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Physicochemical properties and melting behavior of coconut milk ice cream with Melinjo (*Gnetum gnemon* Linn.) leaves incorporation

Threechart Chonlatarn[a,b]* and Praphan Pinsirodom[a]

[a] *Program in Foodservice Technology and Management, School of Food Industry, King Mongkut's Institute of Technology Ladkrabang, Bangkok, 10520 Thailand*

[b] *Suan Dusit University, Trang Center, Trang, 92130 Thailand*

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Abstract

Melinjo (*Gnetum gnemon* Linn.), locally known in Thailand as "Liang," is a widely consumed vegetable in Southern Thailand and often referred to as the "queen of local vegetables" due to its nutritional and health-promoting properties. However, old leaves remain underutilized. This study aimed to evaluate the effects of Melinjo leaf incorporation on the physicochemical properties and melting behavior of coconut milk ice cream. Ice cream formulations were prepared with 5%, 10%, 15%, and 15% (pulp-separated) leaves (w/w), and their physicochemical and melting characteristics—including color parameters, pH, apparent viscosity, overrun, melting rate, induction time to the first drip, and time to 50% drip-through—were analyzed. Increasing Melinjo leaf content significantly decreased L* values while increasing a* and b* values ($p \leq 0.05$). Leaf incorporation slightly elevated pH and significantly increased viscosity ($p \leq 0.05$), whereas overrun decreased with higher leaf levels, likely due to the influence of dietary fiber and phenolic compounds on air incorporation. Furthermore, Melinjo addition significantly reduced the melting rate and prolonged both induction time to the first drip and time to 50% drip-through ($p \leq 0.05$). Overall, incorporation of 15% Melinjo leaves was found to optimize melting resistance and functional properties. These results highlight the potential of Melinjo leaves as a functional ingredient for the development and quality enhancement of coconut milk ice cream and related plant-based frozen desserts.

Introduction

Melinjo (*Gnetum gnemon* Linn.), locally known as "Liang" in Thailand, is a perennial plant native to Southeast Asia and the western Pacific islands. It naturally grows in regions such as Mizoram and Assam in India, southern Thailand, Indonesia, Malaysia, the Philippines, Fiji, and Australia. The plant typically reaches a height of 2-3 m and remains evergreen throughout the year. In Thailand, the young leaves and tender tips are commonly consumed and have long been used in traditional medicine. Their slightly astringent

* Corresponding Author
e-mail: 65086011@kmitl.ac.th

taste is attributed to phenolic compounds (Maisuthisakul et al., 2007).

The nutritional and functional properties of *G. gnemon* have been extensively studied. According to Anisong et al. (2022), its fruits and seeds are widely used in food products in India and Indonesia. The leaves, although less popular than the fruit and seed, contain valuable nutrients, including proteins rich in branched-chain amino acids (BCAAs), vitamin A, dietary fiber, minerals, and chlorophylls. Additionally, they exhibit bioactive properties such as antioxidant and antidiabetic activities, making them a promising raw material for food, nutraceutical, and medicinal applications. Rungruang and Chanthachum (2009) reported that ethanolic extracts of chlorophyll from *G. gnemon* leaves showed antioxidant activity across three leaf stages such as apices, young leaves, and old leaves. Among them, old leaves contained the highest total chlorophyll, whereas total phenolic content did not differ significantly. Antiradical activity, measured by EC_{50} using the DPPH radical scavenging method, was greatest in both young and old leaves.

Ice cream, the most widely consumed frozen dairy dessert, is traditionally produced from milk solids, with or without milk fat, and typically aerated during processing. Its composition and definition vary across regions due to different regulations and traditions (Goff & Hartel, 2013). In Thailand, coconut milk ice cream is particularly popular, offering a unique flavor profile that appeals to both locals and tourists. Coconut milk ice cream is also a versatile product within the food service industry, where it is adapted to consumer trends.

