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# ผลของการใช้เวย์โปรตีนไอโซเลท และซอยโปรตีนไอโซเลทเป็นสารทดแทนไขมันต่อคุณสมบัติทางเคมีกายภาพ และคุณสมบัติทางประสาทสัมผัสของไอศกรีมช็อคโกแลตไขมันต่ำ

## Effects of Whey Protein Isolate and Soy Protein Isolate as Fat Replacers on the Physicochemical and Sensory Properties of Low-Fat Chocolate Ice Cream

สุภาวิณี แสนทวีสุข[1*] และ นันทพร อัคนิจ[2]

Supawinee Saentaweesuk[1*] and Nuntaporn Aukkanit[2]

*[1]สาขาวิชาวิทยาศาสตร์และเทคโนโลยีการอาหาร คณะวิทยาศาสตร์และเทคโนโลยี มหาวิทยาลัยราชภัฏพระนครศรีอยุธยา*

*[2]สาขาวิชาวิทยาศาสตร์และเทคโนโลยีการอาหาร คณะวิทยาศาสตร์และเทคโนโลยี มหาวิทยาลัยราชภัฏสวนสุนันทา*

*[1] Division of Food Science and Technology, Faculty of Science and Technology, Phranakhon Si Ayutthaya Rajabhat University*

*[2] Division of Food Science and Technology, Faculty of Science and Technology, Suan Sunandha Rajabhat University*

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## บทคัดย่อ

งานวิจัยนี้มีวัตถุประสงค์เพื่อศึกษาผลของสารทดแทนไขมันเวย์โปรตีนไอโซเลท และซอยโปรตีนไอโซเลท ต่อคุณสมบัติทางเคมีกายภาพ และคุณสมบัติทางประสาทสัมผัสของไอศกรีมช็อคโกแลตไขมันต่ำ โดย ศึกษาการใช้สารทดแทนไขมันที่ระดับแตกต่างกัน 3 ระดับคือร้อยละ 0.4, 2.5 และ 5.0 โดยน้ำหนัก พบว่าการใช้สารทดแทนไขมันทำให้ไอศกรีมมิกซ์มีความหนืดเพิ่มสูงขึ้น เมื่อลดปริมาณไขมันในสูตรลงมีผลทำให้อัตราการละลายเพิ่มขึ้น ส่วนค่าโอเวอร์รันมีแนวโน้มลดลง โดยเมื่อไขมันในสูตรที่ระดับเดียวกันการใช้ซอยโปรตีนไอโซเลทจะให้ค่าโอเวอร์รันสูงกว่าการใช้เวย์โปรตีนไอโซเลท ($p \leq 0.05$) จากการวิเคราะห์เนื้อสัมผัส พบว่าตัวอย่างที่ใช้ซอยโปรตีนไอโซเลทมีค่าความแข็งมากกว่าตัวอย่างที่ใช้เวย์โปรตีนไอโซเลท และสูตรควบคุม ปริมาณของแข็งทั้งหมดมีแนวโน้มเพิ่มขึ้นเมื่อใช้สารทดแทนไขมันเพิ่มขึ้น โดยตัวอย่างที่ใช้เวย์โปรตีนไอโซเลทเป็นสารทดแทนไขมันที่ระดับไขมันในสูตรร้อยละ 5.0 โดยน้ำหนัก มีค่าปริมาณของแข็งทั้งหมดสูงที่สุด ($p \leq 0.05$) การใช้เวย์โปรตีนไอโซเลททำให้ตัวอย่างมีค่า pH ต่ำกว่าการใช้ซอยโปรตีนไอโซเลท สำหรับการประเมินทางคุณภาพทางประสาทสัมผัส พบว่าตัวอย่างที่ใช้สารทดแทนไขมันเวย์โปรตีนไอโซเลท ที่ระดับไขมันในสูตรที่ระดับร้อยละ 2.5 และ 5.0 โดยน้ำหนัก ได้รับคะแนนความชอบในทุก ๆ ด้านใกล้เคียงกับสูตรควบคุมมากที่สุด ($p > 0.05$) งานวิจัยนี้พบว่าไอศกรีมช็อคโกแลตที่มีไขมันในสูตรร้อยละ 2.5 โดยน้ำหนัก โดยใช้เวย์โปรตีนไอโซเลทเป็นสารทดแทนไขมันเป็นสูตรที่มีศักยภาพในการพัฒนาเป็นผลิตภัณฑ์ไอศกรีมช็อคโกแลตไขมันต่ำ โดยมีคุณสมบัติทางเคมีกายภาพ และทางประสาทสัมผัสที่ใกล้เคียงสูตรควบคุม และยังเป็นที่ยอมรับของผู้บริโภค

**คำสำคัญ** : ไอศกรีมไขมันต่ำ; สารทดแทนไขมัน; เวย์โปรตีนไอโซเลท; ซอยโปรตีนไอโซเลท; คุณสมบัติทางเคมีกายภาพ

## Abstract

This research aimed to study the effects of whey protein isolate (WPI) and soy protein isolate (SPI) as fat replacers on the physicochemical and sensory properties of low-fat chocolate ice cream. The fat levels of the ice cream mix were altered at three different concentrations: 0.4, 2.5, and 5.0% (w/w). Experimental results showed that the use of fat replacers increased the viscosity of the ice cream mix. When the fat content was reduced, the melting rate increased, while the overrun tended to decrease. At the same level of fat content, the use of SPI yielded higher overruns ($p \leq 0.05$) than the use of WPI. Texture measurements showed that SPI samples had higher hardness ($p \leq 0.05$) than the WPI samples and the control formula. The total solid content tended to increase with the use of higher content fat replacers. Samples at 5.0% fat containing WPI as a fat replacer showed the highest total solid content ($p \leq 0.05$). The use of WPI resulted in a lower pH than the use of SPI. Sensory evaluation of the sample ice cream showed that using WPI fat replacers in 2.5% and 5% fat yielded sensory characteristics similar to the values of the control sample ($p > 0.05$). In this case, the properties of low-fat chocolate ice cream with WPI in 2.5% fat were found to most closely resemble the properties of the control sample.

