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Durian rind–derived low methoxyl pectin as a clean-label stabilizer for reduced-fat chocolate ice cream

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ABSTRACT

Durian rind is an abundant by-product that can be converted into low-methoxyl pectin for use as a clean-label stabilizer in reduced-fat ice cream. In this study, low-methoxyl pectin was recovered from durian rinds by hot citric-acid treatment (pH 1.6, 80°C, 60 min, solid-to-solvent ratio 1:20 g/mL) and incorporated into a reduced-fat chocolate ice cream mix at 0.17, 0.34, 0.50, and 0.67 wt%. Mix viscosity (25°C, 20 rpm), pH, overrun, hardness, time-to-first-drip, 120-minute meltdown, and room-temperature structural images (25°C) were evaluated over 0–120 minutes, alongside sensory acceptance. All formulations maintained pH 6.3–6.6. Increasing pectin raised viscosity and lowered overrun from 119% (no pectin) to 73% (0.67 wt% pectin). A high content of pectin (above 0.50 wt%) markedly improved melt resistance but yielded excessively viscous and poorly whipped mixes. The 0.34 wt% formulations provided the best balance of minimal dose with an overrun of 83%, a hardness of 19.17 N, and a meltdown of 34.22%, which is highly competitive compared to the control, while also resulting in a delay of the first drip from 11 to 41 minutes. Sensory evaluation confirmed that the taste, texture and overall liking were acceptable at pectin concentrations of 0.34% to 0.67%. The study indicated that 0.34-0.50 wt% durian-rind pectin produces a reduced-fat ice cream with whipping ability, texture, and melt resistance comparable to higher-fat counterparts, whereas higher doses impair aeration. The findings position durian-rind low-methoxyl pectin as a circular, clean-label ingredient that enables reduced-fat ice cream with a full–fat–like quality, translating fruit waste valorization into a tangible, market-ready product.

1. Introduction

Worldwide, the food industry struggles with the accumulation of surging volumes of fruit by-products. Durian, a flagship crop across Southeast Asia, illustrates the problem starkly. Barely one-quarter of each fruit is consumed, while the bulky peel is often discarded in landfills or through open dumping. The rising demand for durian translates into an ever-larger stream of peel waste that must be managed responsibly. In Vietnam, annual durian production is estimated to generate at least 150,000 t of rind each year, based on Vietnam's 2024 output (0.85–1.2 Mt) and the typical non-edible fraction of 67–85 % in durian fruit (with rind as the major component) (Tam, 2024). Extrapolated against current production, this translates to millions of tonnes of peel-rich biomass annually, highlighting both an environmental burden and an opportunity for valorization. Recent valorization studies have shown that these residues can be converted into valuable ingredients (Trigo et al., 2020). Among them, pectin, a natural, multifunctional polysaccharide valued for its gelling, thickening, and emulsifying capabilities, as well as documented health benefits, has received particular attention (Li et al., 2021).

From a functional standpoint, durian-rind pectin is attractive because it can be recovered at useful yields and often exhibits a low degree of esterification, with high galacturonic acid content, enabling calcium-responsive gelation at low sugar levels (Jong et al., 2023; Wai et al., 2010). These features distinguish it from many commercial citrus pectins, which are primarily used as high-methoxyl gellants (Liang et al., 2022). They also make durian-rind pectin well-suited to fat-reduced milk products, where increased serum viscosity and Ca^{2+}-mediated junction zones can stabilize air-cell lamellae and improve melt resistance without heavy sucrose loads (Muse & Hartel, 2004; Zhang et al., 2018). The degree of esterification and galacturonic acid content vary with cultivar and extraction conditions; hot-acid protocols, such as those used here, commonly yield low-methoxyl material (Wai et al., 2010; Jong et al., 2023).

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Growing health awareness has fueled consumer demand for reduced-fat foods, driven by evidence linking high dietary fat intake to an increased risk of cardiovascular disease, hypertension, and obesity (McGhee et al., 2015). Some valorisation studies on pectins from jackfruit peel, mangosteen rind, and citrus-processing by-streams demonstrate functional utility in reduced-fat foods (Mbaeyi-Nwaoha et al., 2019; Ma et al., 2025; Zhang et al., 2018). Pectin is already incorporated into various low-fat formulations due to its strong water-binding, gelling, and emulsifying capacities, which can replicate the mouthfeel typically provided by fat (Lim et al., 2015). Lim and co-workers demonstrated that pectin extracted from yuja pulp could be added to cake batter to lower fat levels without compromising baking performance.

Ice cream, typically high in fat (10–16 %) and calories, has prompted the dairy industry to explore methods for creating lower-fat varieties. Unlike conventional ice cream, reduced-fat ice cream has issues with taste and texture (Akalın et al., 2008). Ice cream manufacturers are seeking alternatives to milk fat to create products that meet consumer preferences. Beyond waste valorization and clean-label trends, recent ice cream studies illustrate complementary stabilization routes relevant to this work. Green extraction and surface-active biopolymers obtained through pulsed-electric-field methods have been successfully applied in ice cream systems (Shahi et al., 2021). Plant-based matrices (soy–sesame) map the structural, thermal, and rheological requirements to reproduce dairy-like body and meltdown control (Ghaderi et al., 2021). Upcycled botanicals, such as freeze-dried persimmon peel, enhance hardness and melt resistance while aligning with circular economy goals (Yosefiyan et al., 2024). Additionally, encapsulated Indigofera tinctoria adds antioxidant/color functionality with favorable overrun and melting behavior (Shadordizadeh et al., 2023). At the interface, dilatational rheology studies on β-lactoglobulin/high-methoxyl pectin mixtures clarify how protein–pectin interactions stabilize air-cell lamellae, providing mechanistic insight that complements the low-methoxyl pectin–Ca^{2+} approach pursued here (Rafe et al., 2022). Zhang et al. (2018) characterized pectin extracted from wastewater generated during the production of canned citrus fruit and evaluated its application as a fat replacer in ice cream. Adding pectin to ice cream can increase the viscosity, overrun, and hardness while reducing the ice cream's melting point. It effectively conveys that the addition of 0.72 % pectin to ice cream reduced the fat content by 45 % without significantly impacting its sensory properties.

Building on our group's earlier efforts to transform Agri-food by-products into functional ingredients (Tran et al., 2022; Tran & Dang, 2023; Huynh et al., 2024), the study is the first to exploit durian rind, an agri-food by-product rich in pectin, through high-temperature citric acid treatment to obtain "clean" pectin and apply it directly as a stabilizer for reduced-fat chocolate ice cream. Formulations containing 0–0.67 % (w/w) durian-rind pectin were compared with a full-fat control to determine the minimum dosage that preserves the characteristic overrun, texture, pH stability, and melt resistance expected of premium ice cream, as well as customer acceptance, aligning waste-valorization goals with consumer demand for healthier frozen desserts. Unlike prior studies on yogurt/mayonnaise (which lack gas–ice phases) and on citrus-derived pectin in ice cream, this work establishes a minimal effective dose of durian-rind pectin that achieves a full–fat–like overrun, texture, and melt resistance, while also introducing a time-lapse structural collapse visualization as a new application-relevant metric.

2. Materials and methods

2.1. Materials and chemicals

Fresh Ri6 durian rinds were collected from a retail outlet in Ho Chi Minh City, Vietnam. Sound rinds were rinsed, air-dried, and trimmed to remove the green outer layer, retaining only the white mesocarp for pectin recovery. The mesocarp was diced into 2 × 2 × 2 cm pieces, dried overnight at 60 °C to a moisture content of 10–15 %, milled, vacuum-packed, and stored in a desiccator until use.

