



Characterization of Vegetable Ice cream with improved Nutritional Qualities

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Ice cream is a nutritious and delicious product enjoyed in frozen form in all regions of the world. In recent times, consumer demand has increased for ice cream that consists of functional ingredients to fulfill not only the nutritional needs of the body but also to help manage health-related conditions. There is a need to replace cow/buffalo milk with vegetable milk to address lactose intolerance problems. Sweet potato is rich in starch, vitamin C, vitamin A, fiber, potassium, iron, and protein, and it also contributes to food security. The primary purpose of the research was the preparation of ice cream for lactose-intolerant patients and to offer a wide range of functional ingredients to tackle high cholesterol issues in dairy ice cream. The key component in the ice cream was soymilk, which was combined with coconut cream. A varying proportion of sweet potato flour (5%, 10%, 15%, and 20%) was used, and the obtained results were analyzed statistically. The physicochemical, antioxidant, textural, and sensory properties of prepared ice cream samples were investigated. The obtained results after the physicochemical analysis of vegetable-based ice cream revealed that the addition of sweet potato flour increased total solids, ash, and protein, while moisture and fat contents were decreased significantly. The total solid content of ice cream increased from 32.16% to 38.13%, and the solids-not-fat content of the samples increased from 19.41 % to 28.23 %. Protein content increased from 3 % to 5 %, and ash content increased from 0.74% to 1.37% with the increase in sweet potato flour percentage. Textural analysis revealed that overrun percentage and resistance to melting decreased, and viscosity increased from 1821 cp to 3918 cp. Total phenolic content and antioxidant activity by DPPH also increased from 32-95 mg GAE/g and 3.21-14.23%, respectively. Among all the treatments, highly appreciated ones were with 5% and 10 % sweet potato in terms of all sensory attributes.

Keywords: Soymilk, Nutritional qualities, Ice Cream, sweet potato flour.

Introduction:

The ice cream market is growing rapidly, reaching \$54.80 billion in 2016 and expected to reach a 4.1% compound annual growth rate (CAGR) by 2025 [1][2]. However, rising concerns of environmental impacts of raising dairy animals, greenhouse gas emissions, methane emissions from livestock animals, as well as lactose indigestion (60%), allergy, and cholesterol impacts of cow milk on health have paved the way for alternative dairy options [2][3][4][5]. Hence, moving towards vegan trends has increased to approximately 0.1% of the global population, with higher incidences in the US, Italy, and the UK. The global vegan products market reached \$22.6 billion in 2020 and is estimated to hit 40.6 billion by 2026. Vegetarians advocate for plant-based alternatives to dairy milk for better health, to manage lactose intolerance, and to reduce the environmental impact of raising dairy animals [6][7]. The lactose-free dairy market is the fastest-growing segment, and is expected to reach €9 billion turnover by the end of 2023 and outgrow overall dairy (7.4% vs. 2.3%). Plant-based ice cream alternatives (PBIAs) are becoming increasingly popular due to their protein content and amino acid balance. Commercially available ice creams often lack beneficial nutrients like vitamins, natural antioxidants, pigments, and polyphenols [8].

Plant-based diets are cardioprotective and beneficial for diseases like type 2 diabetes, obesity, and hypertension. They contain fiber, antioxidants, Mg, and phytochemicals, which increase insulin sensitivity and glycemic control. Moreover, vegan diets have been linked to increased longevity, reduced cancer and cardiovascular disease incidence, and improved quality of life [9][10]. Probiotic plant-milk-based food development uses major carrier matrices like soymilk, rice-milk, and coconut-milk, with other matrices like maize, oats, quinoa, buckwheat, chickpea, peanut, cashew, hemp, and walnut-milk being the major ingredients. Soymilk, almond, rice, and coconut milk are major contributors to global production, used in plain, flavored, and sweetened nondairy milk beverages [10][11]. Soy milk can be used to produce probiotic ice cream, with lecithin acting as an emulsifier and soy proteins forming a gel-like structure. Soy protein, with natural phytochemicals like isoflavones, has been recognized by the Food and Drug Administration (FDA) for health claims as it offers higher Fe, K, Mg micronutrients, and less Na than dairy milk. It has been shown to reduce cholesterol, malignancies, and prevent osteoporosis and bone resorption [12][13].

Sweet potato, a versatile and under-exploited food crop, is produced over 90 million tonnes annually by Asian and African countries, particularly China and Bangladesh. Orange-fleshed sweet potato is an exemplary source of β -carotene, with 276.98 $\mu\text{g/g}$ of β -carotene [14], and rich in anthocyanin, phenolics, minerals, fiber, vitamin C, and B-6. It has a naturally sweet taste, making it safe for diabetic patients, and shows antioxidant, antidiabetic, and cardio-protective effects, which help in controlling inflammation, cancer, and chronic diseases [15][16][17]. Coconut cream is a complex molecular fluid containing carbohydrates, minerals, lipids, and proteins from ripened coconut (*Cocos nucifera*), with a fat content ranging from 15% to 40% [18]. Coconut cream contains highly digestible unsaturated fats that liquefy at 37°C, making it an ideal ice cream fat substitute. Coconut milk and cream have 3.3 and 6.7 g/100g protein and 26.7 and 73.3 g/100g total fat, respectively [19][20].

Innovative ice cream varieties gain popularity due to rising demand and rising disposable income in the economy. Meeting consumers' demands for nutritionally improved innovative products for raising a healthy lifestyle has posed many challenges to food processors. They have to meet dietary requirements, as this requires industries to move towards innovation and fill gaps to survive in the market [20][21]. Moreover, the rheological aspect, particularly the viscosity of cream mixes, is a challenge in the technology of PBIAs [22]. Hence, the current research aimed to develop a vegan ice cream with soymilk, sweet

potato starch, and coconut cream, and to evaluate the quality and sensory acceptance of the developed product.

Materials and Methods:

Preparation of raw material:

Preparation of soy milk:

Locally purchased dried soybeans (100 g) were cleaned, washed in deionized water, and soaked for 14 h in 1 kg of distilled water at 4°C. After being drained, the soaked soybeans were blended in a blender at a low speed for 5 min in 1 kg of hot water. The mixture was then warmed at 80°C for 10 min and filtered four times using a muslin cloth, yielding 850 g filtrate, and stored at 4°C after cooling [23].

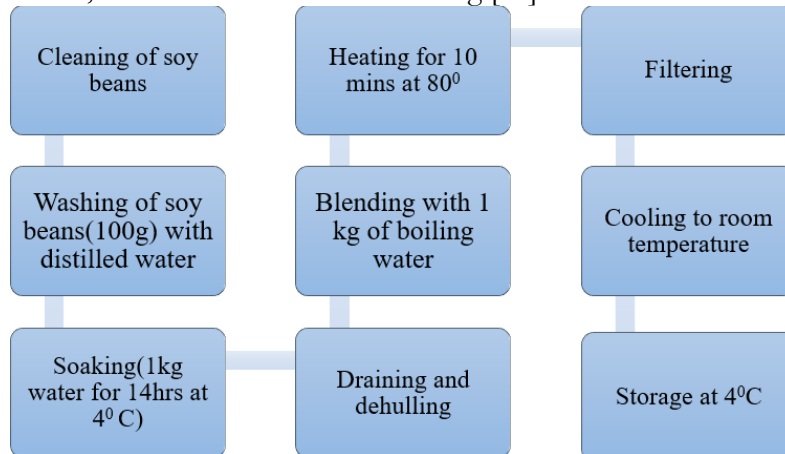


Figure 1. Preparation of soy milk [24]

Sweet potato flour preparation:

Locally purchased sweet potatoes were cleaned, washed, peeled, and then diced into 1 cm-wide cubes. Diced cubes were blanched, dehydrated in a tray dehydrator at 60°C for 10 h, cooled down, and ground to fine powder [25].

