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Impact of different dairy wheys on quality parameters of ice cream

Roberta Barbosa de Meneses[1*], Débora Conceição Carvalho Moura[2], Deusdélia Teixeira de Almeida[2], Eliete da Silva Bispo[2], Leonardo Fonseca Maciel[2], Maria Helena Miguez da Rocha-Leão[3], Carlos Adam Conte-Junior[3]

[1] Instituto Federal de Alagoas, Maceió, AL, Brasil. E-mail: betha_eng@yahoo.com.br
[2] Universidade Federal da Bahia, Salvador, BA, Brasil. E-mail: debora.c.c.moura@gmail.com; deliata@uol.com.br; elibispo@ufba.br; lfmaciel@ufba.br
[3] Universidade Federal do Rio de Janeiro, Rio de Janeiro, RJ, Brasil. E-mail: mhrl@eq.ufrj.br; carlosconte@hotmail.com

ABSTRACT: This study aimed to evaluate the effects of different dairy by-products (ricotta, butter, and cheese wheys) on ice cream production and their impact on quality parameters. Chocolate ice creams were developed differing their main ingredients (100% ricotta or butter or cheese wheys or whole milk) and were evaluated by nutritional composition, pH and titratable acidity, water activity, melting and desorption behavior, instrumental color and texture, microbiological and sensory analyses. The results showed that different by-products application in ice cream significantly reduced ($p < 0.05$) the fat content (40% on average), presented lower ($p < 0.05$) pH difference, and no variation ($p > 0.05$) for water activity. Instrumental texture and color of the ice creams with ricotta, cheese, and butter wheys presented slight alteration ($p < 0.05$), indicating greater hardness and color intensity, which was not observed and did not affect the sensory tests. Even the greatest melting resistance in the melting point (0.73 g min^{-1}) ($p < 0.05$) showed no signs of desorption ($p > 0.05$). In the acceptance test, the samples developed with ricotta, butter, cheese, and whole milk obtained good values of overall liking (averages 6.76, 6.07, 6.95, and 7.15, respectively), and most of the consumers (equal to or greater than 53.75%) said they would buy the products. In general, although these dairy by-products reduced nutritional values, their application in ice creams showed a potential alternative to the dairy industry.

Key words: butter whey; cheese whey; dairy dessert; reuse; ricotta whey

Impacto de diferentes soros lácteos nos parâmetros de qualidade do sorvete

RESUMO: O objetivo deste estudo foi avaliar os efeitos da aplicação de diferentes subprodutos lácteos (soros de ricota, da manteiga e do queijo) no sorvete e seu impacto nos parâmetros de qualidade. Os sorvetes de chocolate foram desenvolvidos diferindo de seus principais ingredientes (100% soro de ricota ou soro de manteiga ou soro de queijo ou leite integral) e foram avaliados pelas análises de composição nutricional, pH e acidez titulável, atividade de água, comportamento de derretimento e desoramento, cor e textura instrumental, microbiológicas e sensoriais. Os resultados mostraram que a aplicação dos diferentes subprodutos no sorvete reduziu significativamente ($p < 0.05$) o teor de gordura (40% em média), apresentou baixa ($p < 0.05$) diferença de pH e não houve variação ($p > 0.05$) para atividade de água. A textura instrumental e a cor dos sorvetes com soros de ricota, de queijo e de manteiga apresentaram discreta alteração ($p < 0.05$), indicando maior dureza e intensidade de cor que não foram observadas e não afetaram os testes sensoriais. Mesmo a maior resistência à fusão no ponto de fusão (0,73 g min^{-1}) ($p < 0.05$) não mostrou sinais de dessorção ($p > 0.05$). No teste de aceitação, as amostras desenvolvidas com soros de ricota, de queijo, de manteiga e leite integral obtiveram bons valores de preferência geral (médias 6,76, 6,07, 6,95 e 7,15, respectivamente) e a maioria dos consumidores (igual ou superior a 53,75%) disse que compraria os produtos. Em geral, embora a aplicação desses subprodutos lácteos tenha provocado a redução do valor nutricional, a aplicação deles em sorvete se mostrou uma alternativa em potencial à indústria láctea.

Palavras-chave: soro de manteiga; soro de queijo; sobremesa láctea; reutilização; soro de ricota

* Roberta Barbosa de Meneses - E-mail: betha_eng@yahoo.com.br (Corresponding author)
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Introduction

The dairy industry processes milk in products such as yogurt, ice cream, butter, cheese, and various types of desserts through different processes. During the manufacture of these dairy products, large amounts of effluents with high organic load are produced, reflecting high levels of chemical oxygen demand (COD) and biochemical oxygen demand (BOD). These by-products can impose serious challenges on local sewage treatment systems and represent a significant environmental issue (Rivas et al., 2010).

