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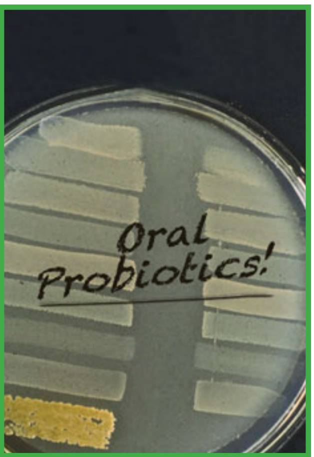

Product characterization and antioxidant potential of rice-based jamun (*Syzygium cumini* L.) powder-supplemented extruded snacks

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Abstract

Antioxidant enriched snacks prepared by supplementing rice flour with *jamun* powder were assessed for product quality and antioxidant activity. Rice flour was supplemented with 5, 10, 15 and 20 % hot air and freeze dried *jamun* powder for the preparation of the snacks. The quality parameters of extrudates, that is, the expansion ratio and water absorption index, decreased with increasing *jamun* powder supplementation levels, whereas bulk density (g/cm^3), hardness and water solubility increased. Sensory scores were found to be highest for 10% *jamun* powder (hot air and freeze dried) supplemented snacks which were chosen for further studies. Antioxidant activity improved significantly upon incorporation of *jamun* powder into rice snacks. Anthocyanins were not detected in control samples, while freeze dried *jamun* powder-supplemented snacks had 9.52% higher anthocyanins than hot air dried *jamun* powder-supplemented snacks. Total phenols increased by 89.72% and 80.42% in supplemented snacks containing freeze dried and hot air dried *jamun* powder, respectively, at a 10% supplementation level.

The study was undertaken to determine the antioxidant potential of *jamun* powder in extruded snacks and to study the functional properties of the developed product.

Introduction

Snack foods provide an important percentage of many consumers' daily nutrient and calorie intake [1]. Emphasis on the consumption of foods rich in natural antioxidants has led to the growth of the functional food market, while globally snack foods are becoming an integral part of the diet of the world's population [2]. Food scientists are exploring opportunities to combine various food sources and develop wholesome healthy products to address health issues among the general population. In view of this, extrusion processing has emerged as a convenient method for food processors to produce functional snack foods with good nutritional value. Applications of extruded products include breakfast cereals and snack foods containing modified starches and flour.

Studies on the relationship between fruit and vegetable intake and various cancers have resulted in the increased consumption of these foods. *Syzygium cumini* (*jamun*) is a minor fruit crop that is widely known for its nutraceutical properties.

Health benefits ascribed to this fruit include anti-diabetic [3], anti-bacterial, anti-inflammatory and

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antioxidant activity and the prevention of gastrointestinal problems [4]. *Jamun* fruit has a slightly astringent sweet sour taste. It is used in processed foods as a nutrient supplement or as a natural colorant. Consequently, the nutraceutical and coloration properties of *jamun* fruit could be exploited to develop value-added extruded products that can add variety to functional foods.

Rice flour is commonly used as a base raw material in the extrusion industry owing to its bland taste, hypoallergenicity and ease of digestion [5], whereas wheat has a higher protein and lower starch content compared to rice and corn, resulting in harder and less expanded extruded wheat products. The use of fruit powders in extruded snacks to improve the functionality of products is increasing. Camire *et al.* [6] studied the functionality of fruit powders in extruded corn breakfast cereals. Limsangouan *et al.* [7] also studied the functional properties of cereal and legume-based extruded snacks fortified with the by-products of herbs and vegetables. *Syzygium cumini* powder has high antioxidant activity and its potential in extruded snacks should be explored. Moreover, supplementation of rice-based extruded snacks with *jamun* powder can provide new opportunities for the snack food market while simultaneously increasing the market for *jamun* fruit. Therefore, the present investigation was undertaken where *jamun* fruit was turned into *jamun* powder using hot air drying and freeze drying processes, the *jamun* powder was used in rice-based extruded snacks and the antioxidant potential and other quality characteristics of *jamun* powder-supplemented extruded snacks were investigated.

Materials and methods

Materials

Fresh *jamun* (*Syzygium cumini* L.) fruit and rice flour were obtained from the local market in Ludhiana, India.

