Assiut Journal of Agricultural Sciences 56 (1) 2025 (88-99)
ISSN: 1110-0486 / EISSN: 2356-9840
Website: http://ajas.journals.ekb.eg/
E-mail: ajas@aun.edu.eg

(Original Article)

Utilization of Acid Whey in the Manufacture of Low-Fat Ice Milk

Ahmed M. Asar[1*]; Osama S.F. Khalil[2] and Mohamed A. Ghanimah[3]

[1]Dairy Science and Technology Department, Faculty of Agriculture & Natural Resources, Aswan University, Aswan, 81528, Egypt.
[2]Dairy Science Department, Faculty of Agriculture, Beni-Suef University, Egypt
[3]Department of Dairy Science, Faculty of Agriculture, Kafrelsheikh University, Kafr El-Sheikh 33516, Egypt

*Corresponding author: ahmed.asar@agr.aswu.edu.eg
DOI: 10.21608/AJAS.2025.326320.1411
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Abstract

The present study aimed to evaluate the impact of acid whey (AW) on the properties of low-fat ice milk. Low fat ice milk mixes were prepared using skim milk powder, cow cream, stabilizer and emulsifier, and sugar. The six treatments were prepared as follows: full-fat (6% fat) and low-fat (1.5% fat) mixes were prepared without AW, whereas low-fat served as a control. The low-fat treatments T1, T2, T3, and T4 were prepared with 30, 40, 50, and 70% acid whey, respectively, instead of distilled water. The results showed that the use of AW resulted in a significant change in the physical properties of the mixes and low-fat ice milk. The full-fat sample exhibited higher melting resistance compared with the low-fat treatments. The mineral content differed significantly among the ice milk treatments. The use of AW significantly increased the calcium, phosphorus, and magnesium content in the low-fat ice milk samples, whereas the full-fat sample had the lowest corresponding values. The control low-fat ice milk had the highest flavour and total acceptability scores, while the differences in flavour scores among T1, T2, and T3 treatments were not significant. Low-fat ice milk treatment made with 70% AW exhibited the lowest total acceptability score.

Keywords: *Acid whey, Low-fat ice milk, Mineral contents, Physical properties, Quality.*

Introduction

The dairy industry has been striving to develop suitable utilizations of dairy byproducts such as whey. Whey is produced during cheese production and casein preparation. This fluid represents approximately 90% of the milk volume used for cheese production and retains approximately half of the nutrients found in milk, resulting in high disposal costs (Flores *et al.*, 2023; Sakkas *et al.*, 2023).

In Egypt, as in most parts of the world, whey utilization or disposal remains an issue for the surrounding environment because of its high biological oxygen demand (Sakkas *et al.*, 2023).

Currently, this by-product liquid is recognized as a source of bioactive and functional compounds, particularly proteins, peptides, water-soluble vitamins, and

Received: 15 October 2024/ Accepted: 15 December 2024/ Published online: 5 January 2025

minerals that were originally present in milk. It has become customary for the dairy industry to classify whey into two types: sweet whey and acid whey (Trejo-Flores *et al.*, 2023). Acid whey contains more lactic acid, calcium, and phosphorus and has lower protein content than sweet whey (Menchik *et al.*, 2019). In general, the composition and attributes of whey depend on several factors, including thermal treatment of milk, the type of coagulation and cheese, and casein preparation method (Szafrańska *et al.*, 2024). A considerable portion of whey produced globally is still not valorized because the small- and medium-sized dairy industries lack the dimension required to invest in cheese whey valorization (Trejo-Flores *et al.*, 2023).

The functional and technological properties of whey have led to its use as a cost-effective raw material to replace milk in traditional dairy products. Consequently, the dairy industry has sought innovative techniques to utilize this valuable co-product to produce more sustainable, more affordable, and healthier dairy products. One potential use for dairy byproducts is ice cream (Cortellino and Rizzolo, 2018).

