RESEARCH ARTICLE OPEN ACCESS

Effect of Pearl Millet and Sweet Potato Incorporation on Texture, Nutritional Profile, and Glycemic Index of Functional Ice Cream

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Abstract:

In recent years, there has been a growing awareness among consumers regarding the relationship between diet and health, leading to an increased demand for functional foods that provide benefits beyond basic nutrition. Traditional ice cream is generally characterized by high levels of sugar and fat and lacks essential nutrients such as dietary fiber. The present study was undertaken to develop a nutritionally enhanced, fiber-rich, and low glycaemic index functional ice cream by incorporating pearl millet milk and sweet potato powder as key ingredients. Three different formulations were developed by varying ingredient proportions while keeping other components constant. The prepared ice cream mixes were subjected to standard processing techniques including pasteurization, homogenization, cooling, aging, freezing, and hardening. The developed samples were evaluated for physicochemical properties, nutritional composition, and sensory attributes. The results revealed increased dietary fiber, reduced fat content, and improved texture and stability. Sensory evaluation indicated good acceptability, with Trial 2 identified as the most balanced formulation. The study demonstrates that functional ice cream with enhanced nutritional value and acceptable sensory properties can be successfully developed.

Keywords: Functional foods, Ice cream, Pearl millet, Sweet potato, Glycaemic index, Dietary fiber

I. INTRODUCTION

Ice cream is one of the most widely consumed frozen desserts across the world, appreciated for its pleasant taste, smooth texture, and refreshing nature. Traditionally, it is prepared using milk, cream, sugar, and stabilizers, which together provide a rich sensory experience [6]. However, despite its popularity, conventional ice cream is often criticized for its high sugar and fat content and its lack of dietary fiber and essential micronutrients [6]. Regular consumption of such energy-dense foods has been associated with the rising incidence of lifestyle-related disorders such as obesity, diabetes mellitus, and cardiovascular diseases [3].

In recent years, there has been a noticeable shift in consumer preferences toward healthier food options that not only satisfy taste but also contribute positively to overall well-being. This changing demand has led to the emergence of functional foods, which are designed to provide additional health benefits beyond basic nutrition [1], [2]. Functional foods are often enriched with bioactive components such as dietary fiber, antioxidants, vitamins, and minerals [1].

One of the key nutritional concerns in conventional ice cream is its high glycaemic index. Foods with a high glycaemic index are rapidly digested and absorbed, leading to sharp spikes in blood glucose levels [7]. Therefore, reducing the glycaemic response while enhancing nutritional value has become an important area of research.

Millets, particularly pearl millet, are known for their high dietary fiber, essential amino acids, and important minerals [10], [12]. Sweet potato is a nutrient-rich root crop containing complex carbohydrates, dietary fiber, and beta-carotene [15]. The combination of pearl millet milk and sweet potato powder represents a promising approach to developing a functional dessert.

The present study is designed to develop and evaluate a fiber-rich, low glycaemic index functional ice cream enriched with pearl millet and sweet potato.

II. MATERIALS AND METHODS

A. Materials Used

Choosing ingredients carefully directly affects how nutritious and appealing the final food item turns out [6]. Pearl millet (Pennisetum glaucum) was obtained from a nearby farm market, ensuring that the grains were clean, mature, and free from impurities [10]. Sweet potatoes (Ipomoea batatas) were selected based on uniform size, color, and absence of physical damage [15]. Fresh cream and milk were procured from a reliable local dairy source. Refined sugar, food-grade stabilizers, and vanilla essence were used in the formulation [6]. Distilled water was used for preparation and laboratory analysis to avoid contamination. All chemicals and reagents used for physicochemical analysis were of analytical grade [6]. The raw materials and developed ice cream product are shown in Fig. 1.

Fig. 1: Raw materials used in the study (pearl millet and sweet potato) and the developed functional ice cream.