Hot air drying and freeze drying of *jamun* pulp

Fresh and fully ripe *jamun* fruits were washed thoroughly under running tap water. The fruits were gently heated in their own juice on a hot plate maintained at 60°C for 10 min. Seeds were removed manually and a uniform pulp was obtained by passing the seedless material through a fruit strainer. The pulp was spread as a thin layer on 40 × 80 cm trays and dried in a cabinet hot air drier (Frederick Herbert-Design 20, Bombay, India) at 40 ± 5°C for 8 h. The positions of the trays were periodically changed and the material was dried until a constant weight was attained. In the second batch, the pulp was spread as a thin layer on the stoppering trays of a freeze drier (FreeZone Freeze Dry Systems, Labconco, KS, USA). The pulp was dried at -30°C and 0.004 mBar pressure for 60 h. The conventional hot air dried and freeze dried material was ground finely, packed in laminated aluminium foil bags and refrigerated until further study.

Sample preparation for extrusion

Rice flour and iodized salt were procured from the local market in Ludhiana, India. Batches of rice flour (1 kg each), salt (2%), hot air and freeze dried *jamun* powder (5, 10, 15 and 20% supplementation) were mixed in a ribbon blender (G L Extrusion Systems New Delhi, India) for 10 min to ensure uniform blending. Control samples containing rice flour and salt (2%) without *jamun* powder were also extruded at the same time. The blends were dried at 40°C to obtain a final moisture content of 15 %.

Extruder and processing conditions

A Clextral BC 21 (Clextral, Firminy, France), co-rotating and intermeshing twin screw extruder was used for extrusion. The barrel diameter and its length to diameter ratio (L:D) were 2.5 mm and 16:1, respectively.

The extruder had four barrel zones. The temperatures of the first, second, third and fourth (compression and die zone) zones were maintained at 40, 70, 100 and 150°C, respectively, throughout the experiments. The diameter of the die opening was 6 mm. The extruder was powered by a 8.5 KW motor with a constant screw speed of 500 rpm. Raw material was fed into the extruder by a single screw volumetric feeder (DS & M, Modena, Italy).

Quality evaluation of extruded snacks

Expansion ratio

Five random pieces of extrudate were selected from each sample and the diameter was measured using a vernier calliper (Baker Gauges India, Pune, India). The expansion ratio was then calculated as the average ratio of the diameter of extrudates to the diameter of the die [8].

Bulk density

The bulk density of extrudates was calculated by measuring the actual dimensions of the extrudates. Five random pieces of extrudate were selected from each sample and their length (L) and diameter (d) were measured using a vernier calliper (Baker Gauges India). The mass (m) of the extrudate was also recorded. The bulk density (g/cm^3) was calculated according to the method of Alvarez-Martinez *et al.* [9] and the average value reported:

$$\text{Bulk density (g/cm}^3\text{)} = \frac{4\text{m}}{\prod \text{d}^2\text{L}}$$

Water absorption and solubility indices

The water absorption index (WAI) and water solubility index (WSI) of rice extrudates were determined using a modification of the method of Anderson *et al.* [10]. The extrudate samples were ground and passed through a 500 µm sieve. A sample (2.5 g) was then placed in a tarred centrifuge tube and 30 ml distilled water was added at 25°C. The tube was shaken, with care taken to avoid lumping in order to produce a smooth dispersion. After standing for 30 min (with intermittent shaking every 10 min), the sample was centrifuged at 3000 rpm for 15 min. The supernatant was decanted into a tarred aluminium pan and dried at 130±1°C in a hot air oven until a constant weight was attained. The weight of the gel remaining in the centrifuge tube was noted. The results were expressed as the average of two measurements:

$$\text{WAI (g/g)} = \frac{\text{Weight gain of gel}}{\text{Dry weight of extrudate}}$$

$$\text{WSI (g/g)} = \frac{\text{Weight of dry solids in supernatant}}{\text{Dry weight of extrudate}} \times 100$$

Sensory evaluation

Jamun-supplemented extruded snacks were evaluated for sensory attributes (appearance, colour, flavour, texture and overall acceptability) using a nine-point hedonic scale [11]. Seven healthy panellists aged 22–55 years from the Department of Food Science and Technology, PAU, Ludhiana were selected to evaluate the sensory properties of supplemented snacks.