It is known that dairy wheys have bioactive substances with positive effects on human health, like peptides and the presence of low-fat in general. More specifically, cheese wheys have proteins of high biological value regulating various physiological functions in human body such as blood pressure, glycemic response, inflammatory processes, and improvement of immune system (Athira et al., 2015). In addition, ricotta wheys have high lactose content (Sansonetti et al., 2009), and butter wheys have less lactose and the of phospholipids, which play an important role in many metabolic processes in human organisms, including *in vitro* anticancer properties according to Kuchta-Noctor et al. (2016).

Among the alternatives that minimize environmental impact considering nutritional and technological potentials, dairy effluents can have a positive impact not only on consumers' health, but also on cost savings. One of these benefits is the low cost of raw materials, which reduces production costs when there is partial or total replacement of the quantities of milk, eggs, fats, sugar, and even protein from the formulations of several processed dairy products, as shown by several studies (Sakhale et al., 2012; Castro et al., 2013; Gerhardt et al., 2013; Božanić et al., 2014; Cortellino & Rizzolo, 2018; Hickey et al., 2018).

Among the dairy desserts, ice cream is one of the most popular and consumed by all age groups in the world, but its high level of lipids has been associated with the increase of cholesterol levels in the blood (FAO, 2013; Agrawal, 2016). Cheese whey is used in the manufacture of ice creams and sundaes and has excellent features such as water binding capacity, foam formation, high nutrition value, and it is a fat substitute (Balthazar et al., 2017) nevertheless, there are no reports regarding butter whey and ricotta whey.

It is well known that high bad cholesterol levels in human blood represent risks to health, and, when not properly treated before disposal, different milk by-products represent risks to environment, which indicates the relevance of their reuse. In this way, the current study aimed to produce chocolate ice creams using industrial dairy by-products (ricotta whey, cheese whey, butter whey) in order to add value to this production chain. Whey ice creams were evaluated according to physicochemical, microbiological, technological, and sensory quality attributes.

Materials and Methods

Formulation, processing, and storage of ice creams

The by-products were obtained from rennet cheese, ricotta, and butter production of an agro-industry located at the Federal Institute of Alagoas (Satuba/AL/Brazil). The frozen samples were sent in thermal boxes within 12 hours, to the Food Technology Laboratory (FTL) of the School of Pharmacy at the Federal University of Bahia (Salvador/BA/Brazil).

The other ingredients used in the ice cream production (Table 1) were purchased from a local market in Salvador/BA/Brazil.

Three batches of each formulation (four formulations in total – Table 1) were prepared in different days and ice cream samples were collected for triplicate analysis. The chocolate ice cream samples were prepared at the FTL (Salvador/BA/Brazil). Table 1 summarizes the four ice cream formulations, owned and developed in this study, differing only by the presence of various by-products and milk. The mixtures were homogenized, pasteurized (80ºC for 30 seconds), matured (kept at 4ºC for 12 hours), placed into the ice cream maker (Cuisinart® ICE-100, EUA) for 30 to 40 minutes, until reaching consistency, and distributed into 250 mL polypropylene containers to be stored at –18°C until analysis.

Nutritional composition

Moisture (drying), ashes (muffle burning), dietary fibers (enzymatic-gravimetric method), and proteins (Kjeldahl) were determined by using the Association of Official Analytical Chemists methods (AOAC, 2012). Fat content was determined by the Bligh and Dyer method (Bligh & Dyer, 1959), and carbohydrates were obtained by the difference between the

Table 1. Formulations of the chocolate ice creams.

Ingredients (%)	Cheese Whey	Ricotta Whey	Butter Whey	Milk
Whole milk (Italac®)	---	---	---	58.14
Cheese whey	58.14	---	---	---
Ricotta whey	---	58.14	---	---
Butter whey	---	---	58.14	---
Sucrose (DA BARRA®)	17.44	17.44	17.44	17.44
Milk cream (Nestlé®)	11.63	11.63	11.63	11.63
Stabilizer/Thickener (Selecta®) (corn starch, guar gum, and xanthan gum)	0.58	0.58	0.58	0.58
Emulsifier (Selecta®) (monoglycerides of distilled fatty acids, salts of fatty acids, sorbitan monostearate, and polyoxyethylene sarbine monostearate)	0.58	0.58	0.58	0.58
100% Cocoa powder (Nestlé®)	11.63	11.63	11.63	11.63

mentioned elements (Nifext fraction). Energetic content was determined based on the Atwater coefficient of proteins, lipids, and carbohydrates as 4 kcal g^{-1}, 9 kcal g^{-1}, and 4 kcal g^{-1}, respectively. All analyses were performed in triplicate.

pH and titratable acidity

pH was measured directly using a digital pH-meter (model DM-23 Digimed; Digicrom Analítica Ltda. - Brazil) previously calibrated with pH 4.0 and 7.0 buffer solutions. Titratable acidity was measured by titration with 0.1 N NaOH and results were expressed as % lactic acid, according to the AOAC methods (AOAC, 2012). All analyses were performed in triplicate.