Compositional analysis of raw material:

The moisture, ash, and protein content of soy milk, coconut cream, and sweet potato powder were determined by a hot air oven, a muffle furnace, and a Kjeldahl apparatus, respectively. The crude fat of sweet potato powder was determined by the Soxhlet apparatus, while the fat content of soy milk and coconut cream was determined by the Gerber method. The crude fiber of sweet potato flour was measured gravimetrically after acid digestion and solubilization of other materials present [26].

Ice cream formulations:

A total of 5 ice cream mixes were prepared, including a control sample (DC₀), using standard formulation (sucrose 15%, MSNF 12%, milk cream 10%, stabilizers and emulsifiers 0.35%). Four vegan ice cream mixes were prepared using coconut cream (American Gardens, USA), sugar, soy milk, sweet potato powder, and stabilizer and emulsifier (CMC and soya lecithin, respectively) with formulations of VIC1 (10%, 12%, 11%, 5%, and 0.35%), VIC2 (10%, 12%, 11%, 10%, and 0.35%), VIC3 (10%, 12%, 11%, 15%, and 0.35%) and VIC4 (10%, 12%, 11%, 20%, and 0.35%), respectively. Overall, the quantity of ingredients was set according to standard ice cream composition, except for sweet potato powder, and water was added to make the ice cream composition to 100%.

All the formulations were mixed by a mechanical stirrer for 10 min at 45-50°C and pasteurized at 75°C for 20 min in a water bath (Hh-S6 Six Holes Water Bath, China) while being constantly stirred, followed by homogenization (Sigma Lab Centrifuge 3K30, UK) at 2000 psi for 2 min. After that, samples were cooled in a refrigerator (SANYO SR-L6111W, Japan) at 15°C and aged for 8 h at 4°C. Aeration was done using an aerator machine with

simultaneous freezing in a continuous freezer at -5 °C. Samples were filled into 1L containers and stored in a blast freezer (SANYO MDF-U4086S, Japan) at -25°C [27].

Table 1. Treatment plan

Formulation	Coconut Cream	Sugar	Soy Milk	Sweet Potato Powder	Stabilizer+ Emulsifier
VIC1	10%	12%	11%	5%	0.35%
VIC2	10%	12%	11%	10%	0.35%
VIC3	10%	12%	11%	15%	0.35%
VIC4	10%	12%	11%	20%	0.35%

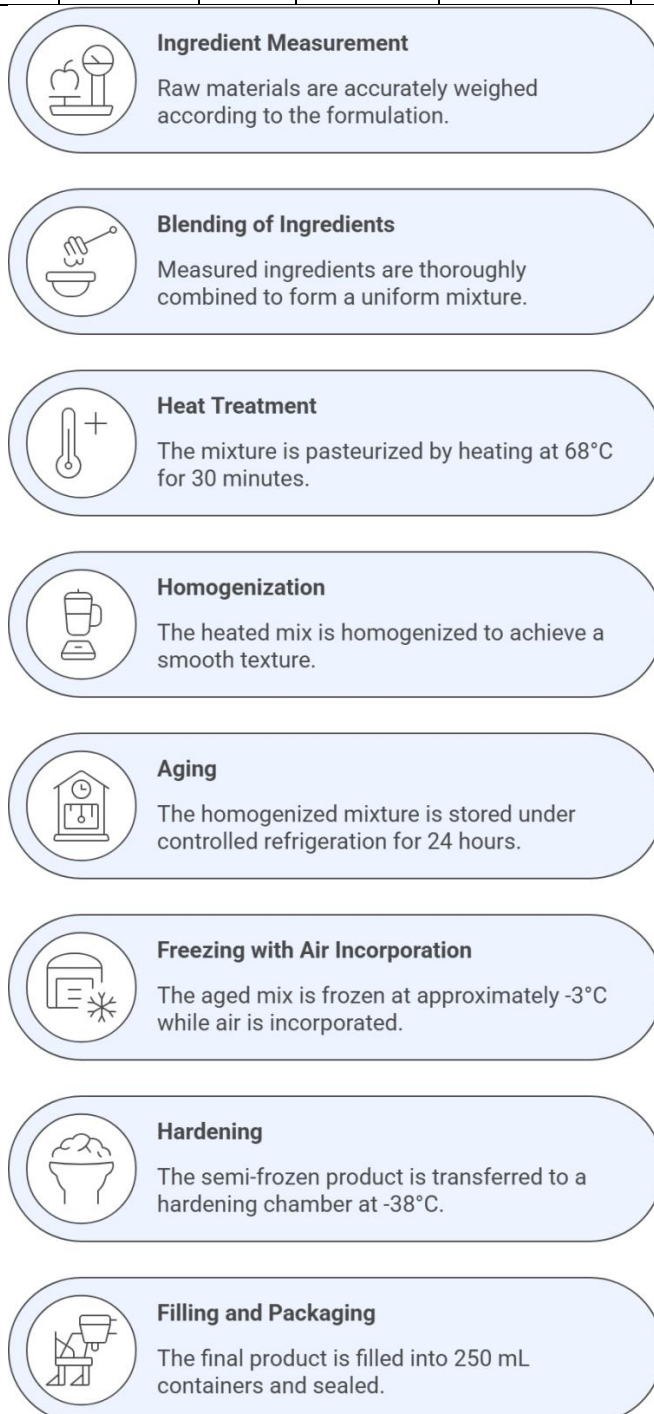


Figure 2. Preparation of sweet potato-based ice cream [27]

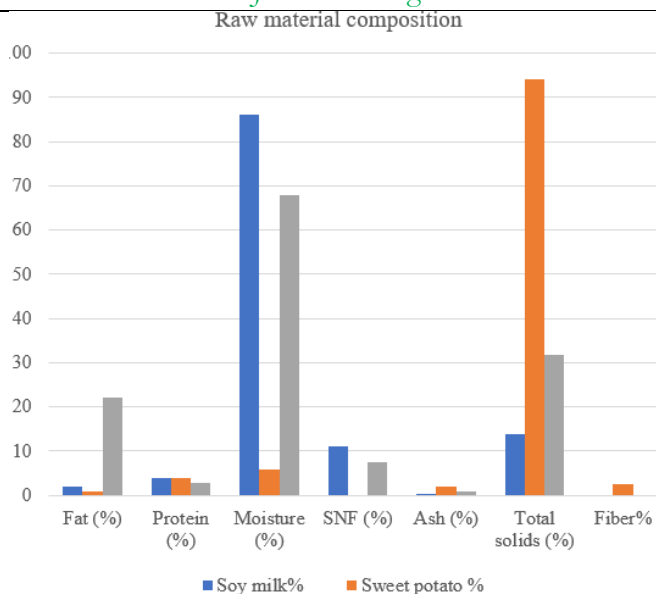


Figure 3. Graphical representation of raw material composition

Textural analysis of vegan ice cream:

Hardness:

Texture analyzer (TA-XT21, Secure Microsystems Ltd., UK) with a 6 mm probe was set at 210 mm/s penetration speed, 250 pps data acquisition speed, 5 mm penetration depth, 3 mm/s post speed, and 10 mm/s test speed. Peak compression force exerted by the probe to penetrate through the sample (-15°C) was noted down as the hardness of ice cream [27].

Viscosity:

Thawed ice cream samples were placed under a rheometer (Brookfield LVDVE-230, MA, US), equipped with spindle number 4 set at 0-100/s rising shear rate and viscosity variations written down after 30 sec intervals at 4°C [28].

