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Plant-Based Ice Cream: Processing, Composition and Meltdown Properties Analysis

Victor Vicent Matabura
Department of Food Science and Technology, University of Dar es Salaam, P. O. Box 35134, Tanzania. E-mail address: victorvicent10@gmail.com
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Abstract

Plant-based foods have become a popular option for consumers due to their positive impacts on health and resulting changes in lifestyle. To preserve the quality of non-dairy ice cream during distribution and consumption, it is essential to understand its proximate composition and meltdown properties. In this study, cashews, coconut, and bananas were used as raw materials. Cashew milk and coconut cream were prepared separately and mixed at different ratios to make non-dairy ice cream. The proximate composition of the formulated ice cream was measured using the official standard methods. The meltdown properties, including drip-through (%), height (mm), and temperature (°C) were also assessed. The results indicated significant differences ($p < 0.05$) in the proximate components of the produced ice creams. An increase ($p < 0.05$) in protein, fibre, fat, and ash content was observed, as the amount of coconut cream increased, while the moisture content decreased, and the carbohydrate content remained unchanged. Furthermore, the meltdown properties of the ice cream changed significantly ($p < 0.05$) as the amount of coconut cream increased. The quantitative data on proximate composition and meltdown properties presented in this paper are valuable for maintaining ice cream quality and consumer convenience in the frozen food business. They also provide deeper insight into non-dairy desserts.

Keywords: Plant-Based Food; Ice Cream; Proximate Composition; Meltdown Properties.

Introduction

The human population is projected to reach 9.7 billion by 2050, posing threats to global food security, social and economic activities, and the environment (Miller et al. 2021). To address this challenge, sustainable food systems and alternative processing methods that enhance food security are necessary. As such, plant-based milk substitutes, including alternative food sources, are becoming increasingly popular, particularly in the vegan food sector, to diversify diets (Aydar et al. 2020, Matabura and Rweyemamu 2022).

According to Aydar et al. (2020), plant-based foods are widely consumed due to their health benefits and lifestyle changes. These foods are excellent substitutes due to their high concentrations of micronutrients, antioxidants, and bioactive compounds, which are linked to a reduction in non-communicable diseases (Aydar et al. 2020). Additionally, plant-based foods can serve two functions, i.e., functional and nutraceutical foods, providing health advantages (Pistollato et al. 2018). However, some plant-based sources contain anti-nutritional elements, limiting their bioaccessibility and bioavailability (Platel and Srinivasan 2016, Rousseau et al. 2020). Hence, alternative processing methods are necessary to overcome this limitation. Non-dairy milk sales were reported to be US$14 billion and are expected to grow at a rate of 8% per year over the next ten years, according to transparent market data for plant-based milk utilisation (TMR 2019). Furthermore, plant-based diets are becoming popular due to environmental concerns (Aydar et al. 2020, Matabura and Rweyemamu 2022, Tulashie et al. 2022). For instance, Matabura and Rweyemamu (2022) developed a plant-based beverage rich in nutrients to enhance food nutrition and security. In this context, the use of cashew milk, coconut cream, and banana fruit is becoming increasingly important and attracting attention to the food industry (McClements et al. 2019).

Cashew is an economic agricultural crop in Tanzania, consisting of cashew kernel, shell, and cashew apple, which supports the livelihood of 75% of households in cashew-growing areas of Tanzania (URT 2021). Tanzania is one of the major cashew producers globally. However, improper postharvest handling, preservation, and processing methods cause 90% of cashews to be exported as raw materials (Dimoso et al. 2021). The coconut palm is primarily produced in tropical areas of Asia and Africa, and coconut milk is a form of emulsion produced from coconut kernels (Patil and Benjakul 2018). These food items are good sources of several nutrients, including proteins, healthy carbohydrates, essential fatty acids, vitamins, minerals, dietary fibres, and antioxidants (Trox et al. 2010). Harnessing the potential contributions of cashew and coconut, processing these plant-based materials through the production of non-dairy ice cream is indispensable. Plant-based materials are mostly rich in ingredients in terms of nutritional quality, especially improved protein, antioxidants, vitamins, and minerals (Platel and Srinivasan 2016, Rousseau et al. 2020, Matabura and Rweyemamu 2022). Besides, plant-based foods can provide both food and nutritional security to many low-income countries (Walsh and Gunn 2020, Tulashie et al. 2022). However, there is no information in the literature on non-dairy ice cream made using cashew milk and coconut cream as the primary ingredients and then enriched with banana.