Water activity

Water activity (Aw) was obtained by direct measurement in an Aqua-Lab digital thermo-hygrometer (AquaLab Lite model; Decagon Devices Inc. - USA) at a controlled temperature of 25 ± 2ºC, in triplicate.

Melting behavior

Following the method described by Mahdian et al. (2012), with some modifications, the ice cream samples were stored in plastic recipients (~40g/50mL) at -18ºC before the melting test. The samples were carefully removed from the plastic recipients and placed onto a wire mesh (1 cm^2) at a controlled temperature of 25 ± 1°C. A funnel in a graduated cylinder, both previously weighed, was placed beneath the mesh to collect the melted ice cream.

The dripped weight was measured every 5 minutes for 1 hour. The assay was performed in triplicate for all samples. Melting rates were determined by finding the angular coefficient through linear regression of the ratio weights/volumes recorded, of each ice cream sample, versus time.

Desorption of ice cream samples

Samples of the melted ice cream that showed desorption were sent to the separation funnel and the whey fractions of the samples were collected and weighed, according to the methodology of Cheng et al. (2015), with some modifications. This procedure was also carried out in triplicate.

Instrumental color

The color of the samples was determined in triplicate by instrumental measurement using a Minolta colorimeter (Chroma Meter, CR-400 - Japan), where measurements were expressed in L* (transition from black (0) to white (100)), a* (transition from green -a* to red +a*) and b* (transition from blue -b* to yellow +b*). The colorimeter was calibrated using a white reference plate before measurements with illuminant D65, and the standard observer was 2°.

Texture Profile Analysis (TPA)

Each ice cream sample, stored in 250 mL plastic recipients, was removed from the freezer (-18 °C) and immediately placed onto a styrofoam platform as a way of inhibiting the loss of temperature during analysis. The assay was performed at room temperature (18 ± 2°C) using a TA.XT Express Texture Analyzer (Stable Micro System, United Kingdom) and Exponent Software to determine the hardness (peak force during penetration (N)).

Considering two sample recipients for each ice cream formulation, three measurements were made in each one, thus recording six measurements for each type of ice cream. Penetrations were made by P/6 stainless steel cylindrical probe with non-truncated tip, attached to a 10 kg load cell and an angle of 45°. Each styrofoam platform with sample was placed at the center of the metal base of the equipment and the penetrations were performed following the conditions similar to El-Nagar et al. (2002): penetration distance = 25 mm, force = 0.1 N, and probe speed pre, during and post penetration = 1 mm s^{-1}.

Microbiological analysis

The microbiological quality of the ice creams was assessed to provide some degree of confidence that the processing and handling were done under sanitary conditions, in accordance with the national and international norms established (Christian et al., 1983; Brazil, 2001) and methodologies described by American Public Health Association (APHA, 2001), considering, *Staphylococcus aureus*, thermotolerant coliforms at 45 °C, and *Salmonella* spp.

Sensory analysis

Using an evaluation form, the degree of acceptance of the products was evaluated using a nine-point hedonic scale (1= extremely disliked to 9= extremely liked), counting on the participation of 80 untrained, trustworthy panelists, who evaluated the following attributes: appearance, aroma, flavor, texture, and overall liking. The panelists also indicated their intention to purchase through a five-point hedonic scale (1= certainly would not buy to 5= certainly would buy). Additionally, the ice cream samples (in 30ml plastic containers) were removed from the freezer (-18 °C), immediately served and presented to each panelist in individual sensory booths (controlled temperature 18–20°C) in a balanced and random order.

The Acceptance Index (AI%) of the ice creams was calculated by the percentage of the panelists who indicated that they “Slightly liked”, “Moderately liked”, “Very much liked”, and “Extremely liked” the ice cream samples.

In order to comply with principles of ethics in research with human beings, the project was approved by the Ethics in Research Committee of the Clementino Fraga Filho University Hospital (opinion technic issued nº 2.422.279/2017). Thus, for the participation agreement and application of the questionnaire, a free and informed term of consent was used.

