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Extraction and characterization of chickpea protein isolate and its application in the development of a plant-based frozen dessert

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The purpose of this study was to develop a plant-based frozen dessert fortified with chickpea protein isolate (CPI) and then assess its physicochemical, functional, and sensory qualities. CPI was selected for its high protein content (84.69%) and positive functional properties, including solubility (60.2%), foaming capacity (62.37%), and emulsion capacity (69.54%). The formulations S1, S2, and S3 represented 5%, 10%, and 15% CPI, respectively. As the CPI concentration increased, the pH rose from 6.68 to 6.98, while the titratable acidity decreased from 0.18% to 0.15%. The protein content ranged from 3.89% to 4.03%, and the fat content slightly decreased from 4.07% to 3.97%. Viscosity increased from 2317 to 2709 cP, but the overrun reduced from 31.56% to 28.78% as the CPI increased. The melting resistance improved, and the melting time increased from 47.78 to 51.05 minutes. The enhanced melting resistance was attributed to the emulsifying and foaming properties of CPI, which stabilized the fat globules and air cells and slowed the ice crystal growth during melting. Sensory evaluation revealed that the formulation containing 10% CPI (S2) was the most similar to the control in terms of overall acceptability. These findings demonstrate the potential of CPI as a functional protein source in non-dairy frozen desserts, providing an enhanced texture and stability while maintaining an acceptable sensory quality.

Sustainability spotlight

This study encourages sustainable food innovation *via* the development of a non-dairy frozen dessert with chickpea protein isolate (CPI) and oat drink, both of which are resource-efficient, plant-based ingredients. Chickpeas are drought-tolerant and require little irrigation, and oats provide health advantages and have a lower environmental impact than dairy. This frozen treat decreases greenhouse gas emissions by replacing animal-derived components, addresses lactose sensitivity, and promotes vegan diets. The formulation retains favorable sensory and functional qualities, making it a viable alternative to traditional ice creams. This study supports global sustainability goals by providing a healthy, low-impact, and inclusive product for environmentally concerned and health-sensitive consumers.

1. Introduction

The demand for non-dairy-based beverages has increased by 61% since 2012. New diets like vegetarian and vegan have also increased the demand for plant-based drink alternatives (PBDAs). PBDAs are made from water extracts of plants like legumes, nuts, and grains. They are called "drinks" or "beverages" instead of "milk".[1] High levels of saturated fats and cholesterol are present in animal-based foods that are linked to high risk of cardiovascular diseases. However, fruit and vegetable rich diet are linked to reduced risk of cardiovascular diseases. The environmental impact of animal agriculture has increased consumer interest in sustainable foods. A critical overview of the dairy industry is necessary because cows are a major greenhouse gas source. Cows are bigger greenhouse gas emitters than other livestock. Livestock production contributes to only 18% of the total greenhouse gas emissions.[2] Lactose is a sugar in milk. 65% of the global population has a reduced lactose digestion ability. A milk-free diet can lower the risks of cardiovascular diseases, cancer, atherosclerosis, and diabetes. Its downsides include lower protein content, limited mineral/vitamin absorption, and potential oral health issues.[3] Plant-based drink alternatives are essential for the vegan food industry. They are crucial for lactose-intolerant and cow milk-allergic consumers. However, the protein content in plant-based drinks is low, except for soy drinks. A nutritional assessment of PBDAs has not been extensively explored. PBDAs are naturally low in fat, but vegetable oils are added in them for the creamy texture.[2]

Proteins are important in frozen desserts because they help create and stabilize its structure, including the foam and lipid

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emulsion. They also play a role in how fat globules come together during freezing. Adding more protein can make a frozen dessert healthier and change its texture. Soy and pea proteins are popular plant-based choices because they can hold water, form gels, absorb fat, and make emulsions. However, they may neither have good protein quality nor will they be easily digestible as animal-based proteins from meat, dairy, and eggs. Chickpea (*Cicer arietinum* L.) is a widely grown and consumed legume crop globally. Chickpea is economical and nutrient-dense with 20–22% protein. Drought resistance, affordability, and high protein content make it promising. Its cultivation and use can contribute to sustainable, protein-rich food solutions.[4] Chickpea has a comparable protein content to other legumes like common beans and soybeans. Chickpea protein has high bioavailability and digestibility (48–89.01%). The main storage proteins are globulins (legumin and vicilin) and albumins. Chickpea proteins have a good amino acid balance (Glu, Asp, Arg, Leu, Phe, Lys, and Ser) and are deficient in sulfur-containing amino acids Met and Cys. Heat treatment enhances their nutritional quality by removing anti-nutritional factors. They are a valuable protein source for vegans, plant-based diets, and low socioeconomic groups. Albumins (15–25%) and globulins (60–80%, vicinin and legumin) are major fractions. Albumins have a higher nutritive value due to lysine and sulfur amino acids. Chickpea proteins have a high biological value, balanced amino acids, and low anti-nutritional factors. Their potential health benefits and functional properties make pea proteins versatile.

Oats (*Avena sativa* L.) are rich in protein, soluble fiber, and bioactive compounds. Bioactive compounds include β-glucans, phenolic compounds, and phytic acid. These elements are important for nutrition and health benefits.[5] Their benefits include preventing type II diabetes and reducing cholesterol. Oats have a high protein content (15–20 g/100 g) compared with other cereal grains (7–14 g/100 g). Oat protein contains all essential amino acids, including lysine. Peptides from hydrolyzed oat proteins have anti-oxidant, anti-inflammatory, anti-fatigue, and anti-hypertensive effects. Oat drinks have emerged as prominent plant-based drinks globally. Oat drinks have surpassed almond drinks in sales in the UK.[6]

Fat globules inhibit ice crystal growth and prevent coarseness.[7] Ingredients include sugars, lipids, stabilizers, and water. A homogeneous blend and proper emulsification are crucial for quality. Developing a non-dairy frozen dessert with a creamy texture is challenging. Dairy fats play a key role in the creamy mouthfeel. Coconut oil, used in many plant-based frozen desserts, is high in saturated fats. Replacing saturated fats with unsaturated fats can reduce heart disease risk by around 13%.[8]

The objective of this study is to extract and characterize the protein isolate from chickpeas, assess its functional characteristics, proximate its composition, and investigate its potential use to develop a plant-based frozen dessert. The study specifically aims to evaluate the physical, chemical, functional, nutritional, and sensory qualities of the final product while utilizing the incorporation of chickpea protein isolate at different concentrations using the oat drink as the base.

2. Materials and methods

2.1. Procurement of raw materials

The raw material required to extract the protein isolate from chickpeas (Kabuli) was collected from an agricultural store, Lovely Professional University, Punjab, India. The collected chickpeas were washed properly with tap water to remove dust and other foreign particles. The washed chickpeas were kept in a tray drier at 60 °C for 8 h to obtain the optimum moisture content for the preparation of the chickpea powder, as presented in Fig. 1. The moisture content was studied in an oven at 105 °C till it attained a constant weight.[9]

2.2. Preparation of the chickpea powder

The dried chickpea grains were ground into a fine powder with the help of a grinder. The powder was then filled into plastic bags (Ziploc) and kept in a locker at room temperature to avoid moisture and contamination.

