

Effects of palm sugar substitution on the proximate composition and thermal properties of ice cream

Nurul Zaizuliana Rois Anwar^{1*}, Mifthah Haziqah Mohd Fauzi¹, Nur Amni Farhah Mat Nor¹, Zarinah Zakaria¹, Tengku Farizan Izzi Che Ku Jusoh¹ and Norshazila Shahidan²

¹School of Food Industry, Faculty of Bioresources and Food Industry, Universiti Sultan Zainal Abidin, Besut Campus, 22200 Besut, Terengganu, Malaysia

²Faculty of Science and Technology, Programme of Food Biotechnology, Universiti Sains Islam Malaysia, 71800 Nilai, Negeri Sembilan, Malaysia

ARTICLE HISTORY

Received : 3 September 2025

Accepted : 21 November 2025

Online : 30 September 2026

KEYWORDS

palm sugar,
ice cream,
proximate composition,
thermal behaviour

✉ * CORRESPONDING AUTHOR

Dr. Nurul Zaizuliana Rois Anwar
School of Food Industry, Faculty of
Bioresources and Food Industry,
Universiti Sultan Zainal Abidin, Besut
Campus, 22200 Besut, Terengganu,
Malaysia
Email: zaizuliana@unisza.edu.my

ABSTRACT

Ice cream is a frozen dessert made primarily from milk, skimmed milk, and whipping cream, and is sweetened with either sugar or artificial sweeteners. As consumers increasingly lean towards healthier food choices, developing ice cream varieties that reduce sugar intake has become a key focus in the food industry. This shift is largely motivated by the awareness that consuming calorie-dense foods can lead to serious health problems like obesity and diabetes, especially in children and young adults. However, substituting ingredients in ice cream formulation can significantly impact its properties. Thus, this study aims to evaluate the proximate composition and thermal properties of ice cream formulated using palm sugar as a sweetener. Five ice cream formulations were tested, each containing different ratios of sucrose to palm sugar: F1 (100:0), F2 (80:20), F3 (50:50), F4 (20:80), and F5 (0:100). The proximate composition was analysed using AOAC methods. To assess thermal behaviour, a Differential Scanning Calorimeter (DSC) was employed to measure the enthalpy values. Incorporating palm sugar as a sweetener led to notable changes, with an increasing trend in moisture, protein, and fat content as the amount of palm sugar increased ($p < 0.05$), with the highest in F5 ($67.35 \pm 0.09\%$ moisture, $2.39 \pm 0.17\%$ protein, and $4.23 \pm 0.77\%$ fat). The thermal analysis of ice cream showed that ice cream with a higher amount of palm sugar produced a lower enthalpy value. The overrun of the ice cream was lower when using palm sugar; the lowest was 23% (F5) and it produced a higher melting rate due to the structure of the palm sugar. These results suggest that palm sugar has the potential to be successfully used in ice cream production.

© 2026 UMK Publisher. All rights reserved.

1. INTRODUCTION

Ice cream is a semi-solid cold food product produced from an unfrozen mixture of ingredients (Romulo et al., 2021). It is known as a frozen type of dessert, but it also has different definitions in several countries. In basic terms, ice cream combines air, milk fat, water, non-fat milk solids, stabilizers, sweeteners, flavourings, and emulsifiers. According to the Food Act 1983 (Act 281), ice cream should have at least 10% of either milk fat, vegetable oil, or a combination of both. The process of making an ice cream involves heating and then freezing a mixture of fat, milk solids, and sugar, either with or without another ingredient. Ice cream is basically an oil-in-water emulsion, foam, ice crystals, and other colloids in the form of casein micelles and other proteins.

Sweeteners play an important role in the making of ice cream to impart mouthfeel to the consumers. The choice of sweetener(s) used by the producer depends on the type of ice cream to be produced. A variety of sweeteners are widely used in the production of ice cream, such as aspartame,

fructose, and mainly sucrose due to rheological and economic considerations (Ahmed et al., 2023). These sweeteners affect the freezing point of the ice cream resulting in a harder ice cream texture. The fat destabilisation values of the ice cream were greatly impacted by the varied sugars used in its manufacturing. Different sweeteners affect the physical, chemical, and sensory properties of the ice cream (Ozdemir et al., 2007).

Currently, palm sugar is in high demand as it is used primarily in sweet soy sauce, drinks, sweets, and a variety of traditional dishes (Saputra et al., 2019). One of the most popular additions to current dairy products is the addition of palm sugar to yoghurt, as it is marketed as a healthier substitute for sucrose as a sweetener (Suharto & Kurnia, 2022). Palm sugar is derived from the sap of palm flowers and gives the distinct caramel flavour to the ice cream while enhancing its aroma, colour and texture, when used as a sweetener substitute. The process of producing palm sugar involves seven steps which include harvesting the sap,

boiling, skimming the impurities, cooling the sap, moulding, drying, and lastly grinding. It is widely acknowledged that palm sugar has a very high nutritional content. Fresh sap is high in protein, phenolics, vitamin B, and micronutrients (zinc, copper, and iron), as well as essential minerals (potassium, magnesium, nitrogen, and phosphorus). It is believed that the potassium in palm sugar aids in controlling high blood pressure and sugar metabolism. Moreover, palm sugar has anti-inflammatory and cardiovascular properties as well as immunological and respiratory system benefits (Hebbbar et al., 2018). According to Kongkaew et al. (2014), it has been reported that palm sugar contains considerably high amounts of polyphenols and flavonoids. Recent research has also proven that it can give a lot of benefits to the consumers and is suitable as a sweetener in the food industry. Additionally, the presence of Maillard reaction products during the heating process of plant sap allows the formation of antioxidant compounds, thereby enhancing the antioxidant content of the sugar (Victor & Orsat, 2018).