Statistical analysis

Statistical analyses were performed using the Statistica 7.0 Software (StatSoft - USA). One-way analysis of variance (One-way Anova) and Tukey HSD test, at a significance level of 0.05, were used to define the difference between each ice cream formulation. For an overview of the parameters that were affected by the addition of different wheys and milk to ice creams, Principal Component Analysis (PCA) was performed with all obtained data.

Results and Discussion

Nutritional composition

Nutritional characteristics are presented in Table 2 (milk, by-products, and ice creams). The dairy by-products had higher values of moisture compared to the whole milk, different from to the behavior of the other nutrients (ashes, lipids, proteins, carbohydrates) and energetic value, where all of them were smaller. This emphasizes that only the butter whey showed similarity to milk regarding ash results. There is little information on the composition of dairy effluents, nevertheless the results of the present study were very close to those found by other researches that also characterized different types of wheys, such as ricotta whey (Bald et al., 2014), cheese whey (Bald et al., 2014), and butter whey (Morin et al., 2006).

There are no studies in the literature about total or partial replacement of milk by ricotta, rennet cheese, and butter wheys in ice cream. Following the composition behavior of the different wheys and milk used in the different formulations, it can be observed that the milk substitution with dairy by-products had a significant influence on the proximate composition of ice creams, increasing moisture (between 4.63 and 5.93%), whereas reducing ashes (between 0.84 and 0.95%), lipids (between 35.71 and 43.97%), proteins (26.14 and 29.11%), carbohydrates (2.52 and 3.82%), and energetic content (5.76 and 14.59 kcal) (Table 2). This can be attributed to the composition of dairy wheys, which contain higher moisture and lower amount of ashes, lipids, proteins, carbohydrates, and energy value compared to whole milk (Meneses et al., 2020).

The most significant change was observed in the lipid content, which allowed to classify the samples developed with different wheys as reduced fat by standards set by the International Dairy Food Association (IDFA), since they showed a decrease of more than 25% when compared to the sample developed with milk (IDFA, 2020). This situation, which consequently reflects on the reduction of the energy value, is advantageous for providing health benefits related to the intake of low-fat foods (WHO, 2003; Vidal et al., 2018). Whole milk had a higher lipid content and energy value in relation to butter whey, cheese whey and ricotta whey, respectively, and, when applied to ice cream, suffered the same behavior. The success of lipid fraction and energy value reduction was also observed in the study of Rodrigues et al. (2006), adding dairy by-products to ice cream.

The moisture in the present study ranged from 64.63 to 68.46%, which coincides with most of the results found by different authors who analyzed milk-based ice cream: Rodrigues et al. (2006) with 55 to 59%; Boff et al. (2013) with 63 to 70%, and Bery et al. (2014) with 54%. As in the main ingredients of this study, ice creams containing whole milk showed lower moisture compared to those containing butter whey, cheese whey and ricotta whey, respectively.

In the present study, the mean values of ash content found in the chocolate ice cream accord with those in the literature, also for chocolate ice cream, as verified by Rodrigues et al. (2006) with 1.27%, Boff et al. (2013) with 1.24%, and Bery et al. (2014) with 1.17%. Although whole milk showed a higher ash content than butter whey, ricotta and cheese wheys presented the lowest rates without variation between their values. When applied to ice creams, they showed a slightly different behavior: those developed with whole milk and butter whey had similar ash values therefore higher than the similar values of those developed with ricotta and cheese wheys, which also showed no difference between their values.

Table 2. Proximate composition, energetic content, water activity, pH, and tritable acidity of by-products, milk, and ice creams.

	Ricotta		Butter		Cheese		Milk	
	Whey	Ice cream	Whey	Ice cream	Whey	Ice cream	Whole milk	Ice cream
Moisture (%)	94.47±0.31 a	68.46±0.31 a	91.36±0.51 c	66.39±0.09 c	93.53±0.46 b	67.62±0.42 b	84.80±0.55 d	63.03±0.44 d
Ashes (%)	0.48±0.03 c	1.22±0.05 b	0.87±0.02 b	1.39±0.03 a	0.46±0.01 c	1.23±0.07 b	0.95±0.04 a	1.40±0.01 a
Lipids (%)	0.02±0.00 d	2.51±0.02 d	0.58±0.10 b	2.88±0.15 b	0.28±0.03 c	2.62±0.00 c	3.15±0.21 a	4.48±0.27 a
Proteins (%)	0.51±0.04 d	2.63±0.13 c	3.04±0.00 b	3.06±0.11 b	0.76±0.01 c	2.74±0.14 c	3.28±0.00 a	3.71±0.08 a
Carbohydrates (%)	4.51±0.17 c	25.18±0.23 c	4.14±0.11 d	26.35±0.10 b	4.96±0.27 b	26.02±0.60 b	7.83±0.32 a	27.38±0.30 a
Energetic (kcal $100g^{-1}$)	20.26±1.36 d	133.83±1.28 d	33.94±2.38 b	143.56±1.38 b	25.41±1.75 c	138.62±1.93 c	72.79±1.44 a	164.68±2.64 a
Aw	0.70±0.01 a	0.69±0.01 a	0.70±0.00 a	0.69±0.00 a	0.70±0.00 a	0.70±0.00 a	0.71±0.01 a	0.68±0.02 a
pH	4.41±0.07 d	5.21±0.11 c	4.86±0.09 c	5.31±0.11 c	6.36±0.05 b	6.13±0.12 b	6.62±0.06 a	6.40±0.06 a
Titratable acidity (in lactic acid)	0.52±0.01 a	0.95±0.04 a	0.39±0.08 b	0.94±0.14 a	0.21±0.01 c	0.44±0.02 b	0.19±0.01 c	0.41±0.05 b