Colour analysis

Colour analysis was performed with a MiniScan XE Plus colorimeter (HunterLab, Reston, VA, USA). Colour readings were expressed by Hunter values for L^*, a^* and b^*. The value of a^* ranges from −100 (greenness) to +100 (redness), that of b^* from −100 (blueness) to +100 (yellowness) and that of L^* (indicating lightness) from 0 (black) to 100 (white). The hue angle was calculated using the formula $\tan^{-1} b^*/a^*$.

Texture analysis

The textural quality of the snack samples was examined for compression force using a TA-XT2i Texture Analyzer (Model TA-HDi; Stable Micro Systems, UK). A P75 compression probe (75 mm diameter, aluminium cylinder) was applied to measure the compression force required for sample breakage, which indicates hardness. The testing condition was 1.0 mm/s pre-test speed, 2.0 mm/s test speed, 10.0 mm/s post-test speed and distance 5 mm.

Proximate composition

Hot air dried and freeze dried *jamun* powder was evaluated for titratable acidity by titrating known volumes of aliquots against 0.1 N NaOH and expressed as percent malic acid [12]. Total sugars and reducing sugars were estimated according to the methods of Lane and Eynon [13]. Crude fibre was estimated by the acid-alkali method (Fibertec; FOSS, Hilleroed, Denmark) [14]. Total ash and crude protein content was estimated as per AOAC [13]. The physico-chemical characteristics of supplemented snacks such as moisture, ash, crude protein and crude fibre, were determined using AACC methods [14].

Bioactive analysis

Ascorbic acid was determined using a direct colorimetric method [12] and expressed as mg/100 g. The total anthocyanin content of the samples was analysed by a spectrophotometric method [13] and expressed as mg/100 g. Total phenolic content was determined according to the Folin-Ciocalteu spectrophotometric method [14]. A 5 g sample was mixed with 80% methanol (50 ml) and refluxed for 2 h. A 0.2 ml aliquot was added to 0.8 ml of distilled water. Thereafter, 5 ml of fresh Folin-Ciocalteu reagent (10-fold dilution) was added and the mixture allowed to equilibrate for 8 min followed by the addition of 4 ml of saturated sodium carbonate solution. The mixture was incubated in the dark at room temperature for 60 min and the absorbance of the mixture was observed at 765 nm (Spectronic 20; Bausch & Lomb, USA). The results were expressed as mg GAE/100 g by taking gallic acid as reference material to construct a standard curve.

Antioxidant activity

Antioxidant activity was determined by the DPPH (2,2-diphenyl-picrylhydrazyl) method according to Brand-Williams *et al.* [15] with some modifications. Samples (5 g) were extracted with 80% methanol for 2 h and filtered. Then an aliquot was collected and the volume made up to 100 ml with 80% methanol. The assay contained 2 ml of sample aliquot, 2 ml of Tris HCl buffer (pH 7.4) and 4 ml of 0.1 mM DPPH. The contents were immediately mixed and the reduction in absorbance was continuously recorded for 30 min at 517 nm (Spectronic 20). The antioxidant activity was calculated according to following formula:

$$\text{Antioxidant activity (\%)} = \frac{\text{Control absorbance (0 min)} - \text{Sample absorbance (30 min)} \times 100}{\text{Control absorbance (0 min)}}$$

Statistical analysis

The results were expressed as the mean ± standard deviation (n=3). Data were analysed using Student's t test for fresh and processed *jamun* pulp, and data collected from *jamun* pulp-supplemented snacks were subjected to variance (ANOVA) analysis and the results compared using Duncan's multiple range test with $p \leq 0.05$ considered significant. SPSS 18.0 statistical software (SPSS Inc.) was used.

Results and discussion

Quality assessment of *jamun* powder-supplemented extruded snacks

Expansion ratio

The puffing characteristics of extrudates are described by both the expansion ratio and bulk density. Data on the effect of level of supplementation with *jamun* powder on the expansion ratio are given in Table 1. The expansion ratio decreased with increasing levels of supplementation with hot air dried and freeze dried *jamun* powder in rice-based extrudates with a significant ($p \leq 0.05$) decrease observed at higher supplementation levels. The expansion ratio was in the range of 2.32–1.40 for *jamun* powder-supplemented extrudates. Increasing sugar levels in the fruit powder may have increased the viscosity of the feed mix; additionally, sugar would have competed for the moisture in the feed mix and made it unavailable for complete starch gelatinization and reduced extrudate expansion at the die exit [16]. A similar decreasing expansion ratio was found by Sarkar *et al.* [17] on incorporation of cactus pear fruit powder in rice-based extrudates. In a comparison of drying methods, a non-significant effect on the expansion ratio of extrudates was found: freeze dried *jamun* powder-supplemented extrudates had a slightly lower expansion ratio (2.32–1.40) than hot air dried *jamun* powder-supplemented extrudates (2.32–1.46), which might have been due to the slightly higher sugar content in freeze dried *jamun* powder.