Ice cream is one of the most widely consumed frozen desserts in the world. It consists of air, water, milk fat and solids-not-fat (SNF), sweeting agents, flavours stabilizers and emulsifiers. Several recent studies have focused on the use of liquid whey in the manufacture of ice cream. Meneses *et al.* (2020) reported that Ricotta whey and rennet cheese whey can be used as milk substitutes in the manufacture of ice cream. Trejo-Flores *et al.* (2023) reported that the use of cheese whey and mango seed kernel waste allows the preparation of a high-quality ice cream base. Mykhalevych *et al.* (2024) used a blend of whey protein isolate and nonhydrolyzed whey concentrate for the manufacture of ice cream.

In recent years, low-fat ice milk has gained popularity because consumers are more conscious of avoiding overeating of fat. Food technologists have responded to these demands by offering low-fat and low-calorie products.

The aim of this study was to investigate the impact of adding acid whey at different ratios (30, 40, 50, and 70%) instead of water on several properties of low-fat ice milk.

Materials and Methods

Materials

Acid whey (AW) from Kariesh cheese (acid coagulated, low-fat soft cheese) was obtained from a local market in Qena, Egypt. The chemical composition of AW was 5.70% total solids, 0.7% protein, 0.10% fat, 0.7% ash. The whey was filtered through cheesecloth to be ready for use in ice milk manufacturing. Commercial-grade sugar was purchased from the local market. Stabilizer (guar gum) was obtained from Rama Gum industries, and emulsifier (mono and di-glycerides) was obtained from Misr Food Additives (MIFAD). Skim milk powder (97% TS) was purchased from Dairy America ™, USA. Fresh cow cream (46% fat) was obtained from the pilot plant of the Department of Dairy Science and Technology, Faculty of Agriculture and Natural Resources, Aswan University.

Methods

Formulation of ice milk bases and ice milk processing

Ice milk mix formulations were prepared using the procedure outlined by Marshall and Arbuckle (2000). The six mixes were prepared as follows: the full-fat mix was formulated to contain 6% fat, 10% SNF, and 15% sugar, 0.5% stabilizer and emulsifier, while the control low-fat ice milk base was formulated to contain 1.5% fat, 13% SNF, and 15% sugar, 0.5% stabilizer and emulsifier. The formulations are shown in Table 1, considering that acid whey was used instead of water to prepare low-fat mixes at concentrations of 30, 40, 50, and 70% for treatments T1, T2, T3, and T4, respectively.

Skim milk powder was combined with sugar, stabilizer and emulsifier to obtain a dry mixture. Afterwards, distilled water (40°C), acid whey (for low-fat treatments), and fresh cream were mixed, and the temperature was elevated to 65°C to facilitate the addition of the dry mixture, with gentle and continuous stirring to ensure thorough incorporation. The mixes were heat treated (80°C/5 min), cooled (5°C), and aged (5°C/6h). After aging, the mixes were frozen and whipped at -5°C for 20 min in an ice cream machine (Model Golden-719, Italy). The ice milk samples were collected, transferred to 100 mL plastic cups, covered, and kept at -20°C until analysis. Three replicates were performed for each treatment on different days.

Table 1. Formulations used for making different treatments of ice milk

Ingredients (g)	Treatments*					
	CF	CL	T1	T2	T3	T4
Sugar	150	150	150	150	150	150
Stabilizer and emulsifier	5	5	5	5	5	5
Fresh cream	130	32.6	32.6	32.6	32.6	32.6
Skim milk powder	95.5	132.4	115	109.3	103.5	90.66
Distilled water	620	680	397	303.1	208.9	-
Acid whey	-	-	300	400	500	721.74

*CF: control full-fat (6% fat); CL: control low-fat (1.5% fat) ice milk. Treatments T1, T2, T3, and T4 as CL with 30, 40, 50 and 70% acid whey instead of water, respectively.