Meltdown:

Samples (25 g) were placed over a 2 mm mesh size sieve, kept on top of a beaker, and the time required for the sample to melt at 25°C was noted. The volume of the melted material was calculated using a volumetric cylinder.

Overrun:

By following the procedure given by [29], the total weight of ice cream and molten ice cream was noted, and overrun was assessed using the formula:

$$\text{Overrun} = \frac{\text{Wt. of mix} - \text{Wt. of ice cream}}{\text{Wt. of mix}} \times 100$$

Physico-chemical analysis of Ice cream:

The pH, titratable acidity, total solids, ash, fat, and protein content were determined using a pH meter, titrimetric method, gravimetric method, muffle furnace, Gerber method, and Kjeldahl apparatus, respectively.

Antioxidant Analysis:

Total phenolic content:

The Folin-Ciocalteu method was utilized for determining the total phenolic content of ice cream as described by [30] and [31]. Initially, water and methanol-soluble phenols of ice cream samples were extracted for 12 h in a solution of 50% methanol, then centrifuged at 1500 rpm and filtered through Whatman No. 4 filter papers. After that, 0.2 mL of sample extract and 8 mL of distilled water were combined in a 10 mL tube and mixed with 2.5 mL Folin-Ciocalteu reagent. After 4 min, 2 mL of Na₂CO₃ solution was added, and the solution was incubated for 2 h at 25°C. The absorbance of the solution was checked at 760 nm using

a spectrophotometer (IMRECO UV-Vis Model U2020), and the results were recorded as grams of Gallic acid equivalent (g GAE)/L of the extracted sample.

DPPH:

The ice cream sample was extracted for 12 hours using a 25 ml 500 ml l1 methanol solution. 1.2 ml of methanol, 1.5 ml of 0.5 mmol/l DPPH, and 0.3 ml of the sample were added to 1.5 ml of the mixture and filtered through Whatman No. 4 papers in methanol. After 90 minutes at room temperature, the absorbance at 517 nm was measured [32][33]. The following estimate was made for the radical scavenging ability of DPPH.

$$\text{"Scavenging effect\%} = [(A_0 - (A - A_b)) / A_0] \times 100 \text{"}$$

Whereas,

Without a sample, A_0 is the DPPH value.

DPPH and the sample's value are equal to A .

A_b is the sample's value when DPPH is not present.

Sensory Evaluation:

The sensory evaluation of texture, taste, appearance, mouthfeel, flavour, and overall acceptability was done using a nine-point hedonic scale [34].

Statistical Analysis:

Variance analysis (ANOVA) was used to statistically analyse the data at a significance level of 5% [35]. The comparative analysis of variance was performed using the statistical program Statistics 8.1. Three categories were used to categorize the value: significant, highly significant, and non-significant.

Results:

Analysis of raw material:

Soy milk, as shown in Table 2, showed a moderate fat content (2.1%) and relatively high protein level (4.01%), making it a valuable plant-based protein source. Its high moisture content (86.03%) indicates that it is a diluted system, which contributes to its fluid consistency and suitability as a base in beverage or ice cream formulations. The solid-not-fat (SNF) content (11.07%) reflects the presence of proteins, sugars, and minerals, supporting its nutritional quality. Sweet potato powder exhibited very low moisture (5.7%) and high total solids (94.2%), indicating its stability and longer shelf life. It contained moderate protein (3.79%), low fat (0.79%), and a notable fiber content (2.49%), which enhances its functional and health-promoting properties. The relatively higher ash content (2.01%) suggests a good mineral presence. These characteristics make it suitable as a thickening agent and functional ingredient to improve texture and nutritional value. Coconut cream, in contrast, showed a very high fat content (22.07%), which is responsible for its rich texture and creamy mouthfeel. However, it had lower protein (2.78%) compared to soy milk and sweet potato powder. Its moderate moisture (67.8%) and total solids (31.7%) indicate a semi-solid consistency.

Table 2. Chemical composition of Soy milk, Sweet potato powder, and Coconut cream

Constituents	Soy milk%	Sweet potato powder%	Coconut cream%
Fat (%)	2.1±0.03	0.79±0.01	22.07±0.30
Protein (%)	4.01±0.02	3.79±0.05	2.78±0.04
Moisture (%)	86.03±0.85	5.7±0.09	67.8±0.24
SNF (%)	11.07±0.16	-	7.5±0.11
Ash (%)	0.3±0.005	2.01±0.03	0.96±0.01
Total solids (%)	13.97±0.21	94.2±0.87	31.7±0.48
Fiber%	-	2.49±0.03	-

Physicochemical analysis of ice cream:

The physico-chemical composition of ice cream varied significantly among treatments (T1–T5) with increasing levels of sweet potato powder. The fat content decreased

significantly ($p < 0.05$) from 12.154% in T1 to 9.90% in T5. In contrast, protein content increased significantly from 2.891% to 5.00% across the treatments. The moisture content showed a decreasing trend, ranging from 66.572% in T1 to 62.01% in T5, while total solids increased significantly from 32.161% to 38.13%. A significant increase in solid-not-fat (SNF) was observed, with values rising from 19.410% in T1 to 28.23% in T5. The pH values remained statistically non-significant among treatments, ranging from 6.33 to 6.34. Similarly, titratable acidity showed no significant differences, with values between 0.129% and 0.132%. The ash content increased significantly ($p < 0.05$) from 0.740% in T1 to 1.37% in T5. Overall, significant differences among treatments were observed for all parameters except pH and acidity.

Table 3. Physico-chemical analysis of Ice cream

Treatments	T ₁	T ₂	T ₃	T ₄	T ₅
Fat %	12.154±0.19 ^a	11.62±0.19 ^b	11.00±0.16 ^c	10.40±0.18 ^d	9.90±0.11 ^e
Protein %	2.891±0.05 ^d	3.02±0.11 ^d	3.32±0.05 ^e	4.01±0.10 ^b	5.00±0.08 ^a
Moisture %	66.572±0.67 ^a	65.89±0.69 ^{ab}	64.69±0.63 ^{bc}	63.11±0.68 ^{cd}	62.01±0.64 ^d
Total solids%	32.161±0.49 ^c	34.12±0.49 ^b	35.15±0.53 ^b	36.85±0.58 ^a	38.13±0.59 ^a
SNF %	19.410±0.30 ^c	22.14±0.29 ^d	24.07±0.36 ^c	26.39±0.46 ^b	28.23±0.43 ^a
pH	6.33±0.08 ^a	6.33±0.10 ^a	6.34±0.09 ^a	6.34±0.10 ^a	6.34±0.10 ^a
Acidity %	0.13±0.002 ^a	0.130±0.002 ^a	0.132±0.002 ^a	0.129±0.002 ^a	0.129±0.002 ^a
Ash %	0.740±0.01 ^e	0.891±0.02 ^d	1.051±0.03 ^c	1.210±0.09 ^b	1.37±0.08 ^a

Means that have distinct alphabets are significantly different from each other.

T₁ = Control

T₂ = 5% sweet potato powder

T₃ = 10% sweet potato powder

T₄ = 15% sweet potato powder

T₅ = 20% sweet potato powder

Textural Analysis of ice cream:

The physical properties of ice cream showed significant differences ($p < 0.05$) among treatments (T1–T5) with increasing levels of sweet potato powder. The viscosity increased significantly from 1821.19 cp in T1 to 3917.12 cp in T5. Similarly, hardness showed a significant increase, ranging from 19.89 N in T1 to 23.76 N in T5. In contrast, the meltdown percentage decreased significantly from 16.09% in T1 to 10.02% in T5. Likewise, overrun also decreased significantly across treatments, with values declining from 39.01% in T1 to 25.31% in T5. Overall, all physical parameters exhibited statistically significant differences among treatments.