2.3. Protein extraction

300 g of defatted chickpea flour was dispersed in 3000 mL of water, and the pH of the solution was adjusted to 9.0 using 1.0 N NaOH. Then, the solution was stirred at room temperature for 1 h, with the pH checked and re-adjusted to 9.0 in a 30-min interval, followed by centrifugation at 6000 rpm for 20 min. Pellet A was discarded, and supernatant A was filtered through a muslin cloth. The pH of the filtered solution was adjusted to 4.9 using 1.0 N HCl to precipitate globulin protein, followed by centrifugation at 6000 rpm for 5 min. Then, supernatant B was discarded, and pellet B was collected and re-dispersed in 200 mL of water by stirring for 2 h at room temperature to ensure full dispersion. The pH of the globulin protein solution was neutralized to 7.0 using 0.1 N NaOH, and then, the globulin protein fraction powder was obtained by freeze-drying for 90 h.[10]

2.4. Proximate analysis and functional properties of chickpea protein isolate

The moisture content of chickpea protein isolate (CPI) was determined using a hot-air oven at 105 °C till it attained a constant weight.[9] The ash content was determined for the charred sample. The crucible was placed in a muffle furnace at 600 °C for 2 h. After that, the crucible was cooled in a desiccator and weighed.[11] The protein content of CPI was determined using the Kjeldahl method using a digestion and distillation unit.[12] The fat content of the CPI powder was determined using the Soxhlet apparatus.[9] The fiber content of CPI was determined using the gravimetric method.[13] The total carbohydrate content was calculated by difference.[14] The carbohydrate percentage was calculated using eqn (1).

$$\text{Carbohydrate (\%)} = 100 - (\text{fat} + \text{moisture} + \text{ash} + \text{fiber} + \text{protein}) \quad (1)$$

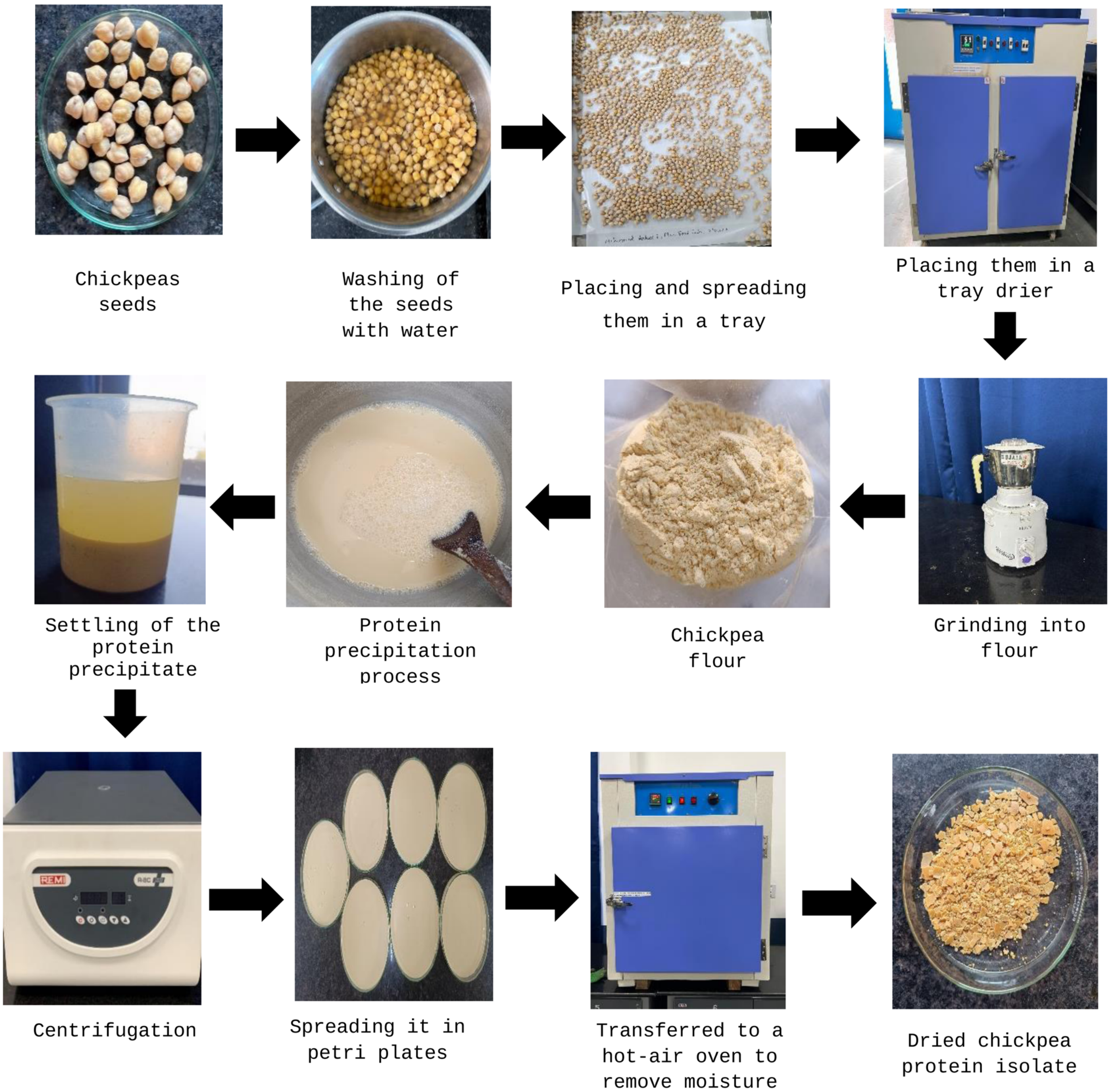

Fig. 1 Flow chart of the preparation of CPI.

2.5. Characterization of CPI

2.5.1 Solubility. Protein solubility (%) was measured according to the procedure reported by Stone *et al.* (2015).[14] 0.2 g of CPI was dispersed in 19 mL of a 0.1 N NaCl solution. The pH was adjusted to 7.00 using either 0.5 N HCl or NaOH, and the mixture was stirred at 500 rpm for 1 h at room temperature. The total solution volume was then adjusted to 20.0 mL with 0.1 N NaCl. The mixtures were left to stand for 10 min to allow precipitation. Subsequently, the solution was centrifuged at 4180 rpm for 10 min at room temperature. The protein content of the supernatant was determined using a micro-Kjeldahl digestion and distillation unit.

$$\text{Solubility (\%)} = \left(\frac{\text{protein content in supernatant}}{\text{total protein content in sample}}\right) \times 100 \quad (2)$$

2.5.2 Water holding capacity and oil holding capacity. The water and oil holding capacities of the protein isolate were assessed using the method described by Tan *et al.* (2014).[15] 0.1 g of the sample was suspended in either 1.5 mL of water or an equal amount of sunflower oil, respectively, for 1 min in a pre-weighed centrifuge tube and then held at room temperature for 30 min. After centrifugation at 5000*g* for 30 min, the supernatant was discarded, and the water and oil holding capacities were determined by weighing.

2.5.3 Emulsifying capacity and emulsion stability. Emulsion capacity and stability were assessed using a method reported by Shen *et al.* (2021).[16] Chickpea protein (1.75 g) was homogenized with 25 mL of distilled water for 30 s using a blender. Subsequently, 25 mL of soybean oil was added to the suspension and homogenized for another 30 s. The resulting emulsion was then centrifuged at 1100 rpm for 5 min. Emulsion capacity (EC) was calculated using eqn (3):

$$\text{EC }(\%) = \left(\frac{H_1}{H_0}\right) \times 100 \tag{3}$$

where H_0 is the total height of the emulsion in the tube and H_1 is the height of the emulsified layer.

For emulsion stability (ES), the emulsion was heated at 80 °C for 30 min and then centrifuged in the same manner. The emulsion stability was calculated similarly to EC.