Analysis of ice milk mixes and ice milk samples

Physical properties

Specific gravity, weight per gallon (kg/gallon), and freezing point of ice milk mixes were determined according to Marshall and Arbuckle (2000).

Analysis of ice milk samples included determination of overrun, specific gravity, and weight per gallon according to Marshall and Arbuckle (2000). The melting rate was determined as follows. Briefly, the sample was put on a wire mesh screen and allowed to thaw at ambient temperature (24±2°C) in a beaker beneath the wire mesh screen until 50% of the sample melted. The weight of the melted ice milk treatments was tracked every 10 min for 60 min to create a sigmoidal curve representing melting kinetics. The slope of the linear part of the plot represents the melting rate (g/min) (Di Criscio *et al.*, 2010).

Colour parameters of ice milk

The colour parameters were measured according to the method of Elwakeel *et al.* (2023) using a colorimeter (CR-400, Konica Minolta, Inc., Japan) and the International Commission on Illumination (ICI) colour coordinates L*, a*, and b* (10° observer at D65 illuminant).

Mineral content

The mineral content, including calcium (Ca), phosphorus (P), and magnesium (Mg) was determined according to the method described by James (1995).

Sensory properties

The sensory properties of the ice milk treatments were evaluated by panelists from Department of Dairy Science and Technology, Faculty of Agriculture and Natural Resources, Aswan University. The stored samples (-18°C) were tempered at ambient temperature for 5 min before sensory evaluation. Scoring was conducted according to Gafour *et al.* (2007) for colour (10 points), body and texture (30 points), melting property (10 points), and flavour (50 points).

Statistical analysis

Statistical analysis was performed using SPSS version 16 computer program (SPSS, Inc., Chicago, IL USA) according to Steel and Torrie (1980).

Results and Discussion

Physical properties of the ice milk mixes

The physical properties of the ice milk mixes are shown in Table 2. The full-fat mix had significantly lower ($P \leq 0.05$) specific gravity and weight per gallon than the control (CL). Replacing distilled water with different concentrations of AW slightly increased the specific gravity and weight per gallon, but the differences among the control and AW-treatments were not significant ($P > 0.05$). Trejo-Flores *et al.* (2023) reported that the density of ice cream mixes decreased with increasing fat content and decreasing SNF content. Generally, the specific gravity and density of the ice cream base have important impacts on the smoothness and consistency of the ice cream. Furthermore, an excessively high mix density may lead to undesirable sensory properties and inappropriate overrun of the product (Kamińska-Dwórznicka *et al.*, 2022).

Table 2 clearly shows that the gradual increase in AW addition led to a significant ($P \leq 0.05$) decrease in the freezing point. Sakkas *et al.* (2023) reported that the freezing point of frozen yoghurt mixes was not affected by the addition of 12.5-18.75% acid whey. Freezing point depression is a crucial factor in the production of ice cream, because it affects the initial and progressive growth of the mean size of the generated ice crystals and their native thermodynamic instability (Goff and Hartel, 2013). Generally, the freezing point decreases when the molecular weight of the solute decreases or the serum phase concentration increases, which may explain the differences in freezing point among full-fat and low-fat mixes.

Table 2. Physical properties of the mixes and ice milk samples as affected by using acid whey.