Ice cream is a frozen dessert produced mainly from cow's milk, cream, and stabiliser agents. However, dairy consumption of ice cream has been associated with health risks, such as lactose intolerance and hypercholesterolemia, according to the studies of Sethi et al. (2016) and McCann et al. (2017). Consequently, more and more people are turning to non-dairy ice cream because it has fewer calories, lactose, and cholesterol, as noted by Walsh and Gunn (2020). Ice cream has two phases: a frozen phase and an unfrozen phase that consists of fat globules, sugars, proteins, stabilisers, and emulsifiers, as well as air bubbles (Muse and Hartel 2004, Pinzer et al. 2012). These constituents provide structural integrity, water-holding capacity, and resistance to the melting of ice cream, as reported by several studies (Cook and Hartel 2010, Daw and Hartel 2015). The meltdown process of ice cream happens in the mouth during consumption or when stored and distributed at warm temperatures (Goff and Hartel 2013).

When ice cream becomes warm, the ice crystals start to melt, and the resulting ice cream solution drips out. Depending on the remaining structures of air bubbles, ice crystals and fat globules, the melting ice cream tends to collapse (Warren and Hartel 2014, 2018). The meltdown is one of the challenges that the frozen food industry faces, and it is crucial for both consumer acceptance and distribution. Therefore, the purpose of this work was to produce non-dairy ice creams using cashew milk, coconut cream, and banana, followed by an evaluation of the proximate composition and meltdown properties.

Materials and Methods

Samples

Cashew (*Anacardium occidentale*), coconut (*Cocos nucifera*), and banana (*Musa acuminata*) were sourced from a supermarket in Dar es Salaam, Tanzania. For experimentations, 20 kg of banana bunches, 10 kg of cashews, and 20 kg of coconuts were obtained. A stabiliser made of locust bean gum, guar gum, and carrageenan was supplied by Sigma-Aldrich (Steinheim, Germany).

Sample preparation

Sample preparation involved soaking the sorted cashew nuts in 15 L of deionised water chilled at 4 °C overnight. The soaking water was discarded, and the soaked cashew samples were mixed with deionised water at a ratio of 1:3 (w/v) and blended using a blender (Vitamix S50 blender, UK) at a rotation speed of 1600 rpm for 2 min. The produced mash was filtered through a 200 µm cheesecloth to obtain cashew milk (Coggins 2022), which was then used as a dairy milk alternative. For coconut milk, mature coconuts were used. The de-husked coconuts were cracked into pieces and the flesh coconut meat was scooped out from the shell and grated. The grated coconuts were mixed with deionised hot water (55 °C) at a ratio of 1:3 (w/v) and blended using a blender (Vitamix S50 blender, UK) at 1600 rpm for 4 min. The resulting slurry was filtered through a 200 m cheesecloth and squeezed to separate coconut milk from the pulp. The pulp was blended three times with deionised hot water to extract more milk. The coconut milk was allowed to settle overnight in a fridge set to -4 °C. The next day, the coconut cream was removed from the mixture, and the water was discarded. Bananas were ripened to stage 5 by placing them at 28 ± 2 °C, as determined by Majaliwa et al. (2019). The banana fingers were washed, peeled, and sliced using a stainless knife.

