Article

Sustainable Ice Cream Base: Harnessing Mango Seed Kernel (Mangifera indica L. var. Tommy Atkins) Waste and Cheese Whey

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Abstract: The agro-food industry plays a crucial role in enhancing living standards; however, inadequate losses and waste management persists as significant challenges within its processes. Particularly, mango and cheese processing generate substantial waste, leading to ecological disruptions, economic losses, and concerns related to food security and public health. To address these issues, this study was aimed at utilizing this waste to produce a high-quality ice cream base, thereby valorizing the discarded materials. This approach not only adds nutritional value but also contributes to food security and sovereignty. The raw materials (cheese whey, oil, and starch) were subjected to physicochemical characterization, leading to the development of three different ice cream base formulations. Subsequently, the ice cream bases were evaluated for their physicochemical properties, leading to the development of three different ice cream base formulations. Moreover, this research showcases a promising solution for effectively valorizing food waste and generating value-added products such as ice cream, thus promoting sustainability and resource optimization within the agro-food industry.

Keywords: waste valorization; ice cream base; cheese whey; mango seed kernel; fluor extraction; starch extraction; oil extraction; chemical composition; sensory evaluation


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1. Introduction

The food agro-industry plays a crucial role in promoting global economic, social, and environmental development, provided it maintains a delicate balance between its operations and environmental preservation throughout its processes, from raw material handling to by-products and waste disposal. Regrettably, improper food losses and waste management remains a persistent issue within this sector, leading to disruptions in abiotic, biotic, and socioeconomic environments, and potentially resulting in economic losses for companies [1]. Consequently, proper elimination of such waste poses a critical management challenge for the numerous food agro-industrial establishments.

According to the Commission for Environmental Cooperation (CEC), in the North American countries (Canada, United States, and Mexico), food losses and waste (FLW) generated in the food supply chain from post-harvest to pre-consumption (including post-harvest food production, processing, manufacturing, transformation and packaging, distribution, retail sales, and food preparation services) are not efficiently utilized. These losses and waste amount to approximately 168 million tons of FLW per year, representing the highest estimated per capita FLW volume in the world [2].

In the case of Mexico, according to the National Council to Prevent Discrimination (CONAPRED, by its Spanish acronym) and the Food and Agriculture Organization of the United Nations (FAO), approximately 37% of food production is classified as FLW, generating around 28 million tons of FLW annually and a per capita production of 249 kg/year [3,4]. On the other hand, the United Nations Economic Commission for Latin America and the Caribbean [5] reports that 23.4% of the Mexican population experiences food insecurity, ranking Mexico 43rd internationally and sixth in Latin America according to the Global Food Security Index (GFSI) in 2022 [6]. Hence, there is a growing interest in implementing processes that allow for the efficient, comprehensive, and sustainable use of waste to produce a wide range of high-value-added by-products, ensuring food sovereignty and security for the population.

In recent years, Mexico has solidified its position as the sixth-largest mango producer in the world, with an annual production of 2.1 million tons [7]. Nevertheless, this fruit ranks as the third most wasted food (54.54%) in the country. From the processing of mangos, by-products such as peels and seeds are obtained, constituting approximately 40–60% of the fruit, which are discarded as waste [8]. Due to its high sugar and water content, both the fruit and its residues decompose rapidly, leading to significant economic losses for small and medium-sized producers in tropical regions of Mexico [9]. On the other hand, Cheese whey is another commonly produced and underexploited waste in the food agro-industry in Mexico. This liquid residue is generated during the milk coagulation process in cheese manufacturing [10]. Commonly, there are two main classifications of cheese whey: acid and sweet whey. These classifications are based on the methods by which they are generated during cheese production. Acid whey is a result of the direct utilization of organic acids or the introduction of lactic cultures during the cheese-making process. These acidification methods promote coagulation and curd formation, leading to the separation of whey from the curd. On the other hand, sweet whey is primarily obtained by coagulating milk proteins using animal or microbial enzymes. One common enzyme used for this purpose is the chymosin complex. This enzymatic coagulation causes proteins to aggregate and form curds, leaving sweet whey as a liquid byproduct [11,12].

Interestingly, this liquid residue still contains approximately 50% of the nutrients present in milk [13], yet it is a highly underutilized by-product in Mexico. It is estimated that 9–10 L of whey are generated for every 1 kg of cheese produced [14]. Currently in Mexico, cheese whey production reaches around 1.6 million tons per year (estimated based on cow’s whole milk cheese production in Mexico) [15], of which 45% is discarded in rivers, lakes, other wastewater facilities, or in the soil, causing a significant loss of nutrients that are not used. Therefore, both wastes (mango and cheese whey) can rise to serious and undesirable sources of environmental contamination and public health concerns.
To date, there are no available data from international regulatory organizations such as FAO or national agencies such as Secretariat of Agriculture and Rural Development (SADER, by its Spanish acronym) regarding the utilization of whey and by-products such as mango peels and seeds to produce value-added products in Mexico. However, the country has been focused on the development process and utilization of these residues. Concerning cheese whey, the primary studies have been related to microbial biomass production [16–18], lactose extraction [19,20], production of fermented beverages [21,22], dietary supplements [23,24], biofuels [25–27], and ice cream base [28–30]. As for mango seed waste, the literature mentions the extraction of oils [31,32], starch [33,34], bioactive compounds [35,36], and biofuels [37,38]. Nevertheless, the combined use of both residues for food production is not very common in Mexico, and there is limited information available when both wastes are employed to create an ice cream base.

Ice cream is a very popular food and is the result of a mixture of different components, including milk fat, protein, complex carbohydrates, sweeteners, emulsifiers, some mineral salts, and water [39,40]. Its high global demand is mainly due to its attributes of freshness and texture, appreciated by consumers [41] and which is the result of the composition and the interactions of these attributes. In Mexico, in the PROY-NMX-F-714-COFOCALEC [42] shows the limits of each component for different categories of ice cream; for example, for milk cream ice cream they are 7.0% minimum butterfat, 2.5% minimum milk protein, and 30% minimum total solids, while for milk ice cream, the minimum limits for the same parameters are 2.0%, 1.5%, and 20%, respectively.