Treatments*	Mixes			Ice milk		
	Specific gravity	Weight per gallon (kg)	Freezing point (°C)	Specific gravity	Weight per gallon (kg)	Overrun (%)
CF	1.0931 ±0.007^{b}	4.9692 ±0.032^{b}	-2.20 ±0.01^{a}	0.8324 ±0.003^{bc}	3.7843 ±0.015^{bc}	53.35 ±0.005^{a}
CL	1.1279 ±0.017^{a}	5.1277 ±0.079^{a}	-2.39 ±0.01^{b}	0.8416 ±0.001^{a}	3.8258 ±0.003^{a}	36.89 ±0.33^{d}
T1	1.1154 ±0.002^{ab}	5.0707 ±0.002^{ab}	-2.81 ±0.02^{c}	0.8375 ±0.001^{ab}	3.8072 ±0.015^{ab}	33.04 ±0.02^{f}
T2	1.1160 ±0.001^{ab}	5.0734 ±0.001^{ab}	-3.01 ±0.02^{d}	0.8286 ±0.000^{c}	3.7669 ±0.001^{c}	34.36 ±0.33^{e}
T3	1.1253 ±0.001^{a}	5.1159 ±0.002^{a}	-3.22 ±0.01^{e}	0.8223 ±0.003^{d}	3.7381 ±0.002^{d}	38.83 ±0.33^{c}
T4	1.1265 ±0.000^{a}	5.1213 ±0.000^{a}	-3.96 ±0.02^{f}	0.7756 ±0.001^{e}	3.5260 ±0.013^{e}	39.59 ±0.33^{b}

*CF: control full-fat (6% fat); CL: control low-fat (1.5% fat) ice milk. Treatments T1, T2, T3, and T4 as CL with 30, 40, 50 and 70% acid whey instead of water, respectively.

The averages with different superscripts are significantly different (P≤0.05). Data are averages ± SE of 3 replicates.

Physical properties of ice milk samples

The physical properties of the ice milk treatments are presented in Table 2. The full-fat sample had significantly lower (P≤0.05) specific gravity and weight per gallon values than those of the control. Contrarily, the full-fat sample exhibited significantly higher overrun value (%) than that of the control and AW-treated samples. This may be attributed to the important function of fat in stabilizing and maintaining the air phase in ice cream during the process of freezing and whipping (Khalil *et al*., 2021).

The specific gravity and weight per gallon significantly (P≤0.05) decreased with increasing AW addition (Table 2), whereas T3 and T4 exhibited the lowest values. The overrun values decreased significantly when 30% AW (T1) or 40% AW (T2) was used; however, using higher AW ratios significantly (P≤0.05) increased the overrun values. This may be due to the higher viscosity of the mixes prepared with AW, which increased the availability and incorporation of air into the low-fat mixes. Furthermore, the increase of overrun was more pronounced in the T4 treatment than in the low-fat treatments. Statistical analysis revealed significant differences (P≤0.05) among the treatments. Sakkas *et al.* (2023) reported that frozen yoghurt made with 12.5–18.75% acid whey had higher overrun values than the control. Furthermore, using dry sweet whey at a concentration of 42% increased the density and decreased the overrun of ice cream (Kamińska-Dwórznicka *et al*., 2022).

These results agree with those of Alfaifi and Stathopoulos (2010). Alvarez *et al.* (2005) reported that the presence of WPC might enhance the initial stabilization of newly formed air bubbles in the freezer.

Colour of the ice milk samples

Fig. 1 illustrates the colour parameters of the ice milk treatments. The lightness (L*) and redness (a*) values of the full-fat sample (76.91, -1.70) were significantly higher than those of the control and AW-treated samples. A clear correlation between L* and lipid content has been previously reported by Roland *et al*. (1999). Furthermore, the lightness and redness of the treatments significantly decreased with increasing AW, whereas T4 had the lowest values (67.11, -2.15). The yellowness (b*) value in T4 was significantly lower than the recorded value, while T2 had the highest value. Our results may be explained by the colour of the AW used.

Most low-fat ice milk treatments exhibited lower L* and a* values than the control, whereas the opposite was observed for b*. This impact of AW agrees with the results of Meneses *et al*. (2020), who found that ice cream made with 75 and 100% ricotta whey (RW) had the lowest L* values, followed by samples prepared with 50 and 25% RW, whereas the sample with 25% RW had lower *a** values than the other treatments.