Table 4. Physical analysis of Ice cream

Parameters	Treatments				
	T ₁	T ₂	T ₃	T ₄	T ₅
Viscosity(cp)	1821.19±0.69 ^e	3245.44±0.88 ^d	3495.04±0.72 ^c	3707.51±0.61 ^b	3917.12±0.89 ^a
Hardness (N)	19.89±0.29 ^d	20.79±0.38 ^c	21.69±0.55 ^c	22.81±0.43 ^b	23.76±0.64 ^a
Meltdown(%)	16.09±0.23 ^a	14.09±0.21 ^b	13.41±0.20 ^c	12.59±0.19 ^d	10.02±0.16 ^e
Overrun (%)	39.01±0.45 ^a	37.21±0.25 ^b	34.19±0.49 ^c	29.90±0.43 ^d	25.31±0.37 ^e

Means that have distinct alphabets are significantly different from each other.

T₁ = Control

T₂ = 5% sweet potato powder

T₃ = 10% sweet potato powder

T₄ = 15% sweet potato powder

T₅ = 20% sweet potato powder

Antioxidant analysis of ice cream:

The total phenolic content (TPC) of ice cream increased significantly ($p < 0.05$) with the addition of sweet potato powder. The values ranged from 32.10 mg GAE/g in T1 to 95.81 mg GAE/g in T5. T1 showed the lowest phenolic content, while T5 exhibited the highest value. Treatments T3 and T2 were statistically similar. Similarly, the antioxidant activity (%) showed a significant increasing trend across treatments. The values increased from 3.22% in T1 to 14.27% in T5. The lowest antioxidant activity was observed in the control (T1), while the highest was recorded in T5. Treatments T2 and T3 were statistically comparable. Overall, both total phenolic content and antioxidant activity differed significantly among treatments and increased with higher levels of sweet potato powder incorporation.

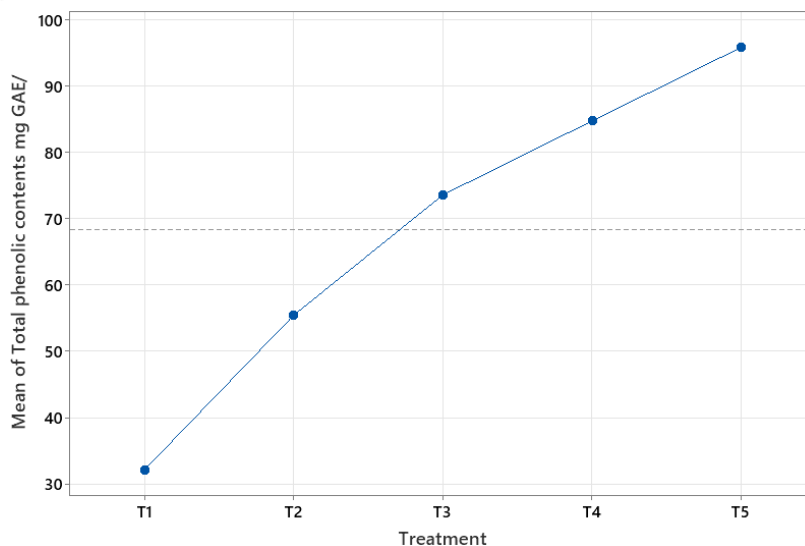


Figure 4. Factorial plot for TPC of Ice Cream

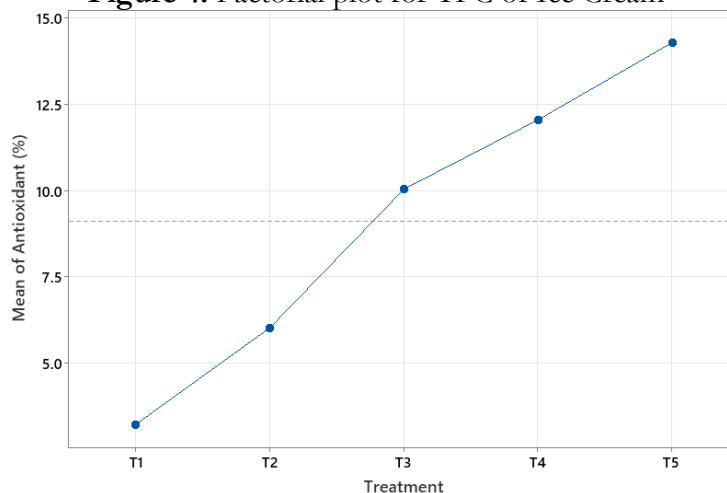


Figure 5. Factorial plot for Antioxidant (%) of Ice Cream

Sensory evaluation of ice cream:

The flavor score was highest in T3 (10% sweet potato flour) with a score of 8, while the lowest score (6.66) was observed in T5 (20%). Treatments T2 and T3 were most preferred by the panelists. The mouthfeel was highest in T1 (control) with a score of 8.33, whereas the lowest score (6.33) was recorded in T5. For taste, T2 and T3 showed the highest acceptability with scores around 7–8, while T5 had the lowest score (6.33). The texture/body showed better acceptability in lower-level treatments (T1–T3), while higher incorporation levels reduced scores. The overall acceptability was highest in T1 (8.33) and lowest in T5

(6.33), indicating a decline in sensory quality at higher levels of sweet potato flour. Overall, moderate incorporation levels (5–10%) showed better sensory acceptance compared to higher levels.

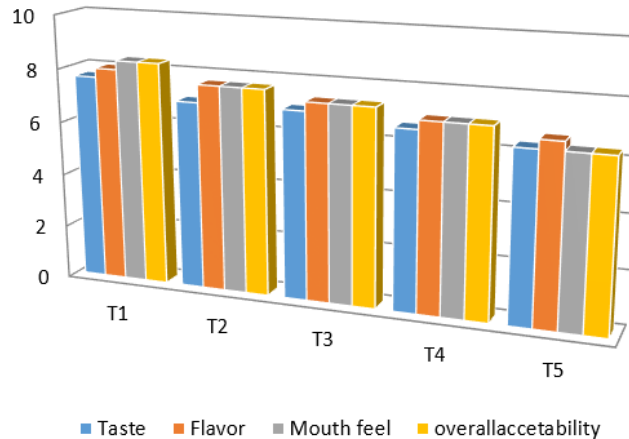


Figure 6. Sensory evaluation of sweet potato-based vegan ice cream

Discussion:

Analysis of raw material:

The chemical composition of soy milk, sweet potato powder, and coconut cream reveals significant variation in their nutritional profiles, which directly influences their functional role in product formulation.

Soy milk:

Soy milk was prepared after crushing and grinding soybeans and was analyzed for different parameters. Table 2 indicates the findings received. This showed the data of the total solids 13.97 %, moisture 86.03 %, the fat 2.1 %, protein 4.01 %, milk solids not fat 11.07 %, and the ash content 0.3 %. Such observations are close to those of [24], which focused on the production and conservation of soy milk. Another study by [36], who studied the physicochemical characterization of soymilk, also showed similar results of moisture, fat, protein, and ash. The current study results align with the findings of chemical analysis of soymilk by [37], who studied the nutritional and physicochemical characterization of soymilk.

Sweet potato powder:

Sweet potato powder was obtained by drying the sweet potatoes in a dehydrator/tray drier. Table 2 indicates the mentioned composition. Sweet potato powder contained 94.2 % of total solids, 5.7 % of moisture, 0.79 % of fat, 3.79 % of protein, 2.49% of fiber, and 2.01% ash content. Such findings are comparable to the findings of [38], who studied the functional properties of sweet potato and wheat flour. The results of sweet potato powder were similar to those reported by [39], who observed the quality characteristics of cereal-based products enriched with sweet potato powder.