Thermal properties of ice cream are affected by its fat composition. While larger clumps of fat globules adsorb at the air-serum interface, fat globules partially combine and aggregate into elongated chains that join to form a three-dimensional fat network. This structural configuration improves resistance to melting and collapse of the structure, decreases coalescence, and increases air cell stability. Increased fat destabilization promotes the development of a stronger fat network, which is necessary to preserve air cell integrity and overall ice cream stability during storage and melting (Liu et al., 2023; Wu et al., 2025). A creamier texture and a slower melting rate are the effects of higher fat content. This is because lipids enable ice to melt more slowly and with a smoother consistency by interfering with the development of ice crystals.

According to Singh et al. (2022), overrun refers to the percentage of ice cream expansion resulting from the quantity of air that is introduced to the product during the freezing process. In order to produce a smoother, lighter texture, air is usually whipped or churned into the mixture when making ice cream. When a batch of ice cream has a 100% overrun, for example, the incorporation of air results in a finished product that has twice the volume of the liquid base. Higher overrun can make the ice cream lighter and softer, whereas lesser overrun frequently produces thicker, richer ice cream. Thus, the volume of the ice cream can be expanded by using fewer ingredients, and there must be some air in it to prevent it from being too firm. Extra air causes the ice cream to melt faster, lose quality, and become gritty in the mouth (Arslan et al., 2023).

Meltdown processes are divided into three phases:

the lag phase, fast-melting phase, and stationary phase. The ice cream loses viscosity during the lag phase as a result of heat penetrating and melting the ice crystals. When the ice cream melts down to the second stage, known as the fast-melting phase, it starts to drip through the wire mesh. During this stage, the residual structures, such as air cells and fat clusters/globules, determine how quickly and to what degree the ice cream collapses. As the meltdown begins to slow, the stationary phase occurs. As discovered in the previous study, altering the structure of ice cream formulations results in varying meltdown characteristics.

While the effects of conventional sweeteners on ice cream quality are well-documented, the potential of palm sugar as a natural alternative sweetener remains largely unexplored. Current studies have been focusing on its nutritional benefits and use in other food products, but its impact on ice cream's physicochemical properties and meltdown behaviour has not been systematically evaluated. There is also a lack of detailed assessment on how palm sugar influences proximate composition (such as moisture, fat, protein, ash, and carbohydrate). Furthermore, thermal properties and melting characteristics remain poorly documented, despite their importance in determining ice cream texture, hardness, and overrun. Therefore, this study is needed to evaluate palm sugar's impact on both proximate composition and thermophysical parameters, which may provide valuable insights for product development, formulation optimization, and the promotion of palm sugar as a natural alternative sweetener in the ice cream industry.

2. MATERIALS AND METHODS

2.1 Ice cream formulations

Five formulations (sucrose:palm sugar ratios of 100:0, 80:20, 50:50, 20:80, and 0:100) were prepared as shown in Table 1. Formulation 1 (F1), which had 100% sucrose and no palm sugar, was used as the control. Palm sugar was substituted for 20% of sucrose in formulation 2 (F2). Formulation 3 (F3) represented a 50% substitution level with equal amounts of palm sugar and sucrose. In formulation 4 (F4), there was an 80% substitution of palm sugar for sucrose, while formulation 5 (F5) was formulated entirely with palm sugar without any sucrose.

2.2 Ice cream preparation

The preparation of ice cream samples was done according to the method described by Yangilar (2015) with some modifications. All of the components were weighed according to the formulations. In order to produce the milk samples, half of the fresh milk and whipping cream were heated to 75 °C. Next, the milk mixture was mixed with sucrose or palm sugar. Then, to avoid lumpiness, the cassava

flour, CMC, GMS, and skim milk powder were added to the milk mixture. The remaining half of fresh milk was then added gradually while the mixture was pasteurized for ten minutes at 75 °C. Once all the ingredients were combined, the heat was turned off, and the mixture was whisked for three to five minutes to increase its aeration before being put into the ice cream machine (Breville Smart Scoop, United States). The ice cream was then frozen for an hour at -30 °C in a blast freezer. Finally, it was transferred into a freezer for 24 hours to freeze.

Table 1: Ice cream formulations.

Ingredients	1 (%)	2 (%)	3 (%)	4 (%)	5 (%)
Fresh milk	63.96	63.96	63.96	63.96	63.96
Whipping cream	17.27	17.27	17.27	7.27	17.27
Sucrose	12.95	10.36	6.48	2.59	-
Palm sugar	-	2.59	6.48	10.36	12.95
Skim milk powder	3.99	3.99	3.99	3.99	3.99
Tapioca flour	1.34	1.34	1.34	1.34	1.34
Carboxymethyl cellulose (CMC)	0.26	0.26	0.26	0.26	0.26
Glycerol Monostearate (GMS)	0.22	0.22	0.22	0.22	0.22

2.3 Ice cream analysis

2.3.1 Proximate analysis

The standard methods of the Association of Official Analytical Chemists (AOAC, 2000) were used to measure the moisture content, ash, protein, fat, crude fibre, and carbohydrate of the ice cream samples. The five ice cream samples were freeze-dried before analysing their ash, protein, fat, and fibre contents. The moisture content was determined by using an oven drying method, while ash content was measured by using combustion in a muffle furnace. Protein was analysed using the Kjeldahl method, fat analysis was carried out by using Soxhlet extraction, and crude fibre analysis was conducted by using acid and alkali digestion method. Lastly, total carbohydrates were calculated by subtracting the sum of moisture, protein, fat, fibre, and ash from a total of 100%.