With respect to b* values, a gradual increase (P≤0.05) was observed with increasing ricotta whey content (Meneses *et al*., 2020). Sakkas *et al*. (2023) reported that frozen yoghurt samples manufactured with acid whey were brighter than the control. Additionally, they reported that the use of acid whey had a significant effect on the colour of greenish, but the colour of yellowish was not affected.

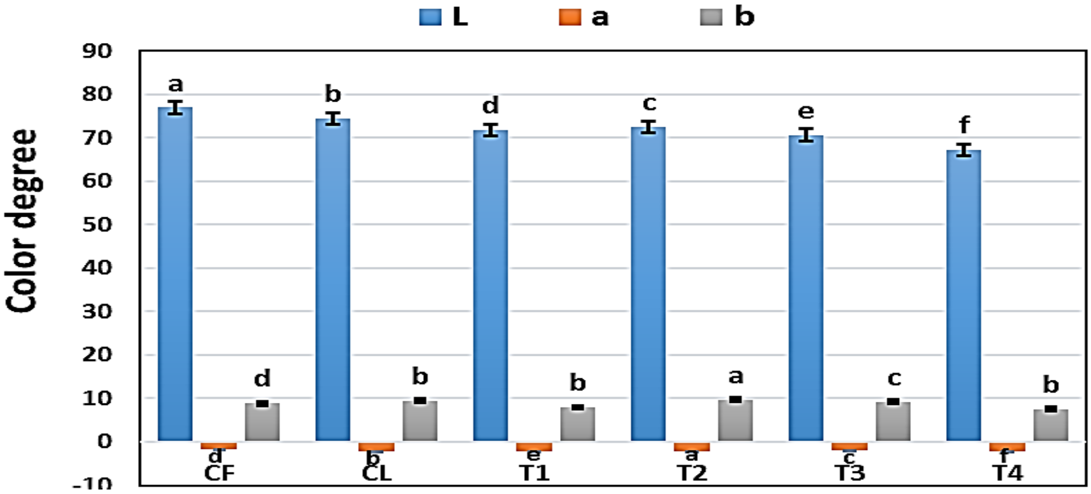

Fig. 1. Color of ice milk samples: L* (lightness), a* (redness) and b* (yellowness). CF: control full-fat (6% fat); CL: control low-fat (1.5% fat) ice milk. Treatments T1, T2, T3, and T4 as CL with 30, 40, 50 and 70% acid whey instead of water, respectively. The different letters above each column for the same color means significantly different (P≤0.05).

Melting rate of ice milk samples

Melting rate is an essential qualitative aspect of ice cream evaluation. An ideal ice cream should have moderate resistance to melt into liquid form when exposed to room temperature for a specific time (Goff and Hartel, 2013). Fig. 2 shows the melting rate, which represents the loss of the tested samples weight over one hour at ambient temperature (25± 1°C). The full-fat sample required a longer time to thaw and was softer than the low-fat treatments. This difference might be attributed to the functional role of fat in the ice cream microstructure and its ability to stabilize air bubbles (Dresselhuis *et al*., 2008).

Fat plays a crucial function in increasing the resistance of ice cream to melt because some fat globules surround air bubbles and stabilize the system (Goff and Hartel, 2013). However, AW significantly affected the melting rate of the low-fat ice milk. The melting rate of the low-fat ice milk decreased significantly with increasing AW ratio. This trend agrees with the findings of Meneses *et al*. (2020), who attributed this impact to a low pH. Several studies have demonstrated that ice cream containing more water requires more time to melt because water has a higher melting point than that of milk fat (Choi and Shin, 2014). Another explanation is associated with the capacity to hold water, which varies with pH difference. The decrease in pH causes changes in the protein structure and consequently, interactions between whey proteins and caseins or whey-whey proteins, increasing the vulnerability of hydrophilic groups to aqueous media and leading to an increase in the ability to bind water (Sfakianakis *et al*., 2015).

