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Physicochemical and sensory properties of coconut milk-based functional ice cream formulated with inulin, protein isolate, and pineapple

Sifat fisikokimia dan sensori es krim fungsional berbasis santan yang diformulasikan dengan inulin, isolat protein, dan nanas

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Abstract

The demand for dairy-free frozen desserts is increasing; however, non-dairy matrices often have weak structures, limited water retention, and sensory defects. This study aimed to optimize a dairy-free ice cream formulated with coconut milk, date syrup, inulin, pea protein isolate, pineapple, and egg yolk, and evaluate its physical, nutritional, and sensory characteristics. Methods: A completely randomized design was used from March to May 2026. Six formulations (control and P1–P5) were tested at Poltekkes Tanjungkarang and Politeknik Negeri Lampung. Physical properties, including water-holding capacity and first dripping time, were assessed based on the proximate composition and sensory acceptability using a 9-point hedonic scale. Data were analyzed using one-way analysis of variance, followed by Duncan's test. The results showed that formulation modifications significantly affected all evaluated profiles ($p < 0.001$). P3 was identified as optimal, with 22.81% protein, 26.52% fat, 13.84% fiber, 43.48% total solids, 47.36% water-holding capacity, and a first dripping time of 240.33 s. P3 also had the highest aroma (6.14), taste (6.51), and mouthfeel (6.19) scores among all the samples. In conclusion, P3 exhibited the most favorable nutritional, physical, and sensory profiles among the tested formulations. This formulation may support the development of nutrient-dense dairy-free frozen desserts, although product classification should be clarified because egg yolk was included.

Keywords: Coconut milk, ice cream, inulin, pea protein, prebiotics, sensory evaluation

Abstrak

Meningkatnya permintaan akan alternatif bebas susu menyoroti perlunya pencuci mulut berbasis nabati yang bergizi tinggi yang mampu mengatasi kelemahan sifat tekstur yang melekat pada matriks non-susu. Penelitian mengoptimasi es krim bebas susu menggunakan matriks santan, sirup kurma, inulin, isolat protein kacang polong (*pea protein isolate*), nanas, dan kuning telur untuk mengatasi tantangan fisik dan sensoris pada matriks nabati. Penelitian dilaksanakan dari Maret hingga Mei 2026 menggunakan Rancangan Acak Lengkap (RAL) dengan mengevaluasi enam formulasi (Kontrol, P1–P5). Pengumpulan data meliputi pengujian sifat fisik (Kapasitas Menahan Air dan waktu leleh pertama), analisis proksimat, dan evaluasi sensoris menggunakan skala hedonik 9 poin. Pengujian dilakukan di Poltekkes Tanjungkarang dan Politeknik Negeri Lampung. Analisis statistik menggunakan uji *One-way ANOVA* dan dilanjutkan uji *Duncan*. Hasil, modifikasi formulasi berpengaruh signifikan terhadap seluruh profil yang diuji ($p < 0,001$). Formulasi P3 menjadi formulasi terbaik, dengan protein 22,81%, lemak 26,52%, serat 13,84%, total padatan 43,48%, daya ikat air 47,36%, dan waktu tetes pertama 240,33 detik. P3 juga memperoleh skor tertinggi pada aroma, rasa, dan mouthfeel. Kesimpulan, P3 menunjukkan profil gizi, fisik, dan sensori terbaik dibandingkan formulasi lain.

Kata Kunci: Evaluasi sensori, inulin, es krim, prebiotik, protein kacang polong, santan kelapa

Introduction

The growing demand for dairy-free foods has encouraged the development of frozen desserts formulated with non-dairy ingredients. This trend is relevant for individuals with specific dietary needs, including those with lactose intolerance and older adults who may benefit from nutrient-dense foods that are easy to consume (Calligaris et al., 2022; Devalekar & Udachan, 2025). In this context, dairy-free ice cream provides an opportunity to expand product diversity while improving its nutritional value and consumer acceptability. However, replacing dairy ingredients remains technologically challenging because non-dairy matrices often have weaker emulsion stability, lower water retention, and less desirable textures than conventional dairy-based ice creams.