An ice cream base is the foundational mixture or liquid that serves as the starting point for making ice cream. It is a crucial component in the ice cream production process and acts as the main building block for the final product. The ice cream base typically consists of a combination of milk or cream, sugar, stabilizers, emulsifiers, and flavorings. The milk or cream provides the creamy texture and richness to the ice cream. The sugar, stabilizers, and emulsifiers provide sweetness to improve the texture, and this prevents ice crystal formation, ensuring that the ice cream maintains a smooth consistency during freezing and storage. Additionally, flavorings, such as vanilla extract, cocoa powder, fruit purees, fruit oils, or other flavorings, are often added to create the desired taste [43]. However, the use of cheese whey, nonconventional starches, or even waste fruit seed oils have been scarcely studied to produce ice cream bases. Therefore, the aim of this research was to harness cheese whey and waste from mango seed kernel (*Mangifera indica* L. var. Tommy Atkins) to create a high-quality ice cream base that maximizes their potential use by adding value to these waste by-products. Additionally, we add the characterization physicochemical of all waste used.

2. Materials and Methods

2.1. Raw Materials

The sweet cheese whey was obtained from an artisanal cheese factory located in Berriozábal, Chiapas, Mexico (16°48’01'' N 93°16’24'' W). Before its use, the cheese whey underwent a process of deodorization with activated carbon and pasteurization, following the NOM-243-SSA1 regulation [44].

The mango (*Mangifera indica* L. var. Tommy Atkins) seeds were provided by Mexifrutas S.A. de C.V. (16°14’10” N 93°53’58” W) in Arriaga, Chiapas, Mexico. Firstly, they underwent a process of selection, washing, and disinfection (immersion in a 15% v/v peracetic acid solution) to ensure hygiene. Subsequently, the cotyledons of the seeds were removed, cut into fractions of approximately half a centimeter, and dried at 45 °C for 24 h until reaching a constant weight. Then, they were ground using a domestic/industrial food processor, sieved through a U.S. number 40 mesh (425 μm), and stored in low-density polyethylene bags. From the flour obtained, a percentage was allocated for oil extraction, and the remaining percentage was used for starch extraction.
2.1.1. Starch Extraction

The starch extraction was carried out following the method reported by Thory and Sandhu [45] with modifications. Briefly, 100 g of flour was mixed with 200 mL of hexane and left to stand for 24 h with agitation. Subsequently, the hexane was removed by decantation, and the moist flour was grounded with 200 mL of 96% ethanol. The obtained suspension was sieved through number 40 (425 µm), 100 (149 µm), and 200 (74 µm) U.S. mesh screens. The residues retained in each mesh were washed with distilled water to recover the maximum amount of starch. Finally, the suspension was allowed to settle, and the precipitate (starch) was dried at 40 °C for 8 h.

2.1.2. Oil Extraction and Purification

The oil extraction was performed following the Soxhlet method (method 920.39) using the official procedure of the Association of Official Agricultural Chemists (AOAC) [46]. Briefly, 10 g of flour was refluxed with hexane at 70 °C for 8 h; subsequently, the solvent was evaporated at 60 °C for 12 h. The oil purification was carried out washed with distilled water in a 1:6 ratio at 50 °C for 6 h with agitation, followed by partial water evaporation at 60 °C for 12 h. Finally, the sample was centrifuged at 4000 rpm to recover the supernatant. The purified oil was stored at 4 °C to prevent rancidity.

2.2. Physicochemical Characterization

The chemical composition of raw cheese whey, flour, and starch samples comprised the determination of moisture content (method 934.01), ash content (method 942.05), total lipid (method 920.39), crude protein (method 954.01), and total dietary fiber (method 985.29) using the official procedures of the AOAC [46]. The carbohydrate was obtained by difference (100% − [% moisture + % ash + % protein + % fat]) according to the report by Espinosa-Solis et al. [47]. In addition to starch, the amylose and amyllopectin content were determined using the Amylose/Amylopectin assay procedure K-AMYL 04/06 kit from Megazyme (Megazyme International, Ireland), the morphology was obtained with a scanning electron microscope (SEM) (JEOL, Model IT300, Boston, MA, USA), the thermal properties were determined using a differential scanning calorimeter (DSC) (DSC 4000; PerkinElmer, Waltham, MA, USA) according to the reported by Tirado-Gallegos et al. [48] and Domínguez-Espinosa et al. [49], color was determined using a CR-400 Minolta colorimeter (Minolta, Tokyo, Japan), and the starch presence was determined qualitatively by the iodine–starch test reported by Aristizábal et al. [50].

The fatty acid profile analysis of the mango seed kernel oil was performed using a gas chromatograph (Agilent Technologies, model 5975 inert XL, Santa Clara, CA, USA), equipped with a DBWax column (Agilent Technologies, Santa Clara, CA, USA) with a length of 60 m, internal diameter of 0.25 mm, and film thickness of 0.25 µm. The analysis started at a temperature of 150 °C, which was maintained for 5 min; subsequently, it was raised to 210 °C using a heating ramp of 30 °C/min. From 210 °C, it was increased to 213 °C at a rate of 1 °C/min, and finally, it was further raised to 225 °C at a rate of 20 °C/min, with a total runtime of 30.6 min per sample. Helium was used as the carrier gas at a flow rate of 1 mL/min, and the injector temperature was set at 250 °C with a split injection ratio of 50:1. Chromatographic signals were identified using a mass spectrometer (Agilent Technologies, model 5975 inert XL, Santa Clara, CA, USA). Mass spectra were obtained using electron impact ionization at 70 eV. For compound identification, the mass spectra obtained for each component were compared with the database HP Chemstation-NIST MS Library version A.00.1995. In addition, the oil samples were determined for the peroxide index [51], acidity index [52], density, and viscosity using the viscometer SVM 3000® equipment (AntonPaar, Graz, Austria).

Finally, the extraction yield of flour, starch and oil were determined according to the Equation (1).

\[
Yield (\%) = \frac{W_{TP} (g)}{W_{RM} (g)} \times 100\% \tag{1}
\]
where the $W_{TP}$ is the total product weight obtained (flour, starch, or oil) and $W_{RM}$ is the raw material weight (dry seed kernel or flour) used.