The physicochemical properties of ice cream—including viscosity, overrun, melting resistance, and microstructure—are strongly influenced by ingredient composition, total solids, and processing conditions. Proteins and fibers enhance viscosity and melting resistance, while sugars and emulsifiers affect crystal formation and texture smoothness (Goff & Hartel, 2013; Tolve et al., 2024). Dietary fibers from oats, fruits, and legumes improve water-holding capacity and reduce melting rates, making them attractive for functional ice cream development (Akesowan, 2009; Tolve et al., 2024). Although Melinjo leaves provide nutritional and functional benefits, their flavor is relatively mild, making them suitable for food applications. This study explores the incorporation of old Melinjo leaves since it is considered an underutilized plant part into coconut milk ice cream to enhance product quality. Efficient utilization of these leaves may expand their value in functional foods. Previous innovations, such as a Thai petty patent by Nopguea (2020), described cow's milk ice cream enriched with 5–20% Melinjo leaves (Thai Petty Patent No. 21056, 2020). Similarly, Abishree (2021) developed ice cream enriched with *Amaranthus cruentus* leaves, which enhanced antioxidant activity, increased dietary fiber, and improved physicochemical characteristics. These findings highlight the potential of leafy vegetables as functional ingredients in frozen desserts.

Despite these developments, research on the incorporation of Melinjo leaves, particularly old leaves, into coconut milk ice cream remains limited. Moreover, the effects of leaf pulp separation on product quality have not been studied. Therefore, this study investigates the influence of Melinjo leaf addition, with and without pulp separation, on key physicochemical properties of coconut milk ice cream, including viscosity, color, pH, overrun, and melting behavior. The findings aim to advance the utilization of local plant-based ingredients in frozen desserts and contribute to the growing field of health-oriented food innovation.

Materials and methods

1. Materials and chemicals

Fresh Melinjo leaves were purchased from a local farm in Trang Province, Thailand. Coconut milk (Ampawa, Thailand), coconut water (Malee, Thailand) composed of 60% aromatic coconut water and 40% regular coconut water, as indicated on the product label, refined white sugar (Mitr Phol, Thailand), sodium chloride (NaCl) (Prung Thip, Thailand), stabilizer and emulsifier blend consisted of guar gum (0.2 g/100 g) and mono-and diglycerides (0.3 g/100 g) (IamSoftServe, Thailand). Standard pH buffer solution (pH 4.0 and 7.0) used to calibrate the pH meter (OHAUS, USA).

2. Preparation of Melinjo leaves

A sample of fresh Melinjo leaves was prepared using a modified method of Yuenyongputtakal et al. (2016) and Ploykhaw et al. (2021) by selecting only old leaves (stage 3). This stage is characterized by dark green leaves, with both the upper and lower surfaces fully green, and variable in size and shape. Typically, the leaves measure 10–20 cm (4–8 in) in length and 4–7 cm (1.6–2.8 in) in width. In contrast, apex leaves (stage 1) are brownish-red or slightly brownish red, turning light green between 7 and 14 day of age, while young leaves (stage 2) become light green between 14 and 25 day of age (Anisong et al.,

2022) as shown in Fig. 1. To ensure the consistency of the chemical composition of Melinjo leaves, only intact leaves free from insect damage or disease were selected. All samples were collected from the same farm in Trang Province, Thailand, where standardized cultivation and harvesting practices were applied to control environmental factors that could influence leaf quality. After harvesting, the leaves were stored at 4±1°C. They were used within 24 h to prevent biochemical changes prior to use.

The Melinjo leaves were rinsed and cleaned, and the midrib of the leaves were removed before cutting into 1-cm pieces. The leaves were then blanched in a 1% concentration NaCl solution at 100°C for 2 min, and immediately soaked in ice cold water for 4 min. The sample was placed on a wire rack to drain the water for 5 min, then bolted with paper before further use in experiments as shown in Fig. 2.

Fig. 1 Appearance and characteristic of each stage of Melinjo leaves

Fig. 2 Preparation of Melinjo leaves

In this study, Melinjo leaves were used in 2 forms: whole leaves and pulp-separated leaves. The nutritional composition of Melinjo leaves has been previously characterized, showing that the raw leaves typically contain approximately 5.0–7.0% protein, 2.5–4.0% fat, 10–15% dietary fiber, and 70-80% moisture, along with essential nutrients such as vitamin A, calcium, and iron (Anisong et al., 2022). However, the pulp separation process, which removes coarse fibrous tissues from the leaves, is expected to alter the nutritional profile. These fibrous components are known to contain high levels of insoluble dietary fiber and cell wall-bound phenolic compounds. As a result, pulp-separated leaves may exhibit reduced fiber content (particularly insoluble fiber) and a slightly lower Total Phenolic Content, but offer a finer texture, improved homogeneity, and enhanced dispersibility when incorporated into frozen dessert matrices (Dhingra et al., 2012; Tolve et al., 2024).