Coconut Cream:

The cream was purchased from the nearby Faisalabad market. The data analysis is presented in Table 2. It revealed that cream constitutes 67.8 % of moisture, 31.7 % of total solids, 22.07 % of fat, 7.5 % of milk solids not fat, 2.78 % of protein, and 0.96 % of ash content. Same results were obtained by [40]. Similar results of proximate analysis were obtained by [41], who analyzed the impact of thermal and non-thermal techniques on the physicochemical quality of high-fat coconut cream.

In general, these ingredients can work together to make a balanced formula. Soy milk adds protein, sweet potato powder adds fiber and solids, and coconut cream adds fat and makes the product more appealing to the senses. This interaction works together to help create a product that is better for you and works better.

Physicochemical analysis of ice cream:

After the manufacturing process, ice cream was subjected to fat, protein, moisture, total solids, pH, meltdown, overrun, mouthfeel, firmness, taste, viscosity, flavor, body, texture, appearance, and overall acceptability analysis. The physical and organoleptic attributes of the ice cream are given below.

Fat:

To prepare vegan ice cream, vegetable fat was utilized. Coconut cream was utilized as a fat source in vegetable-based ice cream. Vegetable fat is healthier and more nutritious than dairy fat. Fat plays a vital part in the creation of the creaminess, richness, texture, and overall taste of ice cream. Normally, fat content in ice cream varies from 10 % to 15 %. This has a beneficial impact in terms of the physicochemical attributes of ice cream, as it facilitates the maintenance of air cells and allows for the attainment of the highest overrun. Ice crystal production was slowed down by the fat globule. Fat offers the ice cream a proper structure. Decreased fat in ice cream will result in a significant decline of structure, viscosity, fatty flavor, textural, and mouth coating problems, such as roughness, icing, shrinkage, and crumbly body. When we raised the amount of sweet potato flour in the ice cream mix, the proportion of fat was decreased. The fat level of ice cream ranged from 12.15 % to 9.87 %. The lowest fat content was found in the sample T5, which is 9.87%. Although the ice cream that contains 20 % of sweet potato (T5) has the lowest amount of fat, owing to the increased sweet potato flour percentage, as shown in Table 3. The fat content was reduced by adding sweet potato flour, which may be associated with the low fat content in sweet potato powder. [42] found that increasing the proportion of dragon fruit puree in ice cream produced the same decreasing trend of fat percentage. The current study's findings are consistent with those of [43], who substituted fat with soybean oils. The findings are consistent with earlier research showing that adding fruit powders or fiber-rich substances to dairy matrices reduced their fat content by dislodging milk particles and altering the structural network. The increasing popularity of plant-based powders as functional ingredients in low-fat ice cream recipes and berry-enriched frozen desserts has also been shown to exhibit similar declining trends [44].

Protein:

The size of the fat globules, the distribution of air cells, the protein-emulsified film adhered to the fat globules, and the physical properties of the proteins encapsulating the air cells all affect the ice cream's rheological properties. Furthermore, the protein in milk can create froth in ice cream. The protein's analysis of variance is listed in Table 3, showing that various proportions of sweet potato powder had a very significant effect on protein levels.

The mean values for the level of protein in the different treatments can be seen in Table 3. The different protein percentages in treatments were 2.89 % to 4.99 %. The maximum protein content of 5.00% was found in a sample containing 20 % sweet potato flour (T5). Moreover, a low level of 2.89% protein of ice cream was recorded at 0 % sweet potato percentage (T1). The protein content of ice cream has therefore increased from T1 to T5. The observations of the current study contradicted the outcomes of [45], who added different concentrations of pumpkin and carrot pulp into the ice cream mix. The inclusion of different concentrations of carrot and pumpkin pulp lowered protein content from 4.28% to 3.60%. Further elucidated the research where the impact of watermelon seed flour on the physicochemical characteristics of ice cream was analyzed, and their research showed that the level of protein in ice cream rose significantly by raising the proportion of watermelon seed flour. The protein content rose from 4.0 % to 6.25 % since watermelon seed flour has an appreciable amount of protein [46]. There was a significant increase in the protein level, from 4.00% to 6.25%, because the watermelon seed contains high protein content. The current research results contradict the outcomes shown by Abbas et al. [47], who described

that the replacement of sugar and fat portions with different substitutes in ice cream reduced the protein level from 8.64 % to 6.04 %. The same trend of protein was observed by [48], who investigated the use of quinoa (*Chenopodium quinoa*), chia (*Salvia hispanica*), and yellow worm larvae (*Tenebrio molitor*) in the production of nutraceutical ice creams.

Moisture:

In ice cream, there is a component that is often overlooked but has a significant impact: water. Water can be added as a solid or a liquid to keep the ice cream in a continuous phase. Measurement of total water content in a product is regarded as an analysis of the moisture. This dictates the ability and consistency of the dairy products to be stored. Various forms of attributes, such as meltdown and overrun, are influenced by it. Overrun and melting resistance are decreased as the moisture content increase, which negatively affects the ice cream's structural behavior. Moisture percentage plays an important part in the emulsion stability of the ice cream. The analysis of variance of moisture for range ice cream treatments is depicted in Table 3.

All treatments indicated that the addition of sweet potato flour had a highly significant impact on moisture content. On the moisture percentage of ice cream. Generally, moisture varies from 62.50 % to 57.71 %, according to the [49] report. In the ice cream T1 containing the 0 % sweet potato, the maximum moisture content was found. While in the T5, which is 20 % sweet potato flour, the lowest moisture content was found. As a consequence, it was obvious that by adding the flour, the moisture level in the ice cream would reduce as the starch granules present in the flour bind the water content in the ice cream. The highest moisture content in the ice cream was 66.56 % in T1 without sweet potato flour, clearly seen in Table 4. The T5 (20% sweet potato flour) ice cream showed the lowest moisture content of around 62.01 %.

The mean table 3 clearly states that there is a highly significant difference between the results of different treatments. All the treatments differ significantly from each other. The reason for this could be the higher value of the total solids in sweet potato flour. Results of [46] also showed a contradiction that by increasing the percentage of watermelon seed flour, the moisture content also increases. The observations of the current study were related to the outcomes of [45], who added different concentrations of pumpkin and carrot pulp into the ice cream mix. The addition of different concentrations of carrot and pumpkin pulp lowered the moisture content from 64.49% to 61.85%. These results are in line with [50] findings that the addition of banana flour, which is high in solids and fibre, considerably reduced the moisture content of ice cream by increasing the amount of solid components that compete for free water. The high dietary fibre and polyphenols in pomegranate peel powder bind water and reduce detectable moisture, according to [51], detection of a drop in the amount of moisture in ice cream that has been supplemented with the powder. As plant-based solids took the role of the water-rich dairy phase, [52] demonstrated that adding more berry powder to frozen desserts consistently decreased moisture, further supporting the moisture-reducing impact of fruit powders. The total solids and moisture are inversely related to one another. The same trend of moisture content was obtained by fig addition as a fat replacer. Moisture content was decreased by increasing the fig concentration, and total solids content increased.

Total solids:

The development of a firm and smooth-textured ice cream body is mainly dependent on total solids, while the excessive number of total solids allows the ice cream to form a sticky, heavy, and soggy body. The higher number of solids affects the overrun and texture, so it is very important to standardize the total solids in the ice cream development. The ice crystal production becomes higher when the total solid proportion

becomes lower. Usually, ice cream comprises 35 to 40% of total solids. To obtain the good texture of ice cream, exposure to high total solids is perhaps more important than other ingredients. When we raised the concentrations of sweet potato flour, the total solids of the ice cream increased due to the high concentration of total solids contained in the flour. When we add flour to the mix, it binds the free water present in the mix, which increases the total solids of the mix and finally of ice cream.