2.3.2 Thermal Analysis

The melting and freezing properties of ice cream were evaluated using a Differential Scanning Calorimeter (DSC), Q200. In a controlled environment, DSC was used to measure the temperatures and heat transfers related to material transitions as a function of time and temperature (Islam et al., 2022). Using a metal spatula, approximately 12

mg of ice cream was put in an aluminium DSC pan and sealed using a sample press. The sample and an identical empty aluminium reference pan were inserted in the chamber using a tweezer. The pans were separated and scanned. In order to prevent the ice cream from melting, the procedure was performed quickly. Both pans were cooled to -50 °C by maintaining an isothermal state for 5 minutes, followed by a controlled heating phase at a rate of 5 °C per minute until 50 °C was reached (Alvarez et al, 2005). The measurement was performed in triplicate. Using the software, the temperature at which the ice cream melted and its enthalpy were determined.

2.3.3 Overrun analysis

The overrun of the ice cream was measured by weighing equal volumes of the ice cream mix and the finished ice cream. A 250 ml empty beaker was weighed. After that, once the container was full with the ice cream mixture, it was weighed again, and the weight of the beaker was deducted.

The overruns were carried out in triplicate. The following formula was used to determine the amount of air included in the ice cream samples:

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

2.3.4 Meltdown analysis

The weight and drip-through of the ice cream were included in the meltdown analysis. The ice cream had a cylindrical form that was 50 mm in diameter and 55 mm in height, respectively. In order to gather drip-through mass, the prepared sample was placed on a wire mesh which was placed on a beaker. Every 10 minutes, the mass of the melting ice cream was measured with an analytical balance. The sample was set for 60 minutes (Matabura, 2023). The experiments were performed in triplicate. The following formula was used to determine the meltdown of the ice cream:

$$\text{Melting} = \frac{\text{Melted mass (g)}}{\text{Initial mass (g)}} \times 100$$

2.4 Statistical analysis

All the measurements were performed in triplicate. Analysis of variance (ANOVA) was conducted on the data using the Statistical Package for Social Sciences (SPSS) software. To facilitate the comparison of mean values among samples, Tukey's test was applied at a significance level of $p < 0.05$.

3. RESULT AND DISCUSSION

3.1 Proximate Composition of the Ice Cream

This study examines the proximate composition of ice cream formulations containing varying amounts of palm sugar. Determining this nutritional information is crucial for providing consumers with accurate information before

consuming the final food products. The different proportions of palm sugar used in the ice cream formulations resulted in varying percentages of moisture, ash, fat, protein, fibre, and total carbohydrate contents. Table 2 below presents the proximate composition of five different ice cream formulations (F1 to F5), detailing their contents.

Table 2. Proximate composition of ice cream samples.

Composition (%)	F1	F2	F3	F4	F5
Moisture	65.51 ± 0.53 ^c	65.92 ± 0.71 ^{bc}	66.27 ± 0.30 ^{abc}	66.96 ± 0.63 ^{ab}	67.35 ± 0.09 ^a
Ash	0.70 ± 0.06 ^a	0.72 ± 0.11 ^a	0.73 ± 0.03 ^a	0.75 ± 0.03 ^a	0.76 ± 0.05 ^a
Fat	2.25 ± 0.45 ^a	2.77 ± 0.53 ^{ab}	3.17 ± 0.63 ^{ab}	3.74 ± 0.58 ^{ab}	4.23 ± 0.77 ^b
Protein	1.83 ± 0.07 ^{ab}	0.51 ± 0.08 ^c	1.20 ± 0.46 ^{bc}	1.62 ± 0.32 ^b	2.39 ± 0.17 ^a
Fiber	0.09 ± 0.31 ^a	0.26 ± 0.38 ^a	0.14 ± 0.10 ^a	0.09 ± 0.09 ^a	0.39 ± 0.35 ^a
Carbohydrate	29.71 ± 0.39 ^a	30.07 ± 0.33 ^a	28.64 ± 1.30 ^{ab}	26.94 ± 1.41 ^{bc}	25.28 ± 0.57 ^c

The results comprised mean ± standard deviation. Different superscript letters in the same row indicate significant differences at $p < 0.05$; $n=3$. Sucrose-to-palm sugar percentages: F1 (100:0), F2 (80:20), F3 (50:50), F4 (80:20), and F5 (0:100).

