER= Volume expansion ratio, ER=Elongation ratio, ASV=Alkali spreading value, WU= water uptake, OAC=Oil absorption capacity, WAC=Water absorption capacity.

Cultivers		VER	ER	ASV	OAC	WAC	Solubility (%)	Swelling power	Foam capacity	Foam Stability
Kalabhat	PR	8.97^{E}	1.60^{BC}	7.00	627.67^{E}	258.65^{E}	32.85^{A}	6.43^{C}	0.12^{C}	0.24^{C}
Banskathi	PR	20.33^{C}	1.71^{AB}	7.00	958.21^{A}	760.20^{B}	6.57^{D}	6.59^{BC}	0.25^{B}	0.53^{B}
JP-73	PR	18.89^{D}	1.86^{A}	7.00	924.39^{B}	571.97^{C}	11.42^{C}	7.75^{A}	0.13^{C}	0.25^{C}
Kabirajisal	PR	22.22^{B}	1.43^{C}	6.89	887.53^{D}	539.73^{D}	17.42^{B}	6.74^{B}	0.12^{C}	0.52^{B}
Dehradun Gandheswari	PR	23.34^{A}	1.88^{A}	7.00	902.53^{C}	927.79^{A}	3.14^{E}	7.82^{A}	0.38^{A}	0.76^{A}
p-Value		<.0001	0.0001	0.080	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Tukey HSD 5%		1.4893	0.1755	NS	8.7693	2.0439	0.0089	0.1844	0.0133	0.0863

($HSD_{0.05}$= 1.489). ***Dehradun Gandheswari*** had the highest VER (23.34), followed by the cultivar ***Kabirajisal*** (22.22). ***Kalabhat*** showed the lowest VER (8.97). It was also reported 2 - 16.2 VER of different Indian PR cultivars[2]. The ER of these PR cultivars ranges from 1.43 - 1.88 and significantly varied ($HSD_{0.05}$= 0.1755) among the cultivars. The ER of PR depends on kernel length of RR and this was well agreement with our result. The ASV did not vary significantly among the cultivars and ranged from 6.85 - 7. It indicated that the kernel became very soft due to destruction of granular structure of starch under popping. The WACs of PR flour at room temperature (30 ºC) varied between 258.65 - 927.79 % and ***Dehradun gandheswari*** ranked first followed by ***Banskathi***. The previous worker reported that the WACs of the rice flours at 25 ºC ranged from 122.64 - 143.35%[15]. As the WAC depends upon polar groups[16], here also WAC had a positive correlation with amylose content (AC) and phytic acid (PA) content but negative correlation with protein content of RR. The scanning electron micrograph of PR showed that the starch granules were blown up into a film arranged in a honeycomb structure resulting expansion of the endosperm and consequently a large numbers of void space were formed into the endosperm. Therefore, many water molecules make different associative forces like H-bond and covalent bond with polar groups of starch chains, proteins and PA of PR flours. The OAC of the PR flours, a reflection of their emulsifying capabilities in product formulations, ranged from 627.67% - 958.21% and significantly ($p<0.0001$) varied among cultivars. ***Banskathi*** showed the highest and ***Kalabhat*** showed the lowest. The OAC is an important parameter since oil acts as flavor retainer and increases the mouth feel of foods[17]. Variations in the presence of non-polar side chains, which might bind the hydrocarbon side chains of oil among the flours, explain differences in the oil binding[16]. In our study, OAC had positive correlation with AC but negative correlation with PC and TSS. It can also be explained by the formation of void space in the endosperms of PR and some hydrophobic interaction. In other way, as the size of the starch granules of PR was higher than RR, the oil retention capacity of PR flour was also higher due to destruction of orientation of starch chains. However, in case of RR flour it was varied between 59.97% (*Faro 46*) to 72.98% (*Faro 40*)[13]. The solubility of PR flour was varied between 3.14 - 32.85 %; highest from ***Kalabhat*** and lowest from ***Dehradun gandheswari***. Solubility indicates the ability of solids to dissolve or disperse in an aqueous solution. Generally, starches with smaller granular size have lower solubility[18]. In contrast, the PR flour of ***Kalabhat*** contains smallest starch granules as compared to others and solubility was higher. There was negative correlation (r= -0.901) between AC and solubility. However, it was reported that solubility of the TGS 25 and TGS 3 was 5.72% and 8.24%, respectively in case of RR starch[19]. In fact, popped rice flour was more soluble in water than brown rice flour at all temperatures and consequently higher solubility was observed in all cultivars. Swelling power, the ability of the starch to hydrate under specific temperature, varied from 6.43 - 7.82 .Greater swelling capacity is an indication of weaker binding forces in the starch granules[20]. But there was very poor correlation between AC and swelling power. However, it was negatively correlated with PC and positively correlated with α-amylase digestability. Foaming capacity of PR flour of different cultivars ranged from 0.12 - 0.38 ml/gm while the foam stability after 1 hr varied from 0.24 - 0.76 ml/gm. Foam capacity and stability show the ability of starch to rapidly adsorb on the air liquid interface during whipping or bubbling and by its ability to form a cohesive visco-elastic film by way of intermolecular interactions. Foam capacity or foam stability showed the positive correlation with PA content.

