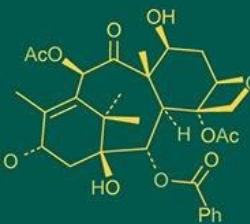
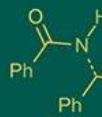


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Physicochemical, functional, and rheological properties of reduced-calorie ice cream enriched with pigmented black rice powder

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Abstract

Pigmented rice varieties, such as red, black, purple, green, and brown, possess nutritional qualities due to their higher concentration of bioactive chemicals compared to standard white rice; yet, their consumption remains low due to inadequate recognition. Currently, pigmented rice is utilized by various industries, including cosmetics, pharmaceuticals, packaging, and food. In this experiment, skim milk powder was substituted with black rice powder (BRP) in a ratio of 0 to 100 percent to formulate reduced-calorie ice cream. It was observed that ice cream mixes with a higher proportion of black rice powder had a higher calorific value. This is because a larger percentage of BRP greatly increases the calorific value of ice cream. Thus, it can be concluded that the formulation of BRP (25%) enriched ice cream showed reduced calorific value. So that manufacturers may use this nutraceutical ingredient in the future formulation of product development.

Keywords: Bioactive, calorific value, nutritional, pigmented rice, pharmaceutical

Introduction

Indian culture venerates rice as an emblem of fertility, good fortune, and prosperity because of its ability to sustain life. The most commonly found pigmented rice varieties are black, brown, red, and dark purple. Pigmented rice, like black rice, contains different bioactive compounds like amino acids, flavones, phenolics, essential oils, sterols, γ -oryzanols, tannin, and tocopherols (Saloni *et al.*, 2025) ^[15]. It also contains different types of antioxidative components such as anthocyanins (ACN) like malvidin-3-glucoside, cyanidin-3-O-glucoside, cyanidin-3-rutinoside, and cyanidin-3, 5-diglucoside, peonidin-3-O-glucoside, cyanidin-3-sambubioside, and cyanidin-3-gentiobioside (Norkaew *et al.* 2019) ^[11]. To carry functional ingredients, there is a requirement for an appropriate vehicle for the delivery of bioactive compounds in the food matrix. For this reason, ice cream is regarded as a good delivery method for bioactive substances. Although ice cream is rich in calories but it is poor in some of the natural antioxidants, dietary fibers, and minerals. So, this study has focused on increasing the nutritional value of ice cream. Nowadays, the demand for nutritional and functional food is growing, which has increased the use of phrases like "all-natural" and "organic" (Saloni *et al.*, 2020) ^[13]. On the other hand, low-calorie foods and confectionary are also rising significantly among consumers who are quality-conscious and seek out low-sugar or sugar-free dairy or food products. In this regard, there is a need to develop or reformulate functional food products that contain reduced calories. Earlier, the use of pigmented rice in the food industry was reported, but there are no studies have been undertaken to formulate reduced calorie ice cream by using black rice powder.

To achieve this, standard and novel ingredients were used to formulate reduced-calorie ice cream. Black rice contains high levels of different anthocyanin polyphenols that have antioxidant properties and are incorporated in the formulation of reduced-calorie ice cream (Saloni *et al.*, 2023) ^[14]. Ice cream typically contains 10-15% of fat, 18-20% of carbohydrates, and 3.5-4.0% of protein, with a 220.82 Kcal/100 g calorific value (Aichayawanich and Wongsai 2022; FSSAI, 2022) ^[2, 7]. To address consumer health concerns, the dairy industry has developed various low-calorie, reduced-fat ice cream products in recent years. However, the quality aspects of these products sometimes do not meet consumer expectations.

Compared with traditional ice creams, products formulated with low-calorie and low-fat content offer a less favorable flavor and degenerative texture. The goal of the current study was to improve the nutritional and functional qualities of regular ice cream by adding black rice powder. As refined sugar has been replaced by coconut sugar, it has a low glycemic index (GI) and high vitamin and mineral content (Hebbbar *et al.* 2022) [8]. Thus, this study aimed to evaluate the effect of adding black rice powder (BRP) on the physicochemical, rheological, and sensory attributes of ice cream and then optimize the formulation of reduced-calorie ice cream.