Bulk density

Bulk density was found to increase proportionally with increasing *jamun* fruit solids level, with a significant ($p \leq 0.05$) increase at higher supplementation levels (above 10 %) for hot air dried *jamun* powder-supplemented extrudates (Table 1).

Bulk density was recorded in the range of 0.12–0.29 g/cm^3 with the highest value recorded at 20%

Supplementation level (%)	Expansion ratio		Bulk density (g/cm³)		Hardness (N)	
	CD	FD	CD	FD	CD	FD
Control	$2.32^{ax}\pm0.12$	$2.32^{ax}\pm0.12$	$0.12^{bx}\pm0.02$	$0.12^{cx}\pm0.02$	$20.14^{dx}\pm0.49$	$20.14^{dx}\pm0.49$
5	$2.17^{abx}\pm0.11$	$2.11^{bx}\pm0.11$	$0.13^{bx}\pm0.03$	$0.17^{bx}\pm0.04$	$20.16^{dx}\pm0.60$	$20.79^{dx}\pm0.68$
10	$2.05^{bx}\pm0.14$	$2.00^{bx}\pm0.13$	$0.16^{bx}\pm0.03$	$0.20^{bx}\pm0.02$	$21.37^{cx}\pm0.47$	$21.92^{cx}\pm0.44$
15	$1.78^{cx}\pm0.10$	$1.72^{cx}\pm0.07$	$0.23^{ax}\pm0.02$	$0.26^{ax}\pm0.03$	$23.38^{bx}\pm0.45$	$24.05^{bx}\pm0.49$
20	$1.46^{dx}\pm0.11$	$1.40^{dx}\pm0.08$	$0.28^{ax}\pm0.03$	$0.29^{ax}\pm0.02$	$24.44^{ax}\pm0.32$	$25.01^{ax}\pm0.34$

Means with a–d superscripts are significantly ($p \leq 0.05$) different within that column, while the superscripts x indicate a non-significant ($p \leq 0.05$) effect of drying within the same row
CD conventional hot air drying, *FD* freeze drying

Table 1 - Effect of *jamun* powder supplementation on expansion ratio, bulk density and hardness of extrudates

supplementation for both hot air and freeze dried *jamun* powder-supplemented extrudates (0.28 and 0.29 g/cm^3, respectively). A non-significant effect of drying method on the bulk density of extrudates was found. Higher bulk density is associated with a low expansion index [18]. Increasing density with increased fruit solids might be due to increasing fibre content as fibre particles tend to rupture cell walls before gas bubbles have expanded to their full potential [19]. *Jamun* fruit is reported to contain glucose and fructose (monosaccharides) as principal sugars and Fan *et al.* [20] observed that monosaccharides reduce expansion to a greater degree compared to disaccharides by decreasing bubble growth formation and increasing cell shrinkage at die exit.

Hardness

The textual property of extrudates was determined by measuring the force required to break the extrudate. Control samples made of only rice flour were less hard as compared to supplemented snacks, and as the level of supplementation increased, hardness increased proportionally (Table 1). A non-significant effect of *jamun* powder incorporation was observed in control samples and extrudates at the 5% supplementation level, but significant ($p \leq 0.05$) variations were observed at higher supplementation levels. Maximum hardness was found in samples containing 20% hot air and freeze dried *jamun* powder (24.44 and 25.01 N, respectively). Dehghan-Shoar *et al.* [21] also reported increased hardness of extrudates prepared from rice flour supplemented with tomato paste and tomato skin. The presence of fruit fibres may interfere with air bubble formation and increase air cell wall thickness [22] resulting in a harder product. No significant effect of drying methods was found on the hardness of supplemented extrudates. Hardness values were in the range of 20.16–24.44 N and 20.79–25.01 N for hot air dried and freeze dried *jamun* powder-supplemented snacks, respectively.

