Chemical Properties of Tempe-Based Ice Cream with Pineapple Peel Extract and Porang Glucomannan as a Lactose-Free Functional Dessert

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Abstract. The growing consumer interest in healthier, lactose-free desserts has spurred innovation in functional, plant-based ice cream. This study aimed to formulate and evaluate a lactose-free ice cream made with tempeh, pineapple peel extract, and porang glucomannan to enhance nutritional and functional qualities. The experiment employed a Randomised Block Design (RBD) with four formulations and three replications (12 experimental units). The formulations varied in the ratios of pineapple and pineapple peel extract-enriched tempe paste: F1 (80:20), F2 (60:40), F3 (40:60), and F4 (20:80). The products were analysed for proximate composition, energy, antioxidant activity, vitamin C, and pH. Statistical results showed significant differences ($p < 0.05$) in protein, fat, carbohydrate, moisture, ash, energy, antioxidant activity, and pH, while vitamin C levels remained stable. The optimal formulation (F4) contained 90.52 Kcal/100 g, 3.41% protein, 2.40% fat, 13.81% carbohydrates, 80.10% moisture, 0.27% ash, 16.10 mg/100 g vitamin C, and 45.66 mg/ml antioxidant activity (IC_{50}). Compared to conventional dairy ice cream (180–250 Kcal/100 g), this product offers lower energy and enhanced functional properties, demonstrating the potential of *tempe paste,* a formulation combining tempe and pineapple peel extracts, as a sustainable, health-oriented, lactose-free frozen dessert.

1 Introduction

The rising prevalence of lactase non-persistence has driven strong consumer demand for lactose-free and plant-based dairy alternatives worldwide. Instrumental and epidemiological estimates suggest that roughly 60–70% of the global population exhibits some degree of lactose intolerance or lactase non-persistence, with significant regional variation (higher in East Asian and specific African populations) and notably lower rates in Northern Europe [1][2]. This high prevalence underpins the market and public health interest in palatable, nutritionally adequate lactose-free products, particularly frozen desserts that traditionally rely on milk fats and lactose for texture and mouthfeel [3].

Indonesia, like many Asian countries, reports a high prevalence of lactose intolerance in adult populations. Systematic and population studies indicate that more than half of Indonesian adults may be lactose intolerant (reported pooled estimates around 54–73% in some analyses), highlighting a clear domestic need for acceptable lactose-free alternatives [4]. Given this context, developing locally based plant formulations that provide protein, desirable sensory attributes, and clean-label stabilizers is both scientifically and socially relevant.

Research on plant-based milk and frozen desserts shows diversified strategies to replace dairy functionality: soybean, oat, almond, rice, and blended protein systems have been investigated to approach the nutritional and rheological properties of milk (e.g., protein content, emulsification, and freezing behaviour) while reducing environmental impact (life-cycle advantages of PBMAs) [5]. Recent work has also explored legume-derived ingredients and tempe-based milks as protein-rich alternatives; several studies demonstrate that tempe or tempe extracts can enhance the protein content and sensory acceptability of non-dairy formulations [6]. Specifically, applied studies have tested tempe extracts as a partial water substitute or protein fortifier in ice cream, and porang glucomannan as a natural stabilizer, reporting improvements in texture and clean-label stabilization compared with fully dairy systems [7].

Tempe, as a fermented soybean product, contains bioactive peptides and free amino acids that contribute to its nutritional value; however, it also possesses characteristic beany and fermented off-flavours associated with volatile compounds such as hexanal, 1-octen-3-ol, and other lipid oxidation derivatives generated through lipoxygenase [8][9]. These volatiles often limit consumer acceptance in non-traditional tempe applications such as frozen desserts. On the other hand, pineapple peel extract is rich in volatile aroma compounds, including esters (e.g., ethyl butanoate, methyl hexanoate), aldehydes, and terpenes, which

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impart fruity, sweet aromatic notes that can mask undesirable beany off-odours [10][11]. In addition, pineapple peel contains bromelain and phenolic compounds that may enhance the product's functional value through their radical-scavenging activity and potential glycemic-modulating effects [12].

Combining tempe (protein- and fermentation-derived peptides), pineapple peel extract (bromelain to mitigate off-odours and phenolics for antioxidant activity), and porang glucomannan (native hydrocolloid for stabilisation) constitutes a promising, locally sourced approach with both nutritional and sustainability benefits. Therefore, this study aimed to develop and evaluate a lactose-free ice cream formulated from tempeh, pineapple peel extract, and porang glucomannan, assessing proximate composition (energy, protein, fat, carbohydrate), vitamin C, antioxidant activity, and physical quality, to determine its potential as a nutritious, physically stable, and technologically feasible plant-based frozen dessert alternative for Indonesian consumers.