Materials and Methods

Materials

Black rice was purchased from local exporters of the Sonitpur district, Tezpur (Assam, India). Toned milk (3.0% fat and 8.5% SNF; minimum), cream (minimum 40% milk fat, Amul, India), Skim milk powder of (Markendeshwar Foods and allied products; Kurukshetra, India), Coconut sugar, Cremodan Sampoorana (Danisco India Pvt. Ltd. Haryana, India) used as a stabilizer and emulsifier in the preparation of ice cream, procured from Varanasi, Uttar Pradesh, India. All chemicals and reagents were of analytical grade and obtained from Sigma-Aldrich (USA).

Formulation and optimization of ice cream mixtures

The basic ice cream mix was produced based on the standards of FSSAI (Govt. of India) ice cream. Fat and total solids content in ice cream mix were standardized using the Pearson square method. Ice cream prepared with 10% milk fat and 36% total solids served as the control. The formulated ingredients were mixed and dissolved for 2 h at room temperature and then preheated at 60 °C for 5 min and homogenized at 2500 psi. The formulations were pasteurized at 85±1 °C for 15 min and then transferred to an ageing vat at 4 °C for 6-12 h. The mixtures were then frozen for 20 min in a continuous freezer. The ice cream samples were packed into plastic containers (100 mL) at a temperature of 5 °C and stored at -18±2 °C until further analysis.

Optimization was done by replacing skim milk powder (SMP) with black rice powder (BRP) at the rate of 0-100%. The ingredient for samples preparation of ice cream (BRP 0, BRP 25, BRP 50, BRP 75, BRP 100) with black rice were toned milk, sucrose replaced with coconut sugar (100%), BRP (at the rate of 0, 25, 50, 75, and 100%), fresh cream (containing 40% fat), and CREMODAN SAMPOORNA® (as a stabilizer and emulsifier), coconut sugar (Table 1). The control ice cream was without the addition of any BRP.

Table 1: Formulations of Reduced-Calorie Ice-Cream Mix

Mix	Formulation
Control	Ice cream mix containing milk (@4.5% fat), sugar (15%), SMP, cream (@40% fat), stabilizer, and emulsifiers (0.5)
BRP 0	Ice cream mix without any replacements of SMP with black rice powder
BRP 25	Ice cream mix formulated with 25% black rice powder
BRP 50	Ice cream mix formulated with 50% black rice powder
BRP 75	Ice cream mix formulated with 75% black rice powder
BRP 100	Ice cream mix formulated with 100% black rice powder

Chemical analysis of black rice powder (BRP)

Moisture, fat, ash, and protein were estimated by using the standard methods of AOAC (2005) [3]. The analysis was performed in triplicate and represented as Mean ± SD.

Total phenolic compounds, antioxidative properties (DPPH% inhibition), and total anthocyanin contents of Black rice powder

The TPCs, DPPH% inhibition, and TAC were determined in the ethanolic extract by using the method of Elkot *et al.* (2022) [6] with slight modifications. To calculate TPC, sample (4 g) was mixed with 40 mL of 50% ethanol, stirred for 1 h, and then filtered by using Whatman No. 1. For TAC, a sample (0.5 g) was mixed with 15 mL of extraction solvent (0.01% v/v HCl in ethanol), and the pigments were extracted by homogenization. After filtration of the extract, the optical density (OD) was measured at 530 nm against a blank, which was the extraction solvent. Results were expressed as mg Cyd-3-glu/100 g. The analysis was performed in triplicate and represented as Mean ± SD.

Physicochemical analysis of the formulated Ice cream

For each parameter, the mean values of three independent replicates were analyzed. Total solids, protein, fat, and ash were assayed based on the recommended methods of AOAC (2005) [3]. The carbohydrate content was determined by subtracting the sum of fat, protein, carbohydrate, and ash from the total solids. The freezing point was determined by using a specific low-temperature thermometer. According to

Elkot *et al.* (2022) [6], overrun was estimated by the difference in volume between the resultant ice cream and the original mix. The Calorific value was calculated based on the estimated contents. The analysis was performed in triplicate.