B. Preparation of Pearl Millet Milk

Pearl millet milk was prepared through a sequence of steps including cleaning, soaking, germination, grinding, and filtration [13]. Initially, the grains were thoroughly washed to remove dirt and foreign materials. The cleaned grains were soaked in distilled water for approximately 10–12 hours at room temperature. After soaking, excess water was drained and the grains were allowed to germinate for 24–48 hours under controlled conditions [13].

The germinated grains were then ground with sufficient water to obtain a slurry. The slurry was filtered through a clean muslin cloth to separate the liquid extract, referred to as pearl millet milk. The extracted milk was stored under refrigeration until further use [14]. Germination was employed to enhance nutrient bioavailability and reduce anti-nutritional factors [13].

C. Preparation of Sweet Potato Powder

Sweet potato powder was prepared by cleaning, peeling, slicing, drying, and grinding [15]. Fresh sweet potatoes were washed thoroughly to remove adhering soil and impurities. The outer skin was removed manually using stainless steel knives. The peeled tubers were sliced into thin, uniform pieces to ensure even drying.

The slices were dried in a hot air oven at 60–70°C until constant weight was achieved, indicating complete moisture removal [17]. The dried slices were then ground into fine powder using a grinder. The powder was sieved to obtain uniform particle size and stored in airtight containers to prevent moisture absorption and contamination.

D. Ice Cream Mix Formulation

The ice cream mix was prepared by combining pearl millet milk, cream, sugar, sweet potato powder, stabilizer, and flavoring agents in predetermined proportions [5], [6]. Three different formulations (Trial 1, Trial 2, and Trial 3) were developed by varying the levels of pearl millet milk and sweet potato powder while keeping other ingredients constant.

All ingredients were mixed thoroughly to obtain a homogeneous mixture. Sweet potato powder was added gradually with continuous stirring to prevent lump formation. Cream was incorporated to provide desired fat content and texture, while sugar contributed to sweetness. Stabilizers were added to improve consistency and reduce ice crystal formation [6]. Vanilla essence was added to enhance flavor.

E. Ice Cream Processing

The prepared ice cream mix was subjected to standard processing steps including pasteurization, homogenization, cooling, aging, freezing, and hardening [6]. The mixture was pasteurized by heating at 80–85°C to ensure microbial safety. It was then homogenized to achieve uniform fat distribution and improve texture [6].

After homogenization, the mix was rapidly cooled to around 4°C and aged for several hours to improve viscosity and stability. The aged mix was then transferred to an ice cream freezer where freezing and aeration occurred simultaneously. Finally, the semi-solid ice cream was hardened at low temperatures to obtain the final product.

F. Physicochemical Analysis

The developed ice cream samples were analyzed for physicochemical parameters including moisture, protein, fat, ash, carbohydrates, and dietary fiber [6]. Moisture content was determined using a hot air oven method. Protein content was estimated using the Kjeldahl method. Fat content was measured using the Soxhlet extraction method. Ash content was determined using a muffle furnace [6].

Dietary fiber was analyzed using standard gravimetric methods [8], and carbohydrate content was calculated by difference. All analyses were carried out in triplicate to ensure accuracy and reliability. The instruments used for physicochemical analysis are shown in Fig. 2

Fig. 2: Instruments used for physicochemical analysis including Soxhlet apparatus, muffle furnace, hot air oven and Kjeldahl apparatus.

G. Sensory Evaluation

Sensory evaluation of the developed ice cream samples was carried out by a panel of trained members. The evaluation was performed using a 9-point hedonic scale, where 1 represented "dislike extremely" and 9 represented "like extremely" [22]. Parameters such as color, flavor, texture, taste, and overall acceptability were assessed.

Samples were coded and presented randomly to avoid bias. The evaluation was conducted under controlled conditions to ensure consistency. The results were recorded and analyzed statistically.

H. Statistical Analysis

The data obtained from physicochemical and sensory evaluations were analyzed using statistical methods. Results were expressed as mean ± standard deviation. Analysis of variance (ANOVA) was used to determine significant differences among formulations. A significance level of $p < 0.05$ was considered for statistical evaluation.