Functional ingredients may improve the nutritional and structural properties of dairy-free frozen desserts. Inulin, a prebiotic fiber, has been used to increase the fiber content and support texture development in food systems (Dahiya & Nigam, 2022b). Coconut milk may function as a fat-rich continuous phase and contribute to emulsion properties while providing medium-chain triglycerides (MCTs) (Duranova et al., 2025). Date syrup has been used as a natural sweetener and may offer an alternative to refined sugar because of its carbohydrate profile and reported glycemic characteristics (Almuzaini et al., 2024; Alqahtani et al., 2025). Pea protein isolate can increase the protein content, and pineapple may contribute fiber, acidity, aroma, and fruit-derived solids (Devalekar & Udachan, 2025). These ingredients may improve the nutritional composition; however, their combined use can alter viscosity, emulsion stability, melting behavior, and sensory quality.

Previous studies have examined dairy-free ice cream matrices using soy, almond, oat, and other plant-based ingredients (Hasan et al., 2024; Matabura, 2023; Ng et al., 2024). However, developing a coconut milk-based formulation enriched with date syrup, inulin, pea protein isolate, and pineapple remains a complex challenge in food technology. Dairy proteins, particularly casein, contribute to emulsification, air incorporation, fat destabilization, and texture formation in conventional ice cream. Their absence may reduce the water-holding capacity (WHC), weaken the structure, and increase the melting rate. However, higher concentrations of fruit puree and plant protein may introduce formulation constraints, including off-flavors, excessive acidity, coarse texture, and chalky mouthfeel (Beegum et al., 2021; Devalekar & Udachan, 2025). These challenges create a trade-off between improving the nutrient composition and maintaining physical stability and sensory acceptability.

Therefore, a systematic formulation approach is needed to identify ingredient combinations that balance nutritional quality, structural integrity, and consumer preferences. Although previous formulations have used single-source proteins or standard dairy alternatives, the interactions among coconut milk, date syrup, inulin, pea protein isolate, and pineapple in a frozen dessert matrix remain insufficiently characterized. Further evaluation is needed to determine how specific formulation ratios affect WHC, first-dripping time, proximate composition, and sensory acceptance.

The use of local ingredients such as coconut milk, pineapple, and date syrup may add practical and economic value to dairy-free frozen dessert development. This study aimed to optimize the formulation of coconut milk-based dairy-free ice cream and evaluate its physicochemical stability, proximate composition, and consumer acceptability of the product. These findings are expected to provide a technological basis for developing nutrient-dense, dairy-free frozen desserts with improved physical and sensory characteristics.

Methods

Study Design and Formulation

This laboratory experimental study was conducted from March to May 2026 using a

Completely Randomized Design (CRD). The independent factor was the formulation variation, consisting of one control and five modified formulations (P1–P5) on a 100% weight basis (w/w). The control formulation used sucrose and skim milk powder adjustment to achieve iso-solid conditions, while the modified formulations incorporated varying proportions of inulin, pea protein isolate, and pineapple puree. Each formulation was produced in three independent batches for experimental replication.

The formulations of the ice cream samples are presented in Table 1. Six experimental formulations were developed, comprising one control (K) and five modified treatments (P1–P5). All formulations were standardized to a 100% total weight basis (w/w) to ensure mass balance consistency across the treatments. The control formulation was adjusted using water as a neutral diluent, whereas the modified formulations replaced conventional dairy components with varying proportions of egg yolk, inulin, pea protein isolate, and pineapple puree, while maintaining constant levels of coconut milk, date syrup, and fiber cream. This formulation design allowed for a systematic evaluation of the effect of functional ingredient substitution on the physicochemical and sensory properties of the final product.