The total solid contents of ice cream were 32.06% to 38.01%, as shown in Table 3. Ice cream with 20 % sweet potato flour (T5) exhibited the maximum total solids, which were 38.01 %. The minimum total solids of 32.06 % were observed in ice cream containing 0 % sweet potato (T1). This fluctuation in total solids may be due to the resultant high level of total solids in the flour. The outcomes of the present research are reported to elucidate with [53], who concluded that ice cream with amla pulp (*Phyllanthus emblica*) had a relatively greater amount of total solids in comparison with the control sample. The total solid level rose by 37.5 % to 38.54 %. It was because of the total solid content present in amla pulp, so the proportion of total solids was increased by increasing the amla pulp. These results are in line with a number of studies that show comparable increases in total solids when fruit powders or plant-derived additives are added. Because banana flour has a high starch and fibre content, found that adding more of it greatly increased the ice cream's total solids. [54] found that ice creams supplemented with black carrot powder had higher total solids, which they attributed to the fruit powder's significant contribution of non-fat solids.

Solids not fat:

Solids not fat derivatives are carbohydrates, protein, and ash content. It generally contains major milk compositional constituents excluding fat and water. It is a key component of ice cream structure because protein activity improves the texture of the ice cream and provides body and structural resistance to the finished product, allowing for larger overrun without the characteristic white or flaky texture. Because of the high concentration of total solids in sweet potato flour, the solids-not-fat of the ice cream also rose with increased percentage of sweet potato flour in ice cream. Comparison of treatment means depicted that the treatment means vary significantly. Increasing the concentration of sweet potato flour improved the solid-not-fat and, more importantly, the protein functionality of ice cream. The solid-not-fat concentration of vegetable-based ice cream varied from 19.35% to 28.14%. The highest solids-not-fat concentration was observed in T5, which was 28.14%, and the lowest concentration was present in T1(control), as depicted in Table 3. The findings observed, who added different concentrations of pumpkin and carrot pulp into ice cream mix, were related to the current study. There was a significant rise in solids, not fat, of ice cream with the addition of pumpkin and carrot pulp. Solids not fat rose from 25.47% to 28.05%. The current study's results closely match those of [55], who discovered that ice cream improved with mulberry molasses had a much higher SNF and ascribed this rise to the high soluble solid content of mulberry derivatives. [56] found that adding fruit powders, such as pomegranate, to ice cream mixes significantly enhanced SNF, which supports the current study's conclusion that fruit-derived powders act as solid-contributing agents. The current findings are in line with those of [57], who highlighted that fruit powders improve the nutrient content in addition to solids and observed increased SNF in frozen desserts improved with plant-based ingredients.

pH:

The pH is one of the renowned physicochemical and quality indicators regarding dairy products. This is influenced by two essential compositional and biochemical changes. As per work demonstrated by [58], the normal pH range of ice cream is 6-7.

The analysis of variance of different treatments for vegan ice cream depicted that various proportions of sweet potato flour had a non-significant influence on pH. Specific pH levels were 6.33 to 6.34 in the treatments. Sweet potato flour addition showed non-significant differences in pH of different treatments, as is clear from the mean values tabulated in Table 3. Some other research produced similar trends with the probiotic ice cream, with the Addition of tempoyak durian lai in ice cream presented by [59]. Another research contradicts the current study in which the pH of ice cream decreased from 6.31 to 6.16 after the inclusion of black tea extract. Mulberry powder integration did not alter the ice cream pH significantly, according to [60], suggesting that mild fruit addition is not enough to counteract the natural buffering action of milk proteins and lipids. Similarly, despite the presence of natural fruit acids, [61] found that adding black carrot powder 15% did not appreciably alter the pH of ice cream. [62] discovered that ice cream enhanced with pomegranate peel kept its pH steady, indicating that fruit powders have more of an impact on the end product's solids content, colour, and nutritional profile than on its acidity.

Acidity:

The measure of acidity means how much lactic acid is produced. Many bacteria can survive as the environment of food commodities changes. Bacteria convert lactose into lactic acid. The acidity increases because of the lactic acid production. When pH decreased, acidity increased.

The acidity of ice creams with varying amounts of sweet potato flour changes non-significantly between different treatments. Likewise, pH is affected by composition and some biochemical changes in the ice cream and is expressed as percent lactic acid. Results of acidity are depicted in Table 3, that expressed the non-significant results in samples showed non-significant acidity results that range from 0.13 to 0.12%. Sweet potato flour does not affect the acidity percentage of the ice cream. As shown in Table 3, the mean values showed a non-significant difference with an increase in the percentage of sweet potato flour. T₁, containing 0% sweet potato flour, has an acidity percentage of 0.13%, and T₅, containing 20% sweet potato flour, has an acidity percentage of 0.12% that is considered the same. So, the increasing concentration of sweet potato flour does not affect the acidity percentage. Mulberry molasses did not considerably alter the acidity of ice cream, according to [60], who attributed the consistency of milk proteins' buffering action. Even if natural fruit acids are present, also found that the acidity of ice cream enhanced with black carrot powder remained unaltered. Fruit powders often affect solids content, colour, and antioxidant qualities rather than acidity, as demonstrated finding that the titratable acidity of ice cream enhanced with pomegranate peel powder remained constant.

Ash content:

The inorganic residue is formed after incineration to remove organic materials in the food sample. It measures the overall mineral content of the meal. Some of the most important minerals found in soy milk are zinc, copper, and magnesium. These micro-minerals are very important for growth and development. Sweet potato also contains several minerals that our body requires. Higher mineral content in the formulation may help slow down microbial growth and can have beneficial effects on the sensory parameters of vegetable-based ice cream. The mean amount of ash content of different treatments is shown in Table 3. The difference measured between treatments showed that the results are highly significant. A slight increase in ash percentage of all the treatments was noticed as the sweet potato flour concentration was raised. The highest ash percentage 1.37% was observed in T₅ with 20% sweet potato flour. The lowest amount of ash 0.74% was present in the control. The same trend of ash percentage was observed in

soy ice cream. According to a different study, the proportion of ash in ice cream increased as the amount of banana peel flour increased. (1.17% to 1.21%) and flour made from banana pulp (0.88% to 1.02%) [63]. In one study, for example, researchers discovered that adding more fruit pulp (such as sapota fruit pulp) to ice cream boosted its ash (mineral) content while also boosting its fibre and carbohydrate content [64]. Similarly, the ash content rose with increasing addition levels when fruit purees, including kiwifruit, were added to ice creams, indicating that the fruit contributed more solid and mineral materials [65].

Textural Analysis:

Viscosity:

Any material's resistance to flow is known as viscosity, and it is often measured in centipoises (cps). Temperature, fat globule size, stabiliser type and quantity, processing procedures (homogenisation and pasteurisation), and storage conditions all influence the viscosity of ice cream. It also describes the flavour and texture of ice cream. A viscosity level that is either too high or too low frequently results in quality defects. While a higher viscosity level reduces overrun, it also adds smoothness and increased resistance to melting. The impact of the interaction between the treatments was significant as viscosity increased with the addition of sweet potato flour. The highest viscosity of 3917.12 cp was ascertained in 20% sweet potato flour (T₄) treatment. Ice cream viscosity was lowest, with no additional 0% flour percentage (T₀). The result of the present research is similar to the observations, in which the viscosity of soy ice cream substantially increased by adding guar gum. The viscosity of chocolate ice cream was substantially increased by adding sugarcane, raisin, and grape molasses as a potential replacer for sucrose. Results of sucrose-replaced ice cream were similar to those of the current research [66]. In comparison to the control, the pomegranate peel powder-fortified ice cream showed better rheological characteristics, higher specific gravity, improved melting resistance, and higher serum-phase viscosity, indicating better water-binding and structural stabilisation. The general idea that plant-derived powders with high fibre or dry matter content strengthen the ice cream matrix is supported by the pattern seen in an investigation using *Adansonia digitata* pulp flour (baobab fruit pulp flour), where replacing a portion of skim milk powder with the plant flour resulted in higher viscosity and enhanced microstructural stability (at moderate replacement levels) [67]. [50], who incorporated the flour of green bananas (pulp or peel) into ice cream mix at modest quantities (1–2%), had similar effects. According to the study, the viscosity of the ice cream mix significantly increased as the amount of banana flour increased in comparison to the control.