### 2.3. Formulation and Evaluation of Ice Cream Base

For the preparation of the ice cream base (Figure 1), a standardized formulation consisted of 17.56% sugar, 0.40% emulsifier (xanthan gum), and 5.77% milk powdered (Nestle Carnation Clavel). Subsequently, cheese whey, oil, and starch were added according to three proposed formulations (Table 1), without exceeding the recommended proportions by Madrid and Cenzano [43]. These ingredients were then mixed at 85°C for 5 min until a smooth, lump-free, uniform, and creamy consistency was achieved. Following the thermal process, the maturation process began at 4°C for 24 h; later, constant mechanical agitation was applied for two hours. After this time, the base was cooled to −12°C using air injection, ensuring no crystal formation. Finally, after 2 h, at −12°C, the base was individually packaged and allowed to mature at −30°C [53] until the moment of conducting physicochemical, functional, and sensory evaluations.

![Figure 1. Flowchart of the general process for ice cream made with cheese whey and mango seed kernel waste.](image)

**Table 1. Ice cream base formulation using agro-waste.**

<table>
<thead>
<tr>
<th>Components *</th>
<th>F1 (%)</th>
<th>F2 (%)</th>
<th>F3 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cheese whey (%)</td>
<td>67.87</td>
<td>63.67</td>
<td>59.27</td>
</tr>
<tr>
<td>Oil (%)</td>
<td>8</td>
<td>12</td>
<td>16</td>
</tr>
<tr>
<td>Starch (%)</td>
<td>0.40</td>
<td>0.6</td>
<td>1.0</td>
</tr>
</tbody>
</table>

* Ice cream base formulation in base to 100 g.

The chemical composition of ice cream base samples comprised the determination of moisture content (method 934.01), ash content (method 942.05), total lipid (method 954.17), and peroxide index [51].
920.39), and crude protein (method 954.01) using the official procedures of the AOAC [46]. The carbohydrate was obtained according to the report by Espinosa-Solis et al. [47]. The freezing point according to the described by Ramírez (2015), the pH was determined using a potentiometer (HANNA, HI5221-01 model, CDMX, Mexico), and finally, titratable acidity was evaluated following the methodology of Ramírez-Navas et al. [54].

The functional parameters assessed in the ice cream base included the freezing point (ISO 5764:2002) using the official standards of the Spanish Association for Standardization (UNE) [55]. The overrun, melting time, and fall time of the first drop of the ice cream values were obtained according to reported by Ramírez-Navas et al. [54]. Additionally, density and viscosity were determined using the SVM 3000® viscometer equipment (AntonPaar, Graz, Austria) and color was determined using a CR-400 Minolta colorimeter (Minolta, Tokyo, Japan).

The sensory evaluation was determined using a hedonic test (Table S1) with the following scale (like it very much, like it, neither like nor dislike it, dislike it, and strongly dislike it) with a panel of 10 trained judges. It is worth mentioning that no samples had added flavor or color, only the ice cream base ingredients (Table 1). The attributes measured were color, smell, taste, and consistency.

3. Results

3.1. Physicochemical Characterization of Raw Materials

The proximal chemical characteristics of the cheese whey, flour, and starch obtained from the mango seed kernel are shown in Table 2.

Table 2. Chemical analysis of flour and starch of mango seed kernel and cheese whey.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Cheese Whey a</th>
<th>Flour b, *</th>
<th>Starch b, **</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture (%)</td>
<td>93 ± 1</td>
<td>4.8 ± 0.16</td>
<td>4.9 ± 0.08</td>
</tr>
<tr>
<td>Ash (%)</td>
<td>0.6 ± 0.02</td>
<td>1.77 ± 0.36</td>
<td>0.15 ± 0.06</td>
</tr>
<tr>
<td>Total lipid (%)</td>
<td>0.3 ± 0.1</td>
<td>11.69 ± 2.06</td>
<td>0.13 ± 0.05</td>
</tr>
<tr>
<td>Crude protein (%)</td>
<td>0.9 ± 0.1</td>
<td>3.36 ± 1.58</td>
<td>0.68 ± 0.03</td>
</tr>
<tr>
<td>Total dietary fiber (%)</td>
<td>0.016 ± 0.003</td>
<td>11.5 ± 0.36</td>
<td>-</td>
</tr>
<tr>
<td>Carbohydrates (%)</td>
<td>10.39 ± 3.115</td>
<td>66.88 ± 4.52</td>
<td>-</td>
</tr>
<tr>
<td>Yield (%)</td>
<td>-</td>
<td>33.07</td>
<td>27.35</td>
</tr>
</tbody>
</table>

*Each value represents the mean of three replicates ± SD. * Percentage values on a dry basis. ** Quantified by the Kjeldahl method. \(N_2\) conversion factor = 6.25.

The chemical analysis of cheese whey reveals valuable insights into its composition, such as moisture content, ash content (minerals), fat, protein, and carbohydrates. Comparing our findings with those of previous studies offers a comprehensive understanding of the variation and significance of these components. Our results indicate a moisture content of 93 ± 1%, aligning with the values observed by Rama et al. [56] (94.9%) and Boudjema et al. [57] (93.6%). De Oliveira et al. [58] noted a similar moisture content of 93.53 ± 0.68% for goat cheese whey. Similarly, Menchik et al. [59] reported values of 96.3–96.7% for ricotta milk whey, while Lievore et al. [60] and Rocha et al. [61] found 94.44% for petit-suisse-type cheese whey. Our findings are in line with these ranges, highlighting the consistent nature of moisture content across different types of whey. The consistent moisture content of cheese whey, as demonstrated through various studies, is a key factor in ice cream production. This needs an appropriate water content to achieve a smooth and creamy texture. Whey’s moisture content, within the observed range, contributes to the desired mouthfeel and texture of ice cream, ensuring a pleasant sensory experience for consumers.

The ash content of 0.6 ± 0.02% in our study contrasts with values reported by other researchers such as Rama et al. [56] (0.3%), Boudjema et al. [57] (0.6%), and De Oliveira et al. [58] (0.62%) for goat cheese whey. Whey is recognized to contain a substantial proportion of minerals, contributing approximately 90% of calcium, potassium, phosphorus, sodium, and magnesium present in milk [62–64]. The transfer of these minerals to cheese whey during curd production further underscores the significance of whey as a valuable
source of these essential elements. The presence of minerals in cheese whey can contribute to the nutritional profile of ice cream. These minerals are not only beneficial for human health but can also influence the sensory attributes of the final product, potentially enhancing its appeal.