Unless stated otherwise, the following chemicals and ingredients were used: Ethanol (96 %, Chemsol, Vietnam; CAS 64–17–5), Hydrochloric acid (37 % w/w, Xilong Scientific, China; CAS 7647–01–0), Sodium hydroxide pellet (≥ 98 %, Xilong Scientific, China; CAS 1310–73–2), Citric acid monohydrate (≥ 99.5 %, Xilong Scientific, China; CAS 5949–29–1), and Phenol red (Xilong Scientific, China; CAS 143–74–8). For ice cream production, Skim milk powder NZMP™ (Fonterra, New Zealand), whipping cream (35 % fat, d-One, Thailand), pasteurized milk (Vinamilk, Vietnam), condensed milk (Vinamilk, Viet Nam), and cocoa powder (VinaCacao, Vietnam) were purchased from the local market.

2.2. Pectin extraction from Ri6 durian rinds

Pectin was extracted using the unpublished method developed by our group. 30 g of durian peel powder was stirred in a citric acid solution under the following conditions: an acid concentration of 0.5 M (pH 1.6), a solid-to-solvent ratio of 1:20 g/mL, a temperature of 80 °C, and an extraction time of 60 min. The extraction was performed in a 1.0 L glass vessel agitated at 700 rpm with a hotplate stirrer. The reaction mixtures were cooled to room temperature, filtered, and washed with a minimum volume of water. The filtrate was precipitated using 96 % ethanol, filtered, and washed with 70 % ethanol to obtain the pectin. The wet pectin was dried overnight at 50 °C to reach constant weight, ground, and stored in a desiccator for further experiments. Pectin yield is reported as mean ± SD from three independent extractions (biological replicates).

2.2.1. Determination of methoxyl content, degree of esterification, and anhydrouronic (galacturonic) acid content

The methoxyl content (MeO), degree of esterification (DE), and anhydrouronic (galacturonic) acid content (AUA) were determined by titration, following the method of José et al. (2022). 0.50 g of pectin was dispersed in a 1:20 (v/v) ethanol–water mixture. A phenol-red indicator was added, and the solution was titrated with 0.10 N NaOH to a persistent pink end-point (V_1). The sample was then saponified with 25 mL of 0.25 N NaOH under vigorous stirring and mild heating, followed by neutralization with 25 mL of 0.25 N HCl. After a second addition of phenol red, the mixture was titrated again with 0.10 N NaOH to the same faint-pink end-point (V_2). Values for MeO, DE, and AUA were calculated from V_1 and V_2 using eq (1)–(3).

$$MeO\,/\,\% = \frac{V_2 \times 0.1 \times 31}{weight\ of\ sample} \times 100 \quad (1)$$

$$DE\,/\,\% = \frac{V_2}{V_1 + V_2} \times 100 \quad (2)$$

$$AUA\,/\,\% = \frac{0.1 \times (V_1 + V_2) \times 176}{weight\ of\ sample} \times 100 \quad (3)$$

Where V_1 and V_2 are the volumes used in the first and second titrations (L), respectively; 31 is the molecular weight of the methoxyl group; 176 is the molecular weight of AUA; the weight of the sample is 0.5 g.

2.2.2. Structural analysis

Fourier-transform infrared spectroscopy (FTIR) was performed using a Bruker spectrophotometer (Bruker BioSpin GmbH, Rheinstetten, Germany) to determine the unique structure of pectin. Transmission spectra were collected using an ATR accessory with a single-reflection diamond crystal (32 scans, 4 cm^{-1} resolution, 4000–400 cm^{-1}).

2.2.3. Microbiological testing

Pectin powder was packed in sterile polyethylene pouches and stored

15 days at ambient temperature (25 ± 2 °C) in a desiccator before testing. A 10.0 g sample was homogenized in 90 mL of sterile 0.1 % peptone water. Decimal dilutions were then prepared. The limit of detection (LOD) for all microbial counts was 10 CFU/g, and values below this were recorded as "not detected" (n.d.). All tests were performed in duplicate and results were expressed per gram of dry sample.

Total Aerobic Mesophilic Count: According to TCVN 11039–1:2015 (TCVN (Vietnamese National Standards), 2015), samples were pour-plated on Plate Count Agar and incubated at 30 °C for 72 h. Plates with 30–300 CFU were counted.

Yeasts and Molds: Following TCVN 13369:2021 (TCVN (Vietnamese National Standards), 2021), samples were spread on DG18 agar and incubated at 25 °C for 5 days. Plates with 10–150 CFU were counted.

Escherichia coli: Detection and enumeration were performed according to VS 64:2022 (Ministry of Health (Vietnam), 2022) and TCVN 7924–2:2008. Samples were pour-plated on TBX agar and incubated at 44 °C for 18–24 h. Blue-green colonies were counted as presumptive *E. coli*, and confirmation was performed biochemically if needed.

2.2.4. Lead (Pb) determination

Lead analysis followed TCVN 8900–8:2012 (TCVN (Vietnamese National Standards), 2012). Approximately 0.50 g of pectin was digested with 65 % HNO_3 using a microwave digestion program. The digested sample was filtered and analyzed by ICP-MS (NexION 1000 PerkinElmer). Method blanks and a certified reference material were included in each batch. The limit of quantification (LOQ) for Pb was ≤ 0.02 mg/kg, and results were expressed as mg/kg on a dry basis. Signals below the LOQ were reported as n.d.

2.3. Preparation of ice cream

Ice cream is prepared according to the procedure described by Zhang et al. (2018) with modifications. Pectin and condensed milk are weighed and dispersed into the pasteurized milk, which is then heated to 60 °C and stirred for 10 min using a hotplate stirrer. The mixture is then enhanced with the addition of whipping cream, skim milk powder, and sifted cocoa powder. The mixture is continuously stirred and whipped for 30 mins at 60 °C, then cooled and subsequently chilled at 4 °C for 6 h to facilitate the complete hydration of all ingredients. After hydration, the mixture is homogenized at 4 °C for 15 mins using a Scarlett electric hand mixer. The homogenized sample was poured into molds and frozen at −15 °C overnight for hardening in an Upright Laboratory Freezer (Haier DW-25L262). The formulation of ice cream samples is shown in Table 1.

2.4. Measurement of physicochemical and textural properties of ice cream

2.4.1. Viscosity

The apparent viscosity of the ice cream mix was measured using a Brookfield DV1 at 25 °C after 1 min of shear. Spindle LV-3 at 20 rpm was used for Samples 1–3, while Sample 4 was checked with LV-4 at the same speed to stay within the 10–90 % torque window. Samples remained out of range even with LV-4 at lower speeds and are reported as n.d. No statistical comparisons were made across different spindle/speed conditions. The viscosity range was measured in centipoise (cP).

2.4.2. pH

The pH of the ice cream mix was measured using a pH meter (model InoLab pH 720, Germany) at 25 °C.

2.4.3. Overrun

Overrun was determined according to Zhang et al. (2018). The liquid mix was weighed in a tared, pre-calibrated 100 mL cup (recorded as m_1). After whipping and freezing, the ice cream was returned to the same cup and leveled exactly to the 100 mL mark (equal to the mix volume), and the mass was recorded (m_2). The cup volume was verified gravimetrically with water, and measurements were done in triplicate. The overrun of the ice cream was calculated using Eq (4):

$$Overrun\,/\,\% = \frac{m_1 - m_2}{m_2} \times 100 \quad (4)$$

2.4.4. Hardness

The hardness of the ice cream was measured using a texture analyzer (TA XT2, Instron Co., USA), calibrated with a 5-kg weight and equipped with a flat-ended stainless-steel cylindrical probe (15 mm diameter, 25 mm length). Ice-cream cups (5-cm diameter, 3-cm depth 3) were tempered at −10 °C for 4 h before testing. Measurements were conducted at 20 °C with a probe speed of 2 mm s^{-1} and a penetration depth of 8 mm. Hardness was defined as the maximum force (N) and is reported as the mean of three independent measurements.