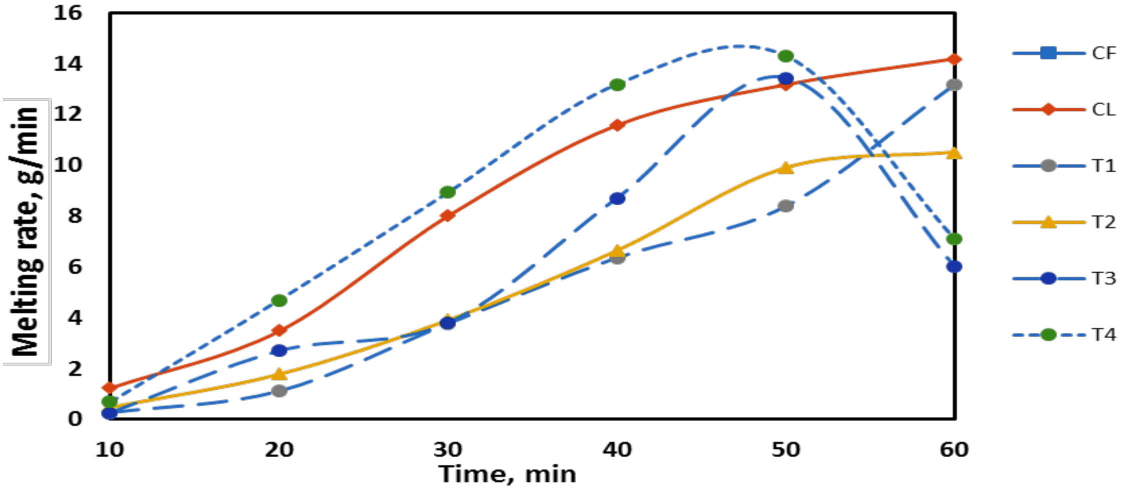

Fig. 2. Melting rate (g/min) at 25±1°C of ice milk samples as affected by using acid whey. CF: control full-fat (6% fat); CL: control low-fat (1.5% fat) ice milk. Treatments T1, T2, T3, and T4 as CL with 30, 40, 50 and 70% acid whey instead of water, respectively.

Mineral content of the ice milk samples

Fig. 3 shows that the mineral content of the full-fat sample (CF) was significantly lower than that of the control (CL) and AW-treated samples. The addition of high AW ratios significantly ($P \leq 0.05$) increased mineral content, and this increase was more pronounced when the highest AW ratio was used. Compared with the control and AW treatments, T4 (70% AW) had the highest ($P \leq 0.5$) Ca, P, and Mg content (24.6, 29.56 and 21.63mg/100gm), while T1 had the lowest (19.33, 20.27 and 14.86mg/100gm). This result can be attributed to the high mineral content of the AW. Acid whey contains high calcium content because the colloidal calcium in the casein micelles in milk, at low pH is solubilized and partitioned into the whey (de la Fuente and Juarez, 2015).

Acidification of cheese milk induces the solubilization of colloidal minerals, which leads to the loss of some minerals in cheese whey. In this respect, Lucey and Fox (1993) reported that the preacidification of cheese milk, the scalding temperature of the curd, and the pH of cheese whey during drainage are the primary factors influencing the loss of minerals, particularly calcium and phosphorus in cheese whey. Further details in this respect are provided by de la Fuente and Juarez (2015).