Our observed total fat value of 0.3 ± 0.1% agrees with the findings of Eckert et al. [65] (0.20%) and De Oliveira et al. [58] (0.45%) for goat cheese whey. However, Menchik et al. [59] reported lower fat values (0.01%) in cottage cheese whey, and Llevore et al. [60] (0.09%) for petit-suisse-type cheese whey. The variation in fat content among different whey types underscores the impact of the cheese-making process on fat retention in whey. Regarding protein content, our result of 0.9 ± 0.1% surpasses that reported by Eckert et al. [65] (0.37%) and aligns with findings by Llevore et al. [60] (0.84%) for petit-suisse-type cheese whey. De Oliveira et al. [58] observed higher values of (1.22%) for goat milk whey. The richness of protein in cheese whey, constituting approximately 0.8–1.0% w/v, positions whey as a noteworthy protein source. The fat content of whey aligns with the fat content found in traditional ice cream recipes. Ice cream’s creamy texture largely results from fat content. The data indicate that whey’s fat content is compatible with the desirable creaminess in ice cream, supporting its potential use as a base. Also, whey’s relatively high protein content is an asset when considering it as an ice cream base. Protein enhances the structure of ice cream and contributes to a smoother texture by interacting with water molecules. Additionally, the amino acids present in whey protein can act as stabilizers, preventing ice crystals from forming and improving the overall stability of the ice cream.

Finally, our carbohydrate content of 10.39 ± 3.115% exceeds that reported by Eckert et al. [65] (5.24%), Barbosa et al. [28] (4.51%) for ricotta cheese whey, and De Oliveira et al. [58] (4.18%) for goat cheese whey. Poveda [64] emphasizes milk lactose (95%) as the primary carbohydrate component, typically ranging from 4.5–5.0% w/v. The higher carbohydrate content in our study highlights the potential variability based on whey type and production processes. The carbohydrate content of whey, including lactose, provides a natural source of sweetness. This could potentially reduce the need for excessive added sugars in ice cream formulations. The observed carbohydrate range in whey aligns with the typical sweetness profile desired in ice cream, allowing for the creation of well-balanced flavors. For these reasons, incorporating whey as a base for ice cream production has the potential to offer several advantages. Its composition aligns with the requirements for achieving a desirable texture, creaminess, and flavor in ice cream. Moreover, the inclusion of whey in ice cream formulations could provide an opportunity to promote its nutritional value, considering its protein and mineral content. By leveraging the insights from the chemical analysis of whey, manufacturers can justify its use as a viable and promising base for creating innovative and appealing ice cream products.

The chemical analysis of mango seed kernel flour reveals that fat (11.69 ± 2.06%) and carbohydrates (66.88 ± 4.52%) are the predominant components, making this raw material a valuable source of these two nutrients. Due to its richness in these components, mango seed kernel flour was selected as the primary raw material for extracting starch (carbohydrate) and oil (lipid) to create the base for our ice cream.

Additionally, the remaining fraction of the mango seed kernel flour consists primarily of organic matter, with a minimal percentage of ash (1.77 ± 0.36%). This finding further underscores the significance of mango seed flour as a valuable ingredient, contributing essential nutrients for our ice cream base and showcasing its promise as a sustainable and nutritious choice.

The starch moisture content was 4.9 ± 0.08%, a value consistent with findings by other authors, such as Silva et al. [66] and Mendes et al. [67], in mango starch of the same variety. Lima et al. [68], Macena et al. [69], and Domínguez-Espinosa et al. [49] performed an analysis and obtained 7.37% for potato starch, 15.36% for avocado starch, and 11.74 for green banana starch, respectively. The starch moisture found in this study, presented value within the expected range established by Brazilian Health Regulatory Agency (ANVISA). According to ANVISA, RDC Nº 263 (2005), this value should not exceed 15% for corn.
starch, 21% for potato starch, and 18% for cassava [70]. The starch ash content (0.15 ± 0.06) was similar when compared to that reported in the literature. However, Onias and Cavalcanti [71] obtained 0.07% of ash with the same variety of mango. Conventional starches presented higher ash contents than mango. Lima et al. [68] found 0.96% for corn starch and Lovera et al. [72] found 2.54% for cassava starch.

The starch protein content was 0.68 ± 0.03%. For mango of the same variety, the percentage found was 5.60%, according to Mendes et al. [67], and 2.49%, according to Onias and Cavalcanti [71]. The protein content found in this study was similar than those found by Lovera et al. [72] for potato starch (0.11%), and by Macena et al. [69] for avocado seed starch (1.97%). The starch total lipid content was 0.13 ± 0.05 higher values were found by Onias and Cavalcanti [71] with 4.60% and Silva et al. [66] with 4.67% for mango starch of the same variety. For other nonconventional sources of starch, such as plantain and jackfruit, studied by Pelissari et al. [73] and Jamjarytam [74], 0.02% and 0.03% were found, respectively. The low values (less than 1%) of ash, total lipid, and crude protein suggest a good quality starch, since it is highly purified.

Table 3 shows the physicochemical and functional characteristics of mango seed kernel starch (expressed on a dry basis). This raw material presented as a light brown powder with a velvety texture and the extraction process had a yield of 27.35%. These results showed that the starch yield from mango seed kernel is like conventional starch sources, such as cassava (18.00–29.33%) [75] and nonconventional starch sources, such as tarap (17.8%) [76], banana (13.57–16%) [77,78], and bamboo (3.12–19.15%) [79–81].

### Table 3. Physicochemical and functional characteristics of mango seed kernel starch.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values a</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Physicochemical characteristics</strong></td>
<td></td>
</tr>
<tr>
<td>Amylose (%)</td>
<td>37.78 ± 0.56</td>
</tr>
<tr>
<td>Amylopectin (%)</td>
<td>62.21 ± 0.58</td>
</tr>
<tr>
<td>Amylose/amylopectin ratio</td>
<td>0.60 ± 0.02</td>
</tr>
<tr>
<td>a*</td>
<td>3.74 ± 0.03</td>
</tr>
<tr>
<td>b*</td>
<td>16.47 ± 0.33</td>
</tr>
<tr>
<td>L*</td>
<td>70.30 ± 0.47</td>
</tr>
<tr>
<td>C*</td>
<td>16.89 ± 0.03</td>
</tr>
<tr>
<td>(\delta_{hue})</td>
<td>77.2 ± 0.53</td>
</tr>
<tr>
<td>Iodine–starch test</td>
<td>Positive</td>
</tr>
<tr>
<td>Granule shape</td>
<td>Oval and spherical</td>
</tr>
<tr>
<td>Granule size (µm)</td>
<td>18.7 ± 1.9</td>
</tr>
<tr>
<td><strong>Functional characteristics</strong></td>
<td></td>
</tr>
<tr>
<td>Pasting temperature (°C)</td>
<td>72 ± 0.13</td>
</tr>
<tr>
<td>(T_0) (°C)</td>
<td>73.1 ± 0.14</td>
</tr>
<tr>
<td>(T_p) (°C)</td>
<td>78.49 ± 0.03</td>
</tr>
<tr>
<td>(T_e) (°C)</td>
<td>86.77 ± 0.36</td>
</tr>
<tr>
<td>(\Delta H_{gel}) (J/g)</td>
<td>17.16 ± 0.79</td>
</tr>
<tr>
<td>WAI (g/g)</td>
<td>2.26 ± 0.12</td>
</tr>
<tr>
<td>WSI (%)</td>
<td>21.63 ± 0.25</td>
</tr>
<tr>
<td>SP (gwater/gstarch)</td>
<td>23.22 ± 3.57</td>
</tr>
</tbody>
</table>