I. Flow chart of Methodology

The overall methodology followed in the study is presented in Fig. 3.

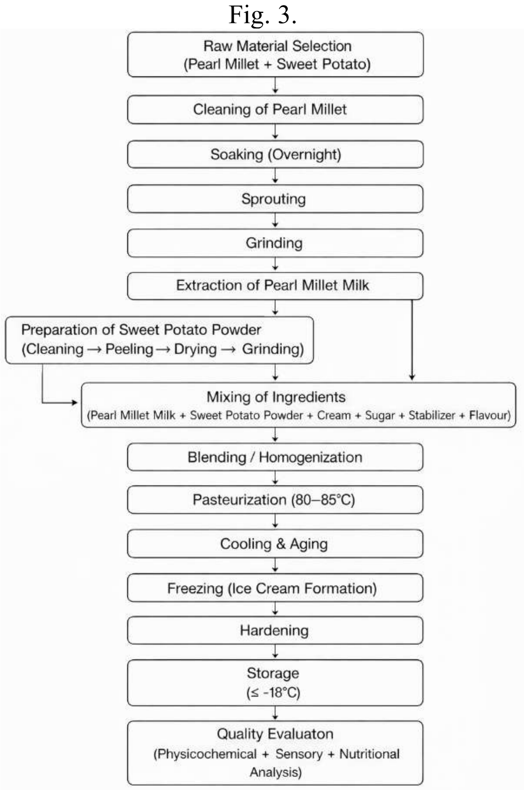

Fig. 3: Flowchart of methodology for the development of fiber-rich, low glycaemic index functional ice cream incorporating pearl millet and sweet potato.

III. RESULTS

The developed ice cream formulations (Trial 1, Trial 2, and Trial 3) were evaluated for nutritional composition, physicochemical properties, and sensory attributes. The results obtained from the analyses are presented below.

A. Nutritional Composition

The nutritional composition of the developed ice cream samples is presented in Table I.

Table I Nutritional Composition of Ice Cream (per 100 g)

Parameter	Trial 1	Trial 2	Trial 3	p-value
Moisture (%)	61.0 ± 1.0	63.0 ± 1.0	64.0 ± 1.0	<0.05
Dietary Fiber (g)	3.0 ± 0.5	4.2 ± 0.6	7.0 ± 1.0	<0.01
Protein (g)	4.0 ± 0.5	4.0 ± 0.5	3.5 ± 0.5	>0.05
Fat (g)	11.0 ± 1.0	10.0 ± 1.0	9.0 ± 1.0	<0.05
Carbohydrates (g)	28.5 ± 1.5	27.5 ± 1.5	26.5 ± 1.5	<0.05
Ash (g)	0.7 ± 0.1	0.8 ± 0.1	0.9 ± 0.1	<0.05

The results showed an increase in moisture and dietary fiber content from Trial 1 to Trial 3. Fat and carbohydrate content decreased progressively across the formulations, which is consistent with findings reported for fiber-enriched food products [8]. Protein content remained relatively constant. The variation in dietary fiber content across formulations is shown in Fig. 4 and the comparative nutritional composition is presented in Fig. 5

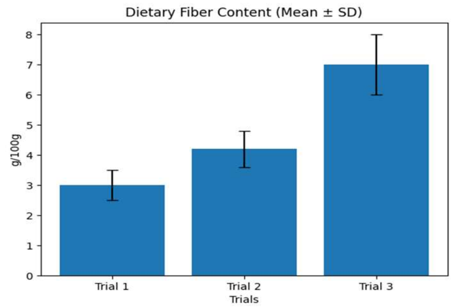

Fig. 4: Effect of formulation on dietary fiber content of developed ice cream (Mean ± SD)

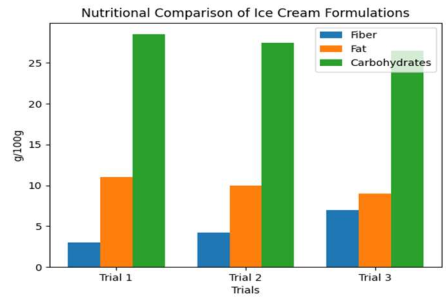

Fig. 5: Comparative nutritional composition of developed ice cream formulations.