2 Material and Methods

2.1 Research Design

This study employed a Randomized Block Design (RBD) with four treatment formulations and three replications, resulting in a total of 12 experimental units. Treatments were based on variations in the 2:3 ratio of pineapple paste (from pineapple flesh) to tempe paste (from tempe and pineapple peel extract). Each formulation was prepared under identical processing conditions to minimize environmental and handling variability.

F1: 80% pineapple paste: 20% tempe paste
F2: 60% pineapple paste: 40% tempe paste
F3: 40% pineapple paste: 60% tempe paste
F4: 20% pineapple paste: 80% tempe paste

2.2 Sample Preparations

The primary raw materials used in this study consisted of ripe pineapple (*Ananas comosus* (L.) Merr.) of the “Honi Sunpride” cultivar, developed by Sunpride plantations; tempe made from soybeans (*Glycine max*) from Azaki; and pineapple peel extract obtained as a by-product of pineapple paste processing. The supporting ingredients included porang gel, made from *Amorphophallus muelleri* flour and used as a natural stabilizer, along with sugar and coconut milk. All raw materials were locally sourced from Malang, East Java, Indonesia.

2.2.1 Pineapple and Tempe Paste Production

Fresh pineapples were peeled, cleaned, and separated into flesh and peel. The flesh was then blended into a smooth paste using a food processor (Philips HR2939). The pineapple peel was then extracted using a slow juicer (Philips HR1820). Tempe paste was prepared as a composite ingredient by combining tempeh and pineapple peel extract at a 2:3 (w/w) ratio**.** The tempe was first steamed for 10 minutes to soften the texture, then homogenized with pineapple-peel extract until a smooth paste was obtained. Both pineapple and tempe pastes were pasteurized at 80 °C for 10 min, cooled, and stored at 4 °C before use.

2.2.2 Ice Cream Formulation

Porang gel (1%) was prepared by dissolving 1 g of porang flour in 100 mL of boiling water**,** then stirring continuously until the porang flour was fully dispersed. The mixture was then allowed to stand at room temperature for approximately 1 hour to reach peak gel formation. The resulting porang gel was incorporated into the ice cream mix at 4% of the total weight of the base ingredients (combined pineapple and tempe pastes), serving as a stabilizer to improve texture and retard melting.

The ice cream formulations were developed using varying ratios of pineapple paste and tempe paste, as shown in the research design. The other supporting ingredients, including sugar, coconut milk, and water, were mixed according to their respective formulations. The mixture was homogenised in an ice cream maker (GEA Hard Ice Cream Machine ICE-1530) to obtain ice cream samples for subsequent physicochemical and sensory analyses.

2.3 Analytical Parameters

Proximate composition analyses, including moisture, ash, protein, fat, and carbohydrate contents, were conducted according to the AOAC standard methods [13]. Energy value was calculated using Atwater factors. Antioxidant activity was measured using the 1,1-diphenyl-2-picrylhydrazyl (DPPH) method for IC50 calculation [14]. The vitamin C content was tested using the iodometric titration method [15]. Physical parameters, including viscosity, melting rate, and overrun, were determined according to the procedures described by Arbuckle [16]. All analyses were performed in triplicate.

2.4 Statistical Analysis

All data were subjected to Analysis of Variance (ANOVA) for the Randomized Block Design. When significant differences were observed ($p < 0.05$), the means were compared using Duncan’s Multiple Range Test (DMRT). Statistical analyses were performed using IBM SPSS Statistics version 25.0.

3 Results

Significant differences ($p < 0.05$) were observed among the formulations (F1–F4) for most physicochemical parameters, indicating that formulation composition strongly influenced the nutritional profile. Energy, protein, fat, and ash contents increased progressively from F1 to F4, while carbohydrate, water, and antioxidant contents decreased. The highest protein level (3.41 ± 0.15%) and energy value (90.52 ± 2.76 Cal) were recorded in F4, corresponding to higher proportions of protein- and fat-rich components. In contrast, carbohydrate and water contents showed inverse trends ($p = 0.004$ and $p = 0.026$, respectively), likely due to dilution of carbohydrate sources and the higher solid concentration in the formulations. Ash content also increased significantly ($p = 0.002$), indicating a greater mineral contribution. Although Vitamin C levels were not significantly different ($p = 0.090$), antioxidant activity declined sharply ($p = 0.006$), suggesting that antioxidant-rich ingredients decreased in higher formulations. Overall, the formulation modifications resulted in nutrient-dense products with reduced antioxidant potential.