Each value represents the mean of three replicates ± SD. Onset temperature (\(T_0\)), peak temperature (\(T_p\)), and ended temperature (\(T_e\)).

The amylose content of starches plays a pivotal role in influencing various properties, such as gelatinization behavior, retrogradation tendencies, swelling capacity, and susceptibility to enzymatic action. Accurate quantification of amylose content holds significant importance in food processing due to its direct impact on product quality. In this case, the average amylose and amylopectin contents were determined to be 37.78 ± 0.56% and 62.21 ± 0.58%, respectively. According to Mitchell [82] classification, this places mango seed kernel starch in the category of high amylose content (>25%). Comparative analysis reveals similarities and distinctions between starch obtained from Tommy Atkins mango.
The SP and WSI are commonly linked to each other due to the bonds established between amylose and amylopectin. Amylopectin is more readily digestible due to its branched structure, and it is broken down faster than amylose. The pasting and gelatinization temperatures of starch reflect the points at which it undergoes structural changes upon exposure to heat. For ice cream, this value is pertinent as it correlates with the starch’s ability to initiate gelatinization, implying the extent of starch swelling and molecular reorganization [89]. For ice cream, this value is pertinent as it correlates with the starch’s ability to interact with water and other ingredients during freezing and churning. A higher $\Delta H_{gel}$ suggests greater starch–water interaction potential, which can lead to enhanced texture and creaminess in the final product.

![Figure 2. DSC analysis from Tommy Atkins mango seed kernel starch.](image)

The variation in the morphology and size of starch granules may be due to biological origin, plant physiology, and amyloplast biochemistry. This may also be due to variations in mango cotyledon starches of three varieties (namdokmai, kaew, and chokanan). The average diameter of the starch granules ranges from 13.80 µm to 19.91 µm. The range of mango seed kernel starch granules in size was 18.7 ± 1.9. The results are consistent with those observed by Kaur et al. [85] for mango seed kernel starch granules with 15 µm to 21 µm in size. In a more recent study, Saeaurng and Kuakpetoon [91] made similar observations.

The DSC analysis (Figure 2) from mango seed kernel starch showed values for pasting temperature, $T_o$, $T_p$, $T_r$, and $\Delta H_{gel}$ were 72, 75.1, 79.49, 86.77 °C, and 17.16 J/g, respectively. The pasting and gelatinization temperatures of starch reflect the points at which it undergoes structural changes upon exposure to heat [88]. These temperatures are relevant when incorporating starch into an ice cream base because its production involves heating and cooling phases, where starch functionality matters. If the pasting temperature aligns with the heating process, it can contribute to effective thickening and stabilization, aiding in preventing ice crystal growth during storage. Also, the $\Delta H_{gel}$ indicates the energy required to initiate gelatinization, implying the extent of starch swelling and molecular reorganization [89]. For ice cream, this value is pertinent as it correlates with the starch’s ability to interact with water and other ingredients during freezing and churning. A higher $\Delta H_{gel}$ suggests greater starch–water interaction potential, which can lead to enhanced texture and creaminess in the final product.
The WAI is a measure of the amount of amylose that is released from the interior of the granule when it begins to lose its structure due to water absorption. On the other hand, the SP is a measure of the increase in mass of the starch, not solubilized, because of the absorption of water by the hydroxyl groups of the amylose and amylopectin polymers. The SP and WSI are commonly linked to each other due to the bonds established between starch and water during granule swelling processes. Some authors point out that the proteins and lipids still present in the extracted starch can interact with the amylose and have a direct influence on the solubility values and swelling power. The values obtained for WAI, WSI, and SP (2.26 ± 0.12 g/g, 21.63 ± 0.25%, and 23.22 ± 3.57 gwater/gstarch, respectively).

Regarding the swelling power, the value obtained can be classified as moderate if the classification suggested by Schoch and Maywald [90] is established; this means that it has an intermediate brittleness when subjected to shearing. However, Aristizábal et al. [50] suggest that a low WSI, high WAI, and a high SP are indicative of starches with good quality; therefore, the mango seed kernel starch evaluated can be classified in this category.

The micrographs (Figure 3) of starch samples revealed the presence of starch granules at ×500 and ×5000 magnification. These granules exhibit a range of sizes, varying from small to large, and display an oval to irregular or spherical shape with a smooth surface. The average diameter of the starch granules ranges from 13.80 µm to 19.91 µm. The range of mango seed kernel starch granules in size was 18.7 ± 1.9. The results are consistent with those observed by Kaur et al. [85] for mango seed kernel starch granules with 15 µm to 21 µm in size. In a more recent study, Saeaurung and Kuakpetoon [91] made similar observations in mango cotyledon starches of three varieties (namdokmai, kaew, and chokanan).

![Figure 3. SEM micrographs of the Tommy Atkins mango seed kernel starch: (a) 500× and (b) 5000×.](image-url)

The variation in the morphology and size of starch granules may be due to biological origin, plant physiology, and amyloplast biochemistry. This may also be due to variations in amylose and amylopectin content (the smaller starch grains tend to have a higher proportion of amylopectin compared to amylose) and structure, which in turn play an important role in controlling the size and shape of starch granules [92]. This is because amylopectin is more readily digestible due to its branched structure, and it is broken down faster than amylose.