Table 1. Formulation profile of coconut milk-based ice cream mix with modified functional components and plant-based emulsifiers (% w/w)

Ingredients	K (Control)	P1	P2	P3	P4	P5
Coconut Milk (%)	45.00	45.00	45.00	45.00	45.00	45.00
Date Syrup (%)	14.32	14.32	14.32	14.32	14.32	14.32
Fiber Cream (%)	5.00	5.00	5.00	5.00	5.00	5.00
Egg Yolk (%)	0.00	10.00	8.00	6.00	4.00	2.00
Inulin (%)	0.00	9.68	8.18	6.68	5.18	3.68
Pea Protein Isolate (%)	0.00	1.00	2.00	3.00	4.00	5.00
Pineapple Puree (%)	0.00	15.00	17.50	20.00	22.50	25.00
Water / Balancer (%)*	35.68	0.00	0.00	0.00	0.00	0.00
TOTAL BASIS (%)	100.00	100.00	100.00	100.00	100.00	100.00

*Note: Water was utilized strictly in the control formulation as an inert balancer to maintain an iso-mass 100% basis against the functional solid ingredients used in the modified treatments.

Materials and Ingredients

The primary ingredients consisted of coconut milk (Cocos nucifera L.) obtained from fresh mature coconut meat without water addition, date syrup (≈70°Brix), fresh egg yolk, inulin powder (≥95% purity; chicory-derived), pea protein isolate (≥90% protein dry basis), commercial oligosaccharide-based fiber cream, and fresh pineapple (Ananas comosus L. Merr.) puree. Pineapple puree was prepared by blending fresh pulp without adding water and filtering through an 80-mesh sieve to remove coarse fibers.

All chemicals used for proximate analysis were analytical grade and complied with American Chemical Society standards (Merck, Darmstadt, Germany), including sulfuric acid (H_2SO_4), sodium hydroxide (NaOH), boric acid (H_3BO_3), hydrochloric acid (HCl), n-hexane, and Kjeldahl catalyst tablets ($CuSO_4$ and K_2SO_4).

Equipment

Ice cream was produced using a laboratory-scale ice cream maker with constant agitation, high-speed blender, and high-shear homogenizer (Ultra-Turrax T25, IKA, Germany). The temperature was monitored using a K-type thermocouple (±0.1°C), and the weight was measured using an analytical balance (Mettler Toledo, ±0.0001 g).

Proximate analysis was performed using a drying oven (Memmert, Germany), muffle furnace (Carbolite), Soxhlet extractor, and Kjeldahl digestion-distillation system. Physical property measurements included a centrifuge (≤6,000 rpm), digital penetrometer, and standard volumetric glassware.

Ice Cream Production Procedure

Coconut milk was preheated to 40°C and mixed with date syrup, inulin, pea protein isolate, fiber cream, egg yolk, and pineapple puree under continuous agitation until homogeneous. The mixture was pasteurized at 80°C for 5 min using a modified High-Temperature Short-Time (HTST) process, followed by homogenization at 12,000 rpm for 5 min.

The mixture was rapidly cooled to 4°C and aged for 12 h. Freezing and churning were performed at −4 to −5°C for approximately 20 minutes at 80 rpm. The resulting ice cream was hardened at −18°C for 24 h prior to analysis.

The overall production workflow of coconut milk-based functional ice cream, including mixing, thermal processing, homogenization, aging, freezing, and hardening, is illustrated in Figure 1. This schematic was developed to provide a clear representation of the sequential processing steps used to formulate all experimental treatments.

Figure 1. Schematic of functional ice cream production process

Physical Property Analysis

The first dripping time was measured at 25 ± 1°C by recording the time until the first melt droplet was formed from a standardized ice cream sample placed on a wire mesh.

The water holding capacity (WHC) was determined by centrifuging 5 g of sample at 4,000 rpm for 20 min at 4°C and calculating the retained water as WHC (%) = (Wf/Wi) × 100.

The melting rate was evaluated by recording the volume of melted ice cream at 5-minute intervals for 35 min at 25 ± 1°C.