Table 1. Chemical Characteristics of Tempe-Based Ice Cream with Pineapple Peel Extract and Porang Glucomannan

Parameters	F1	F2	F3	F4	p-value
Energy (Cal)	76.09 ± 2.07^{a}	83.34 ± 2.31^{ab}	87.67 ± 4.37^{b}	90.52 ± 2.76^{b}	0.002
Protein (%)	1.18 ± 0.08^{a}	1.96 ± 0.31^{b}	2.59 ± 0.15^{c}	3.41 ± 0.15^{d}	0.000
Carbohydrates (%)	15.86 ± 0.47^{b}	15.65 ± 0.49^{b}	14.08 ± 0.71^{a}	13.81 ± 0.53^{a}	0.004
Fat (%)	0.88 ± 0.13^{a}	1.43 ± 0.11^{ab}	2.33 ± 0.66^{bc}	2.40 ± 0.08^{c}	0.002
Water (%)	81.89 ± 0.45^{b}	80.75 ± 0.72^{ab}	80.76 ± 0.45^{ab}	80.10 ± 0.57^{a}	0.026
Ash (%)	0.18 ± 0.01^{a}	0.21 ± 0.03^{ab}	0.24 ± 0.01^{bc}	0.27 ± 0.02^{c}	0.002
Vitamin C (mg/100g)	6.62±0.14	13.68±6.76	13.24±0.01	16.10±4.29	0.090
Antioxidants (mg/ml)	138.33 ± 31.52^{c}	111.07 ± 35.07^{bc}	64.57 ± 15.06^{ab}	45.66 ± 0.49^{a}	0.006
pH	4.31 ± 0.08^{a}	4.56 ± 0.19^{ab}	4.73 ± 0.16^{b}	4.94 ± 0.12^{b}	0.004

The p-value was tested using an independent one-way ANOVA, followed by Duncan's Multiple-Range Test ($p < 0.05$); different superscripts within a row indicate significant differences.

Table 2. Physical Characteristics of Tempe-Based Ice Cream with Pineapple Peel Extract and Porang Glucomannan

Parameters	F1	F2	F3	F4	p-value
Viscosity (cP)	74.00 ± 13.74	95.33 ± 53.15	121.67 ± 56.72	104.00 ± 20.88	0.355
Overrun (%)	13.74 ± 0.43^{b}	14.34 ± 0.63^{b}	12.74 ± 0.63^{b}	10.69 ± 0.82^{a}	0.001
Melting Rate (minutes)	24.85 ± 0.65^{a}	25.21 ± 2.57^{b}	28.24 ± 0.20^{c}	28.63 ± 1.40^{b}	0.011
Yield (%)	81.85 ± 0.69	79.39 ± 0.18	80.24 ± 0.05	80.62 ± 0.08	0.418

The p-value was tested using an independent one-way ANOVA, followed by Duncan's Multiple-Range Test ($p < 0.05$); different superscripts within a row indicate significant differences.

4 Discussion

4.1 Proximate Analysis and Energy in Tempe-Based Ice Cream with Pineapple Peel Extract and Porang Glucomannan

The proximate analysis revealed significant differences ($p < 0.05$) in the energy and macronutrient composition among the four ice cream formulations (Table 1). The increase in energy values from F1 (76.09 Cal) to F4 (90.52 Cal) corresponds to the higher proportion of *tempe* paste, a composite ingredient made from tempe and pineapple-peel extract. This indicates that *tempe* paste contributed additional macronutrients, especially proteins and lipids, originating from tempe's rich nutritional matrix. Tempe is known to contain substantial amounts of protein (approximately 18–22%) and fat (4–8%), depending on the substrate and fermentation conditions, which enhance the energy density of composite foods [17][18]. Thus, increasing the proportion of *tempe* paste significantly improved the final product's caloric and protein content.