2.5.4 Foaming capacity and foaming stability. Foaming capacity and stability were measured following the method described by Shen *et al.* (2021).[16] 0.5 g of protein was dispersed in 50 mL of deionized water in a beaker. The suspension was homogenized for 2 min at 20 000 rpm and then immediately transferred to a graduated cylinder, and its volume was recorded (V_1). Foaming capacity (FC) was calculated using eqn (4):

$$\text{FC }(\%) = \left(\frac{V_1 - V_2}{V_0}\right) \times 100 \tag{4}$$

where V_0 is the initial volume of the protein suspension and V_2 is the volume of the protein suspension after homogenization at 0 min.

The total volume was recorded at 0, 15, 30, 45, 60, 75, and 90 min. Foam stability (FS) was calculated using eqn (5):

$$\text{FS }(\%) = \left(\frac{V_t}{V_0}\right) \times 100 \tag{5}$$

where V_t is the volume of foam at a specific time after homogenization.

2.5.5 Bulk density and tapped density. To determine the bulk density of the protein powder, 2 g of the sample was added to a 10-mL graduated cylinder, and its volume was recorded. The bulk density was calculated by dividing the mass by the volume (kg m^{-3}). Then, using a glass rod, 150 taps were performed at a constant speed on the powder sample in the graduated cylinder. The tapped density was calculated by dividing the mass by the volume of the sample after tapping.[17]

2.6. Preparation of the optimal plant-based frozen dessert based on the oat drink and incorporating chickpea protein isolate

2.6.1 Procurement of raw materials. The raw material (oats) required to prepare the oat drink was collected from the agricultural store, Lovely Professional University, Punjab, India.

2.6.2 Preparation of the oat drink. The preparation of the oat drink was performed according to the method by Deswal *et al.* (2014) with minor changes.[18] 300 g of organic rolled oats was weighed and mixed with 900 mL of distilled water in a bowl while maintaining a 1 : 3 ratio of oats to water. The oats were allowed to soak for 8 h at room temperature to soften and hydrate the grains. After soaking, the oats were drained and transferred to a blender. Fresh distilled water was added to the blender, maintaining the same 1 : 3 ratio (900 mL of water for 300 g of oats). The mixture was blended at a high speed for 2–3 min until a smooth, homogenous slurry was obtained. After blending, the oat mixture was filtered using a muslin cloth. The oat drink was pasteurized by heating it at 85 °C for 15 s to ensure microbial safety and extend the shelf life. The oat drink was rapidly cooled and stored in an airtight container at 4 °C in a refrigerator until further use in frozen dessert production.

2.6.3 Preparation of the frozen dessert incorporating chickpea protein isolate. The formulation methods for the oat drink-based frozen dessert containing CPI were inspired by Atallah (2017)[19] and Vogelsang-O'Dwy (2021).[20] The samples were prepared using different concentrations of the oat drink combined with varying amounts of CPI (5, 10, or 15%). It was noted during trials that >15% CPI destabilized the protein in the O/W emulsion.[21] A control dessert was also made by following the same steps without adding CPI. For each frozen dessert batch (100 g), the oat drink was mixed with 12% sugar, 5% coconut oil, 0.12% guar gum, 0.2% xanthan gum, 0.3% lecithin, 0.1% salt, and 0.5% vanilla essence. The mixtures were pasteurized at 85 °C for 1 min and then homogenized using an electric mixer to evenly distribute the ingredients. The homogenized frozen dessert bases were rapidly cooled to 4 °C and aged for 12 h in a refrigerator to improve texture and stability. After aging, each base was churned using an electric mixer until reaching the desired consistency. The churned frozen desserts were packed into airtight containers and hardened at −22 °C for 24 h before serving. This standardized method ensured consistency across the different oat drink-based frozen dessert formulations with varying chickpea protein levels as well as the control, allowing for comparative analysis of their properties, as given in Fig. 2 and Table 1.

2.7. Physiochemical properties of the developed frozen dessert

2.7.1 pH. The pH values were measured according to the AOAC 14.022 method. Approximately 10 g of the samples was combined with 100 mL of deionized water and agitated for 5 min. The pH of the resulting filtrate was subsequently measured using a Mettler-Toledo Delta 320 pH meter. Prior to the measurement, the pH meter underwent calibration using buffer solutions with pH values of 4.0 and 10.0.

2.7.2 Titratable acidity. Titratable acidity was expressed as the percent acid present and determined by titration against 0.1 N phenolphthalein as an endpoint indicator. The pH value was obtained using a digital pH meter (Mettler-Toledo Delta 320) after standardizing with buffers.[22]

2.7.3 Protein. The protein estimation of the prepared plant-based frozen desserts was carried out using the Kjeldahl method (AOAC 2005). From the nitrogen content of the samples, the protein content of different samples was calculated by multiplying by a factor of 6.25.[23]

2.7.4 Fat. The fat contents of the developed plant-based frozen desserts were determined using the Soxhlet method.[24] The calculation was performed using a specific formula outlined in ref. 23.

2.7.5 Melting time. To determine the melting time, a metal ring shaped like a cone (stored at −30 °C for 24 h, with a 35-mm