3. Ice cream preparation

Coconut milk ice cream was prepared with varying levels of Melinjo leaf incorporation: 5%, 10%, and 15% whole leaves, as well as 15% pulp-separated leaves. The formulations are presented in Table 1, and the preparation process is illustrated in Fig. 3.

The Melinjo leaves were first blended with coconut water using a high-speed blender (Model HR 2195, Philips, Thailand) for approximately 5 min until smooth. Coconut milk was then added, followed by the gradual addition of dry ingredients. The mixture was stirred at room temperature for 10 min until fully dissolved and subsequently homogenized using a high-shear homogenizer (Model MSM 64110, Bosch, Germany) for 5 min. Pasteurization was performed in a water bath (Model WNB 29, Memmert, Germany) at 69±1°C for 30 min. After cooling, the mixture was aged at 4°C for 24 h before being transferred to an ice cream maker (Model Njoyice, N2 Ice, Thailand) and batch-frozen for 30 min at a draw temperature of –5°C. The final product was stored in a batch freezer (Model HCF428H-2, Haier, China) at –18°C for 24 h. Samples of both the initial ice cream mix and the finished product were collected for subsequent analyses.

For the 15% pulp-separated leaf formulation, the blended leaf–coconut water mixture was strained through cheesecloth and pressed to yield an equivalent weight of coconut water before being incorporated into the standard preparation process.

Table 1 Formulations of coconut milk ice cream with different amount of Melinjo leaves addition

Ingredient	Melinjo leaves addition (per 100 g of ice cream mix)				
	0% (Control)	5%	10%	15%	15% (separate the pulp)
Coconut milk (g)	47	47	47	47	47
Coconut water (g)	38	38	38	38	38
Sugar (g)	14	14	14	14	14
Stabilizer and emulsifier (g)	1	1	1	1	1
Fresh Melinjo leaves (g)	-	5	10	15	15

Source: Modify from Promrith and Tansakul (2022).

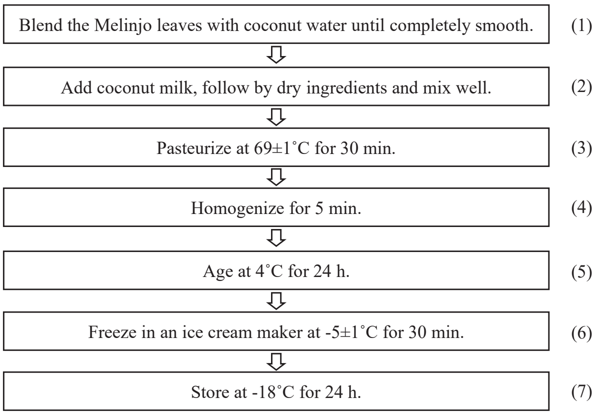

Fig. 3 The process of ice cream preparation
Source: Promrith and Tansakul (2022)

4. Physicochemical properties

4.1 pH Measurement

The pH value was performed according to the modified method of Tolve et al. (2024). The pH was measured using a pH meter(Model ST 3100, OHAUS, USA). The ice cream mix was taken after aging at 4°C for 24 h and allowed to equilibrate at ambient laboratory temperature (25°C) for 50−60 min. The temperature was continuously monitored using a digital thermometer (Model 720, Testo, Germany), and pH measurement was conducted once the ice cream mix reached 25±1°C.

4.2 Color Measurement

The color of the ice cream stored at −18°C for 24 h was measured according to Tolve et al. (2024) using a colorimeter (Model CR-400 Series, Minolta, Japan) with the CIELAB L* a* b* system. The instrument was calibrated using a standard white calibration plate before measurement. The measurements were conducted under a D65 standard illuminant and a 10° standard observer angle, which are commonly used settings for food color evaluation. Results were reported as an average±SD of individual values as L* (lightness), a* (+a = red, -a = green) and b*(+b = yellow, -b = blue).

4.3 Viscosity Measurement

Viscosity of ice cream mixes taken after aging at 4°C for 24 h was analyzed according to the modified method of Moolwong et al. (2023) using a Brookfield viscometer (Model DV2T, Brookfield, USA) with spindle no. 62 at 50 rpm for the sample of control and 15% (with pulp separation) and spindle no. 63 at 180 rpm for the sample of 5% 10% and 15%. A sample of 500 mL was analyzed at 25±2°C. The reading as cP was taken after the motor had been running for 30 sec.