Ice cream mix and making process

The ice cream mix was prepared by combining cashew milk, coconut cream, and banana, and adding water, butter, stabiliser, and sugar, as presented in Table 1. To create the first ice cream (IC_1), the mixture contained 53.60% cashew milk, 18% coconut cream, and 10.90% deionised water. For the second ice cream (IC_2), the mixture included 55.70% of cashew milk, 15% coconut cream, and 11.80% deionised water to make ice cream IC_2. The third sample, ice cream (IC_3), was made with 57.40% cashew milk, 12% coconut cream and 13.10% deionised water. In each mixture, 8% banana, 5% sugar, 4% butter, and 0.5% stabiliser were added. The formulations of the ingredients for ice cream making were established using a D-optimal design expert software (Version 12.0.0). The mixtures were then blended individually using a Vitamix S50 blender (UK) for 2 min at 1600 rpm. After blending, the ingredients for ice cream making were heated to 90 °C for one minute and subsequently cooled in a refrigerator set at 4 °C. The cooled mixture was then left in the refrigerator for 24 hours to mature. The matured mix was homogenised using a hand blender. The homogenised ice cream mix was frozen in a horizontal air freezer set at -20 °C overnight for 12 hours and then left for 24 hours for hardening and storage.

Table 1: Formulation of plant-based ice cream using cashew milk, coconut cream and banana fruit

	Ice cream samples		
Ingredient (%)	IC_1	IC_2	IC_3
Cashew milk	57.40	55.70	53.6
Coconut cream	12	15	18
Banana fruit	7	7	7
Sugar syrup	6	6	6
Stabiliser	0.50	0.50	0.5
Water	13.10	11.80	10.9
Butter	4	4	4

Proximate composition analysis

The proximate compositions of cashew milk, coconut cream, bananas, and ice cream were measured using the standard methods of AOAC (2005). The moisture content was determined by heating to a constant weight in an oven set at 105 °C using the official method 934.01 (AOAC 2005). The protein content was determined using the Kjeldahl method, which includes digestion of the sample, distillation, and then titration using the official method 978.04 (AOAC 2005). The protein content was then estimated using a conversion factor of 6.25. The Soxhlet extraction method (Method 930.09) was used to determine fat content, with petroleum ether being used as the extraction solvent. Fibre content was analysed following the official method 978.10 (AOAC 2005). Ash content was measured by heating to 550 °C in the incinerator, according to the official standard method (Method 930.05). Finally, the carbohydrate content was calculated by the difference method. For a more complete description of how the compositions were analysed, the reader is referred to the official standard methods of AOAC (2005).

Meltdown properties

Meltdown properties were analysed by excising a cylindrical sample with a diameter and height of 50 mm and 53 mm, respectively, from each ice cream type. The meltdown of ice cream was analysed using the method described by Bolliger et al. (2000) and Goff and Hartel (2013). The prepared sample was placed on a wire mesh with seven square holes per cm, which was positioned on a metal stand suspended over a beaker on a scale to collect drip-through mass. The mass of the melted ice cream was measured every 30 min using an analytical balance (Sartorius GMBH, Göttingen, Germany). The meltdown testing was allowed to last for 180 min, which was sufficient for the entire ice cream to drip through the wire mesh. The drip-through was estimated from the ratio of the melted mass (g) divided by the initial mass of ice cream (g) and then expressed as a percentage. Changes in temperature (°C) and height (cm) of the melting ice cream were measured during the testing of the meltdown. A calibrated thermocouple (type T thermocouple with a diameter of 0.2 mm) was put into the centre of the ice cream sample to measure the temperature of the melting ice cream. Four replicate samples were used for each ice cream product, and the meltdown test was performed in a room set at a temperature of 20 ± 1.8 °C. In addition to the meltdown properties, the macroscopic images of ice creams were captured using a digital camera (Panasonic DMC-TZ57, Osaka, Japan) during the meltdown testing. The distance between the camera and the sample was calibrated to capture all the images from a fixed point at a magnification of ×20. Images of the melting ice cream were processed using Image J 1.48v (National Institutes of Health, USA).

Statistical analysis

The resulting data were imported into Matlab (R2017b, Mathworks Inc., Natick, MA, U.S.A), where the statistical analysis was performed. The two-sample Kolmogorov-Smirnov test ($p < 0.05$) was applied to compare the datasets statistically. For each parameter, the measured mean values were estimated as mean and standard deviation data (± S.D.). Three replicates of each parameter were used in the analyses.