Water absorption and water solubility indices

Dispersion of starch in excess water is indicated by the water absorption index (WAI) and dispersion increases with increased starch damage as a result of gelatinization and extrusion-induced fragmentation [18]. The WAI values reduced with increasing level of *jamun* powder in the feed mix (Table 2) due to decreasing starch molecule degradation. The maximum WAI was recorded for control extrudates (5.03 g/g) and the minimum for 20 % freeze dried *jamun* powder-supplemented extrudates (4.71 g/g). Some authors have reported

Supplementation level (%)	WAI (g/g)		WSI (%)	
	CD	FD	CD	FD
Control	$5.03^{ax}\pm0.02$	$5.03^{ax}\pm0.02$	$22.81^{ex}\pm0.07$	$22.81^{ex}\pm0.07$
5	$4.98^{ax}\pm0.01$	$4.95^{bx}\pm0.02$	$22.98^{dx}\pm0.05$	$23.06^{dx}\pm0.03$
10	$4.81^{bx}\pm0.03$	$4.78^{cx}\pm0.04$	$23.11^{cx}\pm0.07$	$23.28^{cy}\pm0.05$
15	$4.75^{bx}\pm0.05$	$4.71^{cx}\pm0.05$	$23.34^{bx}\pm0.03$	$23.45^{by}\pm0.04$
20	$4.60^{cx}\pm0.04$	$4.58^{dx}\pm0.06$	$23.54^{ax}\pm0.02$	$23.62^{ax}\pm0.06$

Means with a-e superscripts are significantly ($p \leq 0.05$) different within that column, while the superscripts x and y indicate a significant ($p \leq 0.05$) effect of drying within the same row
CD conventional hot air drying, *FD* freeze drying

Table 2 - Effect of *jamun* powder supplementation on the water absorption index (WAI) and water solubility index (WSI) of extrudates

that higher WAI values are related to higher starch content, which when it undergoes degradation enhances water absorption [23]. Therefore, control samples have higher WAI values as compared to supplemented samples due to their higher starch content as some starch has been replaced by *jamun* powder in supplemented samples. No significant variation was observed between hot air dried and freeze dried *jamun* powder-supplemented extrudates. The decreasing trend might be due to the dilution of starch with increasing fruit pulp in the feed mix as found by Singh *et al.* [24] who reported a decrease in WAI with the addition of pea grits in extruded rice due to the dilution of starch in rice–pea blends.

On the other hand, the water solubility index (WSI), an indicator of degradation molecules, was found to increase with increasing fruit solids (Table 2). WSI values were in the range of 22.81–23.62 g/g, with highest values observed for hot air dried and freeze dried *jamun* powder-supplemented extrudates at the 20 % level (23.54 and 23.62 g/g, respectively). Increasing values might be due to an increase in the fibre content of the feed mix with increasing supplementation and the components of fibre might have been degraded during the extrusion process [25]. Among the drying methods, a non-significant effect was found for WSI on extrudates except at the 10 and 15 % levels where a significant ($p≤0.05$) difference was found between hot air dried and freeze dried *jamun* powder-supplemented extrudates. The difference might be due to slightly higher fibre content in freeze dried powder compared to hot air dried *jamun* powder.

Colour analysis

The effect of hot air dried and freeze dried *jamun* powder supplementation on the colour values *L**, *a** and *b** and the hue angle of rice-based extruded snacks is given in Table 3. Lightness (L*), redness (*a**), yellowness (*b**) and the hue angle of control extruded snacks were 66.55, 3.86, 17.20 and 77.34, respectively. The incorporation of hot air and freeze dried *jamun* powder in extrudates lowered the L* value significantly ($p≤0.05$) which increased with increasing supplementation level, making the samples darker with increasing *jamun* powder concentration. Chemically, this might be due to Maillard browning reactions at higher temperatures and high sugar levels. Significant ($p≤0.05$) differences in *L** values were also observed among the drying techniques at all supplementation levels. Extrudates supplemented with freeze dried *jamun* powder had comparatively lower *L** values (51.04–32.55) than extrudates supplemented with hot air dried *jamun* powder (53.71–33.95). Lower *L** values have been reported for deep red wines, while lighter coloured wines transmit more light and have higher *L** values [26], which explains the differences between the *L** values of hot air dried and freeze dried samples in the present study; anthocyanins responsible for deep blue coloration might have been degraded more during hot air drying [27] compared to freeze drying.