2.4.5. Meltdown

An ice cream cube (2.0 × 2.0 × 2.0 cm) was prepared to determine the melting rate, following the method of Zhang et al. (2018). The sample was then placed on a 20-mesh stainless steel sieve under a stable temperature of 25 °C. Melted ice cream was collected in a cup below.. The time of the first drip was also recorded during the melting process. The weight of the ice cream in the cup was recorded after 120 mins, and the meltdown was calculated using Eq (5):

$$Meltdown\,/\,\% = \frac{m_4}{m_3} \times 100 \quad (5)$$

Where: m_4 is the cumulative mass of melted ice cream collected in the cup (g) after 120 mins (g); m_3 is the initial mass of the frozen sample (g) (cup tared).

The structural collapse was recorded qualitatively. Visual structural images were taken at 0, 15, 30, 60, 90, and 120 min at 25 °C under standard light conditions.

Table 1
Ice cream formulation.

Materials	Concentration, % w/w					
	Sample C	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Pectin	0	0	0.17	0.34	0.50	0.67
Unsweetened pasteurized milk	67.57	67.57	67.54	67.34	67.23	67.11
Whipping cream powder	22.31	13.51	13.50	13.47	13.45	13.42
Skimmed milk powder	0	8.79	8.77	8.75	8.74	8.72
Condensed milk	8.10	8.10	8.09	8.08	8.07	8.05
Cocoa powder	2.02	2.03	2.02	2.02	2.01	2.03
Fat *	11.20	7.91	7.90	7.89	7.88	7.86
Total solid *	25.76	30.60	30.71	30.81	30.90	31.0

(*) values were computed from weighed formulations; moisture by difference.
Note: Samples 1–5 were normalised to ~7.9 % fat and ~31 % total solids. Minor adjustments in milk, cream powder and skim-milk powder balance fat, MSNF and water to keep these targets constant as pectin increases. Sample C is a high-fat reference (11.2 % fat; 25.8 % total solids) (Goff & Hartel, 2013).

2.5. Sensory evaluation

Following TCVN 3215–1979, 5 trained assessors (2 Male, 3 Female, 22–23 years old, non-smokers screened for good taste–texture discrimination) attended four training sessions on attribute definitions and scale application before rating flavor and texture on a five-point scale (0–5). In parallel, 35 semi-trained panelists (18 male, 17 Female, 18–25 years, non-smokers) underwent two introductory sessions and scored their overall liking on a nine-point hedonic scale, ranging from 'liked extremely' (9) to 'disliked extremely' (1). Each formulation was coded with a random three-digit number, then scooped and served in balanced order under uniform lighting at 25 °C (Relative humidity 82 %), with palate cleansers offered between samples. Informed consent was obtained from all participants, and the study protocol was approved by the Faculty Ethics Committee.

2.6. Microbiological safety evaluation

To verify the microbiological safety of a representative reduced-fat formulation, one ice-cream sample was tested after 15 days of frozen storage at −10 °C. Analyses followed Vietnamese standards:

Total aerobic mesophilic count (TAMC): TCVN 11039–1:2015 (TCVN (Vietnamese National Standards), 2015) (pour-plate on Plate Count Agar, 30 ± 1 °C, 72 ± 3 h).
Yeasts and molds: TCVN 13369:2021 (TCVN (Vietnamese National Standards), 2021) (spread-plate on DG18 agar, 25 ± 1 °C, 5 days).
E. coli: VS 64:2022 (Ministry of Health (Vietnam), 2022) and draft TCVN 7924–2:2008 (TCVN (Vietnamese National Standards), 2008) (TBX agar, 44 ± 1 °C, 18–24 h; biochemical confirmation as required).
Enterobacteriaceae: TCVN 5518–2:2007 (TCVN (Vietnamese National Standards), 2007) (VRBG agar; typical colonies enumerated after 37 ± 1 °C, 24 ± 2 h, with confirmation per the standard).
Salmonella spp. (presence/absence in 25 g)*:* TCVN 10780–1:2017 (TCVN (Vietnamese National Standards), 2017) (pre-enrichment in BPW 37 °C/18–24 h; selective enrichments and plating per the standard).
Results are expressed as CFU/g or CFU/mL; counts < 10 CFU/g are reported as not detected (n.d.). Duplicate plates were prepared at two adjacent dilutions; assays were repeated if QC acceptance criteria were not met.

2.7. Statistical analysis

All experiments and measurements were performed in triplicate, and the statistical results were presented as the average of three independent trials. The results were subjected to one-way ANOVA to assess overall differences, followed by Tukey's HSD test ($\alpha = 0.05$) to identify significant differences among formulations.

3. Results and discussion

3.1. Pectin recovery

In previous studies, the extraction of pectin from durian rinds has not been widely explored. Research by Wai et al. (2009) and Maran (2015) successfully extracted high-methoxy pectin (HMP) using hydrochloric and citric acids, with a maximum yield of 9.35 %. A more recent study by Jong et al. (2023) on Musang King durian rinds examined the effects of various acids on extraction efficiency, AUA, and DE. This research found that mineral acids produced pectin with higher purity than organic acids, but all extracts were classified as low-methoxyl pectin (LMP). While sulfuric acid showed the highest extraction efficiency (10.23 %) and purity (80.58 %), it is not ideal for practical use due to environmental and safety concerns.

The current study achieved a significantly higher pectin recovery yield of approximately 18.63 ± 1.71 % from Ri6 durian rinds. The extracted pectin was classified as LMP (with MeO of 4.31±0.93 %) because its DE was 33.2 ± 0.78 %, which is below the 50 % threshold for LMP. The AUA of 76.92±1.33 %, which satisfied the 65 % threshold specified for food-grade pectin, indicates that the Ri6-durian-rind pectin has a highly purified backbone (EFSA, 2017) and falls within the typical citrus range (58.5–85.4 %) (Singhal & Swami Hulle, 2022). It is also comparable to jackfruit peel pectins, which are reported to contain higher than 65 % uronic/galacturonic acids under appropriate extraction conditions (Leong et al., 2016). Compared with Jong et al. (2023), the AUA of this study, which used an organic acid, was slightly lower than their result, likely due to differences in rind source, extraction conditions, and the complexity of the process. This result highlights the potential of using milder acids (such as citric acid) and different raw materials (like Ri6 durian) to improve recovery and support a circular economy.

FTIR spectra in Fig. 1 displayed the characteristic pectic signature. The peak observed in the region of 3600–3200 cm^{-1} corresponds to the –OH stretching vibration resulting from intramolecular and intermolecular hydrogen bonding in the polygalacturonic acid polymer. The absorption band at 1740 cm^{-1} indicates the presence of the carbonyl ($C=O$) group in the methyl-esterified group ($COOCH_3$). The strong band at 1630 cm^{-1} and the weaker band near 1400 cm^{-1} are due to the stretching vibration of the carboxylate anion ($COO-$). The spectral region between 1200 and 950 cm^{-1} is related to the carbohydrate "fingerprint" region, which is characteristic of each polysaccharide. Specifically, the bands around 1384, 1262, and 1049 cm^{-1} are due to the homogalacturonan structure in pectin. The spectra of the durian rind pectin in this study are in agreement with those of previous works (Jong et al., 2023; Huynh et al., 2024).

Table 2 summarizes the microbiological and heavy metal test results for the pectin powder after 15 days of storage at ambient temperature in a desiccator. All pectin samples showed no detectable Pb, a heavy metal of toxicological concern, and microbial loads (total aerobic mesophiles, *E. coli*, yeasts and molds) remained below the detection limit of 10 CFU/g after two weeks' storage under ambient conditions. These findings confirm that the pectin conforms to the requirements of the Vietnamese national standard for food additives, and is therefore safe for use in the development of subsequent reduced-fat products.