4.4 Overrun Measurement

The overrun of the ice cream was calculated by determining the difference in weight between the ice cream mixture (step 5) and the final ice cream product (step 6) (see Fig. 3), then dividing this difference by the weight of the ice cream product and expressing the result as a percentage (Goff & Hartel, 2013). Measurements were taken using the same container to ensure consistent volume across all samples, with triplicate measurements conducted for each sample.

$$\text{Overrun (\%)} = \frac{\text{Weight of mix - Weight of ice cream}}{\text{Weight of ice cream}} \times 100$$

4.5 Melting behavior

The melting rate of the ice cream was measured using a modified method from Promrith and Tansakul (2022) at 25±1°C. A 100 g ice cream sample, stored in a plastic cylindrical container (7.5 cm diameter, 4.4 cm height) at -18°C for 24 h, was placed on a wire mesh above a 600 mL beaker. The melted portions were weighed every 5 min for up to 60 min. Additionally, the time taken for the ice cream to begin melting (induction time to the first drip) and the time at which 50% of the ice cream had melted (50% drip-through time) were recorded. The meltdown percentage was calculated by dividing the weight of the melted sample by the total sample weight and was plotted against time.

5. Statical analysis

The experiments were done in triplicate and values are reported as the mean±standard deviation. The statical analysis was done using SPSS software (SPSS Version 20, IBM Corp., USA) for the ANOVA and Duncan's New Multiple Range Test to identify difference of the sample at the 95% confidence level ($p \leq 0.05$).

Results and discussion

1. pH values

The pH values of coconut milk ice cream with different amounts of Melinjo leaves addition are shown in Table 2. The addition of Melinjo leaves in ice cream samples resulted in significant increase ($p \leq 0.05$) of the pH values (5.85−5.88) compared to the control ice cream (5.78). However, no significant difference was observed among the coconut milk ice cream samples at all levels of Melinjo leaves addition, and with or without pulp separation. This indicates that the addition of Melinjo leaves in coconut milk ice cream slightly increased the pH values. The pH of fresh Melinjo leaves has been reported to be approximately 6.2 (Anisong et al., 2023) and this is likely to cause the slight increase of pH values found in ice cream samples.

In addition to the intrinsic pH of added ingredients, several other factors can influence the final pH of ice cream formulations. These include the buffering capacity of the base liquid (such as coconut milk), the presence of acidic or alkaline compounds in plant additives, and interactions between ingredients during mixing, aging, or freezing stages (Goff & Hartel, 2013). For instance, plant-derived ingredients rich in organic acids, such as ascorbic, citric, or malic acids may decrease the pH, while leafy vegetables containing alkaline minerals like potassium, calcium, or magnesium may lead to a slight pH increase (Tamime & Robinson, 2007).

Although the observed increase in pH in this study was relatively small, controlling pH remains essential in ice cream manufacturing, particularly in non-dairy systems like coconut milk-based ice cream, where protein stability, emulsion characteristics, and microbiological safety can be pH-sensitive (Goff & Hartel, 2013).

Table 2 pH values of coconut milk ice cream with different amount of Melinjo leaves addition

Amount of Melinjo leaves addition (% by weight)	pH values
Control	5.78±0.08[b]
5%	5.87±0.02[a]
10%	5.87±0.01[a]
15%	5.85±0.03[a]
15% (separate the pulp)	5.88±0.01[a]

Remark: Values are expressed as mean ± SD. Different letters in the same column indicate significant difference ($p \leq 0.05$).

2. Color properties

Table 3 shows the color values (L*, a*, and b*) of coconut milk ice cream samples with different amount of Melinjo leaves addition. Increasing the amount of Melinjo leaves led to a significant decreasing trend in brightness (L*); while the green color value (-a*) and yellow color value (+b*) tended to increase. Results showed that the ice cream with 15% Melinjo leaves had the lowest L* value (60.37±0.36), while a* (-10.34±0.16) and b* (29.81±0.18) values were the highest ($p \leq 0.05$). This trend agrees with the color of Melinjo leaves, which contain chlorophyll, a green pigment found in plants. Typical color and appearance of the control coconut ice cream and samples with Melinjo leaves addition are shown in Fig. 4.