Supplementation (%)	*L**		*a**		*b**		Hue angle (°)	
	CD	FD	CD	FD	CD	FD	CD	FD
Control	$66.55^{ax}\pm0.65$	$66.55^{ax}\pm0.65$	$3.86^{dx}\pm0.33$	$3.86^{ex}\pm0.33$	$17.20^{ax}\pm0.60$	$17.20^{ax}\pm0.60$	$77.34^{ax}\pm0.63$	$77.34^{ax}\pm0.63$
5	$53.71^{bx}\pm0.51$	$51.04^{by}\pm0.61$	$4.24^{dx}\pm0.39$	$5.24^{dx}\pm0.24$	$15.81^{bx}\pm0.29$	$15.12^{bx}\pm0.38$	$74.98^{bx}\pm1.05$	$71.77^{by}\pm0.39$
10	$49.81^{cx}\pm0.82$	$46.58^{cy}\pm0.86$	$5.39^{cx}\pm0.43$	$5.97^{cx}\pm0.32$	$14.91^{cx}\pm0.40$	$14.29^{bx}\pm0.45$	$70.14^{cx}\pm0.98$	$67.29^{cy}\pm0.45$
15	$41.90^{dx}\pm0.79$	$38.96^{dy}\pm0.72$	$6.51^{bx}\pm0.48$	$6.93^{bx}\pm0.52$	$13.62^{dx}\pm0.59$	$13.13^{cx}\pm0.51$	$64.45^{dx}\pm0.69$	$62.21^{dy}\pm0.85$
20	$33.95^{ex}\pm0.67$	$32.55^{ey}\pm0.53$	$7.59^{ax}\pm0.45$	$7.97^{ax}\pm0.46$	$13.03^{dx}\pm0.35$	$12.28^{cx}\pm0.55$	$59.81^{ex}\pm0.85$	$57.02^{ey}\pm0.33$

Means with a–e superscripts are significantly ($p≤0.05$) different within columns, while the superscripts x and y indicate a significant ($p≤0.05$) effect of drying within the same row
CD conventional hot air drying, *FD* freeze drying

Table 3 - Effect of *jamun* powder supplementation on colour values (*L**, *a**, *b**) and hue angle of extrudates

The redness values (a^*) were found to increase significantly ($p \leq 0.05$) with increasing *jamun* powder supplementation levels and this increase was greater in freeze dried samples than in hot air dried samples. Extrudates incorporating hot air dried *jamun* powder had a^* values in the range of 4.24–7.59, while freeze dried *jamun* powder incorporated snacks had values in the range of 5.24–7.97. This indicates higher retention of anthocyanins in freeze dried *jamun* powder than in hot air dried *jamun* powder as a^* values have been positively correlated with anthocyanins [6]. The b^* values that indicate yellowness (+)/blueness (–) were found to linearly decrease with increasing supplementation levels. The b^* value decreased from 15.81 at 5% supplementation to 13.03 at 20% supplementation for hot air dried *jamun* powder-supplemented extrudates and from 15.12 at 5% supplementation to 12.28 at 20% supplementation for freeze dried powder-supplemented extrudates. Lower values were found for freeze dried samples than for hot air dried samples. A reduction in b^* values signifies increasing blueness of the samples, thus, the freeze dried samples were found to have a bluer colour compared to hot air dried samples, which might be due to good retention of anthocyanins in freeze dried powder.

The hue angles of *jamun* powder-supplemented extruded snacks were found to be lower than for control samples. The hue angle decreased proportionally with increasing supplementation levels. The maximum hue angle was reported for the control sample (77.34) and the minimum for freeze dried *jamun* powder-supplemented extrudates (57.02). A significant ($p \leq 0.05$) difference was found between the drying methods for the hue angle of the extrudates, values being lower for freeze dried *jamun* powder-supplemented extrudates compared to hot air dried *jamun* powder-supplemented extrudates. The hue angle and L^* values are well correlated [26], indicating increased sample darkness with increased supplementation level.