Rheological properties of the formulated Ice cream

The methodology proposed by Elkot *et al.* (2022) [6] and De *et al.* (2020) [5] was used to determine viscosity. In brief, after 20 h of storage, the viscosity of the refrigerated ice cream mixture was measured by using a viscometer (Brookfield RH, USA) at 2.5 rpm after 30 s of rotation at 25±1 °C. The melting time was measured by placing a 60 g ice cream sample on a wire mesh (1 mm) at 25±1 °C over a beaker. After 90 min, both the melted and unmelted ice cream were weighed.

Sensory Evaluation of formulated Ice cream

All the ice cream samples were sensory evaluated for flavor, body and texture, melting properties, and color by 15 semi-trained panellists from the staff. All the panellists had previous experience in ice cream evaluation. A hedonic scale from 1 to 9 was used. Scale 1 refers to extreme dislike, and scale 9 refers to extreme liking.

Statistical Analysis

One-way ANOVA (analysis of variance) was used to analyze the information gathered throughout the experiment using SPSS software, version 17.0 (SPSS Inc., Chicago, IL).

A post hoc Tukey test was applied when the homogeneity of variances was assumed and the significance was taken at a 95% level of significance ($p < 0.05$). Experiments were carried out in triplicates.

Results and Discussion

Chemical Composition and Bioactive Compounds of Black Rice Powder (BRP)

The chemical composition of black rice powder (BRP) was analyzed, and it was found that BRP had a moisture content of 10.75% db, with carbohydrates accounting for the majority of its dry matter (74.41%). The protein content was 8.37%, and the fat content was 2.48%. In addition, the total phenolic content (TPC) of BRP was 473.6 mg/100 g and showed 55.75% free radical scavenging activity (DPPH% inhibition). The total anthocyanin content was 130.2 mg Cyd 3-glu/100 g. Earlier, Sompong *et al.* (2011) [16] reported that black rice varieties are a good source of bioactive compounds and have potential antioxidant activity along with the anthocyanin content ranged from 19.40 to 140.81 mg Cyd 3-glu/100 g, the total phenolic content ranged from 336.69 to 665.16 mg as GAE/100 g, and the total antioxidant activity ranged between 59.90 and 83.90% respectively. The antioxidant activity of anthocyanin is mainly conjugated to the concentration and the hydroxylation degree of the phenolic compound, and color reading characteristics showed that black rice powder has a purple colour, making it a valuable technological ingredient in different dairy-food applications (Wattananapakasem *et al.* 2021) [17].

Physicochemical Properties of Reduced-Calorie Ice Cream

As seen in Table 2, total solids (TS) increased significantly ($p < 0.05$; as the level of BRP was increased) when skim milk powder was substituted with black rice powder (BRP) in ice cream compositions. The total solids of different ice cream samples were in the range of 36.57 ± 0.03 to $38.90 \pm 0.03\%$. Because of the composition of ice cream samples and additional BRP, these results were expected. Similar

findings were reported by Elkot *et al.* (2022) [6] for synbiotic ice cream formulations from camel milk. The protein content of different formulations of ice cream was in the range of 3.19 ± 0.05 to $3.89 \pm 0.08\%$. The ice cream mix without any replacements (BRP 0) showed more protein content as compared to the ice cream mix formulated with replacing skim milk powder (SMP) with black rice powder due to the higher protein content of SMP as compared to BRP. Comparable results reported that the replacement of SMP with BRP leads to significant ($p < 0.05$) changes in protein content (Elkot *et al.*, 2022) [6]. The fat content of ice cream formulations was in the range of 8.74 ± 0.02 to $14.74 \pm 0.02\%$. The highest fat content, $14.74 \pm 0.02\%$, was shown by the control ice cream formulation, and significant ($p < 0.05$) differences were observed in the control and other formulations of ice cream samples. However, the differences in fat and protein content at the higher concentrations of BRP were not significant ($p > 0.05$), as observed in Table 2. The carbohydrate content of different formulations of ice cream was in the range of 17.69 ± 0.09 to $18.90 \pm 0.03\%$. The ice cream mix without any replacements (BRP0) showed less carbohydrate content as compared to the ice cream mix formulated with replacing skim milk powder (SMP) with black rice powder. On the other hand, the addition of the BRP significantly enhanced the ash and carbohydrate contents ($p < 0.05$). The ash content of ice cream samples showed in the range of 0.69 ± 0.01 to $0.82 \pm 0.01\%$. The highest ash content was shown by sample BRP 25. As the BRP content was increased, it was found that there was a decrease in ash content due to a lower percentage of ash content of BRP as compared to SMP (Patel *et al.* 2005) [12]. These results are in agreement with Abd and Dewidar (2017) [1] for functional ice cream preparation by using broken rice. Thus, it was found that ice cream formulated by using BRP showed significant reduction in fat, total solids, carbohydrate, and ash content as compared to the control sample, and as the BRP concentrations were increased, chemical compositions of samples were significantly ($p < 0.05$) changed.