In Table 4, the physicochemical properties and fatty acid profile of mango seed kernel oil are presented. The yield oil extraction from mango seed kernel flour reached 20.58%, and this amount is very attractive from an industrial point of view when compared with the yield of oils obtained in cereals; for example, in the case of corn, it is reached an average of 3.8% and in rice, 2.4% [93]. Nzikou et al. [94] report that the oil content present in the mango depends on many factors, such as variety of the plant, the climate of the growing area, ripening phase, harvest time of the seed grains, and the method of oil extraction.

In Table 4, the physicochemical properties and fatty acid profile of mango seed kernel oil are presented. The yield oil extraction from mango seed kernel flour reached 20.58%, and this amount is very attractive from an industrial point of view when compared with the yield of oils obtained in cereals; for example, in the case of corn, it is reached an average of 3.8% and in rice, 2.4% [93]. Nzikou et al. [94] report that the oil content present in the mango depends on many factors, such as variety of the plant, the climate of the growing area, ripening phase, harvest time of the seed grains, and the method of oil extraction.
The mango oil has a mild flavor and aroma, which makes it suitable for certain culinary applications like ice cream base; also, its composition includes fatty acids, antioxidants, and other beneficial compounds that can be used as an ingredient in nutritional supplements or functional foods.

Table 4. Physicochemical characteristics of the Tommy Atkins mango seed kernel oil.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peroxide index (meq O₂/kg)</td>
<td>4.99 ± 0.99</td>
</tr>
<tr>
<td>Acidity index (% oleic acid)</td>
<td>1.58 ± 0.15</td>
</tr>
<tr>
<td>Density (g/cm³)</td>
<td>0.916 ± 0.03</td>
</tr>
<tr>
<td>Viscosity (mm²/s)</td>
<td>41.59 ± 0.1</td>
</tr>
<tr>
<td>Yield (%)</td>
<td>20.58</td>
</tr>
</tbody>
</table>

a Each value represents the mean of three replicates ± SD.

According to the CODEX Alimentarius international food standards (CXS 19-1981) [95] standard for edible fats and oils not covered by individual standards, a maximum peroxide value of 15 meq O₂/kg is established for virgin oils. Values exceeding this limit are considered of poor quality. López-Hernández et al. [96] and Gutiérrez et al. [97] have reported peroxide index values ranging from 0.76 meq O₂/kg to 7.5 meq O₂/kg for mango seed kernel oil. The value obtained in this study was 4.99 ± 0.99 meq O₂/kg fat, falling within the reported range and permissible limits, indicating its stability against oxidation and its classification as good quality. The obtained acidity index is 1.58 ± 0.15% oleic acid. The mango seed kernel oil does not have a specific reference due to being a product under research. For this reason, it was compared according to the standard for cocoa butter (CXS 86-1981) [98]; a maximum acidity index of 1.75% oleic acid is permitted for cocoa butter. Hence, mango seed kernel oil can be considered acceptable since, despite being crude oil, its acidity is low. On the other hand, the density of mango seed kernel oil (25 °C) was 0.916 ± 0.03 g/cm³, similar values were reported by Mahale and Goswami-Giri [99] and López-Hernández et al. [96]. Comparing the relative density range with that of coconut oil (0.908–0.921 g/mL) of standard for named vegetable oils (CXS 210-1999) [100], a significant similarity is observed, indicating that this raw material falls within the established parameters for processed vegetable oils. The viscosity to 25 °C was 41.59 ± 0.1 mm²/s. Typical viscosities for some edible vegetable oils (extra virgin olive oil, sunflower oil, corn oil, canola oil, soybean oil, and coconut oil) range from 30 to 84 mm²/s. Therefore, mango seed kernel oil presents viscosity values like those of edible vegetable oils.

The analysis of the fatty acid profile of mango seed kernel oil (Figure 4) revealed the presence of several fatty acids, including palmitic (10.31%), margaric (0.17%), stearic (41.01%), oleic (39.97%), linoleic (4.90%), arachidic (2.59%), gondoic (0.18%), and behenic (0.53%). Nzikou et al. [94] reported stearic (37.73%), oleic (46.22%), palmitic (6.43%), linoleic (7.33%), and linolenic (2.30%) acids in mango seed kernel oil. Fahimdanaesh and Bahrami [101] also reported saturated fatty acids in mango seed kernel oil as stearic (37.73%) and palmitic (6.43%) acids, while oleic (46.22%), linoleic (7.33%), and
linolenic (2.30%) acids are the main unsaturated fatty acids. In this research, stearic and oleic acids were found to be the predominant fatty acids. Oleic acid is known for its favorable health properties, attributed to its beneficial effects on the lipid profile, antithrombogenic, and antioxidant properties [102]. Additionally, it has been associated with reducing the risk of lipid peroxidation in cell membrane phospholipids and lipoproteins [103]. However, it is worth noting that the balance of saturated and unsaturated fatty acids in mango oil appears to favor saturated fatty acids, constituting approximately 54.44% of the total fatty acids. This finding contrasts with some previous studies that suggested a prevalence of unsaturated fatty acids in mango oil [9,94,104]. The fatty acid composition of mango oil indicates its potential health benefits, particularly due to the presence of oleic acid. Nevertheless, understanding the proportions of saturated and unsaturated fatty acids in mango oil is vital for assessing its overall nutritional impact and potential health implications.

3.2. Evaluation of the Ice Cream Base Formulations

Table 5 provides a comprehensive overview of the physicochemical and functional traits of the three ice cream base formulations: F1, F2, and F3. From a nutritional perspective, all three formulations stand out as commendable options. Each formulation has a balanced composition of proteins, lipids, and carbohydrates, which are pivotal biomolecules for human consumption. While traditionally, the primary fat source in ice cream is derived from milk, these formulations incorporate cheese whey, a low-fat byproduct. This deviation necessitated the introduction of vegetable fat, and the innovative use of lipids derived from mango seeds emerges as a sustainability and efficient alternative.

The lipid content in F2 and F3 is notably higher, categorizing them as premium ice creams. This contrasts with F1, which aligns more with the lipid content of standard ice creams. Given the vital role lipids play in enhancing an ice cream’s sensory attributes, like flavor, creaminess, and overall palatability, F2 and F3 are expected to fare better in sensory evaluations, as outlined by Kruel [105] and Nazaruddin et al. [106].