Moisture content ranged from 65.51% in F1 to 67.35% in F5. F4 and F5 had significantly higher moisture contents compared to F1, as indicated by the differing superscripts. Goff (2006) reported that the milk or other ingredients in the ice cream contributed to its moisture content. Higher amounts of moisture content exhibit low number of total solids. When hardened at the same storage temperature, ice cream mixes with low total solids (high water content) will have proportionately more water to freeze than mixes with high total solids (low water content) (Choi & Shin, 2014). In addition, the ratios of sucrose to palm sugar used in this study also give effects on the moisture content. Nafingah et al. (2019) investigated the impact of fat content and palm sap sugar proportion on the heat stability and hardness of milk chocolate. They reported that sucrose, which is the most popular sugar used in chocolate, has low moisture content and hygroscopic properties, whereas palm sugar has somewhat higher moisture content and hygroscopic properties. Maryani et al. (2021) reported that water content of palm sugar, sugar cane, and coconut sugar is 1.49%, 0.01%, and 0.78%, respectively. This is in line with the results obtained in this study, as the ice cream samples showed higher moisture content when 80% and 100% palm sugar were used in the formulations. The hygroscopic property of palm sugar, defined as the ability of a substance to absorb moisture or water from the air, is the main reason for the greater moisture content observed in ice cream compositions containing 80% and 100% palm sugar. Low-molecular-weight sugars, especially glucose and fructose, which have several hydroxyl (–OH) groups that easily form hydrogen bonds with water molecules, are abundant in palm sugar. These properties improve the ability to bind water and help food systems retain more moisture (Rayappa, 2023). According to Whelan et al. (2007),

hygroscopic elements and amorphous sugar structure that encourage water adsorption cause palm sugar and related amorphous sugars to typically have greater moisture content.

Ash content was relatively consistent across all formulations, ranging from 0.70% to 0.76%, with no significant differences observed among them. It shows that the ratio of sucrose to palm sugar did not affect the mineral content of the ice cream samples. As reported by Silva Junior and Lannes (2011), the moisture content of palm sugar can affect the ash content of ice cream, as higher moisture levels lead to an increase in water-soluble inorganic compounds. Variations in ash content may also result from the processing conditions of both palm sugar production and the ice cream manufacturing process (Lekjing et al., 2022), such as the boiling method of the palm sap, and the processing temperature and duration. In addition to milk fat, protein, and carbs, other ingredients can also impact the ash content in ice cream. For example, the type and amount of milk fat can influence the ice cream's viscosity and melting properties, which in turn can affect its ash content (Silva Junior & Lannes, 2011). In the present study, all ice cream samples were produced using palm sugar processed under consistent conditions, and the same type and amount of milk fat were used across all formulations.

Fat content varied more substantially, with F1 having the lowest value (2.25%) and F5 the highest (4.23%). This suggests a richer formulation in F5. The function of fat in the making of ice cream is way more complicated than the other confectionery products. Firstly, it is crucial for the sensory properties, serving as a flavour carrier and contributing to the rich, creamy texture characteristic of ice cream. Additionally, it plays a vital role in the melting behaviour and storage stability of the ice cream (Persson, 2009). Fat contributes to the creamy texture and smooth mouthfeel of ice cream. It helps to

slow down the melting process, giving the ice cream a more desirable and consistent texture as it melts. Other than that, fat helps to create a stable structure in ice cream by emulsifying with other ingredients, contributing to the formation of small ice crystals and fine air cells and thus resulting in a smoother texture and more stable form. Fat globules are finely distributed and coated with milk proteins and emulsifiers during mix preparation and homogenization, creating a stable oil-in-water emulsion that keeps phase separation at bay and guarantees mix homogeneity (Goff & Hartel, 2013). During dynamic freezing, partial coalescence of fat globules occurs, creating a weak, three-dimensional fat network that is crucial for giving the ice cream matrix structural stability (Muse & Hartel, 2004). This network of fat is essential for binding air cells and improving the product's overall firmness and body. However, the results of this study contradict the findings reported by Asghar et al. (2021), who observed that the crude fat content in coconut sap and sugar palm juice was significantly lower than in sugarcane juice. This discrepancy may be attributed to differences in the varieties of coconut sap analysed. In addition, according to the USDA Food Data Central database, palm sugar has 0 grams of total lipid (fat) per 100 grams. However, according to Silva Junior and Lannes (2011), the type and proportion of sugar (palm sugar) and fat used can interact to affect the thermal and physical qualities of the ice cream in addition to the fat amount. The interactions between palm sugar and palm fat components appear to play a key effect.

As shown in Table 2, the protein content of F2 decreased significantly when the palm sugar was added in the ice cream formulation. Water content in the palm sugar may have diluted the protein, resulting in decreased protein content. It then increased significantly when the amount of palm sugar was increased. Sucrose is a refined sugar that contains no protein, while palm sugar is a minimally processed natural sweetener that contains a small amount of protein and other nutrients. As more palm sugar is added, more protein is introduced into the mix, causing the overall measured protein content of the ice cream to increase. The increment of protein content in ice cream was also probably due to the process involved during the development of ice cream. This fact can be supported by a previous study which reported that the development of ice cream's structure, such as its emulsification, whipping, and water-holding ability, is facilitated by proteins (Goff, 1997). During ice cream production, foaming is essential, and milk proteins are well-known for their foaming ability. Consequently, milk proteins help to stabilize the air interface in the ice cream, contributing significantly to its overall structure and structural stability (Patel et al., 2006). The findings of this study differ from those

of previous research by Silva Junior and Lannes (2011) who found that the protein content remained consistent across all ice cream formulations, indicating that palm sugar did not significantly impact the protein content of the ice cream. Despite that, Naknean et al. (2009) had mentioned that the increase in protein content during heating was due to concentration rather than a decrease caused by the Maillard reaction. The protein concentration of palm sap increases when it is heated and concentrated, despite the fact that the Maillard reaction is supposed to lower protein levels. Moreover, the Maillard reaction produces browning in palm sugar but does not always lower protein levels. Browning is generated by the interaction of amino acids with reducing sugars, hence the overall protein levels might not decrease dramatically (Sarkar et al., 2023). Thus, it can be concluded that a high concentration of palm sugar used in ice cream, as in F5 (100% palm sugar), significantly affected ice cream properties compared with the sucrose control (F1, 100% sucrose).