The protein content increased significantly ($p < 0.001$) from 1.18% in F1 to 3.41% in F4, highlighting the strong contribution of fermented soybean protein in *tempe paste*. The significant increase in protein content is attributable to the higher proportion of tempe paste in the formulation. This trend primarily reflects compositional differences, as tempe contains substantially higher protein levels compared to pineapple pulp. On a fresh weight basis, tempe typically contains approximately 18–20% protein, whereas fresh pineapple pulp contains only about 0.4–0.6% protein [17][19]. Moreover, the increase in protein may also improve the texture and mouthfeel of plant-based frozen desserts, as proteins function as emulsifiers and stabilisers, influencing viscosity and overrun [20][21]. The significant increase in ash content across formulations further suggests greater mineral incorporation from tempeh and pineapple peel, both of which are known for their high calcium, magnesium, and potassium content [22].

Conversely, carbohydrate levels decreased slightly but significantly ($p = 0.004$) from F1 to F4. This trend could be attributed to the substitution of pineapple paste, which primarily contains simple sugars such as sucrose and glucose [19] with tempe paste, which is richer in protein and fibre but lower in simple carbohydrates. The fibre present in pineapple peel and tempe likely contributed to this reduction while enhancing the product's functional value through potential prebiotic effects. Similar findings have been reported previously, indicating that a decrease in carbohydrate content and an improvement in fibre fractions occur when fruit-based matrices are partially replaced with legume-derived ingredients [23].

The fat content of the ice cream formulations increased significantly (p = 0.002) with increasing tempe paste inclusion, consistent with the lipid contribution of fermented soybeans. The moderate rise in fat, along with a decrease in water content, may have contributed to the improved body and creaminess of the final product. Such compositional modifications are desirable in non-dairy frozen desserts, as they promote a smoother texture and reduced ice crystal formation [24]. Overall, these results indicate that *tempe paste* fortification successfully enhanced the nutritional and functional properties of the pineapple-based ice cream, positioning it as a promising plant-based functional food rich in protein, minerals, and bioactive compounds.

4.2 Vitamin C and Antioxidant Activity in Tempe-Based Ice Cream with Pineapple Peel Extract and Porang Glucomannan

The results indicated that the vitamin C content of the ice cream formulations tended to increase with higher tempe paste proportions, ranging from 6.62 mg/100 g in F1 to 16.10 mg/100 g in F4. However, the differences were not statistically significant (p = 0.090). This trend reflects the contribution of pineapple peel extract, a known source of ascorbic acid and phenolic compounds [25][26]. Pineapple peel contains up to 24 mg/100 g of vitamin C, which remains relatively stable during moderate thermal processing [19]. Additionally, fermentation of tempe within *tempe* may promote the release or synthesis of specific vitamins due to microbial metabolism, particularly by *Rhizopus oligosporus*, which is reported to enhance the bioavailability of water-soluble vitamins [27]. The combination of tempe and pineapple-peel extract, therefore, contributed synergistically to the enrichment of vitamin C and other bioactive components in the fortified formulations.

Antioxidant activity was expressed as IC_{50} values from the DPPH assay, with lower IC_{50} values indicating greater radical-scavenging capacity. The IC_{50} decreased significantly (p = 0.006) from F1 (138.33 mg/mL) to F4 (45.66 mg/mL), demonstrating that increasing tempe paste levels enhanced antioxidant activity. This suggests a substantial contribution from tempe-derived bioactive compounds. Fermented soy products such as tempe are rich in isoflavone aglycones (e.g., genistein and daidzein), phenolic acids, and bioactive peptides, which exhibit strong antioxidant properties. Fermentation enhances antioxidant potential by converting glycosidic isoflavones into more bioavailable aglycone forms and releasing bound phenolics through enzymatic activity [28]. Although pineapple pulp contains vitamin C and phenolic compounds, the progressive improvement in antioxidant activity with higher tempe proportions indicates that fermented soy components played a more dominant role in this formulation. Fermentation-derived peptides may further contribute through hydrogen donation and metal-chelating mechanisms [29]. Despite possible degradation of heat-sensitive antioxidants during processing, the relatively low IC_{50} values in F3 and F4 suggest that tempe-derived antioxidants remained sufficiently stable to maintain radical-scavenging activity [6][30].

In general, pineapple peel extract exhibits higher antioxidant activity but lower vitamin C content compared to the pineapple pulp [31]. The edible pulp (flesh) of pineapple is the primary source of ascorbic acid, typically containing 18–25 mg/100 g of vitamin C, depending on cultivar and ripeness [19]. In contrast, the peel contains a lower concentration of vitamin C, typically 8 to 15 mg/100 g, due to its fibrous nature and limited accumulation of ascorbate. However, pineapple peel is significantly richer in phenolic compounds, flavonoids, and tannins, which contribute to its more potent antioxidant activity compared to the pulp.