The citric-acid extraction was demonstrated at bench scale; solvent recovery, wastewater treatment, techno-economic analysis, and life-cycle assessment were beyond the present scope but are necessary for industrial feasibility. Addressing these points will refine dosing guidance, extend the applicability beyond the current matrix, and support the adoption of durian-rind LMP as a clean-label stabilizer. With its very low methoxyl content, durian-rind pectin is a promising source of LMP. LMP gels in the presence of calcium, rather than high sugar, making it valuable for low-sugar jams, jellies, and other dietetic confectionery, as well as an excellent stabilizer for reduced-fat ice cream.

3.2. Physicochemical and textural properties of ice cream

Commercial ice cream typically contains 10–18 % milk fat, which influences its structure and taste. Durian-rind pectin, a low-methoxyl type that gels without added sugar, can stabilize reduced-fat products (Assifaouia et al., 2024). We prepared a no-pectin ice cream with 8.03 % fat (Sample 1) and variants with 0.17–0.67 % added pectin to assess its effects. Their typical properties are shown in Table 3.

Ice crystal formation and whipping can destabilize the fat emulsion during freezing, and milk proteins and fat are key to ice cream's structure (Muse & Hartel, 2004). Reduced-fat formulations face additional challenges as reduced fat compromises this network; however, incorporating carbohydrate-based stabilizers increases mix viscosity and helps maintain structure (Schmidt et al., 1993). As shown in Table 3, the apparent viscosity of the ice cream mixes at 20 rpm increased

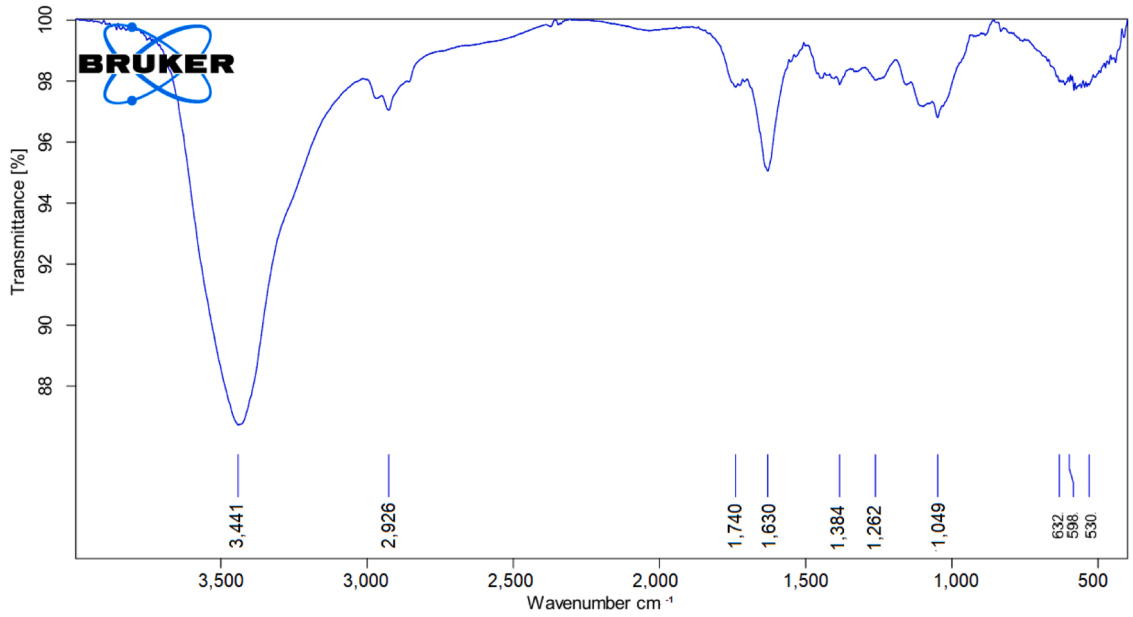

Fig. 1. FTIR spectra of durian-rind pectin.

Table 2
Microbiological and heavy-metal test results for pectin powder.

Parameter	Unit	Result
Total aerobic mesophilic count	CFU/g	< 10
E. coli	CFU/g	< 10
Lead (Pb)	mg/kg	n.d
Yeasts and molds	CFU/g	< 10

n.*d* = not detected, Counts below 10 CFU/g are regarded as "not detected.".

Table 3
Physicochemical and textural properties.

Properties	Sample C	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Viscosity (cP) at 20 rpm	n.d	1423 ±43	12,330 ±65	17,980 ±71	22,360 ±59	n.d
pH at 25 °C	6.73 ±0.14^{a}	6.63 ±0.09^{a}	6.54 ±0.20^{a}	6.54 ±0.36^{a}	6.40 ±0.18^{a}	6.34 ±0.12^{a}
Overrun (%)	75.22 ±3.27^{a}	118.98 ±6.16^{c}	93.54 ±7.42^{b}	83.09 ±4.47^{ab}	80.27 ±9.83^{ab}	72.99 ±3.02^{a}
Hardness (N)	31.59	2.76	4.31	19.17	12.87	15.73
Meltdown (%)	35.13 ±5.65^{a}	66.38 ±1.65^{c}	54.89 ±2.32^{d}	34.22 ±1.09^{a}	18.14 ±2.21^{b}	12.92 ±0.87^{b}
Time of first drop (mins)	19.20 ±2.30^{a}	11.4 ± 0.43^{b}	19.17 ±0.23^{a}	41.40± 0.65^{c}	66.00 ±3.00^{d}	85.00 ±2.00^{e}

Values that exceeded the instrument range at the set condition were reported as n.d.
Values are mean ± SD ($n \geq 3$); Values sharing a letter are not significantly different by Tukey's HSD ($\alpha = 0.05$).

significantly with the addition of pectin. Sample 1 (0 % pectin) exhibited the lowest viscosity (1.4 × 10^3 cP), whereas Sample 2 (0.17 % pectin) rose to 1.23×10^4 cP and Sample 3 (0.34 % pectin) to 1.80×10^4 cP. Sample 4 (0.50 % pectin) further increased to 2.24×10^4 cP, near the upper measurement limit. Samples 5 (with the highest content of pectin) and C (no pectin but higher fat) showed viscosity beyond the measurable limit ("not detected"). This trend aligns with previous reports that hydrocolloid stabilizers, such as pectin, substantially increase the viscosity of ice cream mix, thereby improving resistance to meltdown by restricting serum flow during melting (Zhang et al., 2018). In the case of sample 5, its excessively high viscosity may hinder processing (such as mixing and pumping) and reduce overrun when applied at a higher scale.

Table 3 presents the pH values of various ice cream mix formulations. The pH values decreased slightly with increasing pectin content. This modest decline likely reflects the acidic nature of pectin or its influence on serum buffering. While the effect on protein functionality and gelation in dairy systems is limited within this range, pH should still be monitored to prevent adverse protein destabilization. The pH mix remained within the typical dairy range (6.3–6.7), which is consistent with reports that botanical or clean-label additions at low concentrations rarely alter the buffered milk-salt/casein system (Ghaderi et al., 2021; Shadordizadeh et al., 2023; Yosefiyan et al., 2024). However, our findings differ slightly from the range of 6.15 to 6.34 reported by Akesowan (2009).

Air incorporation is essential for the soft and smooth texture of ice cream. The overrun decreased progressively as the pectin concentration increased. Sample 1 displayed the highest overrun, indicating a highly aerated, "light" structure. As pectin was added, overrun decreased progressively, yielding denser textures in Samples 2–5. Notably, Sample C, despite containing no pectin, exhibited a moderate overrun comparable to mid-level pectin formulations, which is attributable to its dense, fat-rich matrix. The inverse relationship between mix viscosity and overrun is well established: higher viscosity impedes air incorporation and retention (Chang & Hartel, 2002). Lower overrun yields denser, creamier ice cream but may compromise perceived smoothness if excessively low. It was speculated that the use of stabilizers during the whipping process leads to increased viscosity, resulting in lower overrun but more stable foam in the pectin-containing samples (Adapa et al., 2000), mirroring results from plant-matrix and clean-label stabilisation studies where a thicker continuous phase suppresses air uptake during freezing (Ghaderi et al., 2021). Previous studies have also found that adding carbohydrate-based stabilizers to ice cream can reduce overrun compared to traditional formulations (Karaca et al., 2009).