Fibre content remained low across all samples, although it was highest in F5 (0.39%) and lowest in F1 and F4 (0.09%). There were no significant differences in fibre content ($p > 0.05$) across the ice cream formulations. Palm sugar contains soluble dietary fibre called inulin (Trinidad et al., 2010). However, the method used for fibre analysis only measures crude fibre, which detects only the insoluble fibre present in the products. This might explain why no significant differences were observed between samples.

In terms of carbohydrate content, F2 and F1 had the highest levels (30.07% and 29.71%, respectively), while F5 had the lowest (25.28%). The differences were statistically significant, showing an inverse relationship between fat/protein content and carbohydrate levels in these formulations. Introducing palm sugar gives significant effect on the percentage of carbohydrate in the final product, and producing functional ice cream such as low-calorie desserts help to prevent diseases. Palm sugar contained the same calorie content when compared to sucrose but according to Asghar et al. (2021), coconut palm sugar is considered superior to cane sugar because, unlike cane sugar, which only provides calories, coconut palm sugar also offers additional nutrients along with the calories. When compared to refined or unrefined cane sugar, coconut palm sugar is found to contain two times more iron, four times more magnesium, and ten times more zinc. Additionally, coconut palm sugar is rich in essential amino acids needed for protein synthesis and is also a good source of vitamins B1, B2, B3, and B6 (Hebbbar et al., 2015).

3.2 Thermal properties of the ice cream

Table 3 shows the peak temperatures, onset temperatures, and enthalpy values obtained from the endothermic thermogram for all ice cream samples. The ability of ice cream to withstand melting in the presence of high temperature is known as melting resistance. The amount of energy leaving the system is known as the melting enthalpy (ΔH), which is computed by integrating the area of the endothermic peak by using the software. It develops an alteration in the food's overall internal energy (Atik et al., 2021). At constant temperature during melting, the solid and liquid are in thermodynamic equilibrium. Usually, the melting point is reached by gradually increasing the temperature over the melting point range (Hurtt et al., 2004).

Table 3. The peak temperatures, onset temperatures, and enthalpy values of ice cream samples.

Formulation	Peak Temperature (°C)	Onset Temperature (°C)	ΔH (J/g)
F1	-0.51±0.05	-4.87±0.20	178.0±1.17
F2	-1.13±0.12	-5.02±0.90	173.9±2.36
F3	-0.40±0.16	-4.77±0.70	165.8±1.45
F4	-0.70±0.08	-4.79±0.30	171.5±4.25
F5	-0.75±0.03	-4.58±0.10	171.1±6.42

The results comprised mean $\pm$ standard deviation. Sucrose-to-palm sugar percentages: F1 (100:0), F2 (80:20), F3 (50:50), F4 (80:20), and F5 (0:100).

Based on Table 3, the melting enthalpy values of the samples were 178.0, 173.9, 165.8, 171.5, and 171.1 J/g for F1, F2, F3, F4, and F5, respectively. The addition of palm sugar decreased the enthalpy value of the ice cream. It was observed that the enthalpy value of F1 was the highest, suggesting that more energy was required to melt the sugar crystals in F1. This indicates that sucrose has a higher purity than palm sugar. Sucrose has undergone extensive refinement, producing a substance with a purity level exceeding 99.8%. According to Beckett, et al. (2006), the melting point for sucrose was in the range of 186–192 °C. The melting point of the palm sugar that has been used in the current study was in the range of 146–148 °C. This indicates that the melting point of palm sugar is lower than that of sucrose, which explains why samples with higher palm sugar content required less energy to melt. The low melting point of the palm sugar can be affected by the impurities in the palm sugar. This is because palm sugar undergoes minimal processing and retains more impurities and its natural compounds, which contributed to the decrease in enthalpy value (Sarkar et al., 2023). Palm sugar is not as thoroughly purified as refined sucrose; thus, it contains more minerals (such as potassium, calcium, and magnesium), organic acids, proteins, phenolic compounds, and reducing sugars like glucose and fructose. These elements cause a more amorphous or heterogeneous structure with decreased heat

stability by disrupting sucrose's structured crystalline lattice (Asghar et al., 2020). Impurities interfere with intermolecular hydrogen bonds within the sugar matrix and obstruct crystal formation thermally. Because less energy is needed to start the phase change during heating, the melting temperature and enthalpy value (ΔH) are lower.

3.3 Overrun of the ice cream

The proportion of ice cream expansion derived from the quantity of air introduced to the product during the freezing process was referred to as an overrun (Singh et al., 2022). There was a significant difference ($p < 0.05$) between the ice cream samples, which was caused by the concentration of palm sugar in the ice cream.