Data are presented as mean±SD and were analyzed with one-way analysis of variance. Different letters (a-d) in the same line represent statistical significance ($p < 0.05$) among different samples using Tukey test.

The reduction of proteins in different dairy by-products as well as the same behavior with their addition to the ice cream is understood by looking through their technological processes (ricotta whey originates from cheese whey, which in turn comes from milk), which naturally reflect on a lower protein content related to milk (Meneses et al., 2020). Nevertheless, butter whey exhibited a higher protein content in relation to ricotta and cheese wheys and lower when compared to whole milk, since butter is obtained by the extraction of the lipid fraction from milk and not by the precipitation or coagulation of milk proteins as cheese and ricotta (Morin et al., 2006; Walstra et al., 2006; Meneses et al., 2020).

Regarding carbohydrates, as in the main ingredients of this study, ice creams containing whole milk showed higher values compared to those containing cheese whey, ricotta whey and butter whey, respectively. Similar results for carbohydrates were also found by Boff et al. (2013) (22.38%) and Piati et al. (2015) (20.06%) in chocolate ice creams.

As in different dairy wheys and whole milk, none of the ice creams presented fibers (data not shown). Oliveira et al. (2008), when analyzing different types and flavors of ice cream (vanilla, light vanilla, lemon, banana soy, and yogurt) also found no fibers in any of them. However, since there are no legal parameters limiting the addition of elements to ice cream, it is assumed that the different ingredient percentages used might cause differences among formulations and, consequently, differences in the values of their components, including fibers. This was also shown in the study developed by Boff et al. (2013), who identified fibers only in their samples with added orange peel to chocolate ice creams.

pH and titratable acidity

According to the results presented in Table 2, the decreasing behavior of the pH values of the by-products and milk was the same when applied in ice cream: ricotta, butter, cheese wheys, and milk, in this order. Likewise, the titratable acid values increased in the same order. The pH variation may be due to the existence of various acidic compounds in dairy wheys, such as lactic acid, fatty acids, etc (Nunes & dos Santos, 2015). Additionally, it is important to take into consideration the pH proximity between the ice cream samples.

Bald et al. (2014) found average pH values of 6.33, and Macwan et al. (2016) found pH of 6.71 obtained from bovine cheese whey, which corroborates the results found in the present study. Naturally, due to its production process, the pH of ricotta whey was more acidic (mean of 4.41) compared to that of cheese whey, butter whey, and milk. This pH was also more acidic than the average presented by Bald et al. (2014) with a value of 5.44 when analyzing ricotta whey. This variation might be associated with different types of cheese whey used in the production of ricotta, implying different pH in their wheys.

The butter whey analyzed in this study has a pH value of around 4.8, in accordance with the U.S. Food and Drug Administration (FDA), which determines a pH raging from 4.4 to 4.8. The results of pH for the whole milk were close to neutrality, in agreement with the records in the literature for milk (Rodrigues et al., 2006; Walstra et al., 2006).

pH values of ice creams are generally around 6.3, however pH and titratable acidity are parameters that can be influenced by the composition of the mixture, such as the addition of fruits to the formulation and the use of milk of different origins (Correia et al., 2008). In this study, pH and titratable acidity values for ice creams were similar to those of other studies on chocolate ice cream (Rodrigues et al., 2006; Bery et al., 2014).

Water activity (Aw)

As seen in Table 2, although the wheys and even the ice creams developed with different dairy by-products have more moisture than the ones developed with milk, there was no significant difference for water activity (Aw) between them.