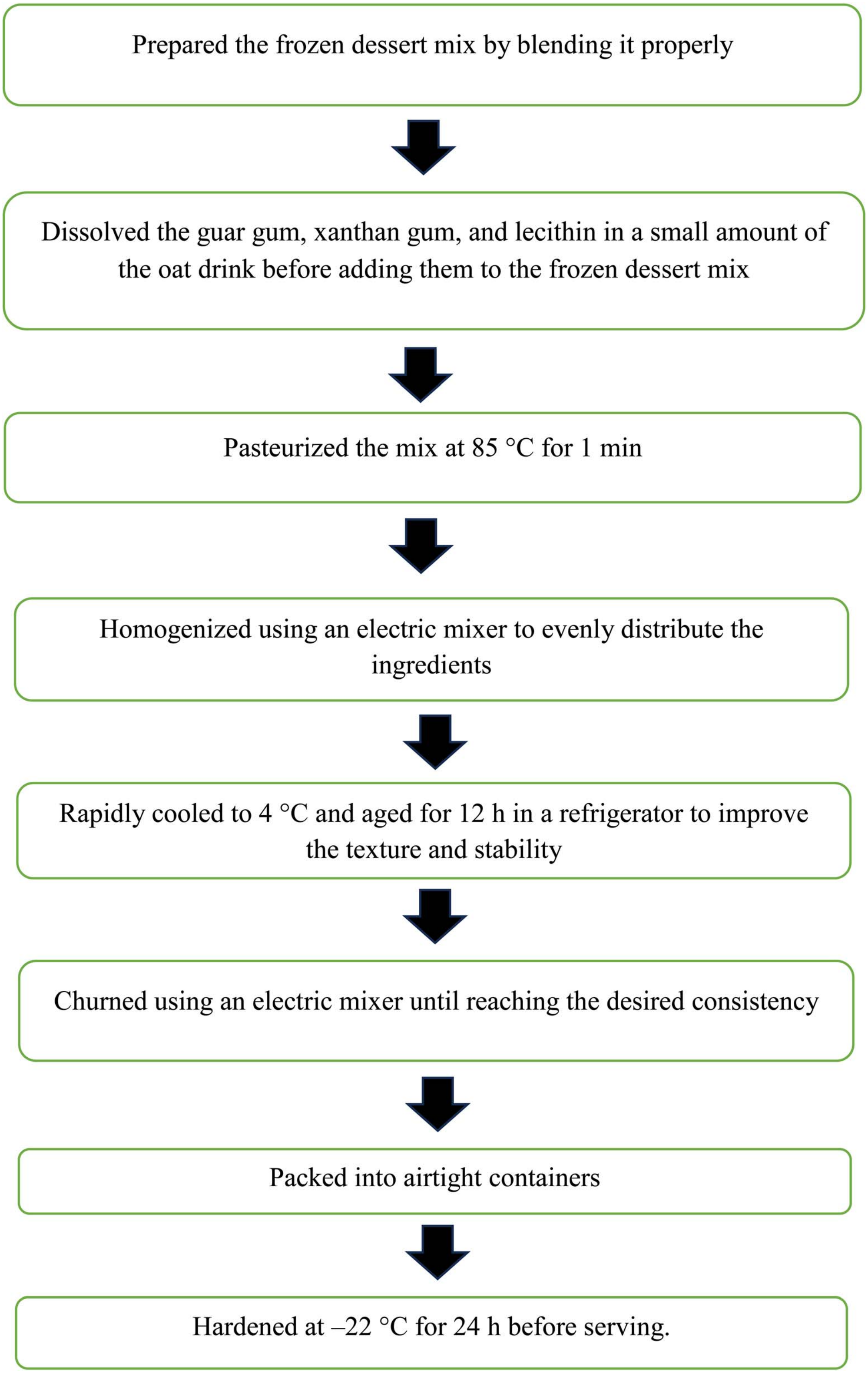

Fig. 2 Flow chart of the preparation of the optimal plant-based frozen dessert based on the oat drink by incorporating CPI.

height, a 35-mm upper diameter, a 25-mm lower diameter, and a volume of 30 mL) was inserted into the sample. Subsequently, the frozen dessert samples were removed from the ring, placed on a funnel with a mesh, and then transferred to a temperature-controlled chamber set at 25 °C. The time taken for the first drop of the melted frozen dessert to drip was then recorded.[25]

Table 1 Formulations of the oat drink-based frozen dessert incorporated with chickpea protein isolate

Formulation	Control (%)	S1 (%)	S2 (%)	S3 (%)
Oat drink	81.78	76.78	71.78	66.78
CPI	0	5	10	15
Coconut oil	5	5	5	5
Sugar	12	12	12	12
Guar gum	0.12	0.12	0.12	0.12
Xanthan gum	0.2	0.2	0.2	0.2
Lecithin	0.3	0.3	0.3	0.3
Salt	0.1	0.1	0.1	0.1
Vanilla essence	0.5	0.5	0.5	0.5

2.7.6 Viscosity. The viscosity of the prepared oat drink-based frozen dessert incorporated with CPI was measured using a rotatory viscometer at an rpm of 50. The spindle used in the viscometer is L0, and the viscosity is reported as cP. The frozen dessert was melted at 4 °C for 24 h before viscosity measurements. The readings were noted and later analyzed.

2.7.7 Overrun. The overrun was calculated using the difference in the weights of a fixed volume of the frozen dessert mixture and the frozen dessert after churning. A gravitational cup was filled with the frozen dessert mixture after aging and weighed; then, the cup was filled with the frozen dessert after creaming. The formula is as follows, and the results were expressed as %.[26]

$$\text{Overrun} = \frac{(M - I)}{I} \times 100 \tag{6}$$

where M is the weight of the developed frozen dessert after aging and I is the weight of the frozen dessert.

2.7.8 Total solids (TS). The total solid content of the frozen dessert was determined according to the AOAC 2005 standards.[27] The total solids of the samples were determined by drying the samples at 105 °C overnight to a constant weight using an air oven.

2.7.9 Sensory evaluation. The sensory evaluation of the samples of the oat drink-based frozen dessert incorporated with CPI was carried out by a panel of 30 semi-trained participants.[28] The panelists were given samples and asked to evaluate the samples for their color, flavor, texture and overall acceptability using a 9-point hedonic scale. Sensory evaluation was performed after obtaining informed consent from all participants before participation. The study was reviewed and approved by the Research Committee of the School of Agriculture, Lovely Professional University (LPU/36124). Participants were fully informed about the study's nature and goals and were free to discontinue participation at any moment. Their information was anonymized and used only for the study.

2.7.10 Statistical analysis. All the statistical analyses were performed using Minitab 20 Statistical software.[29] The statistical analysis of the results was performed by calculating the mean ± standard error from three independent measurements. To evaluate the datasets, a one-way analysis of variance (ANOVA) was conducted for multiple comparisons between the samples. This analysis was carried out at a 95% confidence level. Subsequently, the mean significant difference was determined using Fisher's method at a significance level of $p < 0.05$.

3. Results and discussion

3.1. Proximate analysis of CPI

Proximate analysis was conducted to determine the composition of CPI, including protein, fat, carbohydrate, fiber, ash and moisture. The results obtained for the proximate analysis of the CPI are presented in Table 2. The protein content in CPI was observed to be 84.69%. This was in alignment with the results obtained in another study,[30] which reported a high protein content (83.5%) in CPI. The study showed that the protein content in the two varieties of CPI (84% and 80.57%) is similar to the results obtained.[31] Another study also reported a high protein content (93.96%) in chickpea seed protein isolate, which aligns with the findings of the study conducted by Ramani (2021).[32] The fat content in the CPI was measured to be 2.31%, which agrees with the findings in ref. 31, in which the fat content of two varieties of CPI was found to be 2.47% and 2.25%. In the study of Guler-Akin *et al.* (2021),[33] the fat content was found to range from 4.13% to 4.18%. The fat content in CPI is low because its production involves the extraction and isolation of protein from chickpeas. These processes lead to the reduction of non-protein components like fats, carbohydrates and fibers. The carbohydrate content present in the CPI was 4.99%. The result reported showed that the CPI contained 4.84% carbohydrates.[31] It was also reported that the carbohydrate content was found to be slightly lower, *i.e.*, 2.96%.[32] Like the fat content, the carbohydrate percentage present in CPI was also less because of the reduction of non-protein components during the isolation of CPI.[31] The fiber content was only 0.38% of the composition of the CPI. This is because the isolation of protein in the CPI makes it a highly concentrated source of protein with minimal non-protein components. The observation agrees with the literature.[31] The CPI was found to have only a 3.34% moisture content. Another study had very similar values of moisture contents, *i.e.*, 3.67% in one and 3.34% in

Table 2 Proximate analysis of CPI

	Protein (%)	Fat (%)	Fiber (%)	Moisture (%)	Ash (%)	Carbohydrate (%)	Ref.
Obtained results	84.69 ± 1.53	2.31 ± 0.50	0.38 ± 0.02	3.34 ± 0.23	4.27 ± 0.27	4.99 ± 2.09	
Results reported in literature	78.00 ± 2.1	3.5 ± 0.40	3.8 ± 0.30	3.30 ± 0.20	2.9 ± 0.30	11.8 ± 1.5	48
	84.00 ± 0.38	2.47 ± 0.01	0.44 ± 02	3.67 ± 0.10	4.58 ± 0.00	4.84 ± 0.31	49
	86.37 ± 0.47	2.25 ± 0.04	0.14 ± 0.02	3.34 ± 0.06	4.76 ± 0.11	8.95 ± 0.35	50

another variety of CPI.[31] The low range of the moisture content in CPI is likely due to the drying process it underwent during production. This is important for maintaining the stability, quality and shelf life of the CPI. The ash content in CPI typically ranged from 2–5%. In the study, it was found to be 4.27%. This agrees with the findings of Mesfin *et al.* (2021).[49] The low range of the ash content is necessary to maintain the functional properties of the CPI.