Figure 1 shows the overrun values among the five formulations. It can be observed that the overrun values varied significantly ($p < 0.05$). F1 exhibited the highest overrun at approximately 33%, which was significantly higher than that of F5, which had the lowest overrun (24%). The use of 20%, 50%, and 80% palm sugar in the ice cream formulations did not significantly affect the percentage of overrun. The lower overrun observed in F5 may be attributed to a higher concentration of total solids or palm sugar, which could increase mix viscosity and inhibit air incorporation. Francisca et al. (2025) found that as the dry matter (total solids) content increases, the viscosity of the mix also increases. Higher viscosity makes the mixture thicker, which hampers the incorporation of air during whipping, because a viscous base resists bubble formation and expansion. Other than that, differences in fat content or freezing parameters may also influence the efficiency of air entrapment.

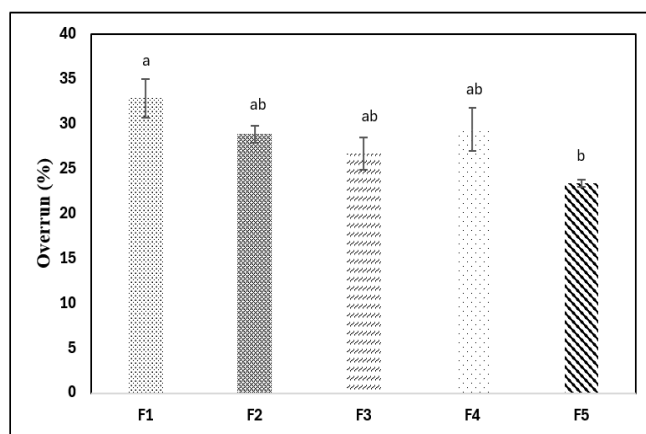


Figure 1: Overrun values of ice cream samples.

In contrast, F1's higher overrun suggests that its formulation and processing conditions were more conducive to air incorporation, potentially due to lower mix viscosity or optimized aeration conditions. The rheological characteristics of the ice cream mixture, including viscosity and serum phase

behaviour, have a major effect on overrun. During dynamic freezing, mixes with lower apparent viscosity typically make it easier for air to penetrate and disperse, enabling a larger volume of air to be integrated before the structure stiffens (Wu et al., 2025). On the other hand, high viscosity can prevent air bubbles from forming and restrict overflow, particularly in the later stages of freezing when the temperature decreases rapidly.

Sucrose has the ability to lower the freezing point of the ice cream. The ice cream's viscosity and ice crystal formation were impacted by the freezing point. A higher overrun was possible because of the smaller ice crystal and smoother ice cream texture that were developed, which helped in stabilising the air bubble for the overrun. Palm sugar crystals adhered to one another, resulting in the formation of agglomerates. The layers may exist because of the relatively high moisture content and the presence of the hygroscopic materials, which include fructose, glucose, and amorphous sugar (Saputro et al., 2019). The larger particle size resulted in a lower overrun, as larger particles may hinder the incorporation of air into the ice cream during aeration.

3.4 Meltdown properties of the ice cream

Meltdown is an indicator of ice cream's stability, directly influencing consumer acceptability by affecting texture, shape retention, and overall sensory experience. Three stages of ice cream meltdown are represented by the lag phase, the fast-melting phase, and the plateau phase of the sigmoid curve that was commonly used to represent the ice cream meltdown curve. When the first drop passed through the screen, as indicated by the induction time, the lag phase came to an end. The ice cream meltdown rate was used to describe the slope of the fast-melting phase.

The melting curves of the five ice cream samples are presented in Figure 2, expressed as the weight (g) of melted ice cream over a period of 60 minutes. The meltdown of the ice cream was recorded and weighed every 10 minutes. It can be seen that the weight of the ice cream increased as the time taken increased for all ice cream samples. F5 exhibited the highest melting rate, accumulating approximately 63 g of melt after 60 minutes. In contrast, F1 showed the slowest melting rate, with a final melt weight of approximately 52 g, indicating improved melting resistance. F2, F3, and F4 followed similar trends, with intermediate melt weights between F1 and F5, suggesting moderate melting stability.

The high melting resistance in F1 may be linked to its higher overrun resulting from more effective emulsification, which stabilizes the air cells and matrix structure during thermal exposure. This was also probably due to the concentration of sucrose in the formulation. Apart from

increasing overrun during freezing, the viscosity also increased with high sucrose concentration, thus reducing the size of the air bubbles (Silva Junior & Lannes, 2011). With the increase in viscosity, the meltdown rate decreased. The reduced melting resistance observed in F5 could be attributed to its lower overrun (as shown in Figure 1), which implies a denser structure with less entrapped air. Additionally, a higher concentration of palm sugar in F5 may have contributed to a lower melting point due to its influence on freezing point depression and water-binding capacity. This could also be caused by the presence of impurities that affect the melting point (Sarkar et al., 2023). When a substance contained impurities, the crystalline structure's uniformity was interrupted. The crystalline structure, such as refined sucrose, was uniform and well-organized. This structure has a higher and more constant melting point since it needs a certain quantity of energy (heat) to breakdown. Thus, the presence of impurities could lower the melting point (Saputro et al., 2019).

These findings are in agreement with the results in Table 3 which suggest that higher enthalpy values are associated with slower melting rates and enhanced thermal stability, while lower enthalpy values correspond to greater susceptibility to melting, particularly when accompanied by lower overrun and variations in sugar composition.