The measured hardness of fully frozen samples increased with pectin up to a point but showed non-monotonic behavior at higher levels and in fat-rich formulations. As shown in Table 3, Sample 1 exhibited the lowest hardness (2.76 N). Sample 2 rose modestly to 4.31 N (0.17 % pectin). Sample 3 (0.34 % pectin) reached 19.17 N, indicating a substantial strengthening of the frozen structure. Sample 4 (0.50 % pectin)

measured 12.87 N, and Sample 5 (0.67 % pectin) measured 15.73 N. Sample C showed the highest hardness (31.59 N). The increase in hardness with moderate pectin addition corresponds to enhanced serum viscosity and network formation, which supports the stabilization of ice crystals and air cells (Zhang et al., 2018). Some studies mentioned that the hardness of ice cream is influenced by various factors, including the amount of air incorporated, the size of ice crystals, and the stability of the fat content (Goff, 2018). However, very high pectin or fat content can produce overly firm, dense textures that may be perceived as excessively hard. An optimal hardness for premium hard ice cream often lies between the extremes observed; in this study, samples 3 and 4 provided a balance between structural strength and palatability.

The melting rate of ice cream, influenced by air content, ice crystals, and fat networks, affects its appeal. Fat stabilizes air cells and, through partial coalescence, helps preserve the ice cream's shape during storage and consumption. Therefore, reduced-fat ice cream has a faster melting rate compared to full-fat ice cream (Zhang et al., 2018). Table 3 indicates that the meltdown over 120 min decreased markedly with the addition of pectin. Sample 1 melted extensively (66.38 %), while Sample 2 improved to 54.89 %. Samples 3 and 4 further reduced meltdown, and Sample 5 reached the lowest meltdown. Sample C (no pectin) exhibited a 35.13±5.65 % meltdown, similar to Sample 3, which is attributable to its high-fat matrix. These results confirm that pectin enhances melt resistance by increasing mix viscosity and stabilizing the serum phase, thereby retarding drainage during melting (Zhang et al., 2018; Javidi et al., 2016). Fat-rich formulations can partly mimic this effect (Sample C), but pectin at moderate levels (0.34–0.50 %) offers more sustained resistance. Comparable slow-melt, higher-firmness outcomes have been reported for ice creams fortified with encapsulated botanical extracts (Shadordizadeh et al., 2023) and upcycled fruit peels such as freeze-dried persimmon (Yosefiyan et al., 2024). Excessively low meltdown (<15 %) at a higher dose (0.67 %) risks over-thickening and depressed overrun, which is a trade-off also noted in related clean-label approaches (Ghaderi et al., 2021; Rafe et al., 2022).

The time to first drip increased progressively with pectin addition, rising from roughly 10 min in the control to around 20 min at low pectin levels and extending beyond 40 min at moderate concentrations, ultimately exceeding an hour at the highest level. The pectin gel network absorbs water, creating "bound water" that is tightly bound to the molecular chain, reducing the amount of "free water" that can dissolve under the influence of temperature increase. This trend confirms that pectin enhances structural integrity under melting by increasing mix viscosity and reinforcing the frozen network (Zhang et al., 2018). A high-fat, no-pectin sample exhibited a moderate delay in dripping due to the fat-driven structure, but it did not match the stability achieved with pectin.

The time-lapse images at room temperature in Fig. 2 reveal a clear gradient of structural stability among the six formulations. The no-pectin reduced-fat sample (Sample 1) collapsed by 30 min, whereas the low pectin content (0.17 %, Sample 2) delayed failure but lost shape by 60 min. Moderate pectin (0.34 %, Sample 3) retained a recognisable block through 60 min, slumped by 90 min, and spread mainly by 120 min. At 0.50 % (Sample 4), the shape was maintained for 90 min, and a thick disc remained at 120 min. The highest pectin content (0.67 %, Sample 5) and the high-fat control (Sample C) attempted to maintain their forms throughout the 90–120 min period, with Sample C remaining mound-like and Sample 5 exhibiting only limited spreading. These visual trends align with the quantitative data: increasing pectin lengthened the time-to-first-drip and reduced the 120-min meltdown, effects expected when stabilizers raise serum viscosity and limit drainage during melt. LMP forms calcium-mediated "egg-box" junction zones that strengthen the continuous network and interfacial films, thereby resisting collapse; higher molecular-weight/longer homogalacturonan regions further support junction-zone formation (Patova et al., 2024). In ice cream, melt resistance depends strongly on the properties of the serum phase and the interfacial structure. Higher mix viscosity slows down drip-through, and fat/air lamellae that are better reinforced resist coalescence and height loss during melting (Wu et al.,

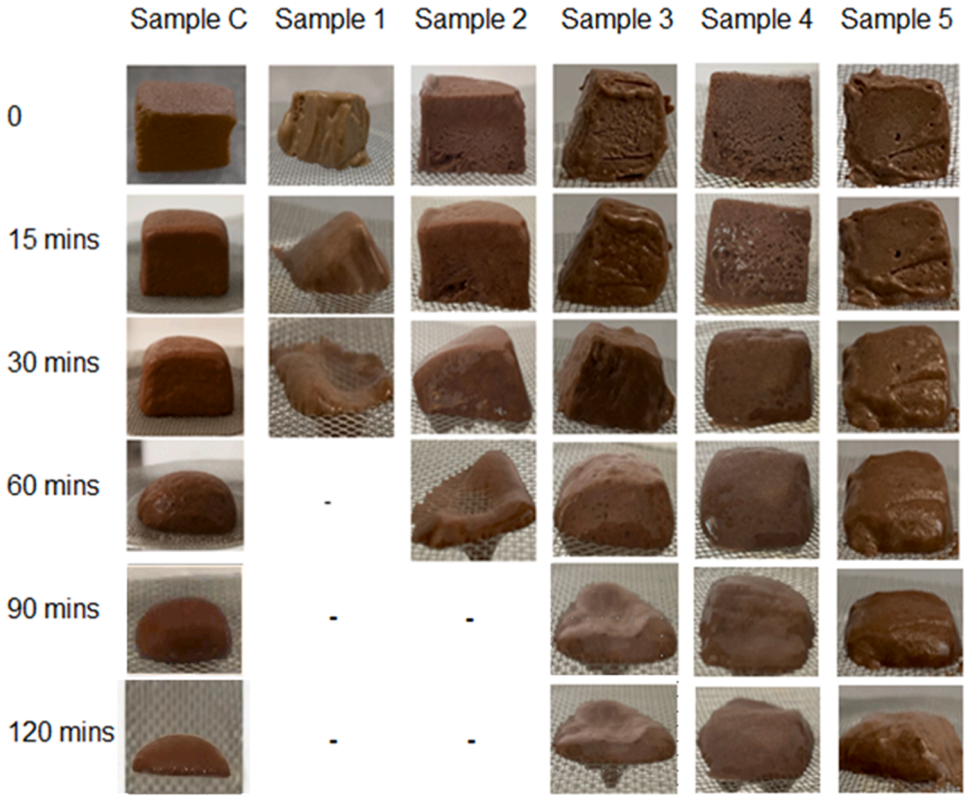

Fig. 2. Structural collapse of ice cream samples (0–120 min, 25 °C, standard lighting).