Interestingly, ice cream with 15% Melinjo leaves and with pulp separation showed significant higher L* value (70.85±0.17), but similar a* and b* values compared to all other samples with pulp included. This indicates that pulp separation can improve the brightness of coconut milk ice cream with Melinjo leaves addition.

Similar findings were reported in the study of Boonman et al. (2024), which investigated the incorporation of *Tiliacora triandra* leaf extract into ice cream. An increased level of *T. triandra* extract resulted in lower L* (lightness) values and more negative a* values (indicating a stronger green hue). This phenomenon is attributed to the presence of natural plant pigments such as chlorophylls, anthocyanins, and carotenoids in the leaf extract. Chlorophylls (primarily chlorophyll a and b) are green pigments that absorb red and blue light, resulting in green reflection and hence increased negative a* values. Carotenoids, including lutein and β-carotene, are yellow to orange pigments that absorb light in the blue region, leading to increased b* values (yellow tone). Although anthocyanins are typically associated with red, purple, or blue coloration depending on the pH, they may also contribute to overall color complexity in the product matrix. The combined effect of these pigments reduces light reflectance and contributes to a darker and more saturated green appearance. These results emphasize the influence of pigment-rich plant extracts on the optical properties of frozen dessert formulations and align with the observed trends in the present study involving Melinjo leaves.

Table 3 Color properties of coconut milk ice cream with different amounts of Melinjo leaves addition

Amount of Melinjo leaves addition (% by weight)	Color values		
	L*	a*	b*
Control	83.60±0.23[a]	4.24±0.09[a]	-0.54±0.24[c]
5%	68.66±0.31[c]	-9.36±0.22[b]	28.15±0.04[b]
10%	63.66±0.28[d]	-9.38±0.15[b]	29.34±0.54[a]
15%	60.37±0.36[e]	-10.34±0.16[c]	29.81±0.18[a]
15% (separate the pulp)	70.85±0.17[b]	-10.31±0.11[c]	29.67±0.35[a]

Remark: Values are expressed as mean ± SD. Different letters in the same column indicate significant difference ($p \leq 0.05$).
L* coordinate indicates darkness or lightness; ranges from black (0) to white (100). (+a*) is the red direction. (-a*) is the green direction. (+b*) is the yellow direction. (-b*) is the blue direction.

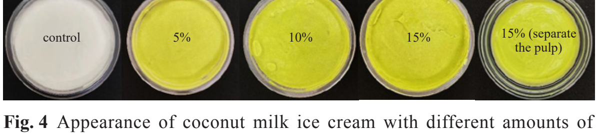

Fig. 4 Appearance of coconut milk ice cream with different amounts of Melinjo leaves addition

3. Apparent viscosity of ice cream mix

The apparent viscosity of coconut ice cream mixes was significantly increased by the addition of Melinjo leaves with a concentration dependent (Table 4). Coconut milk ice cream mixes with Melinjo leaves addition at 5%, 10%, and 15% had viscosity increased from the control sample 33.0%, 57.3%, and 71.2%, respectively. Similar results have been reported by Abishree (2021) in that incorporation of the leaves of *Amaranthus cruentus* into ice cream mix at 5% resulted in 26.1% increase in the mix viscosity. In addition, Erkaya et al. (2012) also reported an observation of the increased viscosity in ice cream with cape gooseberry puree addition. The increased viscosity of ice cream mix in this study was most likely due to the dietary fiber content in Melinjo leaves. Fresh Melinjo leaves contain dietary fiber as high as 4.7 g/100 g (Hoe & Siong, 1999), and studies have shown that the inclusion of high dietary fiber ingredients in low-fat ice cream increases mix viscosity (Tolve et al., 2024). This finding was further supported by the lower viscosity observed in ice cream sample with pulp separation (462.67±1.35 cP) compared to that of the sample without pulp separation (622.43±3.89 cP) at 15% of Melinjo leaves addition.