Hardness:

Firmness evaluates the ice cream's ability to change from its original shape. Various parameters, such as ice crystal size, overrun, volume, ice phase, and fat destabilizing impact on ice cream hardness. The hardness of ice cream depends on different factors like total solids, initial freezing point, and overrun. The firmness of ice cream shows that all findings are significant, which indicates that applying sweet potato flour to ice cream affects ice cream firmness. The texture values ranged from 20 to 27. The analysis revealed that with the addition of sweet potato flour, firmness decreases marginally. Maximum firmness of 23.76 with 20 % flour percentage (T₅) was found in ice cream. While 0 % of sweet potato flour (T₁) showed the lowest mean of 19.89 in terms of hardness. Recent research on ice cream and frozen desserts enhanced with fibres or powders obtained from plants supports these findings. In a study using rowanberry pulp in ice cream, researchers discovered that the hardness of ice cream products considerably increased ($P < 0.05$) as the content of rowanberry pulp rose (up to 20%). Similar to this, a formulation made with *Adansonia digitata* (baobab) fruit pulp flour showed that rheological and textural qualities, such as

hardness and ability to resist breaking down in the frozen matrix, were significantly enhanced when skim milk powder was partially substituted with fruit pulp. When [68] examined a distinctive approach to enhance the properties of low-fat ice cream using date powder, they found similar outcomes. [69] indicated that higher fat destabilization results in higher viscosity. By forming a framework between the ice cream air cells, disrupted fat increased the hardness. Hence, enhance the shear force.

Overrun:

The degree to which air is absorbed while freezing into the ice cream is called the overrun and is determined in volumetric units. By substituting solids, the level of incorporated air can be decreased. If less air is used, it will lead to a thick and soggy body. On the contrary, the high absorption of air will create fluffy body ice cream. Such effect is significantly influenced by many other aspects such as stabilizer, emulsifiers, manufacturing conditions, quantity and sort of fat used, and freezing phase temperature [68]. The mean overrun percentage of ice cream is shown in Table 4, explaining the variation among all ice cream treatments. It was distinctly seen that the highest overrun was reported in the control (T_1) ice cream, showing 39.01%, while the lowest overrun was noted 25.31 % in the ice cream having 20 % sweet potato flour (T_5). Adding flour to the ice cream lowers the values of overrun. [46] also observed that the ice cream overrun was reduced by incorporating watermelon seed flour into ice cream. [70] reported the same conclusions of overrun and identified the same pattern in their study. With the inclusion of apple pulp in the ice cream, the overrun was reduced from 90-72 %. Date fiber's improved viscosity and solids content, which reduced air entrapment after freezing, greatly reduced overrun in ice cream [63]. Since higher fibre and polysaccharide levels stabilise water and fat interactions in the frozen matrix, pomegranate peel powder and berry fruit pulps have also been shown to improve structural stability and melting resistance while reducing overrun [62]. These investigations show that other functional qualities like hardness, viscosity, and melting resistance frequently increase while overrun diminishes, indicating equilibrium between aeration and structural integrity in ice creams with fibre or fruit added.

Meltdown:

Meltdown is one of the most important factors for a product's rheological attributes. A product with a rapid melting rate is extremely undesirable. Many aspects influence the meltdown rate of ice cream, including the incorporated air volume, the fat globule network, and the size of the ice crystals produced during freezing. The air cells are supported by stabilized fat aggregates, which are demonstrated by [70]. Treatments were having a significant impact due to the flour addition. Also, highly significant seems to be the interaction between storage and treatments on the meltdown levels of ice cream. The mean value of meltdown 15.9% to 11.1% in terms of treatment indicated that as the sweet potato flour proportion increased, a decreasing trend was obtained in the meltdown percentage of Ice cream. Furthermore, Table 4 showed that the highest meltdown rate was observed for the T_1 treatment, which was around 16.09 % of vegan ice cream. In vegan ice cream, the lowest meltdown value was reported by about 10.02% when the treatment of 20 % sweet potato flour (T_5) was used. Comprehensively, the major impact of sweet potato flour at the melting levels can be confirmed by the argument that ice cream fat variability and other compositional characteristics substantially influence the melting rate of ice cream.

Such findings are followed by several other researchers, such as [71], who clarified that the ice cream treatments indicated that the 5 %, 10 %, and 15 % concentration of guava pulp in the ice cream had significant impacts. With the inclusion of the guava pulp, the meltdown of the guava ice cream decreased. Meltdown fell from 56-29 %. The control sample is 56 mL/60 minutes, whereas 29 mL/60 minutes by T_3 reported the lowest meltdown. [62] presented that the incorporation of raw or refined materials into the ice

cream induces a declining effect in melting resistance. In its research, the incorporation of Doum syrup and pomegranate peel revealed the same pattern for meltdown as presented by current research. Because pomegranate peel has a greater fibre and solids content than control, it stabilises the frozen matrix and reduces free water mobility, which results in a considerable decrease in the rate of melting when added to ice cream [62]. Similarly, it has been demonstrated that adding rowanberry increases the water-binding capacity and total solids of ice cream, improving its resistance to melting [72]. Elevated polysaccharide content has been shown to increase viscosity and structural stiffness in fiber-fortified ice creams, resulting in slower melting and improved form stability under ambient settings.

Antioxidants:

Total Phenolic content(TPC):

Phenolic contents are extremely volatile and readily oxidized to produce brown, high molecular weight products. The treatment means indicate that the addition of different concentrations of sweet potato flour increases the total phenolic content of vegetable ice cream. T₅ showed the highest TPC content of 95g/ml with 20% sweet potato powder, and T₀ control showed the lowest TPC, as observed in Figure 4. The increase in total phenolic content of ice cream may be due to the high polyphenols of sweet potato.

The same increasing trend of total phenolic content was presented by [31]. In this research, different concentration of microencapsulated pistachio peel extract was added to ice cream. The peel extract addition had a highly significant impact on various treatments. Total phenolic contents were increased from 2-3.7 fold. According to [44], mulberry-enriched ice cream had noticeably more TPC and antioxidant activity than the control, indicating the fruit's bioactive components. Similarly, it was demonstrated that adding powdered blueberry peels to ice cream significantly increased TPC in a dose-dependent way, improving the product's functional value [73]. According to these investigations, phenolics obtained from fruit can successfully enhance the antioxidant profile of frozen sweets and are stable under the circumstances of ice cream manufacture.

Free radical scavenging activity (DPPH):

Sweet potato is an excellent source of naturally occurring bioactive compounds, so its inclusion in different products will improve the products' antioxidant capacity. All carotenoids, including beta carotene, are antioxidants. An antioxidant is a chemical that prevents other molecules from oxidising, thereby protecting the body from free radicals. Antioxidants prevent or reduce oxidative damage by scavenging free radicals from biological cells. Due to this reason, the integration of sweet potato will have a nutritionally beneficial impact on the final product, ice cream.