2019). Like earlier research, adding pectin to ice cream makes it thicker, firmer, and less prone to melting (Zhang et al., 2018). However, too much pectin can hurt aeration by making the mixture too thick. Visually, the sequence confirms that low- or no-stabilizer mixes collapse rapidly; moderate fat or low pectin delays the collapse; and pectin at 0.34–0.50 % strikes an optimal balance, retaining a recognizable shape over one hour without an impractically dense texture. Higher pectin (0.67 %) further slows collapse but may compromise aeration and processing. Thus, these images succinctly illustrate how formulation choices govern an ice cream's ability to withstand ambient conditions.

Across all samples, pH remained within a narrow range (6.3–6.7) and did not markedly affect protein functionality. The observed inverse relationship between viscosity and overrun, as well as the positive correlation between viscosity and hardness, with drip time and melt resistance, confirms the fundamental principles of ice cream structure. Hardness increased with pectin level in parallel with higher apparent serum viscosity. This association is consistent with LMP-mediated water immobilisation and possible reinforcement of air-cell lamellae through transient Ca^{2+} junction zones, which would resist deformation during penetration. However, ice-crystal size and distribution were not quantified in this study, and these microstructural features can also influence perceived firmness. Accordingly, hardness changes are not attributed solely to serum-phase effects. Notably, moderate pectin levels (0.34–0.50 % w/w) strike an optimal balance, delivering significant improvements in melt resistance and delayed collapse while maintaining reasonable aeration and texture. Sample C's intermediate stability underscores fat's contributory role, but its limited extension of drip time relative to pectin-containing samples highlights the superior efficacy of moderate hydrocolloid addition. Formulations with very high pectin content (over 0.50 %) or fat content achieve maximal stability but risk impractically high viscosities and an excessively dense mouthfeel.

Tukey's HSD ($\alpha = 0.05$) corroborates the main conclusion: Formulations with 0.34–0.67 % pectin showed significantly lower meltdown and longer time-to-first-drip than the control; overrun did not differ significantly from the control, and pH was unchanged across treatments; and the no-pectin reduced-fat sample performed considerably worse on melt-related end-points. These results suggest that moderate pectin preserves aeration while improving melt stability.

This work established the minimal effective dose of durian-rind LMP in a reduced-fat chocolate ice-cream matrix, but several limitations temper the breadth of the conclusions. First, long-term storage behavior, freeze–thaw stability, and heat-shock stability, as well as associated ice-crystal dynamics, were not measured. Second, rheology was used as a whippability index under fixed conditions rather than for complete characterization; flow curves were not acquired, nor were they paired with microstructural imaging. Future work will optimise Ca^{2+} cross-linking, couple microstructure (using cryo-SEM) with rheology to deepen structure–function links, and evaluate freeze–thaw/heat-shock stability. Third, the texture analyzer lacked temperature control, preventing hardness testing at 4 °C, as in Zhang et al. (2018). Samples were tempered at −10 °C for 4 h and then measured in a 20 °C room. Because hardness near the softening range is highly temperature-sensitive, minor warming during loading likely increased variability; consequently, hardness showed large standard deviations. Future studies should utilize a temperature-controlled fixture to test at 4 °C (or a defined subzero set-point) and record the core temperature at puncture to minimize variance.

3.3. Sensory evaluation of reduced-fat ice cream

Sensory results in Table 4 align with the physicochemical profiles: Sample 1 (no pectin, lower fat) scored lowest in taste, texture, and overall liking, reflecting its weaker structure and faster melting properties. Sample C (high fat, no pectin) achieved the highest taste, texture, and overall liking. Pectin-containing samples (Samples 2–5) scored similarly, with taste ranging from 4.42 to 4.50, texture from 4.38 to 4.52, and overall liking from 7.29 to 7.60, indicating that moderate pectin levels (0.17–0.67 %) were preserved, resulting in an acceptable mouthfeel. Sample 3 (0.34 % pectin) matched Sample C in overall liking (7.69) despite lower fat, confirming that 0.34–0.50 % pectin can compensate for fat reduction by maintaining pleasing texture and taste. Sample 4 also performed well (overall liking 7.43). Sample 5 (0.67 % pectin) had a slightly lower liking (7.29), suggesting that a high stabilizer may begin to affect aeration.

Table 4
Sensory evaluation of reduced-fat ice cream.

Sensory attributes	Sample C	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Taste	4.58 ± 0.08^{a}	4.16 ± 0.05^{c}	4.42 ± 0.04^{b}	4.50 ± 0.07^{ab}	4.50 ± 0.10^{ab}	4.40 ± 0.10^{b}
Texture	4.56 ± 0.09^{a}	3.96 ± 0.05^{d}	4.38 ± 0.08^{b}	4.46 ± 0.05^{abc}	4.52 ± 0.04^{ac}	4.42 ± 0.08^{b}
Overall liking*	7.69 ± 1.47^{a}	6.49 ± 1.80^{b}	7.60 ± 1.56^{a}	7.69 ± 1.69^{a}	7.43 ± 1.56^{a}	7.29 ± 1.79^{ab}

* 9-point hedonic scale: 1 - Dislike extremely 2 - Dislike very much 3 - Dislike moderately 4 - Dislike slightly 5 - Neither like nor dislike 6 - Like slightly, 7 - Like moderately, 8 - Like very much, 9 - Like extremely

Values are mean ± SD (taste/texture $n = 5$; overall liking $n = 35$); Within a row, values sharing a letter are not significantly different by Tukey's HSD ($\alpha = 0.05$).

ANOVA indicated a significant effect of formulation on taste and texture (both $p < 0.001$; $F(5,24) = 47.27$), and a minor but significant impact on overall liking ($p < 0.05$; report $F(5204) = 2.68$). Tukey's HSD showed that the no-pectin reduced-fat sample (Sample 1) scored significantly lower than the other formulations for both taste and texture. The formulations with 0.34–0.50 % (Samples 3–4) were statistically indistinguishable from the high-fat control (Sample C) in terms of taste and texture, while the formulations with 0.17 % and 0.67 % pectin (Samples 2 and 5) were generally intermediate. For overall liking, Sample 1 differed from the control and the pectin-containing formulations, whereas Samples 2–5 did not differ from the control (as indicated by the letters in Table 4).

Thus, formulations with approximately 0.34–0.50 % pectin achieve sensory acceptance comparable to that of a high-fat control, balancing structure and mouthfeel without compromising taste or overall appeal. Additionally, they achieve compatibility between measured physical properties (adequate viscosity, controlled overrun, sufficient hardness, delayed drip, and limited meltdown) and desirable sensory attributes, supporting their suitability as balanced hard-serve ice cream formulations. In this study, sensory evaluation relied on a modest laboratory panel; therefore, broader consumer acceptance across demographic groups remains to be verified in the subsequent study phase.

3.4. Microbiological quality of the representative formulation

Based on the techno-functional and sensory screening (Tables 3–4; Fig. 2), Sample 3 (0.34 wt % pectin) was selected for microbiological verification (Table 5) because it offered the best overall balance—adequate aeration (overrun ≈ 83 %), moderate hardness (19.17 N), low meltdown (34 %), and overall liking statistically indistinguishable from

Table 5
Microbiological evaluation of Sample 3 (0.34 wt % pectin) after two weeks of frozen storage at –10 °C.

Parameter	Unit	Result
Total aerobic mesophilic count	CFU/g	31
E. coli	CFU/g	< 10
Enterobacteriaceae	CFU/g	< 10
Salmonella spp.	/25 g	n.d
Yeasts and molds	CFU/g	19

n.*d* = not detected, Counts below 10 CFU/g are regarded as "not detected.".

the high-fat control. The purpose of this test was to confirm safety compliance for a representative, consumer-acceptable formulation, rather than to compare microbiology across all variants.