It is clear that water activity plays an important role in food quality, especially regarding the representation of water availability for the development of microorganisms and the occurrence of spoilage reactions (Rahman & Labuza, 2007). The values in this study were lower, and therefore supposedly more stable than those in the ice cream found by Correia et al. (2008) and Piati et al. (2015), with approximately 0.97 of water activity when using dairy ingredients in the elaboration of the dessert.

Melting behavior

It is expected from a good ice cream to have moderate melting resistance in the form of uniform homogeneous liquid and the appearance of the original mixture (without phase separations), presenting a natural color and particles regularly distributed, since a certain consistency must be maintained when the ice crystals melt. Inhomogeneity can be identified by the presence of clots, scum, air bubbles of large and/or varied sizes, or by the separation of phases (Bodyfelt et al., 1988).

Fat plays a significant role in determining the melting rate of ice cream and it is responsible for increasing the resistance to this phenomenon, since part of the globules surrounding the air bubbles stabilizes the system (Bodyfelt et al., 1988; Guinard, et al. 1997), but interestingly, according to Table 3, the ice cream developed with milk (with higher lipid contents) had the highest melting rate when compared to the samples developed with different dairy wheys, which in turn presented no significant between them. Water holding capacity can be a hypothesis, which is different depending on the type of proteins. In milk, the main proteins found are caseins, whey proteins (globulin and albumin), and proteins from membranes of fat globules (Jovanović et al., 2005; Walstra et al., 2006). Casein retains approximately 3g of water g^{-1}, while whey proteins retain 1g of water g^{-1}; however, heat treatment during ice cream production increases the water holding capacity of whey proteins resulting in similar or higher water holding capacity compared to that of casein (Jovanović et al., 2005; Walstra et al., 2006). Another explanation is that more time is required to melting when the ice cream contains more

Table 3. Melting rate, color parameters (CIELab), hardness, and acceptance of ice creams.

	Ricotta whey	Butter whey	Cheese whey	Whole milk
Melting rate (g min^{-1})	0.67±0.01 [b]	0.67±0.02 [b]	0.67±0.01 [b]	0.73±0.03 [a]
L*	37.63±0.52 [c]	39.99±0.28 [a]	38.37±0.37 [c]	40.69±0.75 [a]
a*	8.33±0.15 [d]	9.97±0.26 [b]	9.47±0.15 [c]	10.57±0.08 [a]
b*	3.38±0.10 [d]	4.46±0.04 [b]	3.76±0.28 [c]	6.18±0.18 [b]
Hardness (N)	38.43±0.92 [a]	35.77±0.69 [c]	37.04±0.46 [b]	33.99±1.07 [d]

Data are presented as mean±SD and were analyzed with one-way analysis of variance. Different letters ([a-d]) in the same line represent statistical significance ($p < 0.05$) among different samples using Tukey test.

water, which has a higher melting point than milk fat (Choi & Shin, 2014).

Desorption of ice cream samples

None of the samples presented syneresis and it was not possible to quantify the whey fraction (data not shown). A hypothesis for this would be that, according to Bodyfelt et al. (1988) and Tharp et al. (1998), proteins strongly influence phase separation after melting, since ice creams containing high protein concentration in water are generally less stable in this aspect than the ones with less protein. Assuming that a good ice cream should not show phase separation during and after melting, all samples met this quality parameter.

Instrumental color

Color is one of the most important quality attributes that influences consumer's choices and is directly linked to the appearance of dairy products (Aidoo et al., 2017).

As observed in Table 3, the ice creams with milk and butter whey (no significant difference between them) were the lightest (higher value of L*) when compared to ice creams developed with cheese whey and ricotta whey (also with no significant difference between them). The white color of milk results from the presence of colloidal particles, such as milk fat globules and casein micelles, capable of scattering light in the visible spectrum (García-Pérez et al., 2005), which explains the high L* value of the milk ice cream in comparison to that of cheese whey and ricotta whey ice creams. Additionally, considering the obtaining process of the evaluated dairy wheys, butter whey is the closest to milk in relation to lipid and casein contents, yet cheese whey and ricotta whey have reduced lipid and casein contents compared to whole milk (Morin et al., 2006; Bald et al., 2014; Qiu et al., 2015; Cortellino & Rizzolo, 2018). Roland et al. (1999) also found that ice cream lightness values increased as fat content also increased when analyzing the effects of fat content on ice cream properties.

In addition to that, there was a reduction of greenness (a*) and yellowness (b*) of the butter whey (visibly opaque like milk) and whole milk, followed by the cheese whey and ricotta whey, in this order. Due to the presence of cocoa powder, the reduction of redness (a*) was observed in the ice cream samples (a typical feature of this ingredient) (Aidoo et al., 2017).