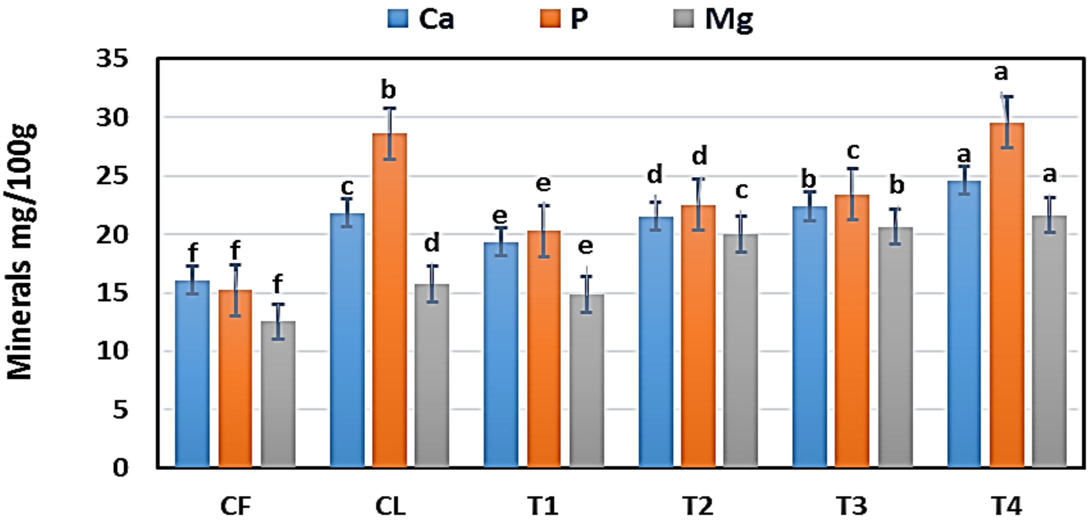

Fig. 3. Minerals content (mg/100g) of the ice milk samples. CF: control full-fat (6% fat); CL: control low-fat (1.5% fat) ice milk. Treatments T1, T2, T3, and T4 as CL with 30, 40, 50 and 70% acid whey instead of water, respectively. The different letters above each column for the same mineral means significantly different (P≤0.05).

Sensory properties of the ice milk samples

The sensory evaluation of the ice milk treatments is shown in Fig. 4. The data show that the differences in the scores given for colour, body and texture were statistically insignificant, while full-fat sample had slightly higher score for the melting property. The control sample had higher flavour and total acceptability scores (46.5, 88.3) than the other low-fat ice milk samples. No significant differences in flavour scores were found among the T1, T2, and T3 treatments, while T4 had the lowest flavour and total acceptability scores (38.34, 77.8). This trend agrees with the results of de Meneses *et al.* (2021). Additionally, Meneses *et al.* (2020) found some adverse effects of whey on flavour of ice cream. Generally, the control sample had the highest total acceptability score, while the T4 sample had the lowest overall acceptance score.

There is a scarcity of sensory studies that evaluate the acceptance and propensity of purchasing ice milk supplemented with AW. The main drawback of using whey in dairy products has been related to adverse sensory impacts, which are strongly associated with the whey type, amount of whey added, type of dairy product, and processing conditions applied (Cortellino and Rizzolo, 2018). It may be of interest to reveal the advantages of using Karish cheese whey, as shown in our study. This whey is salt-free and fat-free, since Karish cheese is traditionally manufactured from skim milk, while dry salting or brining in brine is normally applied for the salting process (Mehanna, 2021).