Table 5 reports the results after 15 days at −10 °C: no *E. coli, Enterobacteriaceae*, or *Salmonella* spp. were detected, while total aerobic mesophilic count (31 CFU/mL) and yeasts/molds (19 CFU/mL) remained within the limits specified by TCVN 7402:2019 for ice cream. Lead (Pb) was not detected (TCVN 8900–8:2012). The addition of 0.34 % durian-rind pectin did not compromise hygiene status relative to national specifications for ice cream, supporting its suitability as a clean-label stabilizer from a safety perspective. From an applied standpoint, these data suggest that the formulation can be stored in a home freezer without microbial quality loss, aligning with typical consumer use windows. This supports the practical feasibility of incorporating durian-rind pectin into ice cream formulations intended for consumer markets.

4. Conclusions

Durian rind, an abundant agro-industrial by-product, can be transformed into a valuable source of LMP, which demonstrated promising application in reduced-fat ice cream. LMP enhances melt stability in reduced-fat ice cream by immobilising serum water (raising continuous-phase viscosity) and forming transient Ca^{2+}-mediated junction zones that reinforce air-cell lamellae and interfacial films, thereby suppressing drainage and coalescence during warming and delaying first drip and structural collapse. Within integrated formulations, a minimal effective dose of 0.34 wt % delivered the most balanced performance. The 0.34–0.50 wt % range of pectin maintained adequate overrun, increased hardness, and reduced meltdown by approximately 80 % (the first drip was extended to 41 min). Thus, a modest addition of durian-rind LMP can reproduce the creamy body and controlled melt typical of reduced-fat ice cream, enabling 30 % fat reduction without compromising quality. These outcomes provide a dual benefit: effective valorization of durian waste, aligned with the circular economy and Sustainable Development Goals, and a clean-label stabilizer supporting the growing market for healthier frozen desserts. To translate this formulation into a marketable product, a staged program of follow-on work, including pilot-scale manufacturing, shelf-life and cold-chain stability assessments, regulatory and safety evaluations, and consumer validation, will be required as part of a longer-term commercialization strategy in the future.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used ChatGPT and Grammarly in order to improve readability and language. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

CRediT authorship contribution statement

Trung Dang-Bao: Writing – review & editing, Validation, Methodology, Investigation, Data curation. **Uyen D.H. Huynh:** Writing – review & editing, Resources, Investigation. **Truc T.X. Mang:** Writing – original draft, Visualization, Formal analysis, Data curation. **Uyen P.N. Tran:** Writing – review & editing, Supervision, Project administration, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

References

Adapa, S., Dingeldein, H., Schmidt, K. A., & Herald, T. J. (2000). Rheological properties of ice cream mixes and frozen ice creams containing fat and fat replacers. *Journal of Dairy Science, 83*(10), 2224–2229. https://doi.org/10.3168/jds.S0022-0302(00)75146-1

Akalın, A. S., Karagözlü, C., & Ünal, G. (2008). Rheological properties of reduced-fat and low-fat ice cream containing whey protein isolate and inulin. *European Food Research and Technology = Zeitschrift Fur Lebensmittel-Untersuchung Und -Forschung A, 227*, 889–895. https://doi.org/10.1007/s00217-008-0887-5

Akesowan, A. (2009). Influence of soy protein isolate on properties of ice cream. *Thai Journal of Agricultural Science, 42*(1), 1–6. https://www.thaiscience.info/journals/Article/TJAS/10469543.pdf.

Assifaouia, A., Hayrapetyan, G., Gallery, C., & Agoda-Tandjawa, G. (2024). Exploring techno-functional properties, synergies, and challenges of pectins: A review. *Carbohydrate Polymer Technologies and Applications, 7*, Article 100496. https://doi.org/10.1016/j.carpta.2024.100496

Chang, Y., & Hartel, R. W. (2002). Development of air cells in a batch ice cream freezer. *Journal of Food Engineering, 55*, 71–78. https://doi.org/10.1016/S0260-8774(02)00034-5

EFSA (European Food Safety Authority). (2017). *Re*-evaluation of pectin (E 440i) and amidated pectin (E 440ii) as food additives. *EFSA Journal, 15*(7), 4866. https://doi.org/10.2903/j.efsa.2017.4866

Ghaderi, S., Mazaheri Tehrani, M., & Hesarinejad, M. A. (2021). Qualitative analysis of the structural, thermal and rheological properties of a plant ice cream based on soy and sesame milks. *Food Science & Nutrition, 9*, 1289–1298. https://doi.org/10.1002/fsn3.2037

Goff, H. D. (2018). Ice cream and frozen desserts: Product types. *Ref. module food sci.* https://doi.org/10.1016/B978-0-08-100596-5.21754-5

Goff, H. D., & Hartel, R. W. (2013). *Ice cream* (7th ed.). New York: Springer. https://doi.org/10.1007/978-1-4614-6096-1

Huynh, U. D. H., Nguyen, C. D. H., Le, N. L. B., Le, K. T. K., Nguyen, T. T. T., Mang, T. X. T., & Tran, U. P. N. (2024). Recovery of beneficial compounds from fruit waste for application to potential skincare products. *Chemical Engineering Transactions, 113*, 325–330. https://doi.org/10.3303/CET2413055

Javidi, F., Razavi, S. M. A., Behrouzian, F., & Alghooneh, A. (2016). The influence of basil seed gum, guar gum and their blend on the rheological, physical and sensory properties of low fat ice cream. *Food Hydrocolloids, 52*, 625–633. https://doi.org/10.1016/j.foodhyd.2015.06.016

Jong, S. H., Abdullah, N., & Muhammad, N. (2023). Effect of acid type and concentration on the yield, purity, and esterification degree of pectin extracted from durian rinds. *Results in Engineering, 17*, Article 100974. https://doi.org/10.1016/j.rineng.2023.100974

José, P., Karina, G. J. P., & Lorena, V. (2022). Optimization and preliminary physicochemical characterization of pectin extraction from watermelon rind (Citrullus lanatus) with citric acid. *International Journal of Food Science, 2022*(1), Article 3068829. https://doi.org/10.1155/2022/3068829

Karaca, O. B., Güven, M., Yasar, K., Kaya, S., & Kahyaoglu, T. (2009). The functional, rheological and sensory characteristics of ice creams with various fat replacers. *International Journal of Dairy Technology, 62*(1), 93–99. https://doi.org/10.1111/j.1471-0307.2008.00466.x

Li, D. Q., Li, J., Dong, H. L., Li, X., Zhang, J. Q., Ramaswamy, S., & Xu, F. (2021). Pectin in biomedical and drug delivery applications: A review. *International Journal of Biological Macromolecules, 185*, 49–65. https://doi.org/10.1016/j.ijbiomac.2021.05.089

Liang, W., Zhang, Y., Zhang, L., & Chen, S. (2022). Physicochemical characteristics and functional properties of high methoxyl pectin with different degree of esterification. *Food Chemistry, 373*, 131558. https://doi.org/10.1016/j.foodchem.2021.131806

Lim, L., Inglett, G. E., & Lee, S. (2015). Response to consumer demand for reduced-fat foods: Multi-functional fat replacers. *Japan Journal of Food Engineering, 11*, 147–152. https://doi.org/10.18494/jjfe.11.147

Leong, C. M., Noranizan, M. A., Muhammad, K., & Choo, W. S. (2016). Physicochemical properties of pectin extracted from jackfruit (Artocarpus heterophyllus) and chempedak rinds using various acids. *International Food Research Journal, 23*(3), 973–978.