Results and Discussion

Proximate composition of ingredients

The results of the proximate composition analysis for cashew milk, coconut cream, and banana fruit are shown in Table 2. Most of the proximate compositions (g/100 g of sample on a wet basis) were found to vary considerably ($p < 0.05$). Cashew milk had a significantly higher amount of moisture content (85.78 ± 0.87) when compared to banana fruit (68.91 ± 0.50) and coconut cream (59.15 ± 0.62). The protein content was high in coconut cream (4.21 ± 0.10), while the protein contents of cashew milk (2.73 ± 0.38) and banana fruit (2.68 ± 0.11) did not differ significantly ($p > 0.05$). Coconut cream had a high-fat content (19.44 ± 0.75), while cashew milk had a low-fat content (3.42 ± 0.26), and fat was not found in banana fruit. Banana fruit contained much more fibre and carbohydrates than cashew milk and coconut cream, as depicted in Table 2. Both cashew milk and coconut cream had insignificant differences ($p > 0.05$) in ash and fibres, as shown in Table 2. These differences in the proximate compositions are likely due to the different ingredients used.

Most of the proximate composition data obtained in this study differ from those reported in the literature (Baiyeri et al. 2011, Igutti et al. 2011, Tamuno and Monday 2019, Coggins 2022). For example, Tamuno and Monday (2019) reported different proximate compositions for cashew milk, including protein content of 5.00%, fat content of 5.49%, ash content of 0.90%, carbohydrate content of 5.95%, and moisture content of 82.66%. Coggins (2022) stated the proximate compositions of protein (0.93 ± 0.07), fat (0.39 ± 0.08), ash content (0.39 ± 0.12), and carbohydrate (1.39 ± 0.15) in cashew milk with a very high moisture content of 96.92 ± 0.09, all in g/100 g of sample. In the case of coconut cream, Igutti et al. (2011) reported a protein content of 2.4%, fat of 1.0%, ash content of 0.36%, carbohydrate of 31.2%, and moisture content of 65.0%. According to Baiyeri et al. (2011), banana fruit contains 0.35% protein, 1.43% fibres, 0.33% ash, 15.96% carbohydrate, and 81.68% moisture. These differences in proximate compositions could be due to various reasons, including processing conditions, cultivar differences, agroecological conditions, and inherent components of the materials, i.e., cashew milk, coconut cream, and banana fruit. These proximate compositions suggest that these materials could be cost-effective and alternative ingredients for producing plant-based ice cream (Aydar et al. 2020, Matabura and Rweyemamu 2022), which are currently increasing in the market.

Table 2: Proximate composition of ingredients: cashew milk, coconut cream, and banana fruit. The data are presented as mean ± standard deviation ($\bar{x}$ ± SD). The means with different superscripts in the same row are significantly different at $p < 0.05$.

	Proximate composition (g/100 g sample on a wet basis)		
Component	Cashew milk	Coconut cream	Banana fruit
Moisture	85.78 ± 0.87^{a}	59.15 ± 0.62^{b}	68.91 ± 0.50^{c}
Ash	2.45 ± 0.32^{ab}	2.28 ± 0.01^{a}	1.78 ± 0.41^{b}
Fat	3.42 ± 0.26^{a}	19.44 ± 0.75^{b}	NF
Protein	2.73 ± 0.38^{a}	4.21 ± 0.10^{b}	2.68 ± 0.11^{a}
Fibre	1.13 ± 0.18^{a}	1.20 ± 0.20^{a}	2.77 ± 0.24^{b}
Carbohydrate	4.02 ± 0.15^{a}	13.74 ± 0.42^{b}	23.85 ± 0.30^{c}

**NF = Not found.*

Proximate composition of ice cream

The ice creams were evaluated for proximate composition, and the results are shown in Table 3. The quantitative data for moisture, ash, protein, fat, and fibre contents showed significant differences ($p < 0.05$) as the cashew milk decreased and the coconut cream increased. The moisture content decreased significantly ($p < 0.05$) from 64.10 ± 1.41 to 59.30 ± 1.20 g/100 g for the IC_1 and IC_3 samples, respectively. The fat, protein, ash, and fibre contents increased significantly ($p < 0.05$) from IC_1 to IC_3 samples. The increase in protein and fat contents is evident since the coconut cream, which has high amounts of protein and fat, was increased from IC_1 to IC_3. However, the results for carbohydrates showed no change ($p > 0.05$) as cashew milk decreased and coconut cream increased (Table 3). The differences in the proximate compositions of the ice creams IC_1 to IC_3 are evident due to the use of different raw materials, which were found to have varying proximate constituents, as shown in Table 2. Additionally, the ratios used during blending (Table 1) may have resulted in various interactions.