It is observable from Figure 5 that antioxidant capacity was improved with a rise in the concentration of sweet potato powder. T₅, which had 20% sweet potato powder, showed the highest antioxidant activity, which was 14.27%. The significant increase in antioxidant activity of all ice cream samples may be due to the high carotenoids of sweet potato.

The current research results for antioxidant activity are similar to the results obtained by [53]. Ice cream enriched with processed amla (shreds, pulp, preserve) showed the same increasing trend for antioxidant capacity. Another research presented the same trend of free radical scavenging activity by [74]. The results of the TPC analysis indicated that the papaya seeds had a high total phenolic content. Moreover, the papaya seeds' strong antioxidant activity was demonstrated by DPPH and FRAP. When rowanberry pulp was added to ice cream at several concentrations (up to 20%), it was found that the antioxidant capacity (DPPH) rose noticeably as the pulp content rose [72]. Similarly, it was demonstrated that adding powdered blueberry peels to ice cream significantly increased TPC in a dose-dependent way, improving the product's functional value [73].

Sensory Evaluation:

The integrated sense of taste, mouthfeel, and aroma is termed flavor. The flavor identified by [75] is a mixture of taste, smell, and mouthfeel. The flavor is a sensory sense of aroma and taste. Frozen commodities must have flavors that are potent enough to withstand freezing temperatures, processing conditions, and capable of attracting consumers [76]. The treatment being granted a top score of 8 ice cream with 10 % sweet potato flour (T3). Minimum score was 6.66 with 20% sweet potato flour (T5). The raised proportion of flour eventually maximizes the product's flavor. T2 and T3 ranked the best in terms of taste, which the sensory group enjoyed very much. The rational explanation for good taste was the disparity in ice cream, like T3, and T2 ranked 7.6 and 7.3, respectively. T3 was the highest treatment of all the samples in terms of taste and was given 8. In the mouth, the action or the overall expression of food is considered mouthfeel. Whether the product is fine, fluffy, crystalline, sticky, or greasy, parameters are used to evaluate it. The feeling of fattiness in the mouth is attributed to inadequate homogenization, extra fat, and high emulsifier levels. Greasiness is felt when the size of fat globules is more than 30-50 mm. Graininess or frozen feeling is caused by the coldness and presence of big ice crystals and insufficient moisture, producing a fluffy substance with poor melting properties [77]. Additional sweet potato flour had a significant influence on the mouthfeel of various treatments. As per panelists, the highest score was 8.33 for control (T1), whereas the lowest score was 6.33 for the 20% sweet potato flour treatment (T5) as observed in Figure 6. Consequently, in contrast to control, [55] recorded mild mouthfeel attributes of ice cream containing 20 % strawberry. The maximum pulp score of 20 % is 7.7, and the control ice cream displayed the lowest score of 4.3. The results suggest that high solids, not fat, in the finished product would eventually improve the mouthfeel of vegan ice cream with an increased proportion of sweet potato flour. The mouthfeel of T1 and T2 treatments was really good, which had 5% and 10 % sweet potato flour, according to the sensory panel. Taste is a flavor experience felt by the taste buds, and it depends primarily on the flavor, texture, and composition of the food component. Taste is the most important aspect of the product's acceptability. Taste is likely more preferred by consumers than any other sensory characteristic. Treatment with 5% and 10 % sweet potato flour (T2 and T3) was granted a flavor score of 7 for vegan ice cream. The minimum score of 6.333 was given by T5. The rise in the proportion of sweet potato flour eventually maximizes the taste of the product up to 10%. T2 and T3 scored the highest on taste in our sample procedure. Texture means the resistance of frozen items to chewiness, bite, and a considerable feel. The texture is easily standardized by controlling mix formation, processing, and freezing. Body defect classification seems to be sticky, fluffy, or soggy. The small size of ice crystals is extremely important for appealing texture. The better whipping properties and better textural properties of the ice cream increased melting resistance along with storage stability [78]. Body and texture effects physical consistency of the ice cream, which consists of the total solids and their interaction with air. The panelists identify these indicators by way of the sense of touch and sight. The strong structure of the body and smooth texture are attractive ice cream attributes that differ in formulation with an added proportion of khoa. Strong quality ice cream has a soft, velvety, and delicate feel and is smooth with air cells and tiny ice crystals [75]. The overall acceptability scoring has been measured by a hedonic score of 9 points. It's been shown that the overall acceptability of vegan ice cream is strongly influenced by treatment, and the effect was highly significant. Means of comparison shown in Figure 5 displayed the highest score of 8.33 ice cream with control (T1), while the lowest score of T4 with 20 % sweet potato flour is 6.33. According to [79], the suitability of cowpea and rice as wheat substitutes for making ice cream baskets was assessed. In the sensory evaluation, ice cream baskets made with 20 g of rice flour, 20 g of cowpea flour, and 15 g of water had the maximum acceptance (≥ 4). The overall acceptability

for ice cream earned a hedonic scale score of 8.190, which was attributed to the cumulative influence of all sensory parameters of ice cream. The overall acceptance of ice cream treatments was associated with the first impact and the formation of ice crystals during storage, as regards the assessment of sensory properties.

Conclusion:

The research shows that soy milk-based ice cream with coconut cream and sweet potato flour can become a healthy and functional substitute for regular dairy ice cream. The addition of sweet potato flour had a great impact on the nutritional profile, antioxidant, and viscosity of the product, but lowered fat content, overrun, and melting resistance. The sensory assessment revealed that the most acceptable formulations of sweet potato flour, 5% and 10%, were the most acceptable. Hence, the product is highly promising as a lactose-free, health-conscious dessert that can assist in solving food restrictions and positively influence health outcomes, especially among patients with cholesterol-related issues and lactose intolerance.

Nutritional Implications of the Study:

The study indicates important nutritional implications of developing soy milk-based ice cream enriched with coconut cream and sweet potato flour. The product is lactose-free and therefore can be used by persons with lactose intolerance and dairy allergies. The addition of sweet potato flour enhanced the nutritional profile by adding protein, total solids, solid-not-fat, dietary fiber, and mineral (ash) content, thus improving the nutrient density. Moreover, the pronounced enhancement in the total phenolic content and antioxidant activity indicates possible health advantages associated with the alleviation of oxidative stress and maintenance of overall metabolic health. The formula also exhibited less fat content, and this could be helpful to consumers who are conscious of cholesterol levels and heart health. Though an increase in the concentration of sweet potato flour decreased overrun and melting resistance, the intermediate concentration of flour (5-10) offered an improved balance between nutritional improvement and sensory acceptability. In general, the product developed can be regarded as a functional and healthy frozen dessert, especially useful among health-conscious consumers and people with dietary limitations.

Future Recommendations:

Further studies should explore the use of other vegetable-based flours (e.g., carrot, beetroot, pumpkin) to enhance the nutritional diversity and functional properties of ice cream.

Optimization of formulation is recommended to improve sensory acceptance at higher sweet potato flour levels (15% and 20%), particularly focusing on texture and flavor balance.

Shelf-life studies should be conducted to evaluate microbial stability and storage behavior of vegetable-based ice cream under different conditions.

In vivo and in vitro studies are suggested to validate the health benefits, especially antioxidant activity and cholesterol-lowering effects.

The use of natural stabilizers and emulsifiers could be investigated to improve overrun and melting resistance without compromising nutritional quality.

Consumer acceptance studies on a larger population should be carried out to assess market potential and preferences.

Exploration of sugar alternatives (e.g., stevia, dates, or low-glycemic sweeteners) is recommended to develop diabetic-friendly variants.

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