Chemical and nutritional compositions of RR and PR

Amylose content of RR of different cultivars significantly (p<0.0001) varied from 5.32 - 26.58 % and the cultivar *Banskathi* showed the highest AC while lowest AC was recorded from *Kalabhat* (**Table** 3). In PR almost similar trend was observed as in RR. The AC of PR varied between 3.99 - 23.94% and *Dehradun Gandheswari* showed the highest whereas *Kalabhat* showed lowest. Most consumers prefer rice with intermediate AC ranged between 20-25%[21]. Some traditional medicinal rice of South India namely *Veeradangan, Kavuni, Navara* and *Kathanellu* also posses 20.12 to 27.19 % amylose[22]. Rice were categorized based on their amylose content into waxy (0 - 2%), very low (3 - 9%), intermediate (20 - 25%) and high (>25%). Juliano reported that rice with higher amylose content tended to have a hard texture, while rice with lower amylose content tended to have a softer texture. The longer amylopectin chains and higher amylose content could provide a favorable milieu for inter or intra-molecular interactions of starch with other components, such as protein and lipids resulting hardness of the grain. On the other hand, lower AC may inhibit this interaction and softness of grain is created. The cultivar *Banskathi* showed high AC (>25%) while *JP-73, Kabirajisal, Dehradun gandheswari* showed intermediate (20 - 25) amylose. Difference in AC of the rice cultivars could be due to various factors such as genotype, environmental conditions, and cultural practice, and is also affected by the ecological conditions and soil type during plant growth. AC also plays a key role in the digestion of starches, as starches with low amylose content digests easily than that of high amylose content. However, it was showed that contents of total and hot-water-insoluble amylose and protein had no relation to popping expansion[2] but lower AC of rice were significantly associated with better popping quality[14]. In our study, the positive correlation was observed between AC and VER of PR (Table 4). Therefore, it can be concluded that AC was not the sole determinant of good quality PR; some other factors are responsible for this.

Gel consistency (GC), the tendency of the cooked rice to harden after cooling, of the rice cultivars could be categorized as soft (61 – 100 mm) medium (41- 60 mm) and hard (25 - 40 mm). In this study, all the RR showed soft GC except *Banskathi* (39.67 mm), while the GC of PR ranged from 34 - 75mm and little hard consistency was observed from all the cultivars as compared to RR. In fact, GC is inversely proportional with AC, cooking time and gelatinization temperature. Therefore, GC is an important parameter

Table 3—Biochemical and nutritional compositions of Raw Rice (RR) and Popped Paddy (PP).