Sensory Evaluation

Sensory evaluation involved 37 untrained panelists selected based on the following inclusion criteria (healthy, non-smokers, and no allergy to the study ingredients). Ethical approval was obtained from the Health Research Ethics Committee of Poltekkes Tanjungkarang (No. 014/Perst.E/KEPK-TJK/II/2026).

Samples (≈15 g) were served at −4 ± 1°C in coded containers following a randomized presentation order. The attributes evaluated included color, aroma, taste, texture, mouthfeel, and overall acceptance using a 9-point hedonic scale.

Proximate Analysis

Moisture content was determined by oven drying at 105°C (AOAC 930.15). The ash content was determined using a muffle furnace at 550°C (AOAC 942.05). Protein content was analyzed using the Kjeldahl method (AOAC 920.87), fat content using Soxhlet extraction (AOAC 960.39), and crude fiber using acid-base digestion (AOAC 962.09). The carbohydrate content was calculated by difference (Latimer, 2023).

Statistical Analysis

All data are expressed as the mean ± standard deviation of three independent replicates. Normality was tested using the Shapiro–Wilk test and homogeneity using Levene's test.

One-way ANOVA was used to assess the differences among the formulations, followed by Duncan's multiple range test at $\alpha = 0.05$. Non-parametric alternatives (Kruskal–Wallis and Mann–Whitney U tests) were applied when assumptions were not met. Statistical analyses were performed using the SPSS software (IBM Corp., USA).

Result and Discussion

Table 2 presents the physical properties of the coconut milk-based functional ice cream, including the first dripping time, water holding capacity (WHC), and melting rate expressed as the area under the curve (AUC). The formulation significantly affected the first dripping time ($p < 0.001$), WHC ($p = 0.038$), and melting rate AUC ($p < 0.001$). These findings indicate that differences in the proportions of functional ingredients altered the structural stability and thermal behavior of the ice cream matrices.

For the first dripping time, the formulations were separated into two statistical groups. P4 showed the longest first dripping time at 395.00 ± 21.66 s, which was statistically comparable to of that the Control and P2. In contrast, P5 showed the shortest first dripping time at 219.67 ± 17.01 s, followed by P3 and P1, respectively. Although P5 had the shortest initial dripping time, it exhibited the lowest overall melting AUC, suggesting that initial dripping time alone does not fully explain the complete melting behavior of the product.

WHC also differed significantly among the formulations. P5 showed the highest WHC value at 82.27 ± 18.00%, although this value did not differ significantly from the Control, P1, P2, and P4 values. P3 had the lowest WHC value at 47.36 ± 16.20%, which differed significantly from the other formulations. This result indicates that P3 had weaker water retention and lower structural integrity than the other formulations did. Therefore, although P3 exhibited favorable sensory and nutritional characteristics, its physical stability remained limited compared to that of the control and higher-fiber formulations.

The melting behavior was further evaluated using AUC to reduce the interpretation bias from overlapping melting curves. A lower AUC indicates a lower cumulative melt volume and better thermal stability. P3 showed the highest AUC value of 415.0 ± 14.3 mL·min, indicating poor melting stability. The Control, P1, and P2 groups formed a comparable group with AUC values of 400.0 ± 15.5, 405.0 ± 10.2, and 395.0 ± 12.8 mL·min, respectively. P4 showed a significantly lower AUC value at 350.0 ± 11.5 mL·min, whereas P5 showed the lowest AUC at 275.0 ± 9.8 mL·min. These results suggest that P5 exhibited the best overall resistance to melting, despite its relatively short initial dripping time.