3.2. Functional properties of CPI

The functional properties of the CPI were tested, and the results are presented in Table 3. The solubility of the CPI was found to be 60.2%. This aligns with the solubility of the two varieties of CPI (61.08% and 59.34%) in another study.[31] The foaming capacity and foaming stability of the isolate were 62.37% and 81.92%, respectively. It was reported in another study that the foaming capacity was found to be 50% and the foaming stability was 76%.[31] Protein is the major component influencing the foaming capacity. The high protein content in the isolate enhances its foaming capacity and foam stability.[34] More proteins and low-molecular-weight surfactants are examples of surface-active molecules that quickly diffuse to the air/serum interface and stabilize the air cell. To further stabilize the foam, flexible molecules may also change their molecular conformation by diffusing or denaturing within the freshly created interfacial layer.[35]

The emulsion capacity and emulsion stability of the CPI were observed to be 69.54% and 15.10%, respectively. It was found that the emulsion capacity and emulsion stability were 81.92% and 69.54%, respectively.[31] The emulsion stability was also improved by the addition of lecithin (0.3%). The development of protein interfacial layers, which aid in the stabilization of oil droplets, is responsible for the increased emulsion capacity. Similarly, the emulsifying stability index exhibited the same trend as the emulsifying activity.[36]

The CPI had a WHC of 1.79 mL g^{-1}, whereas the OHC was 1.87 mL g^{-1}. A similar range of values for WHC (1.93 mg mL^{-1}) and OHC (2.03 mg mL^{-1}) was recorded by Mesfin *et al.*[31] in their investigation. A protein's WHC is its capacity to hold onto water against gravity through physicochemical interactions, mainly through hydrogen bonding with hydrophilic side-chain groups like carboxyl, carbonyl, amino, and hydroxyl groups.[36] OHC is caused by the expansion of intermolecular gaps created during succinylation, which improves the physical interaction between succinylated proteins and oil. Stronger protein–oil binding is made possible by the additional spaces the added succinyl groups create within the protein structure.[36] Higher porosities and surface areas generally lead to higher oil absorption capacities.[37] The bulk density was recorded to be 0.68 g cm^{-3}, while the tap density was 0.77 g cm^{-3}.[31] In his findings, it was stated that the bulk densities were 0.70 g cm^{-3} and 0.65 g cm^{-3} for the two varieties of CPI, whereas the tapped densities were 0.77 g cm^{-3} and 0.75 g cm^{-3} for the two varieties, respectively. Bulk density and tapped density are crucial parameters for understanding and predicting the behavior of powders. Bulk density, in particular, plays a vital role in characterizing powder flow properties. Density is a critical variable that guides the design of processes involving the volumetric or gravimetric handling of materials, such as those where a specific mass of a powder needs to be compacted into a final product form. Examples of such processes include the manufacturing of pharmaceutical tablets, ceramic supports, batteries, cosmetic compacts, and others. The accurate determination of density is essential for optimizing these processes and ensuring a consistent product quality.[38]

3.3. Effect of the addition of CPI on the gross composition of the developed frozen desserts

The gross compositions of the developed frozen desserts formulated from the oat drink by incorporating CPI at three concentrations, *i.e.*, 5%, 10% and 15%, are shown in Table 4. The pH, titratable acidity and protein content were notably affected by the percentage of CPI added. The pH is a crucial factor affecting the texture, stability and overall quality of the frozen dessert, and it was found to be significantly ($p < 0.5$) affected by the addition of CPI. The pH level of the control was 6.53. The pH values at CPI levels of 5%, 10% and 15% were recorded to be 6.68, 6.79 and 6.98, respectively, while the control displayed a pH value of 6.53. The values obtained showed that as the proportion of the CPI increased, the value of pH also increased and was also higher than the pH of the control itself. According to Sivasankari *et al.* (2019),[39] the pH values of frozen desserts increased as the percentages of pea and chickpea protein increased. Similarly, these values are in alignment with the findings of another study.[33] Because of the natural qualities of the chickpea proteins, their ability to act as a buffer, and their interactions with other components in the frozen dessert mixture, adding CPI to this mixture raised its pH. Elevating the pH of a frozen dessert often results in better emulsification, increased stabilizer functionality, optimal ice crystal formation, and improved protein solubility and stability. A smoother, creamier texture and possibly a more appealing flavor profile may be the outcome of these modifications. Proteins' and buffer components' crystallization behaviors during freezing can be affected by elevated pH. The size and shape of ice crystals can be impacted by pH shifts in the freeze concentrate caused by the pH-dependent sequence and extent of buffer salt crystallization.[40]

Table 3 Functional properties of CPI

Solubility (%)	Foaming capacity (%)	Foaming stability (%)	Emulsion capacity (%)	Emulsion stability (%)	Water holding capacity (mL g^{-1})	Oil holding capacity (mL g^{-1})	Bulk density (g cm^{-3})	Tapped density (g cm^{-3})
60.2 ± 1.52	62.37 ± 1.5	81.92 ± 0.45	69.54 ± 0.45	15.10 ± 0.48	1.79 ± 0.1	1.87 ± 0.07	0.68 ± 0.02	0.77 ± 0.01

Table 4 Effect of the addition of CPI on the gross composition of the developed frozen desserts

Samples	pH	Titratable acidity (%)	Protein (%)	Fat (%)
Control	6.53 ± 0.03^{d}	0.19 ± 0.02^{a}	4.13 ± 0.02^{a}	4.11 ± 0.03^{a}
S1	6.68 ± 0.03^{c}	0.18 ± 0.01^{ab}	3.89 ± 0.05^{c}	4.07 ± 0.02^{ab}
S2	6.79 ± 0.03^{b}	0.16 ± 0.01^{bc}	3.93 ± 0.04^{c}	4.02 ± 0.04^{bc}
S3	6.98 ± 0.04^{a}	0.15 ± 0.01^{c}	4.03 ± 0.05^{b}	3.97 ± 0.02^{c}

At higher protein contents in the frozen dessert, the protein solubility is extremely sensitive to pH variations. A higher pH can help in maintaining the stability and solubility of proteins, though the precise effects vary depending on the protein and buffer system.[41]

The titratable value was observed to decrease from the control to the formulated frozen desserts, while the pH increased. The control showed a 0.19% titratable acidity, while the samples with the CPI addition rates of 5%, 10% and 15% showed titratable acidities of 0.18%, 0.16% and 0.15%, respectively. The reduction in the titratable acidity is due to the high pH value of isolate.[33] The shift in the pH caused by the addition of CPI, the proteins' tendency to move towards their isoelectric point and their inherent buffering capacity collectively lead to a decrease in the titratable acidity as the pH of the oat drink-based frozen dessert mixture increases. The protein content of the three formulations showed a gradual increase: 3.89% with 5% addition of CPI, 3.93% with 10% addition of CPI, and 4.03% with 15% addition of CPI, whereas the control exhibited a higher protein content of 4.13%. This is because the produced control has a greater concentration of complete proteins from the oat drink compared with the samples containing the oat drink and CPI, both of which are plant-based. The control group's higher protein content could be a sign of improved stability and emulsification, which would result in a better texture and creaminess. These results were compared with the findings of Guler-Akin *et al.* (2021),[33] in which the protein content ranged from 3.99% to 9.53%, and the increase was associated with the incorporation of a higher quantity of protein isolate. The fat content was the highest in the sample formulated by the addition of 5% CPI. It was found to be 4.07%. There was a gradual decrease in the fat contents of the samples containing 10% and 15% CPI, and the fat content was recorded to be 4.02% and 3.97%, respectively.

The control had a fat content of 4.11%. A decrease in the fat content was observed with an increase in the concentration of CPI. A similar range of the fat content, 4.13% to 4.18%, was observed in the study by Guler-Akin *et al.* (2021).[33] The fat content in the formulated frozen desserts was observed to decrease compared to the control. This is because the oat drink used in the formulation is plant-based and thus has less fat than the control.