The literature reported no data on the proximate composition of ice cream made with cashew milk, coconut cream, and banana fruits for comparison with the current results. Therefore, these findings reveal innovative information, which is crucial to the dessert industry but scarce to the food science community.

Table 3: Proximate composition of the ice cream developed. The data are expressed as mean ± standard deviations ($\bar{x}$ ± SD). The means with different superscripts for the same row are significantly different at $p < 0.05$.

Component	Proximate composition (g/100 g sample)		
	IC_1	IC_2	IC_3
Moisture	64.10 ± 1.41^a	61.82 ± 1.05^b	59.30 ± 1.20^c
Ash	0.62 ± 0.05^a	0.75 ± 0.06^b	0.93 ± 0.04^c
Fat	6.04 ± 0.52^a	7.87 ± 0.34^b	10.46 ± 0.71^c
Protein	3.71 ± 0.27^a	3.80 ± 0.48^{ab}	4.60 ± 0.52^b
Fibre	1.85 ± 0.10^a	2.18 ± 0.24^{ab}	2.54 ± 0.32^b
Carbohydrate	23.68 ± 2.14^a	23.58 ± 1.80^a	22.17 ± 2.16^a

Meltdown properties

Figure 1 presents microscopic images of ice creams acquired at various time points of the meltdown using a digital camera. The images of ice creams IC_1, IC_2, and IC_3 are displayed in the first, second, and third rows, respectively. Meltdown properties, including drip-through (%), changes in height (mm) and temperature (°C), were then measured for each ice cream sample, as presented in Figure 2a-c. During the first 30 min, all the ice creams showed no drip-through (%). After 60 min, ice creams started to drip out, with no significant differences ($p > 0.05$) observed between IC_1, IC_2, and IC_3 (Figure 2a). However, IC_1 melted completely during the 150 min, resulting in 100% drip-through, while IC_2 and IC_3 only dripped through approximately 55% and 38%, respectively. At the end of the meltdown analysis, i.e., 180 min, IC_2 and IC_3 had drip-through of 66% and 10.01%, respectively, indicating that IC_1 melted faster than IC_2 and IC_3.

Previous studies have shown that the compositions of ice creams, such as protein and fat contents, air volume, and ice phase fractions, as well as fat coalescence, can affect the rate of meltdown (Koxholt et al. 2001, Sofjan and Hartel 2004, Goff and Hartel 2013, Wu et al. 2019). Ice with a high amount of air tends to melt slowly during the meltdown process because air bubbles lessen heat transfer into ice cream, thereby delaying ice crystal melting and, eventually, the meltdown rate. Additionally, ice cream with a relatively high air volume fraction can have less material drip out. The study of Koxholt et al. (2001) and several other studies have reported similar findings.

Changes in the height of the melting ice cream are presented in Figure 2b, which shows various melting curves with the meltdown process divided into three stages: lag, fast-melting, and plateau phases. All the ice cream samples exhibit a lag phase during the first 30 min, where no change in height was detected. This suggests that the shape of the ice cream was maintained during this period. Then, for all the three ice creams, a fast-melting phase was observed between 30 and 150 min, during which rapid changes in height were measured. Changes in height were quantified to be from 52.00 ± 1.85 mm to 0.00 ± 0.04 mm for IC_1, 52.00 ± 1.80 mm to 20.12 ± 1.10 mm for IC_2 and from 50.00 ± 1.85 mm to 30.10 ± 0.74 mm for IC_3 (Figure 2b). In other words, the morphology of the ice creams undergoes a drastic change ($p < 0.05$) during the fast-melting phase. These results were consistent with an increasing trend in drip-out that was observed for each ice cream sample, as shown in Figure 2a. Finally, the meltdown process showed a plateau phase from 150 to over 180 min for all the ice cream samples. This means that no further significant changes in height were noticed for IC_1, IC_2, and IC_3. The melting curve of IC_1 is consistent with the previous findings reported by Wu et al. (2019). These authors investigated the effects of ice cream composition, such as overrun and stabiliser on the melting characteristics and identified three phases during the meltdown of the ice cream.