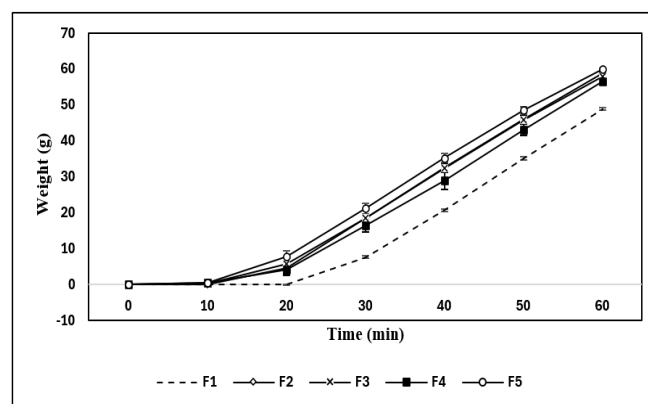


Figure 2: Melting curves of ice cream samples.

4. CONCLUSION

In conclusion, the ratio of sucrose and palm sugar affected the ice cream properties. The addition of palm sugar in the formulation increased the moisture, protein, and fat content of ice cream, while the carbohydrate content of ice cream decreased with the increasing amount of palm sugar in the ice cream formulation. The thermal analysis of ice cream showed that ice cream with a higher amount of palm sugar produced a lower enthalpy value. Meanwhile, the overrun of the ice cream was lower when using palm sugar and produced a higher melting rate. These findings highlight the potential of palm sugar to be incorporated as a natural sweetener in ice cream formulation, offering alternative functional properties

compared to sucrose. However, it is recommended that in future studies, the formulations of the ice cream can be improved to see a more significant result. A storage study can also be conducted to understand how the storage time affects the quality and stability of the ice cream.

ACKNOWLEDGMENT

The authors would like to thank Universiti Sultan Zainal Abidin for the research support (UniSZA/2022/DPU2.0/10) and facilities rendered. The funder had no involvement in the study design, data collection, analysis, or interpretation, nor in the writing of the report or the decision to submit the article for publication.