Interestingly, the ice cream sample with pulp separation still exhibited 27.2% higher mix viscosity over the control sample (Table 4). This higher viscosity could be attributable not only to the soluble fiber remaining in the ice cream mix after pulp separation, but also a present of phenolic compounds released from the Melinjo leaf. Melinjo leaf cultivated in Thailand has been reported to contain total polyphenol content around 26-34 mg GAE/g dry weight (Rungruang & Chanthachum, 2009). Additionally, findings from Pangastuti et al. (2024) in an ice cream model system show that the incorporation of phenolic acids at concentrations of 2 and 10 mg/g significantly increased the apparent viscosity, delayed the onset of melting by up to nearly 300%, and reduced meltdown rates. These effects were attributed to the formation of protein–phenolic acid complexes that mediate fat aggregation and promote network formation within the frozen matrix. These results support our finding that the phenolic compounds in Melinjo leaves, such as gallic acid and stilbenoids, may similarly interact with coconut milk proteins in the ice cream matrix, thereby enhancing viscosity, structural cohesion, and melting resistance.

Table 4 Apparent viscosity of coconut milk ice cream with different amounts of Melinjo leaves addition

Amount of Melinjo leaves addition (% by weight)	Viscosity (cP)
Control	363.67±2.25[e]
5%	483.67±1.53[c]
10%	572.00±3.53[b]
15%	622.43±3.89[a]
15% (separate the pulp)	462.67±1.35[d]

Remark: Values are expressed as mean ± SD. Different letters in the same column indicate significant difference ($p \leq 0.05$).

4. Overrun

Overrun results of the coconut milk ice cream with different amount of Melinjo leaf addition are shown in Table 5. It is obvious that increasing the amount of Melinjo leaves in the coconut milk ice cream tended to decrease the overrun. The overrun significantly reduced from 46.88±0.64% for the control ice cream to 41.23±0.55% for the sample with 15% Melinjo leaf inclusion. However, the ice cream sample with 15% Melinjo leaf and pulp separation only showed a slight decrease of overrun (45.07±0.87%) compared to the control, indicating an effect of dietary fiber on the reduction of ice cream overrun. This finding aligned with other reports including Bulan et al. (2022) found that increasing the amount of Jerusalem artichoke puree led to a decreasing trend in overrun of milk ice cream. In addition, Khongsit (2023) observed that increasing the amount of custard apples in reduced calorie ice cream resulted in the reduction of overrun. Abishree (2021) has also reported a decreased overrun of ice cream with 15% Amaranthus cruentus leaf addition (overrun 36.88%) compared to the control (overrun 48.02%).

The main structure of ice cream consists of fat, protein, and air cells. A present of dietary fiber can interfere with air cells, affecting the fat globules, which may not be able to form a strong enough network (fat coalescence) to trap the air generated during the whipping process of ice cream. As a result, the overrun of ice cream decreases (Yuenyongputtakal et al., 2016). In addition, the increased viscosity due to dietary fiber can increase the resistance of ice cream mixture during whipping, making it harder to incorporate air into the ice cream structure (Khongsit, 2023).

This mechanism helps explain the observed differences in overrun values between commercial dairy-based ice cream and the coconut milk ice cream developed in this study. Commercial milk-based ice creams typically have an overrun ranging from 60% to 120%, depending on the formulation, product type (premium or standard), and air incorporation methods (Muse & Hartel, 2004; Goff & Hartel, 2013). In contrast, the overrun values of the developed coconut milk ice cream were considerably lower, with the control sample (without Melinjo leaves) having an overrun of 46.88±0.64%, and the samples containing 5–15% Melinjo leaves showing progressively reduced values. Notably, even the highest overrun among the Melinjo-enriched samples, namely the 15% leaf with pulp separation sample (45.07±0.87%) remained below typical commercial dairy ice cream. These differences could be attributed not only to the presence of dietary fiber, which interferes with air incorporation, but also to the absence of milk proteins and the unique emulsification properties of coconut milk fat, which may be less efficient in stabilizing air cells compared to milk fat.

Table 5 Overrun of coconut milk ice cream with different amounts of Melinjo leaves addition

Amount of Melinjo leaves addition (% by weight)	Overrun (%)
Control	46.88±0.64[a]
5%	43.52±0.58[c]
10%	41.54±0.55[d]
15%	41.23±0.55[d]
15% (separate the pulp)	45.07±0.87[b]

Remark: Values are expressed as mean ± SD. Different letters in the same column indicate significant difference ($p \leq 0.05$).