Cultivers		AC (%)	GC (mm)	PA (%)	PC (%)	TSS (mg/g)	Total Antioxidants (ppm AAE/g)	IVSD (mg TSS/g)
Kalabhat	RR	5.32^{D}	75.00^{A}	0.15^{D}	11.74^{A}	7.03^{A}	3147.19^{B}	79.50^{E}
Banskathi	RR	26.58^{A}	39.67^{B}	0.27^{A}	8.34^{C}	3.98^{B}	3167.55^{A}	96.02^{D}
JP-73	RR	21.15^{C}	71.33^{A}	0.16^{CD}	7.06^{D}	3.97^{B}	833.85^{D}	272.61^{A}
Kabirajisal	RR	22.38^{B}	75.00^{A}	0.17^{C}	8.75^{B}	3.24^{D}	739.09^{E}	123.13^{C}
Dehradun Gandheswari	RR	22.69^{B}	74.67^{A}	0.23^{B}	7.07^{D}	3.57^{C}	1093.26^{C}	221.41^{B}
p-Value		<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Tukey HSD 5%		1.0214	5.4502	0.0194	0.2533	0.3211	6.7426	4.3361
Kalabhat	PP	3.99^{C}	75.00^{A}	0.18	10.63^{A}	7.54^{A}	3078.61^{B}	104.14^{A}
Banskathi	PP	23.63^{AB}	58.33^{C}	0.8	9.01^{B}	3.57^{C}	3147.31^{A}	85.53^{B}
JP-73	PP	21.73^{B}	34.00^{E}	0.44	8.28^{C}	3.84^{BC}	1054.55^{D}	72.19^{D}
Kabirajisal	PP	23.59^{AB}	66.00^{B}	0.36	8.70^{BC}	3.52^{C}	1132.14^{C}	42.34^{E}
Dehradun Gandheswari	PP	23.94^{A}	45.67^{D}	0.48	7.06^{D}	3.97^{B}	838.90^{E}	76.39^{C}
p-Value		<.0001	<.0001	0.1444	<.0001	<.0001	<.0001	<.0001
Tukey HSD 5%		2.1093	3.1747	NS	0.7261	0.6811	5.5303	3.4536

AC= Apparent amylose content ; GC= Gel Consistency; PA= Phytic acid; PC= Crude Protein Content (N basis); TSS= Total soluble sugars *RR= Raw rice, PR=Popped rice, AC=Amylose content, GC=Gel consistency, PA=Phytic acid, PC= Protein content, TSS= Total soluble sugars, IVSD= In vitro starch digestibility.

Table 4—Pearson Correlation Coefficients (at 5% level) for physicochemical qualities of raw rice and popped paddy

Pearson Correlation Coefficients, N = 15
Prob > |r| under H0: Rho=0

	RR-AC	RR-GC	RR-PA	RR-PC	RR-TSS	RR-IVSD
PR-LooseBD	-0.80466	0.00663	-0.30362	0.90970	0.89427	-0.69708
	0.0003	0.9813	0.2713	<.0001	<.0001	0.0039
PR-OAC	0.98434	-0.45115	0.58527	-0.90028	-0.92085	0.47583
	<.0001	0.0914	0.0219	<.0001	<.0001	0.0730
PR-PackedBD	-0.91033	0.20835	-0.51144	0.98061	0.92339	-0.67168
	<.0001	0.4562	0.0513	<.0001	<.0001	0.0061
PR-Solubility	-0.90726	0.36984	-0.70163	0.93215	0.84006	-0.57129
	<.0001	0.1748	0.0036	<.0001	<.0001	0.0261
PR-Swelling	0.37017	0.34364	0.03566	-0.80579	-0.49348	0.96478
	0.1744	0.2098	0.8996	0.0003	0.0616	<.0001
PR-VER	0.88249	-0.61998	0.62630	-0.83013	-0.71887	0.46756
	<.0001	0.0137	0.0125	0.0001	0.0025	0.0788
PR-WAC	0.81774	-0.33237	0.78897	-0.81913	-0.75006	0.43051
	0.0002	0.2261	0.0005	0.0002	0.0013	0.1092
PR-breadth	0.42749	-0.74407	0.70877	0.08678	-0.22542	-0.65516
	0.1120	0.0015	0.0031	0.7584	0.4192	0.0080
PR-foamcap	0.43876	-0.21387	0.76552	-0.48005	-0.35692	0.21688
	0.1018	0.4441	0.0009	0.0701	0.1916	0.4375
PR-foamstability	0.60969	-0.13801	0.69021	-0.49528	-0.61923	0.07166
	0.0158	0.6238	0.0044	0.0605	0.0138	0.7997
PR-popping	-0.09708	0.47516	-0.62931	-0.00984	-0.13687	0.21955
	0.7307	0.0735	0.0119	0.9722	0.6267	0.4317

in respect of consumers' acceptance of rice. Some researchers observed that softer GC significantly associated with better popping of rice[14]. But, here we showed that GC had no correlation with popping expansion, which was well agreement with the observation of Bhattacharya *et al*.