Ma, N. B., Tran, N. M., Trinh, P. H., Vo, T. D., Vu, L. T. K., Ton, N. M. N., & Le, N. L. (2025). Characterization, sensory evaluation and oxidative stability of reduced-fat mayonnaise formulated with polysaccharides extracted from mangosteen peels as fat replacer. *The Journal of Agriculture and Food Research, 19*, Article 101747. https://doi.org/10.1016/j.jafr.2025.101747

Maran, J. P. (2015). Statistical optimization of aqueous extraction of pectin from waste durian rinds. *International Journal of Biological Macromolecules, 73*, 92–98. https://doi.org/10.1016/j.ijbiomac.2014.12.019

Mbaeyi-Nwaoha, I. E., Nnamani, C. L., & Ndukwe, O. O. (2019). Evaluation of the effects of pectin extracted from jackfruit (Artocarpus heterophyllus) and passion fruit (Passiflora edulis var. flavicarpa Deg.) peels on the quality attributes of yoghurt from skimmed milk. *Saudi Journal of Pathology and Microbiology, 4*(4), 371–385. https://doi.org/10.21276/sjpm.2019.4.4.17

McGhee, C. E., Jones, J. O., & Park, Y. W. (2015). Evaluation of textural and sensory characteristics of three types of low-fat goat milk ice cream. *Small Ruminant Research : The Journal of the International Goat Association, 123*(2–3), 293–300. https://doi.org/10.1016/j.smallrumres.2014.10.006

Ministry of Health (Vietnam), 2022. Method for detection/enumeration of *Escherichia coli*. VS 64:2022. Ministry of Health, Hanoi, Vietnam.

Muse, M. R., & Hartel, R. W. (2004). Ice cream structural elements that affect melting rate and hardness. *International Dairy Journal / Published in Association with the International Dairy Federation, 14*(3), 275–281. https://doi.org/10.1016/S0958-6946(03)00137-4

Patova, O. A., Kosolapova, N. V., & Golovchenko, V. V. (2024). Complex influence of structural characteristics of low-methoxyl pectins on rheological properties of semi-solid Ca-gels. *International Journal of Biological Macromolecules, 280*(Part 1), Article 135633. https://doi.org/10.1016/j.ijbiomac.2024.135633

Rafe, A., Selahbarzin, S., Kulozik, U., & Hesarinejad, M. A. (2022). Dilatational rheology-property relationships of β-lactoglobulin/high-methoxyl pectin mixtures in aqueous foams. *Food Hydrocolloids, 130*, Article 107683. https://doi.org/10.1016/j.foodhyd.2022.107683

Schmidt, K., Lundy, A., Reynolds, J., & Yee, L. N. (1993). Carbohydrate or protein-based fat mimicker effects on ice milk properties. *Journal of Food Science, 58*(4), 761–763. https://doi.org/10.1111/j.1365-2621.1993.tb06916.x

Shahi, S. K., Didar, Z., Hesarinejad, M. A., & Vazifedoost, M. (2021). Optimized pulsed electric field-assisted extraction of biosurfactants from Chubak (Acanthophyllum squarrosum) root and application in ice cream. *Journal of the Science of Food and Agriculture, 101*, 3693–3706. https://doi.org/10.1002/jsfa.11000

Shadordizadeh, T., Mahdian, E., & Hesarinejad, M. A. (2023). Application of encapsulated Indigofera tinctoria extract as a natural antioxidant and colorant in ice cream. *Food Science & Nutrition, 11*, 1940–1951. https://doi.org/10.1002/fsn3.3228

Singhal, S., & Swami Hulle, N. R. (2022). Citrus pectins: Structural properties, extraction methods, modifications and applications in food systems – A review. *Applied Food Research, 2*, Article 100215. https://doi.org/10.1016/j.afres.2022.100215

Tam A., 2024, Vietnamese innovation: Biochar and wood vinegar production from durian shells, VietNamNet Global, Vietnam <vietnamnet.vn/en/vietnamese-innovation-biochar-and-wood-vinegar-production-from-durian-shells-2315633.html>accessed 27.05.2025.

TCVN (Vietnamese National Standards), 2007. Microbiology of food and animal feeding stuffs—Horizontal method for the enumeration of Enterobacteriaceae—Part 2: Colony-count technique. TCVN 5518-2:2007. Directorate for Standards, Metrology and Quality (STAMEQ), Hanoi, Vietnam.

TCVN (Vietnamese National Standards), 2017. Microbiology of the food chain—Horizontal method for the detection, enumeration and serotyping of Salmonella—Part 1: Detection of Salmonella Spp. Tcvn 10780-1:2017. STAMEQ, Hanoi, Vietnam.

TCVN (Vietnamese National Standards), 2015. Microbiology of the food chain—Horizontal method for the enumeration of microorganisms—Part 1: Colony count at 30°C by the pour plate technique (ISO 4833-1:2013). TCVN 11039-1:2015. Directorate for Standards, Metrology and Quality (STAMEQ), Hanoi, Vietnam.

TCVN (Vietnamese National Standards). (2021). *Microbiology of the food chain—Horizontal method for the enumeration of yeasts and moulds*. Hanoi, Vietnam: STAMEQ. TCVN 13369:2021.

TCVN (Vietnamese National Standards). (2008). *Microbiology of food and animal feeding stuffs—Horizontal method for the enumeration of β-glucuronidase-positive escherichia coli—Part 2: colony-count technique at 44°C using tbx (ISO 16649-2:2001)*. Hanoi, Vietnam: STAMEQ. TCVN 7924-2:2008.

TCVN (Vietnamese National Standards). (2012). *Food—Determination of lead (Pb)—Part 8: atomic absorption spectrometric method*. Hanoi, Vietnam: STAMEQ. TCVN 8900-8:2012.

Tran, U. P. N., Dang, T., Le, P. T. K., Huynh, U. D. H., Nguyen, T. T. H., & Le, T. M. (2022). Encapsulation of betalains extracted from red dragon fruit peels by freeze-drying using microcrystalline cellulose and dragon fruit peel pectin as wall materials. *Chemical Engineering Transactions, 102*, 31–36. https://doi.org/10.3303/CET2312006

Tran, U. P. N., & Dang, T. (2023). Stability improvement of betalains recovered from red dragon fruit peels (Hylocereus polyrhizus) by cellulose-based encapsulation. *Fibers and Polymers, 24*, 2683–2696. https://doi.org/10.1007/s12221-023-1164-0

Trigo, J. P., Alexandre, E. M. C., Saraiva, J. A., & Pintado, M. E. (2020). High value-added compounds from fruit and vegetable by-products: Characterization, bioactivities, and application in the development of novel food products. *Critical Reviews in Food Science and Nutrition, 60*, 1388–1416. https://doi.org/10.1080/10408398.2018.1451928

Wai, W. W., Alkarkhi, A. F. M., & Easa, A. M. (2009). Optimization of pectin extraction from durian rind (*Durio zibethinus*) using response surface methodology. *The Journal of Food Science, 74*(8), C637–C641. https://doi.org/10.1111/j.1750-3841.2009.01331.x

Wai, W. W., Alkarkhi, A. F. M., & Easa, A. M. (2010). Effect of extraction conditions on yield and degree of esterification of durian rind pectin. *Food and Bioproducts Processing, 88*(2–3), 219–224. https://doi.org/10.1016/j.fbp.2010.01.010

Wu, B., Freire, D. O., & Hartel, R. W. (2019). The effect of overrun, fat destabilization, and ice cream mix viscosity on entire meltdown behavior. *Journal of Food Science, 84*, 2562–2571. https://doi.org/10.1111/1750-3841.14743

Yosefiyan, M., Mahdian, E., Kordjazi, A., & Hesarinejad, M. A. (2024). Freeze-dried persimmon peel: A potential ingredient for functional ice cream. *Heliyon, 10*, Article e25488. https://doi.org/10.1016/j.heliyon.2024.e25488

Zhang, H., Chen, J., Li, J., Wei, C., Ye, X., Shi, J., & Chen, S. (2018). Pectin from citrus canning wastewater as potential fat replacer in ice cream. *Molecules, 23*(2), 295. https://doi.org/10.3390/molecules23040925