5. Melting behavior

Incorporation of Melinjo leaves in the coconut milk ice cream significantly slowed down the melting rate of samples as shown in Fig. 5. Changes of melting behavior of the ice cream as affected by the inclusion of Melinjo leaves were also confirmed by the plots of induction time to the first drip (a time at which the ice cream starts to melt) and time at 50% drip-through (a time at which 50% of the ice cream has melted) as illustrated in Fig. 6. The findings indicate that increasing the amount of Melinjo leaves tended to reduce the melting rate and increase the induction time to the first drip and time at 50% drip-through of the ice cream samples. Specifically, the control sample melted almost 100% after 60 min, while the ice cream with 5%, 10%, and 15% Melinjo leaf incorporation melted only 66.22%, 57.40%, and 30.67%, respectively. Similarly, the ice cream with 15% Melinjo leaf addition exhibited 17.4 and 1.5 times higher in induction time to the first drip and time at 50% drip-through, respectively compared to the control sample. The retardation of ice cream melting rate as affected by the Melinjo leaf incorporation would be attributable to the increased dietary fibers, which had better water holding capacity, consequently prevented releases of water from ice cream and better maintain its structure (Chermmongkol et al., 2022). This was supported by a slight decrease in melting rate compared to the control in coconut milk ice cream with 15% Melinjo leaf addition and pulp separation to remove most of the dietary fiber.

Regarding classification of premium and super premium ice creams, melting rate and overrun are considered critical criteria. According to literature, premium ice creams typically have a moderate overrun (60−90%), while super premium ice creams exhibit lower overrun (25−50%) and enhanced melting stability. Additionally, slow melting behavior is often defined by a melting rate below 1.5 g/min or a complete melting time longer than 60 min under ambient conditions (Goff & Hartel, 2013). In this study, the coconut milk ice cream with 15% Melinjo leaf addition showed outstanding melting rate, with only 30.67% melted after 60 min, and significantly longer times for both the first drip and 50% drip-through compared to the control. When considering both melting behavior and overrun characteristics, the sample with 15% Melinjo leaf incorporation showed overrun values below 50%, which aligns more closely with super premium ice cream standards. Thus, it can be reasonably concluded that coconut milk ice cream enriched with 15% Melinjo leaves demonstrates physicochemical properties characteristic of high-quality, possibly super premium ice cream, particularly in terms of its low overrun and enhanced melting stability.

This finding is consistent with other research that reported on the reduction of the melting rate of ice cream incorporating with variety of plant ingredients. Erkaya et al. (2012) found that ice cream with 15% cape gooseberry incorporation melted completely at 75.15 min, while the control ice cream took only 66.45 min. Moreover, a product like low calorie mulberry sherbet has also been shown to exhibit a slower melting rate when increasing amount of mulberry pulp incorporation (Ungkanavin, 2018). Ice cream incorporated with avocado pulp at 20% was also reported to have a decreased melting rate (1.23 g/min.) compared to the control ice cream (7.85 g/min.) (Moolwong et al., 2023).

The physicochemical characteristics of ice cream, specifically viscosity, overrun, and melting behavior exhibit strong interrelationships and are fundamental determinants of the product's texture, structural stability, and overall quality attributes. Viscosity of the ice cream mix significantly influences the extent of air

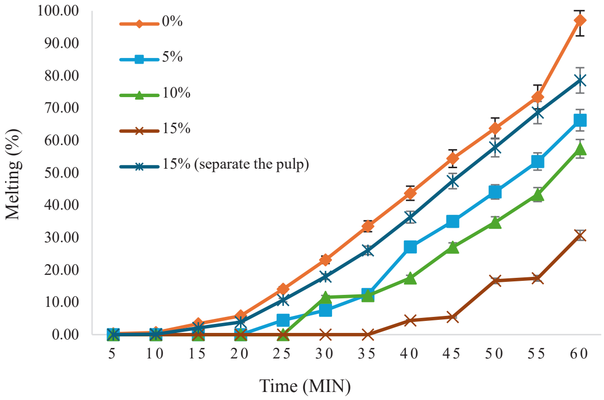

Fig. 5 Melting rate of the coconut milk ice cream with different amounts of Melinjo leaves addition