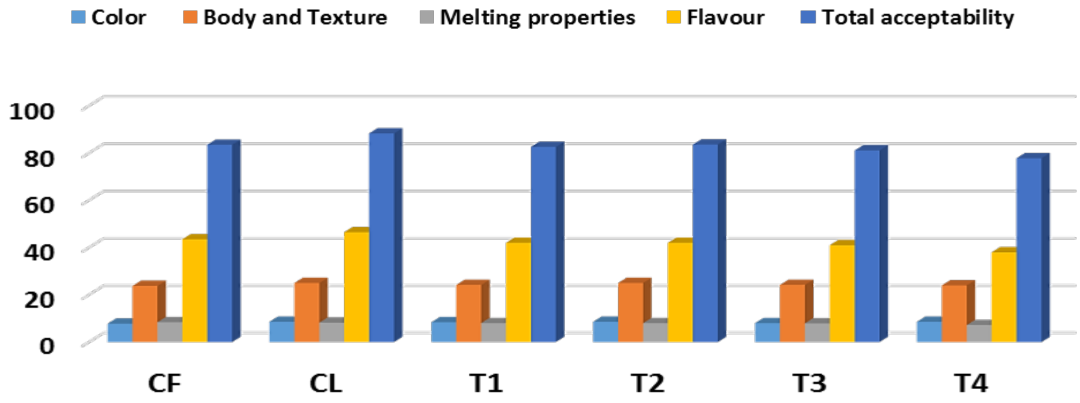

Fig. 4. Organoleptic properties of ice milk samples. CF: control full-fat (6% fat); CL: control low-fat (1.5% fat) ice milk. Treatments T1, T2, T3, and T4 as CL with 30, 40, 50 and 70% acid whey instead of water, respectively.

Conclusions

The present study showed the potential utilization of acid whey as a dairy by-product in the manufacture of ice milk. The addition of different AW ratios resulted in clear changes in the physical properties of the resultant low-fat ice milk. Compared with the full-fat sample, the use of high AW levels significantly increased the Ca, P, and Mg content of the low-fat ice milk. The low- fat ice milk manufactured with 30, 40, and 50% AW had acceptable sensory properties. Therefore, low-fat ice milk with improved nutritional value and health benefits can be successfully manufactured by supplementation with AW.

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استخدام الشرش الحامضي في تصنيع مثلجات لبنية منخفضة الدسم

أحمد محمود عصر[1]*، أسامة صفوت فوزي خليل[2]، محمد عابد غنيمة[3]

[1] قسم علوم وتكنولوجيا الألبان، كلية الزراعة والموارد الطبيعية، جامعة أسوان، مصر.
[2] قسم علوم الألبان، كلية الزراعة، جامعة بنى سويف، مصر.
[3] قسم علوم الألبان، كلية الزراعة، جامعة كفر الشيخ، مصر.

الملخص

الهدف من هذه الدراسة تقييم تأثير إضافة الشرش الحامضي (AW) إلى مخلوط المثلجات اللبنية على العديد من خصائص المثلجات اللبنية المنخفضة الدسم. تم تجهيز مخاليط المثلجات اللبنية باستخدام لبن فرز، وقشدة بقرى طازجة، والمثبت والمستحلب، والسكر. تم تحضيرستة معاملات على النحو التالي: مخلوط كامل الدسم (6 % دهن) ومنخفض الدسم (1.5 % دهن) بدون إضافة شرش حامضي مع اعتبار ان المعاملة المنخفضة الدسم معاملة للمقارنة (كنترول). تم تحضير المعاملات منخفضة الدسم T1، T2، T3، T4 بإضافة 30، 40، 50، 70 % من الماء المقطر المستخدم بالشرش الحامضي، على التوالي. أوضحت النتائج أن استخدام الشرش الحامضي أدى إلى تغييرات معنوية في الخصائص الفيزيائية لمخاليط وعينات المثلجات اللبنية منخفضة الدسم. أظهرت المعاملة الكاملة الدهن مقاومة للانصهار أعلى من عينات معاملات المثلجات اللبنية منخفضة الدسم. اختلف المحتوى من المعادن معنويا بين معاملات المثلجات اللبنية حيث أدى استخدام الشرش الحامضي بنسب عالية إلى زيادة معنوية في محتوى الكالسيوم والفوسفور والمغنيسيوم في عينات المثلجات اللبنية منخفضة الدسم، في حين احتوى الآيس كريم كامل الدسم أقل قيم من هذه المعادن. تميزت عينة الكنترول بأعلى درجات تقييم حسي، بينما لم تكن هناك أي اختلافات معنويه في درجات النكهة بين المعاملات T1، T2، T3. في حين سجلت المعاملة T4 أقل درجات تحكيم حسي.

الكلمات المفتاحية: *الشرش الحامضي، الخواص الطبيعية، المحتوى المعدني، الجودة، مثلج لبنى منخفض الدسم.*