Table 2. Physical property characteristics of coconut milk-based functional ice cream

Treatment	First Dripping Time (seconds) (Mean ± SD)	WHC (%) (Mean ± SD)	Melting Rate AUC (mL/min)
Control (K)	381.00 ± 31.19^{a}	69.39 ± 4.48^{a}	400.0 ± 15.5^{b}
P1	254.33 ± 7.23^{b}	65.16 ± 0.94^{a}	405.0 ± 10.2^{b}
P2	363.33 ± 40.15^{a}	64.75 ± 5.02^{a}	395.0 ± 12.8^{b}
P3	240.33 ± 17.62^{b}	47.36 ± 16.20^{b}	415.0 ± 14.3^{a}
P4	395.00 ± 21.66^{a}	64.11 ± 5.72^{a}	350.0 ± 11.5^{c}
P5	219.67 ± 17.01^{b}	82.27 ± 18.00^{a}	275.0 ± 9.8^{d}
p-value (ANOVA)	< 0.001	0.038	< 0.001

Note: Data are expressed as mean ± SD (n = 3). Different superscript letters (a, b) within the same column indicate statistically significant differences based on the LSD post-hoc test at a 5% significance level (α = 0.05)

Figure 2 illustrates the melting profiles of each formulation over 35 min at room temperature. This pattern supports the AUC results. P3 melted most rapidly and reached a maximum melt volume of 20 mL by 25 min. P1 and P2 also showed relatively rapid melting, with AUC values comparable to that of the control. P4 showed slower cumulative melting than the Control, P1, P2, and P3 groups. P5 demonstrated the highest melting stability, with a minimal melt volume during the early observation period and a total melt volume of 20 mL only at the 35-minute endpoint.

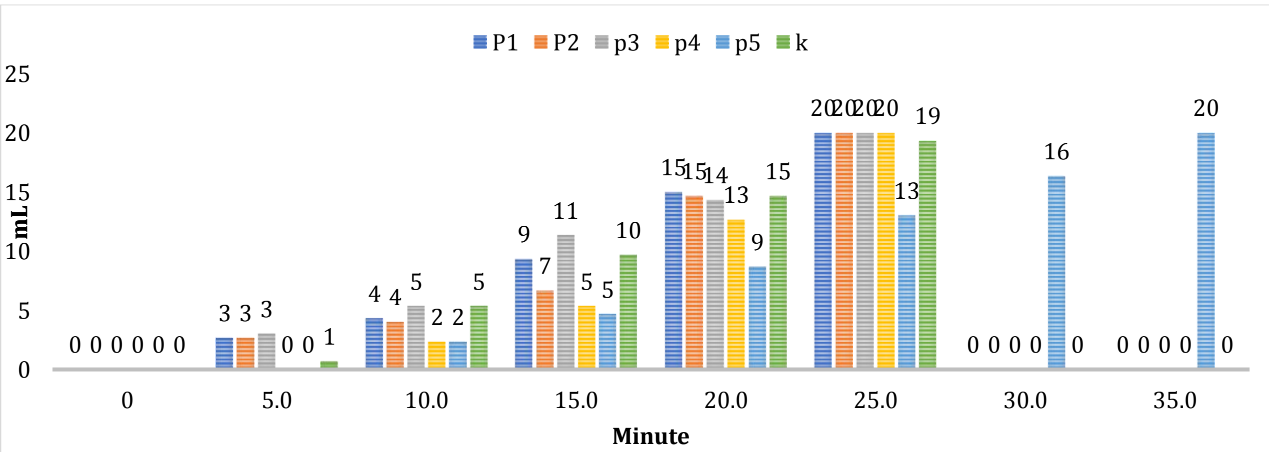

Figure 2. Melting rate of the ice cream

Table 3 presents the sensory acceptability scores for the five modified formulations. The formulation did not significantly affect the panelist preferences for color (p = 0.383), texture (p = 0.274), or overall acceptance (p = 0.097). These findings suggest that the formulations had comparable visual appearance, textural perception, and general acceptability. The color and texture scores ranged from neutral to slightly liked, indicating acceptable sensory homogeneity across the treatments.

In contrast, the formulation significantly affected aroma (p = 0.018), taste (p < 0.001), and mouthfeel (p = 0.001). P3 consistently obtained the highest scores for aroma (6.14 ± 1.57), taste (6.51 ± 1.48), and mouthfeel (6.19 ± 1.51) attributes. For taste, P3 was comparable to P1 but scored significantly higher than P2, P4, and P5. In terms of mouthfeel, P3 was comparable to P1 and scored significantly higher than the other formulations. P4 showed the lowest scores for taste (4.41 ± 1.55) and mouthfeel (4.65 ± 1.49), indicating a lower acceptance of this formulation.