3.4. Effect of the addition of CPI on the physical properties of the developed frozen desserts

The effect of the addition of CPI on the physical properties of the developed frozen desserts is shown in Table 5. The viscosity of the formulation in which 5% CPI was added to the oat drink was 2317 cP. The formulations with 10% and 15% CPI incorporated into the oat drink showed viscosities of 2545 cP and 2709 cP, respectively. The control prepared using the oat drink instead of the oat drink and CPI displayed a viscosity of 2989 cP. The viscosity was observed to increase significantly ($p < 0.5$), and the highest value was observed for the control. Hence, a positive correlation was seen between the proportion of the CPI used and viscosity. This could have a stabilizing effect on air bubbles in the frozen dessert matrix.[42] The viscosity and overflow of the frozen dessert were found to be significantly affected by the inclusion of CPI rather than the milk powder in the study by Guler-Akin *et al.* (2021).[33] It was found that the viscosity of the mixes rose in proportion with the rate at which CPI was added.[33] The addition of CPI could thicken a mixture by forming a network and by binding water. It was also noted that the addition of a minimum amount of xanthan (0.2%) and guar gum (0.12%) improved the viscosity. This is especially helpful for non-dairy recipes, like the oat drink frozen dessert. An increased viscosity can help the frozen dessert mix stay more stable by preventing ingredient separation during freezing and storage.

Overrun describes the percentage of the initial volume of air that is churned into the frozen dessert. CPI can enhance the mix's foaming and emulsification qualities, facilitating better air incorporation. The overrun obtained for the formulation in which 5% CPI was added to the oat drink was 31.56%. There was a subsequent decrease in the other two formulations in which 10% and 15% CPI were added. The overrun was measured to be 29.79% and 28.78% in the 10% CPI formulation and 15% CPI formulation, respectively. On the contrary, the overrun in the control was 32.92%. As the concentration of CPI increased, the

Table 5 Effect of the addition of CPI on the physical properties of the developed frozen desserts

Samples	Total solids (%)	Viscosity (cP)	Overrun (%)	Melting time (min)
Control	50.01 ± 1.23^{a}	2989 ± 1^{a}	32.92 ± 0.03^{a}	45.03 ± 0.05^{d}
S1	48.56 ± 1.41^{a}	2317 ± 2^{d}	31.56 ± 0.25^{b}	47.78 ± 0.02^{c}
S2	48.89 ± 2.00^{a}	2545 ± 11^{c}	29.79 ± 0.08^{c}	49.56 ± 0.02^{b}
S3	49.05 ± 1.40^{a}	2709 ± 3^{b}	28.78 ± 0.03^{d}	51.05 ± 0.03^{a}

overrun decreased. This aligns with the findings of Mesfin *et al.* (2021),[31] in which a negative correlation was found between the concentration of CPI used and the overrun of the developed frozen desserts. The reduced overrun represented a destabilizing effect on the air bubble structure. This showed that an increase in heat transmission could lead to a faster melting rate of the frozen dessert.[43] It was found that as the amounts of soy protein extract and chickpea flour increased, the viscosity also increased, leading to a decrease in the overrun values of the frozen desserts.[44]

Total solids present in the products formulated were observed to be 48.56%, 48.89% and 49.05% in the formulations developed by incorporating 5%, 10% and 15% CPI, respectively. The control showed a slightly higher presence of total solids, *i.e.*, 50.01%. The total solids were seen to increase in proportion with increasing concentration of CPI added. A similar value was obtained, in which the total solids present were 46.4%.[45] The total solids increased with the concentration of CPI added because CPI contributed additional solid content to the formulations. As the concentration of CPI increased, more solid components (such as proteins, fibres, and other constituents) were added to the mixture, thus increasing the total solids proportionally. Additionally, the control using the oat drink had a higher total solids content (50.01%) because oats typically contain a higher concentration of solids, such as proteins, fats, and carbohydrates, compared to the oat drink and CPI. It was noted that the total solids had a greater impact on the capacity of air incorporation into frozen dessert and ice cream.[43]

The melting time of the formulated frozen desserts increased in proportion with the concentration of the CPI added. The first formulation with 5% CPI addition had a melting time of 47.78 min. The second formulation with 10% CPI addition recorded a melting time of 49.56 min. The third formulation with 15% CPI addition had a melting time of 51.05 min. This contrasted with the control, which exhibited a significantly ($p > 0.5$) lower melting time of 45.03 min. This indicates that the incorporation of CPI in the formulations enhances the structural integrity and stability of the frozen desserts and increases the melting time. According to the findings of Guler-Akin *et al.* (2021),[33] the addition of pea protein isolates significantly influenced the melting behaviour of frozen desserts. The frozen desserts having high consistency coefficients melted more slowly due to their higher to flow.[46] The frozen dessert's capacity to maintain its structure in ambient settings is enhanced by the addition of CPI, as evidenced by the longer melting time. The addition of stabilizers (guar gum, xanthan gum, and lecithin) in the formulation of the frozen dessert had contributed to the enhanced texture, stability, and melting resistance.[43] This is probably because the plant-based proteins with stabilizers have superior water binding and emulsification qualities. This improved resistance to melting helps preserve the texture and quality of the frozen dessert for a longer duration, especially in higher temperatures.

3.5. Sensory evaluation

Sensory evaluation plays a crucial role in assessing the quality, acceptability, and overall sensory quality of foods and beverages. The sensory evaluation encompassed various aspects including the appearance, aroma, taste, texture, and overall acceptability, as shown in Fig. 3. Preferences for these sensory characteristics can vary among consumers. The sensory evaluation results included the appearance, color, odor, flavor, texture, and overall acceptability. The sensory analysis showed that the frozen dessert made by incorporating 10% CPI into the oat drink was found to be the most acceptable dessert in comparison with the control sample. The frozen dessert supplemented with protein isolate had lower appearance scores than the control sample, supporting previous findings.[33] Color, a crucial quality attribute, significantly affects consumer preferences and acceptance of food products.[47] Increasing the proportion of protein isolate reduced color scores, likely due to the panelists' familiarity with conventional frozen dessert colors. Similar results were found for the frozen dessert color in another study.[33] The control and S2 showed better taste scores, while the control had the best texture compared to all the other samples. The aroma was influenced by the addition of protein isolate, with the control receiving the highest scores. The control also had superior after-feeling scores. These findings suggest that ingredient proportions affect sensory attributes such as the color, appearance, taste, texture, aroma, after-feeling, and overall acceptability of the frozen dessert. This result is somewhat in agreement with that obtained previously.[33]

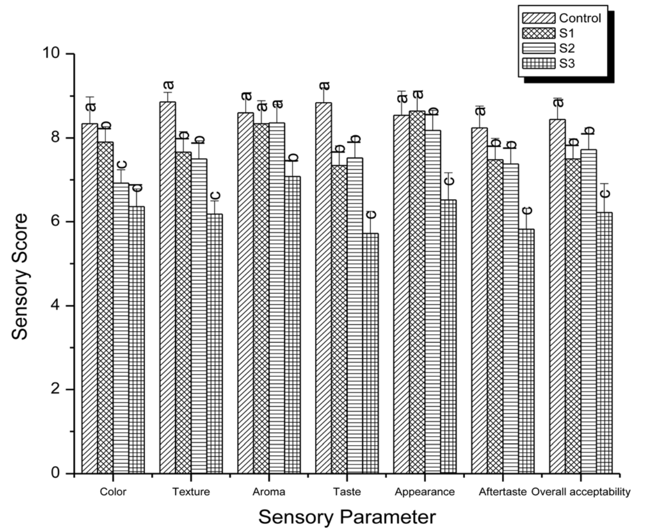

Fig. 3 Sensory evaluation of the control and developed plant-based frozen desserts.