Table 2: Effect of the addition of BRP on the chemical composition (%) of ice cream samples.

Sample	Total Solids (%)	Protein (%)	Fat (%)	Carbohydrate (%)	Ash (%)
Control	38.90 ± 0.03^a	3.82 ± 0.08^b	14.74 ± 0.02^a	18.86 ± 0.09^a	0.74 ± 0.02^{cd}
BRP 0	36.57 ± 0.03^b	3.89 ± 0.08^a	8.74 ± 0.02^d	17.69 ± 0.09^e	0.71 ± 0.02^{cd}
BRP 25	36.71 ± 0.05^{ab}	3.72 ± 0.04^c	8.77 ± 0.04^{cd}	18.01 ± 0.05^d	0.83 ± 0.01^a
BRP 50	37.01 ± 0.07^{ab}	3.54 ± 0.05^d	8.82 ± 0.01^{bc}	18.29 ± 0.03^c	0.80 ± 0.02^{ab}
BRP 75	37.35 ± 0.06^b	3.37 ± 0.04^e	8.85 ± 0.03^b	18.60 ± 0.05^b	0.76 ± 0.03^{bc}
BRP 100	37.37 ± 0.53^b	3.19 ± 0.05^f	8.87 ± 0.02^b	18.90 ± 0.03^a	0.69 ± 0.05^d
BRP 0: Ice cream mix without any replacements of SMP with black rice powder BRP 25: Ice cream mix formulated with 25% black rice powder BRP 50: Ice cream mix formulated with 50% black rice powder BRP 75: Ice cream mix formulated with 75% black rice powder BRP 100: Ice cream mix formulated with 100% black rice powder.					
Data are expressed as Mean $\pm$ SD (n=3). Different alphabetical superscripts in the same column indicate a significant difference ($p < 0.05$).					

Rheological Properties of Reduced-Calorie Ice Cream

The various components that go into making ice cream are crucial to its quality because they determine the product's characteristics. Additionally, the physical properties of the ice cream mixture, as a result of processing methods, can change its look and texture (Elkot *et al.* 2022) [6]. Table 3 shows the physical and rheological properties of ice cream prepared by using black rice powder and compared with the control one. Researchers found that increasing the viscosity

when mixing and freezing allowed for a more even distribution of air into the texture, which in turn enhanced the sample overrun. The overrun percentage of ice cream formulation was in the range of 48.18 ± 0.67 to $49.49 \pm 0.65\%$. The amount of BRP used in the ice cream samples had a significant ($p < 0.05$) impact on the overrun. These results are in contrast with Abd and Dewidar (2017) [1] for ice cream produced from broken rice. Comparable results were reported by Azari-Anpar *et al.* (2017) [4] during a low-fat ice

cream formulation, who incorporated resistant starch and maltodextrin as a fat replacer and observed that, as the increasing resistant starch and maltodextrin concentrations, the percentage of overrun was also increased.