Although the overall acceptance score did not differ significantly among the treatments at the ANOVA level, the post-hoc comparison indicated that P3 had a higher overall score than P4. This finding should be interpreted cautiously because the overall ANOVA result was not statistically significant in this study. Overall, P3 cannot be described as being universally superior in terms of global acceptance. However, it exhibited the most favorable profile for key sensory attributes, particularly aroma, taste, and mouthfeel.

Table 3. Acceptability assessment of coconut milk-based functional ice cream across five formulation variations

Parameter	P1	P2	P3	P4	P5	p-value
Color	6.14 ± 0.95^{a}	5.84 ± 1.17^{a}	5.97 ± 1.14^{a}	5.76 ± 1.04^{a}	5.62 ± 1.50^{a}	0.383^{ns}
Aroma	5.14 ± 1.53^{b}	5.32 ± 1.20^{b}	6.14 ± 1.57^{a}	5.08 ± 1.36^{b}	5.46 ± 1.64^{b}	0.018*
Taste	5.81 ± 1.35^{ab}	5.16 ± 1.57^{bc}	6.51 ± 1.48^{a}	4.41 ± 1.55^{c}	5.43 ± 2.13^{b}	<0.001***
Texture	5.35 ± 1.83^{a}	5.16 ± 1.50^{a}	5.73 ± 1.43^{a}	5.27 ± 1.33^{a}	5.81 ± 1.58^{a}	0.274^{ns}
Mouthfeel	5.68 ± 1.55^{ab}	5.05 ± 1.63^{b}	6.19 ± 1.51^{a}	4.65 ± 1.49^{c}	5.27 ± 1.94^{b}	0.001**
Overall	5.32 ± 2.30^{ab}	4.73 ± 2.13^{ab}	5.76 ± 2.50^{a}	4.35 ± 2.10^{b}	5.14 ± 2.58^{ab}	0.097^{ns}

Note: Data are presented as mean ± standard deviation (SD) (n = 37). Values within the same row bearing different superscript letters indicate significant differences based on the LSD post-hoc test at a 5% significance level. ns = not significantly different (p>0.05); * p<0.05; p<0.01; *** p<0.001

Table 4 shows the proximate composition of the coconut milk-based functional ice cream formulations, including moisture, ash, protein, fat, crude fiber, and carbohydrate content. The formulation significantly affected all proximate parameters (p < 0.001). The values were recalculated using a wet-basis mass balance to avoid inconsistencies between the dry- and wet-basis components.

Moisture content was highest in the Control at 65.28 ± 0.23% and lowest in P3 at 56.52 ± 0.26%, respectively. The lower moisture content in the modified formulations reflects the higher proportion of total solids from the addition of inulin, pea protein isolate, pineapple solids, and other functional ingredients such as maltodextrin. The ash content was highest in P4 at 0.87 ± 0.02%, suggesting a greater mineral contribution from the incorporated ingredients.

The protein content increased substantially in the modified formulations compared to that in the control. P4 had the highest protein content at 10.72 ± 0.15%, followed by P3 at 9.91 ± 0.02%. The Control had the lowest protein content (5.30 ± 0.01 %). The fat content was also highest in P4 and P3, with values of 12.53 ± 0.56% and 11.53 ± 0.02%, respectively. These two formulations were statistically comparable and had significantly higher fat contents than the other treatments.

The crude fiber content followed a similar pattern. P4 showed the highest crude fiber content at 6.91 ± 0.01%, followed by P3 at 6.01 ± 0.04%. The Control had the lowest crude fiber content at 3.17 ± 0.03%. The carbohydrate content, calculated by difference, was highest in P5 (26.82 ± 0.21 %) and lowest in P4 (19.15 ± 0.68 %). The lower carbohydrate content in P4 reflects the greater displacement of carbohydrates by protein, fat, ash, and fiber in the formulation matrix.