Figure 2c shows the temperature evolution of the melting ice cream samples examined by a calibrated thermocouple. The temperature changes from -20 ± 0.5 °C to 20

± 0.4 °C for IC_1, -20 ± 0.5 °C to 19.4 ± 0.3 °C for IC_2, and from -20 ± 0.5 °C to 17.3 ± 0.4 °C for IC_3 were recorded at the end of meltdown analysis. These changes take about 150 min for IC_1 and 180 min for both IC_2 and IC_3. Differences in the final temperatures of the ice cream products could be attributed to variations in their compositions, as discussed in the "proximate composition of ice cream" section. Differences in ice cream composition may hinder heat transfer (Warren and Hartel 2018), especially when the ice cream samples are exposed to the ambient temperature of a room that is maintained at 20 ± 1.8 °C throughout the experiment.

Meltdown properties are critical for maintaining the quality of ice cream and ensuring consumer convenience in the frozen food industry. However, no literature exists on the meltdown properties of non-dairy ice cream produced from cashew milk, coconut cream, and banana fruit, which can be compared to the current results. Therefore, this study addressed a gap in the literature by providing unique data on non-dairy ice cream, which could assist plant-based businesses in managing the growing demands for non-dairy desserts and optimising their processes (McClements et al. 2019, Aydar et al. 2020). Furthermore, plant-based dietary alternatives are becoming increasingly popular in food technology and nutrition.

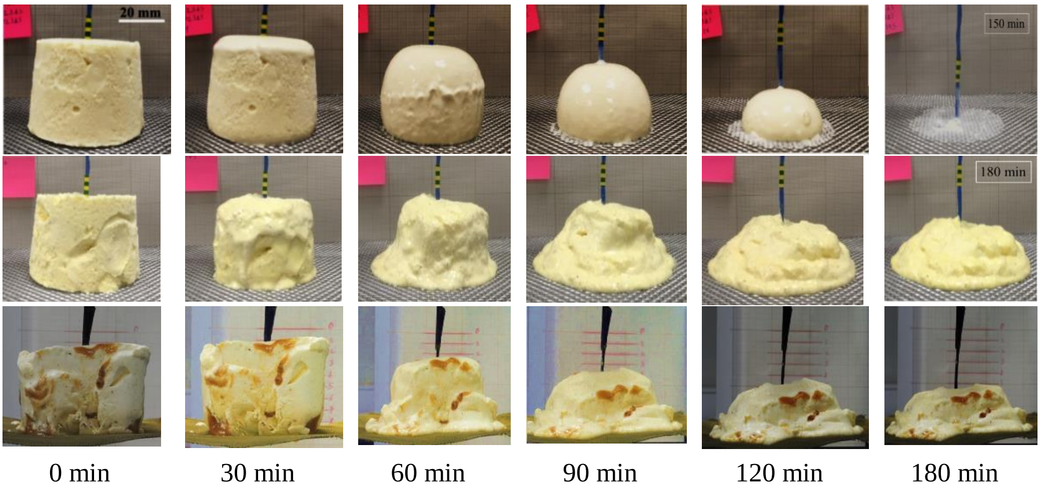

Figure 1: The macroscopic images of ice creams during the meltdown test were acquired using a digital camera (Panasonic DMC-TZ57, Osaka, Japan). The first, second, and third rows show digitised images of ice creams IC_1, IC_2, and IC_3, respectively. The temperature of the ice cream sample was recorded at each time-point using a calibrated type T thermocouple (a dark-blue wire) with a diameter of about 0.2 mm, which was inserted into the centre of the ice cream sample. The scale bar represents 20 mm.