4. Conclusion

This research demonstrated the viability of using CPI and oat drink to create a plant-based frozen dessert with acceptable nutritional, physical, and sensory properties. The findings contribute to the growing body of knowledge on plant-based alternatives in the frozen dessert industry and offer potential solutions for consumers seeking dairy-free options. The functional qualities of frozen desserts made with oats were enhanced by the addition of chickpea protein isolate (CPI). Titratable acidity decreased from 0.19% to 0.15%, and the pH rose from 6.53 in the control to 6.98 at 15% CPI. The melting time increased from 45.03 min in the control to 51.05 min, and the viscosity increased from 2317 cP at 5% CPI to 2709 cP at 15%. While the fat content decreased slightly (4.07–3.97%), the protein content increased slightly (3.89–4.03%) but remained below the control (4.13%). Compared to the control, sensory evaluation revealed that the 10% CPI formulation had the highest overall acceptability. According to these findings, the ideal formulation for plant-based frozen desserts that balances nutrition, usability, and consumer acceptance was 10% CPI. Future research should focus on further optimizing the formulation, exploring additional flavor variations, and conducting long-term stability studies to enhance the commercial potential of this plant-based frozen dessert.

Author contributions

MA: formal analysis, data curation, methodology, resources, original draft writing, NS: supervision, project administration, resources, supervision, writing – review & editing, MS: conceptualization, validation, visualization, writing – review & editing.

Conflicts of interest

The authors declare that there are no conflicts of interest related to this work. The authors also declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

Data availability

The supporting data will be made available on request.

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References

1 F. Reyes-Jurado, N. Soto-Reyes, M. Dávila-Rodríguez, A. C. Lorenzo-Leal, M. T. Jiménez-Munguía, E. Mani-López, *et al.*, Plant-Based Milk Alternatives: Types, Processes, Benefits, and Characteristics, *Food Rev. Int.*, 2023, **39**, 2320–2351.

2 E. Martínez-Padilla, K. Li, H. B. Frandsen, M. S. Joehnke, E. Vargas-Bello-Pérez and I. L. Petersen, In vitro protein digestibility and fatty acid profile of commercial plant-based milk alternatives, *Foods*, 2020, **9**(12), 1784.

3 E. F. Aydar, S. Tutuncu and B. Ozcelik, Plant-based milk substitutes: Bioactive compounds, conventional and novel processes, bioavailability studies, and health effects, *J. Funct. Foods*, 2020, **70**, 103975.

4 R. Kaur and K. Prasad, Technological, processing and nutritional aspects of chickpea (Cicer arietinum) - A review, *Trends Food Sci. Technol.*, 2021, **109**, 448–463.

5 P. M. Arshad, N. Sharma, B. D. Maibam and M. Sharma, Review on effect of innovative technologies on shelf-life extension of non-dairy sources from plant matrices, *Food Chem. Adv.*, 2024, **5**, 100781, DOI: 10.1016/j.focha.2024.100781.

6 A. Wang, Y. Zhu, L. Zou, G. Zhao and J. Wu, Development of protein-enriched biscuit based on oat-milk byproduct fortified with chickpea flour, *LWT-Food Sci. Technol.*, 2023, **177**, 114594.

7 A. Romulo and B. Meindrawan, Marpietylie. Effect of Dairy and Non-Dairy Ingredients on the Physical Characteristic of Ice Cream: Review, in *IOP Conference Series: Earth and Environmental Science*, IOP Publishing Ltd, 2021.

8 Y. Li, A. Hruby, A. M. Bernstein, S. H. Ley, D. D. Wang, S. E. Chiuve, *et al.*, Saturated Fats Compared with Unsaturated Fats and Sources of Carbohydrates in Relation to Risk of Coronary Heart Disease A Prospective Cohort Study, *J. Am. Coll. Cardiol.*, 2015, **66**(14), 1538–1548.

9 N. Thiex, Evaluation of analytical methods for the determination of moisture, crude protein, crude fat, and crude fiber in distillers dried grains with solubles, *J. AOAC Int.*, 2009, **92**(1), 61–73.

10 L. Chang, Y. Lan, N. Bandillo, J. B. Ohm, B. Chen and J. Rao, Plant proteins from green pea and chickpea: Extraction, fractionation, structural characterization and functional properties, *Food Hydrocolloids*, 2022, **123**, 107165.

11 N. Thiex, L. Novotny and A. Crawford, Determination of ash in animal feed: AOAC Official Method 942.05 revisited, *J. AOAC Int.*, 2012, **95**, 1392–1397.

12 D. Abrams, D. Metcalf and M. Hojjatie, Determination of Kjeldahl nitrogen in fertilizers by AOAC official methodSM 978.02: Effect of copper sulfate as a catalyst, *J. AOAC Int.*, 2014, **97**, 764–767.

13 B. Ferjančič, M. Skrt, M. Korošec and J. Bertoncelj, Comparative analysis of dietary fibre determination by AOAC 991.43 and AOAC 2011.25 for frequently consumed foods in Slovenia, *Food Chem.*, 2022, **397**, 133753.

14 A. K. Stone, A. Karalash, R. T. Tyler, T. D. Warkentin and M. T. Nickerson, Functional attributes of pea protein isolates prepared using different extraction methods and cultivars, *Food Res. Int.*, 2015, **76**(P1), 31–38.

15 E. S. Tan, N. Ying-Yuan and C. Y. Gan, A comparative study of physicochemical characteristics and functionalities of pinto bean protein isolate (PBPI) against the soybean protein isolate (SPI) after the extraction optimisation, *Food Chem.*, 2014, **152**, 447–455.

16 Y. Shen, X. Tang and Y. Li, Drying methods affect physicochemical and functional properties of quinoa protein isolate, *Food Chem.*, 2021, **339**, 127823.

17 E. Ermis, K. Ö. Güner and M. T. Yilmaz, Characterization of Hazelnut milk powders: A comparison of spray-drying and freeze-drying, *Int. J. Food Eng.*, 2018, **14**(11–12), 20180085.

18 A. Deswal, N. S. Deora and H. N. Mishra, Optimization of Enzymatic Production Process of Oat Milk Using Response

Surface Methodology, *Food Bioprocess Technol.*, 2014, **7**(2), 610–618.

19 A. A. Atallah and H. Barakat, Preparation of Non-Dairy Soft Ice Milk with Soy Milk, *Adv. Dairy Res.*, 2017, **05**(02), 172.

20 M. Vogelsang-O'Dwyer, E. Zannini and E. K. Arendt, Production of pulse protein ingredients and their application in plant-based milk alternatives, *Trends Food Sci. Technol.*, 2021, **110**, 364–374.

21 X. Qin, Y. Guo, X. Zhao, B. Liang, C. Sun, X. Li, *et al.*, Fabricating Pea Protein Micro-Gel-Stabilized Pickering Emulsion as Saturated Fat Replacement in Ice Cream, *Foods*, 2024, **13**(10), 1–19.

22 M. Krishi Vidyapeeth, I. K. Gadhe, I. R. Shaikh and I. Corresponding Author, Studies on quality evaluation of OAT milk, *J. Pharmacogn. Phytochem.*, 2020, **9**(1), 2275). Available from: https://www.phytojournal.com/.