There are no studies evaluating instrumental color of chocolate ice creams with ricotta whey, cheese whey, and butter whey; therefore, our findings were also compared to other chocolate ice creams. The chocolate ice creams of the current study were lighter than the ice creams developed by Piati et al. (2015) with luminosity between 21.53 and 35.59, when analyzing the addition of chia (*Salvia hispanica* L.) mucilage to chocolate ice creams. Similar results were found by Crizel et al. (2013) when orange fibers were added to chocolate ice cream (L* between 37.02 and 46.24), and also by Li et al. (2015) in chocolate ice creams with added collagen (L* between 41.64 and 43.03).

Texture Profile Analysis (TPA)

The softest ice creams were the ones developed with milk, followed by those developed with butter, cheese, and ricotta wheys, respectively (Table 3). It was observed that the use of dairy by-products increased the maximum penetration force, which means that the ice creams became harder. This is due to the low lipid content present in these dairy by-products. The same performance was observed by Akalin et al. (2008) in low-fat probiotic ice creams. Studies conducted by Guinard et al. (1997) and Akalin et al. (2008) pointed out that hardness is inversely proportional to fat content. Furthermore, according to Guinard et al. (1997), the reduction of fat content promotes an increase in the formation of ice crystals, which in turn provides greater hardness in low-fat ice creams.

Finally, higher values of firmness for whole milk ice creams were found by Aime et al. (2001) (86.30 N) and Whelan et al. (2008) (57.30 N), contrasting Oliveira et al. (2008), who verified 24.04 N of instrumental firmness in a commercial ice cream.

Microbiological analysis

The results obtained from the microbiological evaluation (data not shown) showed that all the analyzed samples were suitable for consumption, presenting values equal or below the limit established (Christian et al., 1983; Brazil, 2001), and therefore safe to perform sensory analysis.

Sensory analysis

In general, ice creams were rated between 6 ("Slightly liked") and 7 ("Moderately liked") (Table 4). Only the butter whey sample differed negatively in relation to the overall liking, aroma, and flavor of the other samples, which showed no significant difference for these attributes. Although the sample with milk was classified as a sample with cheese whey regarding appearance, the latter presented no significant difference from the other samples. A similar behavior was observed for the texture data: the samples with milk, cheese, and ricotta wheys were similar, while the sample with butter

Table 4. Acceptance of ice creams.

	Ricotta whey	Butter whey	Cheese whey	Whole milk
Appearance	6.87±1.30 ^{b}	6.70±1.31 ^{b}	7.11±1.31 ^{ab}	7.41±1.30 ^{a}
Aroma	6.71±1.41 ^{a}	5.96±1.39 ^{b}	7.06±1.39 ^{a}	6.90±1.39 ^{a}
Flavor	6.59±1.28 ^{a}	5.64±1.28 ^{b}	6.91±1.28 ^{a}	7.05±1.27 ^{a}
Texture	6.80±1.30 ^{a}	6.25±1.29 ^{b}	6.76±1.29 ^{ab}	7.15±1.29 ^{a}
Overall liking	6.76±1.26 ^{a}	6.07±1.30 ^{b}	6.95±1.17 ^{a}	7.15±1.19 ^{a}

Data are presented as mean±SD and were analyzed with one-way analysis of variance. Different letters ($^{a-b}$) in the same line represent statistical significance ($p < 0.05$) among different samples using Tukey test.

whey did not significantly differ from the samples with cheese whey.

Another observation worth mentioning is that even samples with different color and hardness by instrumental analysis had practically imperceptible differences of these sensorial attributes by the panelists. According to Abbott (1999), this fact usually happens and, because instrumental measures are more sensitive, they are used to reduce the variations of sensory analysis, which is influenced by several factors.

In regards to purchase intention, although the butter whey sample was the only one that presented the majority of consumers with "probably would buy" in relation to "certainly would buy", 85.00, 77.50, 63.75, and 53.75% of the consumers said they "probably would buy" or "certainly would buy" the ice creams with milk, cheese whey, ricotta whey, and butter whey, respectively.

Unlike Rodrigues et al. (2006) (7.95), the same behavior for "overall liking" scores were observed in other studies that also sensorially evaluated chocolate ice creams: Owni & Khater (2010) (5.77), Bery et al. (2014) (average of 6.93), and Maestrello et al. (2017) (between 6.00 – 7.00).

The Acceptance Indexes (AI%) were 97.50, 96.25, 96.25, and 85.00% for the ice cream with milk, cheese whey, ricotta whey, and butter whey, respectively. According to Dutcosky (2013), a product is considered successful in the market and accepted in terms of sensory properties if its IA ≥ 70%. In this regard, all the developed samples exceeded this mark.