The protein content is another focal point. Averaging at 4.96%, our formulations are comfortably within the range of commercial ice creams, which typically vary between 1.2% and 5%. Importantly, the cheese whey proteins, rich in cysteine (a precursor for the potent antioxidant, glutathione), present a promising avenue for milk substitution in ice cream production.
Table 5. Ice cream base analysis.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>F1</th>
<th>F2</th>
<th>F3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Physicochemical characteristics</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moisture (%)</td>
<td>53.10 ± 0.36</td>
<td>50.94 ± 0.02</td>
<td>55.06 ± 0.16</td>
</tr>
<tr>
<td>Ash (%)</td>
<td>0.40 ± 0.70</td>
<td>0.51 ± 0.67</td>
<td>0.41 ± 0.98</td>
</tr>
<tr>
<td>Total lipid (%)</td>
<td>7.60 ± 2.06</td>
<td>12.31 ± 0.75</td>
<td>15.72 ± 0.67</td>
</tr>
<tr>
<td>Crude protein (%)</td>
<td>5.61 ± 0.15</td>
<td>3.94 ± 0.18</td>
<td>4.33 ± 0.58</td>
</tr>
<tr>
<td>N-free extract (%)</td>
<td>33.30 ± 0.50</td>
<td>31.70 ± 0.36</td>
<td>24.41 ± 0.40</td>
</tr>
<tr>
<td>Density (g/cm³)</td>
<td>987 ± 1.5</td>
<td>987 ± 1.3</td>
<td>985 ± 1.9</td>
</tr>
<tr>
<td>pH</td>
<td>6.49 ± 0.13</td>
<td>6.60 ± 0.03</td>
<td>6.58 ± 0.04</td>
</tr>
<tr>
<td>Titratele acidity (% Lactic acid)</td>
<td>0.144 ± 0.00</td>
<td>0.108 ± 0.012</td>
<td>0.112 ± 0.019</td>
</tr>
<tr>
<td>a*</td>
<td>3.66</td>
<td>3.34</td>
<td>4.54</td>
</tr>
<tr>
<td>b*</td>
<td>-2.74</td>
<td>8.6</td>
<td>7.21</td>
</tr>
<tr>
<td>C*</td>
<td>4.57</td>
<td>9.22</td>
<td>8.52</td>
</tr>
<tr>
<td>°hue</td>
<td>-36.81</td>
<td>68.77</td>
<td>57.80</td>
</tr>
<tr>
<td>Color</td>
<td>L*</td>
<td>61.32</td>
<td>70.89</td>
</tr>
<tr>
<td></td>
<td>C*</td>
<td>4.57</td>
<td>9.22</td>
</tr>
<tr>
<td></td>
<td>b*</td>
<td>-2.74</td>
<td>8.6</td>
</tr>
<tr>
<td><strong>Functional characteristics</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overrum (%)</td>
<td>66.67</td>
<td>42.85</td>
<td>50.01</td>
</tr>
<tr>
<td>Freezing point (°C)</td>
<td>-2</td>
<td>-3</td>
<td>-3</td>
</tr>
<tr>
<td>Fall of the first drop (min)</td>
<td>4</td>
<td>9</td>
<td>16</td>
</tr>
<tr>
<td>Melting time (min)</td>
<td>19</td>
<td>28</td>
<td>46</td>
</tr>
</tbody>
</table>

a Each value represents the mean of three replicates ± SD. F1 (Formulation 1), F2 (Formulation 2), and F3 (Formulation 3).

Water, the main component in ice cream, was consistently maintained between 50–55% across the formulations. So that, our formulations fall within the average range (40–64%) for normal to super-premium ice creams according to a report by Madrid and Cenzano [43]. This water content in the three formulations is attributed to the cheese whey added; this not only ensures an optimal mix of ingredients but also offers a potential cost-cutting solution compared to traditional methods.

The carbohydrate analysis reveals the highest percentages in F1 and F2, driven primarily by lactose and supplemented sugars, particularly sucrose. Also, all formulations benefit from the inclusion of starch, which augments the ice cream’s texture by increasing viscosity. This enhancement restricts the growth in large ice crystals during freezing, yielding a smoother finish. In fat-reduced versions, starch can elevate the mouthfeel, mimicking the texture traditionally provided by fats.

The pH is a critical factor in ice cream production, influencing taste, texture, stability, and overall product quality. A pH range of 6 to 7 as shown in our formulations for ice cream bases is generally acceptable and falls within a typical range for ice cream products. On the other hand, in F1, which had a lower pH value, an increase in the acidity was observed.

The density of the different formulations ranged from 0.94 to 1.08 g/mL. Density variation within the formulations is primarily attributed to their composition: it tends to decrease with increasing fat content and decreasing levels of non-fat solids. Notably, F3, with a higher fat content, exhibited lower density, in contrast to F1, which boasted a higher proportion of non-fatty solids, resulting in its higher density.

The color parameter based on the values of a*, b*, C* and the hue angle confirmed that the ice cream bases formulated exhibit a medium light shade of brown, resembling F1 (#999999), F2 (#b8ab9e), and F3 (#bfb0a6) in hexadecimal color code.

The fall time of the first drop in ice cream production is influenced by its specific formulation. It is generally recommended that ice creams exhibit first drop times exceeding 15 min. It is evident that among the formulations tested, F3 achieved the lengthiest duration for the first drop’s descent. This formulation surpassed the recommended threshold proposed by Soukoulis et al. [107]. In contrast, F1 and F2 exhibited first drop times that fell below the suggested benchmark. However, it is important to note that Campo-Quintero’s et al. [108]
estimation indicates that an individual typically takes around 30 min to fully consume an ice cream. From this perspective, F3 shows a favorable melting time, even F2, which falls slightly short of the recommended time, could still be considered favorable. In contrast, F1 consistently registers melting times that fall below the suggested duration.

The melting time of ice cream stands as a crucial quality parameter that significantly impacts the overall enjoyment of this frozen. This parameter is influenced by a multitude of factors, including the size of ice crystals, lipid content, and overrun, among others. Ice creams with higher fat content or a greater amount of incorporated air typically exhibit a slower melting rate. This is attributed to the insulating effect of the air cells and the stabilizing role of fat in maintaining the foam structure. Consequently, formulations F3 and F2, which are characterized by their higher lipid content, demonstrated superior resistance to melting when compared to F1, despite F1 a mayor overrun value than F2 and F3.