Table 4. Proximate composition profile of coconut milk-based functional ice cream (% w/w)

Treatment	Moisture (%)	Ash (%)	Protein (%)	Fat (%)	Crude Fiber* (%)	Carbohydrate (%)
Control	65.28 ± 0.23^{a}	0.36 ± 0.02^{e}	5.30 ± 0.01^{f}	7.32 ± 0.04^{d}	3.17 ± 0.03^{f}	21.74 ± 0.15^{b}
P1	57.09 ± 0.08^{d}	0.53 ± 0.01^{cd}	8.76 ± 0.10^{c}	10.28 ± 0.03^{b}	5.69 ± 0.04^{c}	23.34 ± 0.12^{a}
P2	58.35 ± 0.41^{b}	0.62 ± 0.01^{b}	7.48 ± 0.04^{d}	9.26 ± 0.18^{c}	4.96 ± 0.01^{d}	24.29 ± 0.22^{a}
P3	56.52 ± 0.26^{e}	0.54 ± 0.02^{d}	9.91 ± 0.02^{b}	11.53 ± 0.02^{a}	6.01 ± 0.04^{b}	21.50 ± 0.18^{b}
P4	56.73 ± 0.12^{de}	0.87 ± 0.02^{a}	10.72 ± 0.15^{a}	12.53 ± 0.56^{a}	6.91 ± 0.01^{a}	19.15 ± 0.68^{c}
P5	57.15 ± 0.07^{cd}	0.57 ± 0.03^{c}	6.91 ± 0.02^{e}	8.55 ± 0.16^{d}	4.07 ± 0.02^{e}	26.82 ± 0.21^{a}

Note: Data are presented as mean ± standard deviation (mean ± SD). Different letters within the same column indicate significant differences based on the LSD post-hoc test at the 5% level ($p<0.05$). Crude fiber is a subset of total carbohydrates and was not subtracted twice in the difference calculation.

The development of functional ice cream from local ingredients requires an appropriate balance between nutritional quality, physical stability, and sensory acceptability. Overall, the present findings show that formulation changes substantially modified the nutritional composition, melting characteristics, WHC, and sensory profile of coconut milk-based functional ice cream. The lower moisture content in the modified formulations compared with that in the control was mainly associated with the increased total solids contributed by inulin, pea protein isolate, pineapple solids, and other added ingredients.

The physical results suggest that the ingredient composition produced two different structural responses. In P4 and P5, higher levels of pineapple fiber and protein likely increased matrix viscosity and improved water immobilization. This effect was reflected in the high WHC of P5 and lower melting AUC values of P4 and P5. A denser matrix can restrict water mobility, reduce heat transfer within the frozen structure, and slow the cumulative melting (Ng et al., 2024; Tolve et al., 2024). However, the first dripping time and AUC results did not always move in the same direction as the other parameters. This indicates that the first dripping time reflects the onset of melting, whereas the AUC better represents the total melt behavior over the observation period.

In contrast, P3 exhibited the lowest WHC and highest AUC, indicating weaker water retention and lower resistance to melting. This response may be related to the competitive hydration among the proteins, inulin, and fruit solids within the ice cream matrix. When several hydrophilic components compete for available water, the matrix may hold water less efficiently, resulting in greater free water mobility and faster melting (Akbari et al., 2016; Li et al., 2024). From a sensory perspective, this lower structural rigidity may support smoother melting in the mouth, faster flavor release, and a more refreshing perception during consumption (Da Silva Faresin et al., 2021).