Sensory analysis

Differences were demonstrated in the appearance, texture, flavour and overall acceptability scores of conventional hot air dried and freeze dried *jamun* powder-incorporated extruded snacks (Fig. 1). Flavour was an important factor in determining the acceptability of supplemented extruded snacks and astringency was found to increase with an increase in supplementation levels. The 10% supplementation level received the highest overall acceptability scores for both hot air and freeze dried *jamun* powder-supplemented snacks (8.21 and 8.18, respectively). The flavour scores for extrudates were in the range of 8.28–5.57.

A harder texture was observed with increasing supplementation levels, which might be due to increasing sugar content in the feed mix at higher levels. Moreover, samples containing higher levels of *jamun* powder (15 and 20%) had a burnt appearance. The degradation of anthocyanin pigment and the Maillard reaction due to the high

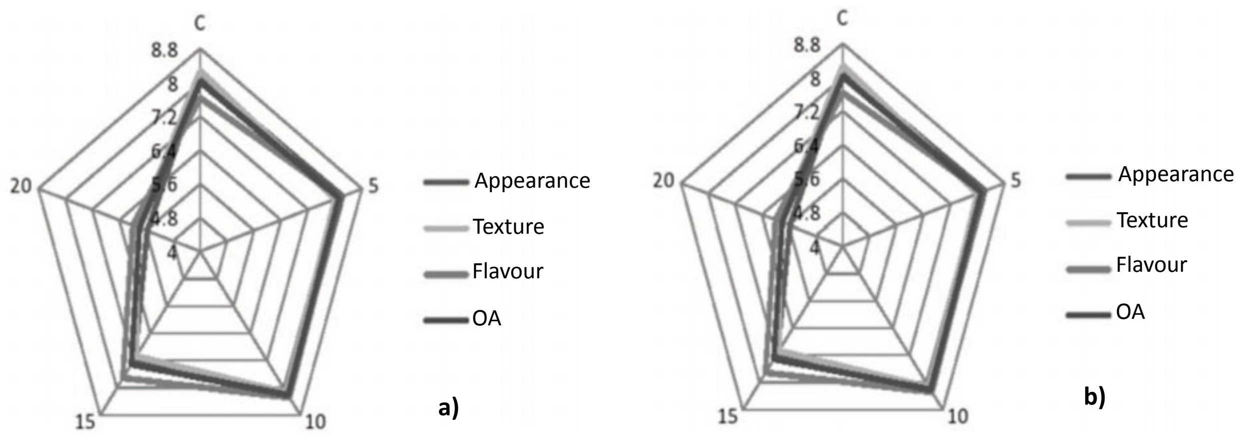

Figure 1 - Cobweb diagram showing the sensory score of different supplementation levels of (**a**) hot air dried *jamun* powder and (**b**) freeze dried *jamun* powder-supplemented rice-based snacks. *CD* conventional hot air drying, FD freeze drying, OA overall acceptability

sugar content of the *jamun* powder are likely to have caused the undesirable darker and burnt colour of the product. Sensory texture values and texture analyser values correlate well with each other, indicating harder samples at higher supplementation levels. In light of the quality characteristics and sensory analysis, supplementation of rice flour with 10% *jamun* powder dried using both methods was selected to prepare extruded snacks for further studies.

Chemical composition of *jamun* powder-supplemented snacks

The chemical composition of rice-based *jamun* powder-supplemented extruded snacks is depicted in Fig. 2. A non-significant effect of drying methods was observed on the moisture content of the samples. The moisture content of control extruded snacks was 4.89 %, while the moisture content of hot air and freeze dried *jamun* powder incorporated extrudates was 5.08 and 5.02 %, respectively. Supplemented extrudates exhibited marginal but significant ($p \leq 0.05$) effects on protein, ash and fibre content with respect to control. Control extrudates were found to have 6.72% protein content followed by freeze dried (6.31%) and hot air dried (6.28%) *jamun* powder-supplemented extrudates. El-Samahy *et al.* [16] reported decreasing protein content in rice-based extrudates with increasing levels of cactus pear concentrate. No significant effect of drying treatment was found on the ash and fibre content of supplemented extrudates. However, with respect to control samples, supplemented samples showed improved ash and fibre content. Ash content increased by 18.57 and 17.61% after supplementation of rice flour with 10 % freeze dried and hot air dried *jamun* powder, respectively. Fibre content was highest in freeze dried *jamun* powder incorporated extrudates (1.97%) and lowest in control samples (1.52%).