Phytic acid content (PA) of different cultivars varied from 0.15 - 0.27% in their RR samples. The cultivar, ***Banskathi*** contains highest (0.27%) and ***Kalabhat*** contains lowest (0.15%) PA. Phytic acid is the major phosphorous storage compound in plant seed and can account for up to 80% of seed in total phosphorous. This is one of the main inhibitors of the availability of divalent cations such as Fe^{2+}, Ca^{2+}, Mg^{2+} and Zn^{2+}. The phosphate groups of phytic acid (***myo***-inositol hexaphosphoric acid) form stable complexes with such cations, thus preventing their bioavailability[23]. Therefore; PA is treated as an anti nutritional factor at certain level. In this study, the PA % of all the cultivars was very low (<0.5%) as compared to others study[24]. The PA content of PR was higher than RR and varied significantly from 0.18 - 0.8%. Higher PA in PR was due to disintegration of starch chain orientation and higher exposure of biomolecules to the extraction medium than in case of RR.

The protein content (PC) of RR was significantly varied from 7.07 - 11.74 % and ***Kalabhat*** showed the highest while lowest PC was found from ***Kabirajisal***. In PR also, the similar trend was observed and ranged from 7.06 - 10.63 %. The PC of Indian rice cultivars (brown rice) generally varied between 6-15% (fresh wt basis). In our study only ***Kalabhat*** could be considered as a high protein (>10%) cultivar but others were under medium range of protein. Protein is considered as a major nutritional component of rice and simultaneously many quality parameters of PR are significantly correlated with it. LBD, PBD and solubility of PR were positively correlated while OAC, WAC, Swelling power, VER were negatively correlated with PC of RR although, Bhattacharya *et al*. reported that peripheral protein of RR was unrelated with popping.

The total soluble sugars (TSS) of RR ranged between 3.24 mg/gm (***Kabirajisal)*** and 7.03 mg/gm (***Kalabhat)***. Higher TSS in ***Kalabhat*** could be due to its softness (very low AC and high GC). Almost similar trend was observed form PR also. The soluble sugar content of rice grain is minor; but, the soluble sugar pool may affect the color and flavor during cooking or processing. It was reported that the content of total soluble sugar in some genotypes was up to

2.27%[25]. Varietal differences exist in this trait when rice grain with normal starch composition is analyzed. Rice endosperm can accumulate soluble sugar late in grain fill after starch biosynthesis has decreased.

The total antioxidant capacity of RR was highest in *Banskathi* (3167.55 ppm AAE/gm) followed by *Kalabhat* (3147.19 ppm AAE/gm) and lowest was recorded from *Kabirajisal* (739.09 ppm AAE/gm). In case of PR, the antioxidant capacity did not affect negatively but in some cultivars higher antioxidant capacity was observed. We assayed this parameter with ABTS+ because it can be soluble in aqueous as well as in organic media and hence, antioxidant activity derived as resultant of both hydrophilic and lipophilic compounds in samples. In rice, phenolics, flavonoids, γ-oryzanol, tocopherol, tocotrianol and anthocyanines are responsible for total antioxidant capacity; among these some are hydrophilic and some are hydrophobic in nature. Generally coloured rice (red or black pericarp) contains higher amount of total antioxidants[26] and thus more nutritious[27]. Likewise, *Kalabhat* (black) and *Banskathi* (red) contain higher antioxidants as compared to others.