REFERENCES

- Ahmed, K. S., Hasan, G. A., Satter, M. A., & Sikdar, K. (2023). Making ice cream with natural sweetener Stevia: Formulation and characteristics. *Applied Food Research*, 3(2), 100309.
- Alvarez, V. B., Wolters, C. L., Vodovotz, Y., & Ji, T. (2005). Physical properties of ice cream containing milk protein concentrates. *Journal of Dairy Science*, 88(3), 862–871.
- Arslan, A., Sagdic, O., Karasu, S., & Tekin-Cakmak, Z. H. (2023). The effect of the use of salep powder obtained from different wild orchid species in Turkey on the rheological, thermal, and sensory properties of ice cream. *Food Science and Technology (Brazil)*, 43.
- Asghar, M. T., Yusof, Y. A., Noriznan, M., Yaacob, M. E., Mohd Ghazali, H., Chang, L. S., Manaf, Y. N. (2020). Effect of processing method on vitamin profile, antioxidant properties and total phenolic content of coconut (Cocos nucifera L.) sugar syrup. *International Journal of Food Science and Technology*, 55(7), 2762–2770.
- Asghar, M. T., Yusof, Y. A., Mokhtar, M. N., Yaacob, M. E., Chang, H. M. G., & Sin, L. (2021). A review of nutritional facts, production, availability and future aspects of coconut palm sugar. *Journal of Nutrition & Food Sciences*, 11(3), 1–8.
- Atik, I., Tekin-Cakmak, Z. H., Avci, E., & Karasu, S. (2021). The effect of cold press chia seed oil by-products on the rheological, microstructural, thermal, and sensory properties of low-fat ice cream. *Foods*, 10(10), 2302.
- Beckett, S. T., Francesconi, M. G., Geary, P. M., Mackenzie, G., & Maulny, A. P. E. (2006). DSC study of sucrose melting. *Carbohydrate Research*, 341(15), 2591–2599.
- Choi, M. J., & Shin, K. S. (2014). Studies on physical and sensory properties of premium vanilla ice cream distributed in Korean market. *Korean Journal for Food Science of Animal Resources*, 34(6), 757–762.
- Fransisca, Rike, T. K. D., Clarissa, C. H. (2025). Development and characterization of new vegan ice cream from tempeh milk enriched with moringa leaf flour. *Indonesian Food Science and Technology Journal*, 8(2), 324–335.
- Goff, H. D. (1997). Colloidal aspects of ice cream – A review. *International Dairy Journal*, 7(6–7), 363–373.
- Goff, H. D. (2006). Ice cream. *Advanced Dairy Chemistry*, 2, 441–450.
- Goff, H. D., & Hartel, R. W. (2013). *Ice Cream* (7th ed.). Springer.
- Hebbbar, K. B., Arivalagan, M., Manikantan, M. R., Mathew, A. C., Thamban, C., George V. Thomas and Chowdappa P. (2015). Coconut inflorescence sap and its value addition as sugar - collection techniques, yield, properties and market perspective. *Current Science*, 109(8), 1411.
- Hurtta, M., Pitka, I., & Knuutinen, J. (2004). Melting behaviour of D-sucrose, D-glucose and D-fructose. *Carbohydrate Research*, 339(13), 2267–2273.
- Islam, M., Belkowska, L., Konieczny, P., Fornal, E., & Tomaszewska-Gras, J. (2022). Differential scanning calorimetry for authentication of edible fats and oils - What can we learn from the past to face the current challenges? *Journal of Food and Drug Analysis*, 30(2), 185–201.
- Kongkaew, S., Chaijan, M., & Riebroy, S. (2014). Some characteristics and antioxidant activity of commercial sugars produced in Thailand. *KMITL Science and Technology Journal*, 14(1), 1–9.
- Lekjing, S., Keawpeng, I., Venkatachalam, K., & Kariia, S. (2022). Impact of different sugar types and their concentrations on salted duck egg white based meringues. *Foods*, 11, 1248.
- Liu, Y., Sala, G., & Scholten, E. (2023). Structural transitions in fat-dominated ice cream networks and their effect on melting behavior. *Food Hydrocolloids*, 139, 108540.
- Maryani, Y., Rochmat, A., Khasini, R. O., Kurniawan, T., & Saraswati, I. (2021). Identification of Macro Elements (Sucrose, Glucose and Fructose) and Micro Elements (Metal Minerals) in the Products of Palm Sugar, Coconut Sugar and Sugar Cane. *Advances in Biological Sciences Research*, 9, 271–274.
- Matabura, V. V. (2023). Plant-based ice cream: processing, composition and meltdown properties analysis. *Tanzania Journal of Science*, 49(2), 446–455.
- Muse, M. R., & Hartel, R. W. (2004). Ice cream structural elements that affect melting rate and hardness. *Journal of Dairy Science*, 87(1), 1–10.
- Nafingah, R., Kurniasari, J., Cahyani, A., Harmayani, E., & Saputro, A. D. (2019). Investigating the impact of palm sap sugar proportion and fat content on heat stability of milk chocolate. *IOP Conference Series: Earth and Environmental Science*, 355(1), 012043.
- Naknean, P., Meenune, M., & Roudaut, G. (2009). Changes in physical and chemical properties during the production of palm sugar syrup by open pan and vacuum evaporator. *As. J. Food Ag-Ind*, 2(04), 448–456.
- Ozdemir, C., Dagdemir, E., Ozdemir, S., & Sagdic, O. (2007). Sucrose on ice cream quality. *Journal of Food Quality*, 31(2008), 415–428.
- Patel, M. R., Baer, R. J., & Acharya, M. R. (2006). Increasing the protein content of ice cream. *Journal of Dairy Science*, 89(5), 1400–1406.
- Persson, M. (2009). Nutritionally optimized ice cream fats. *Lipid Technology*, 21(3), 62–64.
- Rayappa, M. K. (2023). Palmyrah palm (Borassus flabellifer) non-centrifugal sugar - Current production practices as a natural sugar and a promising functional food/additive. *Journal of Agriculture and Food Research*, 14, 100829.
- Romulo, A., Meindrawan, B., Marpietylie. (2021). Effect of dairy and non-dairy ingredients on the physical characteristic of ice cream: Review. *IOP Conf. Series: Earth and Environmental Science*, 794, 012145.
- Saputro, A. D., Van de Walle, D., & Dewettinck, K. (2019). Palm sap sugar: A review. *Sugar Tech*, 21(6), 862–867.
- Sarkar, T., Mukherjee, M., Roy, S., & Chakraborty, R. (2023). Palm sap sugar an unconventional source of sugar exploration for bioactive compounds and its role on functional food development. *Heliyon*, 9(4), e14788.
- Silva Junior E., & Lannes S. C. S. L. (2011). Effect of different sweetener blends and fat types on ice cream properties. *Ciencia e Tecnologia de Alimentos*, 31(1), 217–220.
- Singh, P., Pandey, V. K., & Singh, R. (2022). Effect of palm sugar (Arenga pinnata) and jaggery (Saccharum officinarum) on qualitative characteristics and sensory attributes of ice cream. *International Journal of Industrial Biotechnology and Biomaterials*, 8(2), 11–19.
- Suharto, E. L. S., & Kurnia, Y. F. (2022). Nutritional value and quality of yogurt with addition of palm sugar (Arenga Pinnata Merr). *IOP Conference Series: Earth and Environmental Science*, 1059(1), 012058.
- Trinidad, T. P., Mallillin, A. C., Sagum, R. S., & Encabo, R. R. (2010). Glycemic index of commonly consumed carbohydrate foods in the Philippines. *Journal of Functional Foods*, 2(4), 271–274.
- Victor, I., & Orsat, V. (2018). Characterization of Arenga pinnata (Palm) sugar. *Sugar Tech*, 20(1), 105–109.
- Whelan, A. P., Vega, C., Kerry, J. P., Goff, H. D. (2007). Physicochemical and sensory optimisation of a low glycemic index ice cream formulation. *International Journal of Food Science & Technology*, 43, 1520–1527.
- Wu, B., Atik, D. S., Freire, D. O., Hartel, R. W. (2025). The Science of Ice Cream Meltdown and Structural Collapse: A Comprehensive Review. *Comprehensive Reviews in Food Science and Food Safety*, 24, e70226.
- Yangilar, F. (2015). Properties of Ice Cream with Green Banana Flour. *Food Technol. Biotechnol*, 53(3), 315–323.