B. Physicochemical Properties

The physicochemical characteristics of the developed ice cream are presented in Table II.

Table II Physicochemical Properties of Ice Cream

Property	Trial 1	Trial 2	Trial 3
Texture	Smooth	Smooth	Smooth
Consistency	Good	Excellent	Excellent
Melting Rate	Moderate	Moderate	Slow
Stability	Good	Very Good	Very Good
Overrun (%)	45 ± 2	48 ± 2	50 ± 3

All formulations exhibited smooth texture. Consistency and stability improved from Trial 1 to Trial 3.

Melting rate decreased with increased incorporation of sweet potato powder, which aligns with the known effect of dietary fiber on water retention and melting behavior [6], [8]. Overrun values increased slightly across trials.

C. Sensory Evaluation

The sensory evaluation scores of the developed ice cream are presented in Table III.

Table III Sensory Evaluation Scores (9-point Hedonic Scale)

Attribute	Trial 1	Trial 2	Trial 3	p-value
Colour	7.5 ± 0.3	8.5 ± 0.2	8.0 ± 0.3	<0.05
Flavour	7.8 ± 0.2	8.7 ± 0.3	8.2 ± 0.2	<0.05
Texture	8.0 ± 0.2	8.8 ± 0.2	8.3 ± 0.3	<0.05
Taste	7.9 ± 0.3	8.9 ± 0.2	8.1 ± 0.3	<0.05
Overall Acceptability	8.0 ± 0.2	9.0 ± 0.3	8.3 ± 0.2	<0.01

Trial 2 showed the highest scores across all sensory attributes. Significant differences were observed among formulations, which is consistent with previous studies indicating that balanced incorporation of functional ingredients improves acceptability [5]. The sensory profile of the optimized formulation is shown in Fig. 6.

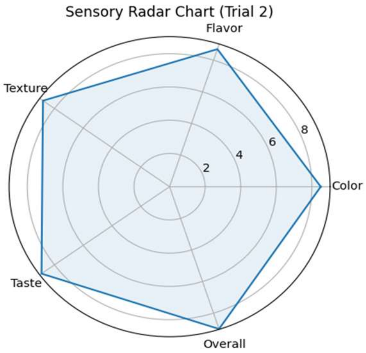

Fig. 6: Sensory profile of optimized ice cream formulation (Trial 2) based on 9-point hedonic scale.

D. Comparison with Conventional Ice Cream

A comparison between conventional ice cream and the developed product is presented in Table IV.

Table IV Comparison with Conventional Ice Cream

Parameter	Conventional Ice Cream	Developed Ice Cream
Fiber	Very low	High
Fat	High	Moderate
Glycaemic Index	High	Low
Nutrition	Moderate	High
Functional Benefits	Absent	Present

The developed ice cream showed improved nutritional and functional properties compared to conventional ice cream, which agrees with earlier studies on functional food development [1], [20].

IV. DISCUSSION

The present study demonstrated that the incorporation of pearl millet milk and sweet potato powder significantly influenced the nutritional, physicochemical, and sensory properties of the developed ice cream. The observed changes across the three formulations indicate that the functional ingredients played a crucial role in improving the overall quality of the product.

A notable outcome of the study was the progressive increase in dietary fiber content with increasing levels of sweet potato powder. This can be attributed to the high fiber content of both pearl millet and sweet potato [10], [15]. Dietary fiber is known to improve digestive health and contribute to better regulation of blood glucose levels [3], [8]. The enhancement of fiber content in the developed ice cream suggests its potential as a functional food suitable for health-conscious consumers.