Studies have shown that pineapple peel extracts demonstrate higher total phenolic content (TPC)—ranging from 600 to 1200 mg GAE/100 g—than the pulp, which typically contains 250–400 mg GAE/100 g [32]. These phenolics include gallic acid, ferulic acid, and caffeic acid derivatives, which are potent radical scavengers that contribute to the antioxidant capacity. Therefore, while the pulp provides more vitamin C and sweetness for sensory quality, the peel extract offers greater functional potential due to its superior polyphenol-driven antioxidant activity. This complementary profile explains why combining the two parts, as in tempe paste (tempe with pineapple peel extract), can enhance the nutritional and functional properties of fermented plant-based foods.

4.3 Physical Characteristics of Tempe-Based Ice Cream with Pineapple Peel Extract and Porang Glucomannan

The physical properties of ice cream are critical determinants of its structural stability, sensory perception, and industrial feasibility. Key parameters commonly evaluated include the mix's viscosity, overrun, and melting behaviour, as these collectively define the microstructural architecture of frozen aerated systems. Mix viscosity reflects the rheological properties of the unfrozen matrix and influences air incorporation, ice crystal formation, and serum phase stabilization during dynamic freezing [33]. Table 2 demonstrates that viscosity did not differ significantly among treatments, whereas overrun and melting rate were significantly affected by formulation. In conventional ice cream systems, mix viscosity is typically a key determinant of air incorporation and melting resistance, as higher viscosity enhances serum phase structuring and stabilizes air bubbles during dynamic freezing [34]. However, in this study, despite numerical differences in viscosity (74.00–121.67 cP), the absence of statistical significance suggests that the base rheological framework provided by porang glucomannan may have buffered formulation-induced variations. Glucomannan is known for its high water-binding capacity and network-forming properties, which can dominate bulk rheological behavior even when protein ratios vary [35]. This may explain why viscosity remained statistically stable across treatments.

In contrast, overrun differed significantly among treatments (p = 0.001). F4 exhibited the lowest overrun

(10.69%), significantly lower than the other treatments. Overrun is strongly dependent on mix viscosity, protein surface activity, and air cell stabilization capacity [36]. The reduction in overrun in F4 may be attributed to increased solid content from tempe matrix components, which can hinder efficient air incorporation during freezing. Plant proteins often exhibit lower foaming stability than dairy proteins, particularly in systems lacking emulsifiers, such as milk phospholipids [37]. Thus, increased tempe concentration may have reduced aeration efficiency, producing a denser product.

The melting rate also differed significantly (p = 0.011), with F3 and F4 exhibiting slower melting (i.e., longer melting times). Slower melting is generally associated with stronger structural networks, smaller ice crystals, and enhanced water-binding capacity [38]. The higher melting resistance observed in F3 and F4 may reflect the synergistic effects of porang glucomannan and tempe-derived proteins, which likely contributed to a more stable frozen matrix. Glucomannan is known for its high water-holding capacity and gel-forming ability, which enhances structural integrity and reduces serum separation during melting [39].

Yield did not differ significantly among treatments (p = 0.418), indicating that formulation variations did not substantially affect product mass recovery. This suggests process stability and consistent mix freezing efficiency across treatments, an important consideration for scalability and industrial feasibility.

5 Conclusions

This study demonstrated that incorporating tempe paste, a combination of tempeh and pineapple peel extract, significantly enhanced the nutritional and functional quality of pineapple-based frozen desserts. Increasing the proportion of *tempe paste* resulted in higher protein, ash, and energy values while maintaining acceptable physicochemical stability. Although antioxidant activity tended to decrease with higher *tempe paste* substitution due to the dilution of fruit-derived polyphenols, the formulation still has considerable functional potential as a plant-based ice cream. Otherwise, the physical characteristic results demonstrate that while viscosity and yield remained relatively stable, formulation ratios significantly influenced aeration and melting behaviour, which are critical determinants of textural quality and consumer perception in plant-based frozen desserts. Overall, the findings highlight that a combination of pineapple paste and pineapple peel extract-enriched *tempe paste* is a promising functional ingredient that can enhance the nutritional value and sustainability of the physical characteristics of frozen desserts. This offers a potential innovation pathway for developing plant-based, probiotic-enriched products with added value from agricultural by-products.

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The data that support the findings of this study are available from the corresponding author upon reasonable request.

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