When it comes to the proper application of whipping and the retention of air cells, viscosity is regarded to be a key factor. The quantity of black rice ice cream blends in the testing mixtures gradually increased, which resulted in an increase in the viscosity of the combination. The viscosity of prepared ice cream ranged from 320.00 ± 2.00 to 511.00 ± 4.00 cP (Table 3), and it was found that the viscosity of the ice cream mix formulated with 100% black rice powder (BRP 100) was the highest. In this respect, polysaccharides, such as black rice powder, have been reported to increase the viscosity. The lowest viscosity was recorded in the absence of BRP 0 (control). These findings were similar to the results obtained by Ibrahim *et al.* (2022) [9], who manufactured ice cream by fortification with okara and probiotics, and higher viscosity was observed in

formulated ice cream. The higher viscosity of the experimental mixes might be partly responsible for the low melting rate of the treatments. The obtained results are in parallel with those of Kavaz (2015) [10], who formulated ice cream by incorporating blackthorn.

The time for the first dripping and complete melting increased by increasing the level of BRP in the ice cream (Table 3). The first drip time and complete melting time of ice cream samples showed in the range of 3.20 ± 0.10 to 6.23 ± 0.35 and 45.33 ± 1.53 to 59.00 ± 1.00 min, respectively. The effect of the addition of BRP at the different levels gave the longest melting time compared with the control. These results show the high resistance of ice cream fortified with BRP against melting. This may be due to the high content of total solids in BRP. Similar trends were observed in low-fat ice cream formulation done by Azari-Anpar *et al.* (2017) [4]. The amount of BRP used in the ice cream samples had a significant ($p < 0.05$) impact on the first dripping and complete melting time.

Table 3: Effect of the addition of BRP on the physicochemical, and rheological properties of Reduced-Calorie Ice-Cream samples.

Sample	Overrun (%)	First dripping time (min.)	Complete Melting time (min.)	Viscosity (cP)	Anthocyanin content (mg Cyd 3-glu/100 g)	Calorific value (Kcal/100 g)
Control	47.13 ± 0.69^d	4.20 ± 0.10^d	47.34 ± 1.58^d	420.00 ± 2.00^d	-	216.68 ± 0.03^a
BRP 0	48.18 ± 0.67^c	3.20 ± 0.10^d	45.33 ± 1.52^e	320.00 ± 2.00^f	-	161.91 ± 0.03^e
BRP 25	$49.01 \pm 0.10^{a,b}$	4.40 ± 0.10^c	$48.00 \pm 1.00^{c,d}$	398.00 ± 8.00^e	18.84 ± 0.08^d	162.67 ± 0.08^d
BRP 50	$49.12 \pm 0.53^{a,b}$	5.10 ± 0.10^b	$53.00 \pm 2.00^{b,c}$	440.00 ± 5.00^c	20.45 ± 0.05^c	$163.41 \pm 0.05^{c,d}$
BRP 75	49.41 ± 0.49^a	5.80 ± 0.20^a	$54.00 \pm 3.00^{a,b}$	473.00 ± 3.00^b	21.93 ± 0.02^b	$164.18 \pm 0.02^{b,c}$
BRP 100	49.49 ± 0.65^a	6.23 ± 0.35^a	59.00 ± 1.00^a	511.00 ± 4.00^a	23.02 ± 0.01^a	164.73 ± 0.01^b
BRP 0: Ice cream mix without any replacements of SMP with black rice powder BRP 25: Ice cream mix formulated with 25% black rice powder BRP 50: Ice cream mix formulated with 50% black rice powder BRP 75: Ice cream mix formulated with 75% black rice powder BRP 100: Ice cream mix formulated with 100% black rice powder. Data are expressed as Mean $\pm$ SD (n=3). Different superscripts in the same column indicate a significant difference ($p < 0.05$).						