The sensory results identified P3 as the most favorable formulation in terms of aroma, taste, and mouthfeel. This formulation contained a balance of fresh pineapple chunks, date syrup, inulin, pea protein isolate, egg yolk, and coconut milk, which likely produced a more acceptable sweet-sour flavor profile. The presence of pineapple and date syrup may have helped reduce the beany note commonly associated with plant-based proteins (Acar et al., 2025; Hasan et al., 2024; Ng et al., 2024). In addition, the combination of inulin and egg yolk may have contributed to the creaminess by improving the emulsion properties and mimicking some sensory functions of milk fat in frozen desserts (Da Silva Faresin et al., 2021; Devalekar & Udachan, 2025; Genovese et al., 2022).

The lower sensory scores of P4, especially for taste and mouthfeel, suggest that excessive incorporation of fruit fiber and protein may reduce consumer acceptance of the product. Although higher fiber and protein contents improve nutritional density and, in some cases, melting stability, excessive solids may produce a dense, gritty, or less pleasant oral sensation. This finding indicates a practical formulation threshold for these products. In the present study, the sensory data suggested that a pineapple fruit component of approximately 20% was more acceptable than higher-fiber formulations.

From a nutritional perspective, P3 offered a strong balance between proximate composition and sensory acceptability of the product. Its protein content was 9.91%, which exceeded the minimum protein requirement for ice cream stated in the SNI 3713:2018. This improvement was mainly associated with the contribution of pea protein isolate and egg yolk. P3 also contained 11.53% fat and 43.48% total solids, calculated from a moisture content of 56.52%. These values exceeded the minimum thresholds for fat and total solids in the SNI 3713:2018. The high protein and total solid contents suggest that P3 has potential as a nutrient-dense frozen dessert with improved nutritional value compared to many conventional plant-based ice creams (Beegum et al., 2021; Sivaprakash et al., 2025).

The crude fiber content of P3 was 6.01%, which adds functional value to this product. In this study, crude fiber was treated as an isolated structural fraction within the total solids to maintain mass balance consistency (Craig & Brothers, 2022; Leahu et al., 2022; Zeba & Fatima, 2025). This compositional profile supports the development of plant-forward frozen desserts that combine local ingredients with improved protein content and added fiber (Hanafi et al., 2021; Matabura, 2023; Ng et al., 2023).

The main contribution of this study is demonstrating the interactions between coconut milk, inulin, pea protein isolate, and real fruit fiber within a frozen dessert matrix. The results showed that nutritional enrichment can improve protein, fat, total solids, and fiber contents; however, these changes must be balanced against physical stability and sensory quality. P3 provided the best overall balance between nutritional value and sensory acceptance, although it exhibited weaker physical stability than P4 and P5. Therefore, P3 may serve as a promising baseline formulation for the further optimization of nutrient-dense, plant-forward ice cream for consumers seeking lactose-free or dairy-reduced frozen dessert alternatives (Genovese et al., 2022; Tolve et al., 2024). This formulation may also support the value addition of local Indonesian agricultural commodities, particularly coconut and pineapple (Hidas et al., 2023).

This study has several limitations. The formulations were prepared at the laboratory scale; therefore, their performance may change under pilot or industrial production. The sensory test involved 37 untrained panelists, which may limit the generalizability of the consumer acceptance findings. This study also focused on short-term physical stability and did not examine storage stability, microbial safety, or shelf life. In addition, proximate analysis did not assess the bioactive compounds, glycemic response, or fatty acid profile. Although P3 exhibited favorable sensory and nutritional properties, its lower WHC and higher melting AUC suggest that further structural optimization is necessary.

Conclusion

This study found that formulation variations were associated with differences in the physicochemical properties, proximate composition, and sensory acceptability of coconut milk-based functional ice cream. Among the tested formulations, P3 exhibited the most balanced profile. It had favorable scores for aroma, taste, and mouthfeel, along with relatively high protein, fat, and crude fiber contents.

However, P3 still had limitations in terms of physical stability, as shown by its lower water-holding capacity, shorter first-dripping time, and higher melting AUC. These findings indicate that P3 can serve as a promising baseline for developing nutrient-dense coconut milk-based frozen desserts. Further formulation refinement should focus on improving water retention and melting resistance while preserving the sensory benefits of P3.

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