23 S. B. Jana, P. M. Bobade and R. S. Singhal, Incorporating post-juicing spent residue of Bacopa monnieri in khakra is a promising approach towards circular economy with nutraceutical benefits, *Food Chem. Adv.*, 2025, **9**, 101111, DOI: 10.1016/j.focha.2025.101111.

24 P. Sáez-Plaza, T. Michałowski, M. J. Navas, A. G. Asuero and S. Wybraniec, An Overview of the Kjeldahl Method of Nitrogen Determination. Part I. Early History, Chemistry of the Procedure, and Titrimetric Finish, *Crit. Rev. Anal. Chem.*, 2013, **43**(4), 178–223.

25 M. Góral, K. Kozłowicz, U. Pankiewicz, D. Góral, F. Kluza and A. Wójtowicz, Impact of stabilizers on the freezing process, and physicochemical and organoleptic properties of coconut milk-based ice cream, *LWT-Food Sci. Technol.*, 2018, **92**, 516–522.

26 M. Güven, M. Kalender and T. Taşpinar, Effect of using different kinds and ratios of vegetable oils on ice cream quality characteristics, *Foods*, 2018, **7**(7), 104.

27 S. S. Nielsen, Moisture and Total Solids Analysis, in *Instructor's Manual for Food Analysis*, 2nd edn, 1998, pp. 23–26.

28 S. Ranganna, *Handbook of Analysis and Quality Control for Fruit and Vegetable Products*, Tata McGraw-Hill Publishing Company, 1986, p. 1112, https://books.google.com/books/about/Handbook_of_Analysis_and_Quality_Control.html?id=jQN8Kpj0UOMC.

29 A. S. V, P. K. Dubey and S. Roy, Development of gluten-free functional snack bar for gluten intolerant population by utilizing pseudocereals and dates, *Food Chem. Adv.*, 2025, **7**, 100999. Available from: https://www.sciencedirect.com/science/article/pii/S2772753X25001157.

30 A. D. Goertzen, M. T. Nickerson and T. Tanaka, The improvement of the functional properties of a chickpea protein isolate through proteolysis with three proteases, *Cereal Chem.*, 2021, **98**(3), 439–449.

31 N. Mesfin, A. Belay and E. Amare, Effect of germination, roasting, and variety on physicochemical, techno-functional, and antioxidant properties of chickpea (Cicer arietinum L.) protein isolate powder, *Heliyon*, 2021, **7**(9), e08081.

32 R. Anusha, S. Deepti, P. Vinita, K. Rajendra and Y. Neelam, Process optimization of chickpea (Cicer Arietinum L.) seed protein isolates for functional foods, *Res. J. Biotech.*, 2021, **16**, 2.

33 M. B. Guler-Akin, F. Avkan and M. S. Akin, A novel functional reduced fat ice cream produced with pea protein isolate instead of milk powder, *J. Food Process. Preserv.*, 2021, **45**(11), 15901.

34 R. Kumar, A. Kumar, L. E. Jayachandran and P. S. Rao, Sequential Microwave – Ultrasound assisted extraction of soymilk and optimization of extraction process, *LWT-Food Sci. Technol.*, 2021, **151**, 112220.

35 S. R. VanWees, S. A. Rankin and R. W. Hartel, Shrinkage in frozen desserts, *Compr. Rev. Food Sci. Food Saf.*, 2022, **21**, 780–808.

36 N. Dnyaneshwar Patil, A. Bains, S. Kaur, R. Yadav, N. Ali, S. Patil, *et al.*, Influence of dual succinylation and ultrasonication modification on the amino acid content, structural and functional properties of Chickpea (Cicer arietinum L.) protein concentrate, *Food Chem.*, 2024, **445**, 138671, DOI: 10.1016/j.foodchem.2024.138671.

37 Y. Meng, T. M. Young, P. Liu, C. I. Contescu, B. Huang and S. Wang, Ultralight carbon aerogel from nanocellulose as a highly selective oil absorption material, *Cellulose*, 2015, **22**(1), 435–447.

38 A. Vasilenko, S. Koynov, B. J. Glasser and F. J. Muzzio, Role of consolidation state in the measurement of bulk density and cohesion, *Powder Technol.*, 2013, **239**, 366–373.

39 R. Sivasankari, G. Hemalatha, S. Amutha, M. Murugan, C. Vanniarajan and T. Umamaheswari, Physical and Sensory Properties of Ice Cream as Influenced by Pulse Protein Concentrates, *European J. Nutr. Food Saf.*, 2019, **20**, 322–328.

40 P. Sundaramurthi, E. Shalaev and R. Suryanarayanan, Calorimetric and diffractometric evidence for the sequential crystallization of buffer components and the consequential pH swing in frozen solutions, *J. Phys. Chem. B*, 2010, **114**(14), 4915–4923.

41 A. A. Thorat, B. Munjal, T. W. Geders and R. Suryanarayanan, Freezing-induced protein aggregation - Role of pH shift and potential mitigation strategies, *J. Controlled Release*, 2020, **323**, 591–599.

42 L. Yan, D. Yu, R. Liu, Y. Jia, M. Zhang, T. Wu, *et al.*, Microstructure and meltdown properties of low-fat ice cream: Effects of microparticulated soy protein hydrolysate/xanthan gum (MSPH/XG) ratio and freezing time, *J. Food Eng.*, 2021, **291**, 110291, DOI: 10.1016/j.jfoodeng.2020.110291.

43 S. Kurian, A. Mounika, T. J. Rao, I. M. Sherman, J. s. Jayakumar, J. Muralitharan, *et al.*, Comparative study between conventional and ultrasonic homogenization techniques on the formulated vegan frozen dessert made using chickpea and mung bean protein isolates, *Food Chem. Adv.*, 2025, **8**, 101042, DOI: 10.1016/j.focha.2025.101042.

44 G. d. G. Pereira, J. V. de Resende, L. R. de Abreu, T. M. de Oliveira Giarola and I. T. Perrone, Influence of the partial

substitution of skim milk powder for soy extract on ice cream structure and quality, *Eur. Food Res. Technol.*, 2011, **232**(6), 1093–1102.

45 M. M. El-Sayed, Use of plant protein isolates in processed cheese, *Nahrung-Food*, 1997, **41**(2), 91–95.

46 M. R. Muse and R. W. Hartel, Ice cream structural elements that affect melting rate and hardness, *J. Dairy Sci.*, 2004, **87**(1), 1–10.

47 O. M. Akusu, G. O. Wordu, C. C. S. Orlu and B. S. Chibor, Physicochemical, Textural and Sensory Characteristics of Instant Noodles Produced from Wheat and Plantain Flour Blends, Spiced with Ginger, *Eur. J. Agric. Food Sci.*, 2022, **4**(6), 34–41.

48 R. Sánchez-Vioque, A. Clemente, J. Vioque, J. Bautista and F. Millán, Protein isolates from chickpea (Cicer arietinum L.): Chemical composition, functional properties and protein characterization, *Food Chem.*, 1999, **64**(2), 237–243.

49 N. Mesfin, A. Belay and E. Amare, Effect of germination, roasting, and variety on physicochemical, techno-functional, and antioxidant properties of chickpea (Cicer arietinum L.) protein isolate powder, *Heliyon*, 2021, **7**, 9.

50 M. Mousazadeh, E. B. Ilia, H. Hassanzadeh, M. Mousavi, G. Askari, H. Kiani, *et al.*, Evaluation of the effect of spray and freeze drying techniques and different pH on the functional properties of protein isolate from chickpea (Cicer arietinum, var. Azad), *J. Agric. Food Res.*, 2025, **19**, 101710. Available from: https://www.sciencedirect.com/science/article/pii/S266615432500081X.