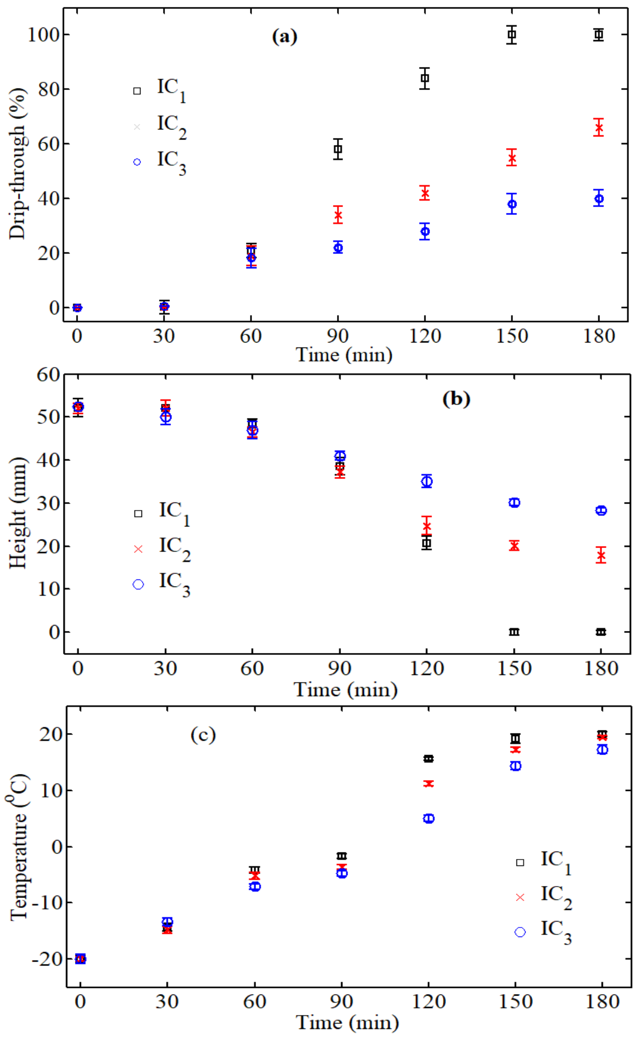

Figure 2: The melting properties; drip-through (**a**), changes of height **(b**), and temperature (**c**) for ice creams IC_1, IC_2, and IC_3 were measured during meltdown analysis.

Conclusions

Plant-based foods are rising worldwide as people become more concerned about sustainable living, environmental issues, and food security. In this context, this comprehensive study presents a method for making non-dairy ice cream using cashew milk, coconut cream, and banana fruit. The study then quantitatively analyses the proximate composition of ice creams, which were found to vary considerably ($p < 0.05$) as the amount of coconut cream increased. Specifically, fat content increased from 6.04 ± 0.52 to 10.64 ± 0.71, protein content increased from 3.71 ± 0.27 to 4.60 ± 0.52, fibre content evolved from 1.85 ± 0.10 to 2.54 ± 0.32, and ash content increased from 0.62 ± 0.05 to 0.93 ± 0.04 in g/100 g of sample, all following IC_1 to IC_3. On the other hand, moisture content decreased significantly ($p < 0.05$) as the amount of coconut cream increased from IC_1 to IC_3, while the carbohydrate content remained relatively constant ($p > 0.05$). The study also analysed the meltdown properties of the ice creams, including drip-through, changes in height, and temperature during melting. The results showed that IC_3 had a slower rate of meltdown compared to IC_1 and IC_2, providing more insights into the phenomenon of the meltdown of ice cream, which is an important consideration for food quality preservation and process optimisation in the food industry.

These data, which are currently scarce in the literature, can be crucial for plant-based and food technology businesses. Further investigation could focus on examining the rheological properties and spatial distributions of the fat globules and air bubbles in ice cream products during the melting process to gain a better understanding of the underlying mechanisms of the meltdown phenomenon.

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Declaration of Competing Interest: The author declares that there are no competing interests to disclose concerning this work.

Availability of Data: The full datasets generated and used by this study are available from the authors upon reasonable request.

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