Finally, analyzing overrun values suggests that while F2 and F3 qualify as premium ice creams (20 to 50% overrun), F1 sits above standard quality (85 to 110% overrun) but does not quite reach premium levels. These findings agree with criteria established by Ibáñez-Figueroa and Maceda-Coello [109] for artisanal ice creams (43–58%), so F2 and F3 fall into this category. The protein-rich nature of our formulations, courtesy of the cheese whey, guarantees emulsification, aeration, and foam stability—crucial parameters for ice cream structural integrity, as indicated by McSweeney and O’Mahony [110]. These results paint a promising picture for the formulations F1, F2, and F3. It is anticipated that F2 and F3, given their enriched lipid, starch content, and favorable physicochemical properties, will outshine in sensory analysis.

To assess the acceptability and preference levels of three distinct ice cream base formulations (F1, F2, and F3), we conducted a hedonic test. This involved a panel of 10 specially trained judges who scrutinized each formulation based on four attributes: color, aroma, taste, and consistency. Notably, these samples were devoid of any added flavoring or coloring agents; they solely contained the ingredients listed in Table 1.

The color is a psychological factor that influences consumer decisions and conditions their response when making a sensory perception. This influence is intricately linked to cultural and age-related factors [111]. Within the realm of sensory analysis, color acts as a preliminary filter in determining a consumer’s acceptance of a particular food item [112].

All three formulations (Figure S1) produced a similar hue (a light brown) attributable to the unconventional sources of the raw materials used. As depicted in Figure 5a, F2 emerged as the preferred choice with a 50% approval rating “like it”, closely trailed by F1 and F3, both at 30% for “like it”. However, F1 and F3 showed an additional 10% and 20%, respectively, for “like it very much”.

The odor is a highly important attribute in sensory tests, but evaluating it is still very complex. However, gauging it accurately remains challenging due to the intricate workings of the nasal system and the myriad scents present in food items [113]. While starches usually bear neutral scents, oils can have aromas based on their sources. For instance, the oil extracted from mango seed kernel almonds possesses a mild fragrance, practically non-existent if we compare it with that of other butters such as cocoa butter. Figure 5b reveals a tie between F1 and F3 (both clinching a 50% approval rating “like it”) followed by F2 at 40%. However, F1 and F3 showed an additional 20% and 10%, respectively, for “like it very much”. These high approval rates suggest that the judges found the scents of all three formulations pleasing. This favorable response can be credited to the harmonious blend of the fatty acids from the mango seed kernel oil and the milky aroma originating from the whey and powdered milk. This indicates not only the successful amalgamation of the components but also the effectiveness of the extraction and preparation methodologies utilized for the ice cream base formulations.
The experience of taste is multifaceted, tapping into various sensory organs. It encompasses elements of aroma, trigeminal sensations, aftertastes, and an overall persistence [114]. A noticeable off-taste in frozen fat products often signals the presence of volatile compounds indicative of rancidity or oxidation [115,116]. Fortunately, our tested formulations were devoid of any such off-putting tastes. The neutral nature of the starch, coupled with the oil's optimal condition—as evidenced by the peroxide and acidity indices in Table 4—ensured a pleasurable taste experience. As shown in Figure 5c, F2 took the lead, garnering a 50% approval rating for “like it” and an additional 10% for “like it very much”. Many judges expressed their appreciation for the taste, noting its dairy undertones in their feedback. F3 also resonated well, achieving an approval score of 40% for “like it” and 20% for “like it very much”. Such positive results suggest that adding flavorings to these formulations would not be overshadowed by any off tastes from the by-products used.

Finally, a crucial attribute of ice cream is the consistency, which can distinguish between a creamy delight and a gritty disappointment. The consistency derives from the interplay between the formulation, the ingredients chosen, and the three-dimensional structure crafted by air bubbles, fat globules, and ice crystals. Collectively, these elements translate to the creamy sensation we associate with quality ice cream. Inappropriate formulation can markedly compromise this essential quality [117]. Vegetable oils play a pivotal role in ice cream texture, imparting consistency, structure, color, flavor, and aroma. Contrarily, starches are neutral, largely absent in flavor and aroma. They may influence color, contingent upon their source and purification processes [115,116]. As per Figure 5d, F2 triumphed in consistency evaluations, securing 60% for “like it so much” and an additional 20% for “like it”. This formulation has a composition of 12% vegetable oil and 0.6% starch, F2 rightly fits the “creamy” category [118,119]. Their research elucidated that a 12% concentration of vegetable oil fosters optimal ice cream consistency. Similarly, studies by [120] explored oils from varied origins and deduced their positive impact on ice cream’s sensory quality. In their assessment, a 12% vegetable fat concentration birthed the most desirable product characteristics—a sentiment echoed by our panel’s fondness for F2.

The three ice cream formulations (F1, F2, and F3) offer diverse attributes catering to varied consumer preferences. F2 and F3, with their premium positioning, might be

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![Figure 5. Evaluation of the ice cream base formulations: (a) Color, (b) Smell, (c) Taste and (d) Consistency. F1 (Formulation 1), F2 (Formulation 2) and F3 (Formulation 3).](image-url)
more appealing for consumers seeking rich and creamy indulgences, while F1 might cater to a more general audience. The inclusion of sustainable ingredients like mango seed kernel oil and cheese whey proteins provides these formulations an innovative edge, potentially setting them apart in a market that increasingly values sustainability and nutritional benefits.

4. Conclusions

The cheese whey’s composition aligns with the characteristics required for high-quality ice cream production. Its inclusion in ice cream formulations could lead to products with desirable sensory attributes and enhanced nutritional profiles. This presents manufacturers with an opportunity to innovate in the ice cream sector, using cheese whey as a promising base material. Also, mango seed kernel starch and oil demonstrate great promise as a versatile ingredient in food processing, especially in applications requiring textural, structural, flavor, creaminess, overall palatability, and water-binding capabilities. Their unique set of physicochemical attributes positions them as a sustainable, nutritious, and functional choice for culinary applications, predominantly for ice cream base formulations. Their use could provide an innovative approach to developing nutritious and sustainable food products.

The three ice cream base formulations—F1, F2, and F3—offer diverse attributes catering to varied consumer preferences. However, F2 consistently ranked high across multiple sensory attributes, making it the most promising candidate in terms of consumer acceptability, offering a base that is both palatable and has the potential for further flavor enhancements.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su151914583/s1, Table S1: Ice cream sensory evaluation instrument; Figure S1: Ice cream base formulations.


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