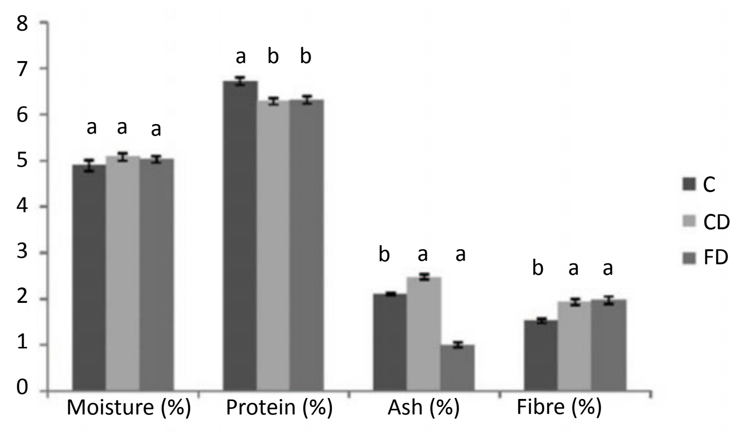

Figure 2 - Effect of incorporation of *jamun* powder on the chemical properties of rice flour-based extrudates; a and b superscripts indicate a significant ($p<0.05$) difference among the control and supplemented extrudates. *C* control, *CD* conventional dried, *FD* freeze dried

Bioactive analysis of *jamun* powder-supplemented snacks

Results given in Table 4 show the concentration of bioactive compounds and antioxidant activity of *jamun* powder-supplemented snacks. Anthocyanins were not detected in control samples. A non-significant effect of drying methods was found on the anthocyanin content of extrudates. Extrudates supplemented with freeze dried *jamun* powder had a higher anthocyanin content (3.22 mg/100 g) than snacks supplemented with hot air dried *jamun* powder (2.94 mg/100 g). This observation might be ascribed to an initial higher concentration of anthocyanins in freeze dried *jamun* powder as compared to hot air dried *jamun* powder [28] as anthocyanins must have been degraded during hot air drying owing to the high temperature [29]. The total phenolic content varied significantly ($p<0.05$) with respect to drying methods, and supplemented snacks were found to have significantly higher total phenols than the control sample (79.70 mg GAE/100 g). Freeze dried *jamun* powder-supplemented snacks had 4.90% higher total phenol content than hot air dried *jamun* powder-supplemented snacks due to the initially high concentration of total phenols in freeze dried *jamun* powder [28]. Antioxidant activity determined by DPPH assay revealed a minimum value for control samples (44.01%) and a maximum for freeze dried *jamun* powder-supplemented snacks (87.81%). The antioxidant values correspond with the amount of anthocyanins and total phenols as both are highly correlated with antioxidant activity [30].

Treatment	Anthocyanins (mg/100 g)	Total phenols (mg GAE/100 g)	Antioxidant activity (%)
Control	ND	$79.70^c \pm 0.60$	$44.01^c \pm 0.35$
CD	$2.94^a \pm 0.29$	$143.80^b \pm 0.70$	$85.20^b \pm 0.50$
FD	$3.22^a \pm 0.36$	$151.21^a \pm 0.51$	$87.81^a \pm 0.39$

Means with different letters in the same column are significantly different ($p \le 0.05$)
CD conventional dried, *FD* freeze dried, *GAE* gallic acid equivalent, *ND* not detected

Table 4 - Bioactive composition of *jamun* powder-supplemented snacks

Conclusion

The addition of *jamun* fruit powder to rice flour improved antioxidant activity, total phenolic content and anthocyanin content in snacks. Freeze drying was found to better retain bioactive components than hot air drying. A decrease in the expansion ratio and WAI was observed at all supplementation levels. Increased darkness of snacks was observed with increasing *jamun* powder supplementation levels with respect to colour values (L^*). *Jamun* fruit powder incorporation in rice-based snacks slightly improved fibre and ash content. Bioactive components were higher in snacks supplemented with freeze dried *jamun* powder than with hot air dried powder. Supplemented snacks received the highest sensory scores at 10% supplementation, while snacks at other supplementation levels were also found to be acceptable except at the 20% level. On the whole, *jamun* fruit can be used as a potential ingredient to enrich and improve the antioxidant status of rice-based snacks.

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Conflict of interest

The authors declare that they have no conflict of interest.

Human and Animal Rights

The article does not contain any studies with human or animal subjects performed by any of the authors.

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