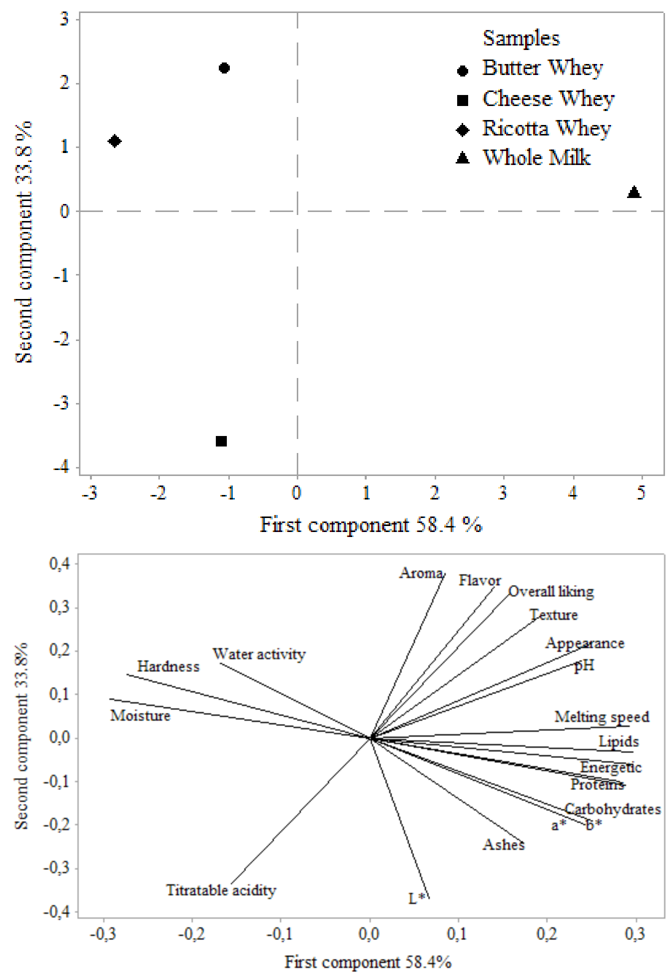

Figure 1. Physicochemical, instrumental, and sensory data of the different formulations of ice cream manufactured from different dairy wheys and whole milk in the plane defined by two principal components.

Principal Component Analysis (PCA)

PCA accounted for 92.20% of the total data variance (Figure 1), with a predominance of the first component (PC1), which contributed to a higher percentage of variance explanation (58.40%) than the second component (PC2) (33.80%). PCA separated all the different ice creams based on physicochemical (nutritional composition, pH, titratable acidity, Aw, and melting), instrumental (color, hardness), and sensory (acceptance) parameters. PC1 separated the ice creams developed with butter whey, ricotta whey, and cheese whey (one group) from the ice cream developed with whole milk (another group). Thus, PC1 separated the ice cream with whole milk from the ice creams with wheys, independently of the whey origin. PC2 separated the ice cream developed with butter whey, ricotta whey, and whole milk (one group) from the ice cream developed with cheese whey (another group). The icecreams developed with butter whey and ricotta whey can be identified by greater water activity, instrumental hardness, and moisture. The ice cream developed with cheese whey can be identified by greater titratable acidity and the one developed with whole milk can be characterized by greater aroma, flavor, overall liking, texture, appearance, pH, melting rate, lipids, carbohydrates, proteins, energetic content, ashes, yellowness, redness, and lightness.

Conclusion

This study analyzed the impact of the addition of different dairy by-products on several quality properties of ice creams. In general, the addition of ricotta whey, cheese whey, and butter whey reduced the nutritional composition, melting rate, pH, greenness (a*), yellowness (b*), and lightness, while increased acidity, and hardness of ice creams. Nevertheless, these changes were less pronounced when adding butter whey. On the other hand, considering the sensory proprieties, ricotta whey and cheese whey demonstrated a greater potential for use in ice creams without compromising overall liking and purchase intention, when compared to ice cream with butter whey. In addition, the ice creams prepared with ricotta, cheese, and butter wheys presented an interesting reduction of lipids and caloric fraction. The water activity (Aw) did not vary between the obtained values, showing a good stability for the ice creams produced.

Thus, the application of cheese, ricotta, and butter wheys in ice creams has shown to be a strong and interesting option to partially or totally substitute milk in their formulations. Consequently, they are a potential alternative with great nutritional, environmental, technological, and socio-economic importance to produce ice creams.

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Compliance with Ethical Standards

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