The calorific value of formulated ice cream samples showed significant ($p < 0.05$) differences, and it was found in the range of 161.91 ± 0.03 to 216.68 ± 0.03 Kcal/100 g. The calorific value of the control sample of ice cream was significantly ($p < 0.05$) higher as compared to ice cream enriched with BRP due to the high-fat content of the control one. It was analyzed that the calorific value of the ice cream mix formulated with SMP was higher than that of the BRP 0 sample due to the replacement of SMP with BRP, and as BRP increases, the calorific value will also significantly ($p < 0.05$) increase. Ice cream mix formulated with a higher content of black rice powder showed more calorific value due to a higher percentage of BRP contributing significantly to the calorific value of ice cream. Thus, it can be concluded that the formulation of BRP-enriched ice cream showed reduced calorific value. So that manufacturers may use this ingredient in the future formulation of product development. Similar findings were reported by Aichayawanich and Wongsas (2022) [2] for 'Riceberry rice' ice cream enriched with *Helianthus tuberosus* extract, and it was found that the calorific value of ice cream was in the range of 170.26 to 220.82 Kcal/100 g.

Sensory evaluation of Reduced-Calorie Ice Cream

The results of the sensory evaluation are shown in Table 4. The sensory properties of the ice cream samples were

affected by the addition of black rice powder. The results demonstrated that the ice cream enriched with more than 25% BRP attained a significantly lower average score than the control ice cream. This was due to its color and flavor and due to the specific taste of BRP. It was found that a significant ($p < 0.05$) difference in body and texture, color and appearance, flavor, and mouthfeel of ice cream mix formulated with the replacement of black rice powder with SMP. The data of body and texture, color and appearance, flavor, and mouthfeel showed in the range of 6.77 ± 0.11 to 8.11 ± 0.01 , 6.70 ± 0.25 to 8.16 ± 0.04 , 6.46 ± 0.36 to 8.28 ± 0.10 , and 6.76 ± 0.11 to 8.25 ± 0.06 , respectively.

Comparable results reported by Elkot *et al.* (2022) [6] during synbiotic ice cream formulation explained that the sensory evaluation results showed that the most acceptable treatments were those formulated with 25% black rice powder. From the panellist's views, only the sample containing 25% of BRP had a mouthfeel that was almost similar to or even better than that of the control sample. Based on the results of the sensory score and calorific value, it could be decided to select BRP 25 formulations to incorporate encapsulated anthocyanin powder in the preparation of anthocyanin-incorporated low-calorie functional ice cream. BRP 25 was more appealing than the other ice cream mix formulated with a higher percentage of BRP.

Table 4: Sensory score of Reduced-Calorie Ice-Cream

Sample	Body and Texture	Colour and Appearance	Flavour	Mouthfeel
Control	8.06±0.14 ^a	8.33±0.07 ^a	8.00±0.01 ^a	8.03±0.05 ^a
BRP 0	8.08±0.11 ^a	8.07±0.04 ^a	8.02±0.01 ^a	8.11±0.09 ^a
BRP 25	8.11±0.01 ^a	8.16±0.04 ^a	8.28±0.10 ^a	8.25±0.06 ^a
BRP 50	7.78±0.06 ^b	7.74±0.06 ^{a,b}	7.31±0.43 ^b	7.42±0.33 ^b
BRP 75	6.77±0.05 ^c	7.30±0.42 ^b	6.79±0.11 ^{b,c}	6.80±0.03 ^c
BRP 100	6.76±0.11 ^c	6.69±0.25 ^c	6.46±0.36 ^c	6.75±0.11 ^c
BRP 0: Ice cream mix without any replacements of SMP with black rice powder BRP 25: Ice cream mix formulated with 25% black rice powder BRP 50: Ice cream mix formulated with 50% black rice powder BRP 75: Ice cream mix formulated with 75% black rice powder BRP 100: Ice cream mix formulated with 100% black rice powder. Data are expressed as Mean ± SD (n=3). Different superscripts in the same column indicate a significant difference ($p<0.05$).				

Conclusions

The use of black rice powder, which is abundant in bioactive chemicals, has found applications in a variety of industries, including the food industry, the pharmaceutical industry, the cosmetics industry, the packaging industry, and the textile industry. Therefore, it is possible to conclude that black rice was utilised as an appropriate functional ingredient in the production of reduced-calorie ice cream, which in turn boosts the functional qualities of products that have been optimised. In the future, research can concentrate on the outcomes of the studies that were conducted to find out more about various pigmented rice as a whole grain or powder that could be employed in the formulation of various functional ice cream or frozen desserts.

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