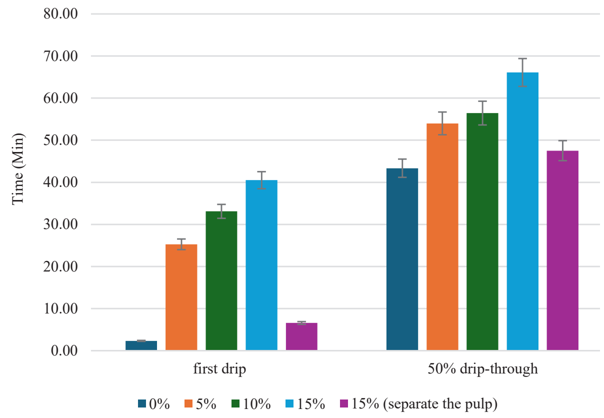

Fig. 6 Induction time to the first drip and time at 50% drip-through of the coconut milk ice cream with different amounts of Melinjo leaves addition

incorporation during freezing and whipping processes, thereby affecting overrun. Higher viscosity increases the resistance to air entrapment, resulting in a lower overrun value (Khongsit, 2023; Yuenyongputtakal et al., 2016). In this study, the addition of Melinjo leaves, rich in dietary fiber and polyphenolic compounds, led to increased viscosity of the ice cream mix. Dietary fibers bind water and contribute to forming a viscous network, while phenolic compounds can interact with proteins to form protein-polyphenol complexes, both of which increase the mix's apparent viscosity (Pangastuti et al., 2024; Tolve et al., 2024). Consequently, this elevated viscosity impedes the coalescence of fat globules and stabilizes the air cells less effectively, reducing the overrun observed in Melinjo-enriched coconut milk ice cream.

Overrun, in turn, affects the melting characteristics of ice cream. Typically, higher overrun ice creams contain more entrapped air, which lowers thermal conductivity and slows melting by acting as an insulator. However, excessive overrun can weaken the structural integrity of the ice cream matrix, leading to rapid meltdown (Muse & Hartel, 2004). The reduced overrun found in the Melinjo leaf-added samples indicates a denser matrix with less air, but potentially stronger structural networks formed by dietary fibers and protein-polyphenol interactions. Such networks improve melting resistance by enhancing water retention and maintaining the integrity of the ice cream structure (Chermmongkol et al., 2022). Moreover, the increased viscosity arising from the dietary fiber and polyphenols also directly contributes to improved melting behavior. The enhanced water-holding capacity reduces the mobility of free water, thereby slowing drip loss and extending the induction time to first drip as well as the time to 50% drip-through (Chermmongkol et al., 2022). Interactions between phenolic compounds and proteins can further strengthen the ice cream matrix through cross-linking, which increases mechanical stability and melting resistance (Pangastuti et al., 2024).

Taken together, the interplay between increased viscosity and decreased overrun induced by Melinjo leaf addition results in coconut milk ice cream with superior melting resistance and desirable texture characteristics. This balance aligns with criteria for premium and super premium ice cream categories, where lower overrun and enhanced melting stability are key quality parameters (Goff & Hartel, 2013). In summary, understanding the relationships among viscosity, overrun, and melting behavior is essential for formulating ice cream products that incorporate plant-based ingredients rich in dietary fiber and bioactive compounds, enabling the development of novel frozen desserts with improved physicochemical properties.

Conclusion

Physicochemical properties and melting behavior of coconut milk ice cream as affected by Melinjo leaves incorporation at different concentrations were investigated. It was found that the increasing amount of Melinjo leaves resulted in coconut milk ice cream with lower L* and higher a* and b* values ($p \leq 0.05$). The addition of Melinjo leaves caused a slight increase in pH and a significantly higher apparent viscosity in the ice cream mixes (p≤0.05), whereas the overrun of the ice cream samples tended to decrease with increasing levels of leaf incorporation. Moreover, the inclusion of Melinjo leaves significantly reduced the melting rate and prolonged induction time to the first drip and time at 50% drip-through of the coconut milk ice cream (p≤0.05). Based on the overall physicochemical properties and melting stability, incorporation of 15% Melinjo leaves can be considered an effective level to maximize melting resistance and functional benefits, such as increased dietary fiber and antioxidant content. These results demonstrate Melinjo leaves' strong potential as a functional plant-based ingredient to improve melting stability in frozen desserts, especially for health-focused niche markets. Future work should include sensory testing, nutritional analysis, and microstructural studies. Combining Melinjo leaves as local plant ingredients can optimize texture and quality, supporting clean-label, health-oriented, and vegan coconut milk ice cream products.

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