A reduction in fat content was observed across the formulations, particularly in Trial 3. This reduction is associated with the partial replacement of cream with sweet potato powder. Despite the decrease in fat, the texture and mouthfeel of the ice cream were maintained, indicating that sweet potato powder contributed to the creamy consistency of the product. This finding highlights the potential of using plant-based ingredients to develop lower-fat alternatives without compromising sensory quality [5], [6].

The carbohydrate content showed a decreasing trend across the formulations, which may be linked to the reduction in added sugar and the inclusion of complex carbohydrates from sweet potato. These complex carbohydrates and resistant starch are digested more slowly, leading to a lower glycaemic response [7], [9]. This supports the objective of developing a low glycaemic index product suitable for individuals with diabetes or those seeking healthier dietary options.

Protein content remained relatively stable across all trials, indicating that the addition of sweet potato powder did not significantly affect the protein contribution of pearl millet milk. This stability ensures that the nutritional balance of the product is maintained while enhancing other functional properties.

The physicochemical properties of the developed ice cream, including texture, consistency, stability, and melting behavior, were found to be satisfactory. The presence of dietary fiber and stabilizers contributed to improved viscosity and reduced ice crystal formation [6], [8]. The slower melting rate observed in higher formulations suggests better water-binding capacity due to increased fiber content. These characteristics are important for product quality and consumer acceptability.

Sensory evaluation results indicated that all formulations were acceptable, with Trial 2 receiving the highest overall scores. This suggests that an optimal balance between pearl millet milk and sweet potato powder is essential to achieve desirable sensory characteristics. The natural sweetness of sweet potato enhanced flavor and reduced the need for added sugar, while the color imparted by beta-carotene improved visual appeal. These findings are consistent with standard sensory evaluation outcomes in food product development [22].

Overall, the findings of this study are consistent with previous research on functional foods and fiber-enriched products [1], [8]. The successful incorporation of pearl millet and sweet potato into ice cream demonstrates the feasibility of developing nutritionally enhanced dairy products without compromising quality. The study highlights the importance of formulation optimization in achieving a balance between health benefits and consumer acceptability [5].

The developed product also shows potential for commercialization, as it combines improved nutritional value with desirable sensory properties. Furthermore, the use of locally available ingredients such as pearl millet and sweet potato supports sustainable food systems and promotes the utilization of underutilized crops [20].

V. CONCLUSION

The present study shows that it is possible to develop a functional ice cream with improved nutritional quality by incorporating pearl millet milk and sweet potato powder. The developed formulations demonstrated higher dietary fiber content along with a reduction in fat, while maintaining acceptable levels of protein and overall composition.

An increase in fiber content was clearly observed with higher levels of sweet potato powder, which contributes to better digestive health and may help in regulating blood glucose levels. At the same time, the reduction in fat content without negatively affecting texture indicates that sweet potato powder can effectively act as a partial substitute for conventional fat sources in ice cream.

The carbohydrate profile of the developed product, mainly consisting of complex carbohydrates and resistant starch, supports a lower glycaemic response. This makes the product more suitable for individuals who require controlled blood sugar levels or prefer low glycaemic foods.

From a quality perspective, the physicochemical properties such as texture, consistency, stability, and melting behaviour were found to be satisfactory. The presence of natural fibers played a role in improving viscosity and maintaining structural stability. Sensory evaluation further confirmed that the developed ice cream was well accepted, with Trial 2 showing the most balanced combination of nutritional improvement and sensory attributes.

Overall, the study indicates that functional ice cream can be successfully developed using locally available ingredients without compromising consumer acceptability. The product offers a healthier alternative to conventional ice cream and holds potential for further development and commercialization.

Future work may focus on determining the glycaemic index through clinical evaluation, studying storage stability over extended periods, and exploring the incorporation of additional functional ingredients to further enhance its health benefits.

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