In vitro starch digestibility (IVSD) is the parameter through which we can get outline information regarding starch digestion as in the gastrointestinal system of us. Here two starch degradation enzymes were used to digest the samples. The α-amylase (EC 3.2.1.1) is endoenzyme that internally hydrolyze α-D-(1,4)-glycosidic linkages of both amylose and amylopectin yielding soluble oligosaccharides, and low molecular weight branched α-limit dextrins. However, amyloglucosidase (glucoamylase) (EC 3.2.1.3) is an exoenzyme, which depolymerizes both α-(1,4)-and α-(1,6)-glycosidic linkages of starch polymers from their non-reducing ends resulting in the complete conversion of starch into glucose[28]. The highest IVSD were recorded from *JP-73* (272.61 mg TSS/gm) followed by *Dehradun gandheswari*, whereas *Kalabhat* showed the lowest (79.5 mg TSS/gm) but in case of PR, higher IVSD was observed from *Kalabhat* (104.14 mg TSS/gm whereas others showed very less IVSD (ranged from 42.34 to 85.53 mg TSS/gm) as compared to RR. The amylopectin/amylose ratio and the amylose-lipid complexes affect the rate of hydrolysis. The extent of digestibility of starches generally decreases as the amylose content increases, although amylose content alone is not a sole predictor of digestibility[29]. Similarly, amylose complexed with lipid is more resistant to attack by hydrolytic enzymes than is free carbohydrate[30]. In *Kalabhat*, most probably the higher PC (11.74%) adversely affect the IVSD although it possessed lowest AC (5.32%) while in *Banskathi*, the IVSD was lower as it showed higher AC (26.58%) and medium PC (8.34%).

Morphological properties of RR and PR starches

The granule size (perimeter) of RR starches from different cultivars ranged between 18.44 and 20.00 µm and 19.21–20.35 µm for PR granules (Table 5; Fig. 2). Microscopic view of starch revealed that the granule surface of RR appeared smooth, polygonal and irregular-shaped, whereas in case of PR it was almost round shaped. *Kabirajisal* and *Dehradun gandheswari* RR starch showed the presence of a fairly large number of large-sized, polygonal granules, while the *Kalabhat* starch had little small-sized granules. The difference in the granule morphology may be attributed to the genetically origin, biochemistry of the amyloplast and physiology of the plant.

Table 5—Light microscopy of Particle size (µm) of Starch granules of RR and PP.

Cultivers		Width (µm)	Length (µm)	Perimeter (µm)
Kalabhat	RR	5.85	5.55	18.44
Banskathi	RR	6.20	5.58	19.25
JP-73	RR	5.85	5.67	19.23
Kabirajisal	RR	5.90	6.04	20.00
Dehradun Gandheswari	RR	5.89	5.83	19.51
Kalabhat	PP	5.17	5.19	19.21
Banskathi	PP	5.63	5.78	19.37
JP-73	PP	5.99	5.78	20.09
Kabirajisal	PP	5.53	5.89	19.41
Dehradun Gandheswari	PP	6.11	5.73	20.35
t-value		0.12	0.28	0.110

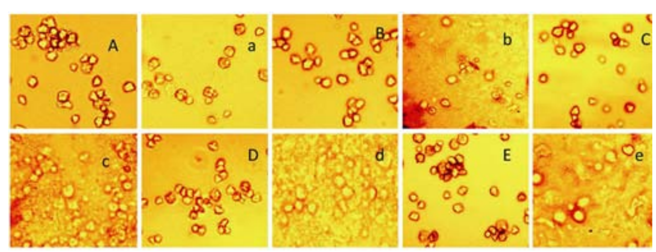

Fig. 2—Light microscopic view (40x) of Starch granules of Raw Rice (A,B,C,D,E) and Popped rice (a,b,c,d,e) of (A,a) *Kalabhat*, (B,b)*Banskathi*,(C,c), *JP-73*,(D,d) *Kabirajisal*, (E,e)*Dehradun Gandheswari.*

Conclusion

The best PR can be screened by two ways either by physicochemical properties or through nutritional parameters. The PR of *Dehradun gandheswari* showed higher VER, ER, ASV, Water absorption capacity (WAC), swelling power, foam capacity, foam stability and moderate length. Simultaneously, PR of *Kalabhat* showed higher protein content (PC), gel consistency (GC), total soluble sugars (TSS), antioxidant capacity and *in vitro* starch digestibility (IVSD). The starch granules of PR were bigger in size than RR starch. Amylose content has positive correlation with OAC, WAC and VER but negatively correlated with BDs and solubilities. IVSD of RR positively correlated with swelling power of PR only. TSS positively correlated with BDs and solubility and negatively correlated with OAC and VER of PR. Therefore, *Dehradun gandheswari* and *Kalabhat* are best for popping.

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