**Keyword** : low-fat ice cream; fat replacers; soy protein isolate; whey protein isolate; physicochemical properties

*Corresponding author. E-mail : supawinee.saen@gmail.com

## Introduction

Nowadays, customers focus on their health and interest in low-fat food products because they can reduce the risk of diseases such as obesity and coronary heart disease (Akalin *et al.*, 2008). Generally, fat is essential in ice cream, as it gives the ice cream its viscosity and affects its flavor, smooth texture, and glossiness (Syed *et at.*, 2018). It is well known that milk and butter products, the main ingredient in ice cream, increase cholesterol levels in the bloodstream. They have been implicated in many diseases, such as cardiovascular disease, high blood pressure, diabetes, and thyrotoxicosis. Therefore, the ice cream products containing these ingredients are less prevalent. Instead, low-fat and low-energy ice creams have been created (Adapa, 2000). Devereux *et al.* (2003) reported that texture is more important than flavor in evaluating the overall acceptability of low-fat products. Decreasing the fat in ice cream directly affects the texture of the ice cream; that is, it makes ice cream less smooth, crumbly, shrinks, and changes its flavor (McClements, 2015). Such ice cream melts faster and has low texture quality, which is unacceptable to customers (Hatipoğlu and Türkoğlu, 2020). To improve quality of low-fat ice cream, fat replacers are used to imitate the functional properties of fat. For example, the viscosity of the ice cream mix controls the growth of ice crystals and water splitting (Gibis *et al.*, 2015). Using fat replacers incorrectly in ice cream products will affect product quality due to the fat effect on ice cream features, including taste, texture, or melting rate (Salem *et al.*, 2016). Selecting the appropriate type and volume of emulsifier and stabilizer for low-fat ice cream affects the viscosity, overrun, melting rate, and sensory attributes of ice cream and makes the product harden with a suitable freezing temperature (Moeenfard and Mazaheri, 2008).

Fat replacers are divided into three groups according to the raw material used in their production: fat, protein, and carbohydrate (Tiwari *et al.*, 2015). Lipid-based fat replacers contain emulsifiers or structured lipids. Carbohydrate-based fat replacers include modified starches, maltodextrins, cellulose derivatives, and inulin (Akbari *et al.*, 2019). Protein-based fat replacers are generally produced from concentrated whey proteins (Goff and Hartel, 2013). The most preferred fat replacers used in ice cream products are protein-based and carbohydrate-based fat replacers (Tiwari *et al.*, 2015; Akbari *et al.*, 2016; Salem *et al.*, 2016). The protein-based fat replacers yield ice cream with a smooth and soft texture, a high overrun, slow melt, increased viscosity, and improved taste (Liu *et al.*, 2018). Many researchers have reported that the use of milk protein concentrate (MPC), whey protein concentrate (WPC), whey protein isolate (WPI), soy protein concentrate (SPC), and soy protein isolate (SPI) as substitutes for milk solid nonfat in the ice cream mix significantly increased the mixes' viscosity (Alvarez *et al.*, 2005; Dervisouglou *et al.*, 2005; Herald *et al.*, 2008; Mahdian and Karazhian, 2013). Yan *et al.* (2021) reported the use of soy protein hydrolysates with hydrolysis degree 4 (SPH4) and their xanthan gum (XG) blends as fat replacers in low-fat ice cream. Dervisoglu *et al.* (2005) revealed that SPC could be incorporated into the ice cream formula in the range of

1.5%–3%, without significantly affecting the physical, chemical, and sensory properties of the product. Akalin *et al*. (2008) indicated that using inulin and WPI in low-fat and reduced-fat ice cream led to increased hardness of the product in comparison with conventional (10% fat) ice cream.

The objectives of this study were to evaluate the suitability of using two protein-based fat replacers, including WPI and SPI, in the quality of low-fat chocolate ice cream and to determine the most appropriate type and amount of fat replacer for such ice cream formulations that would satisfy the pleasure of customers with a health focus.

## Methods

*Materials*

Pasteurized milk with 0% fat and pasteurized cream with 35% fat were purchased from CP-Meiji Co., Ltd. (Saraburi, Thailand). Skim milk powder with 0% fat was procured from ISM Food products Co., Ltd. (Bangkok, Thailand). Cocoa powder was obtained from Sino-Pacific Trading (Thailand) Co., Ltd. (Bangkok, Thailand). Dextrose monohydrate, maltodextrin and fat replacers, including whey protein isolate (WPI) and soy protein isolate (SPI) were received from Krungthepchemi Co., Ltd. (Bangkok, Thailand). Sucrose was procured from Thai multi-sugar industry (Kanchanaburi, Thailand). Stabilizer-emulsifier blends (SEP) and dark chocolate flavor were obtained from Miss Icecream Co., Ltd. (Bangkok, Thailand).

*Preparation of low-fat chocolate ice cream*

The fat content levels of the formula were adjusted at three different levels: 0.4, 2.5, and 5.0%, a formulation calculated using Pearson square. WPI and SPI were then used with a 30% fat replacer in cream (Table 1). The other dry ingredients were 10.58% sugar, 3.85% cocoa powder, 3.85% maltodextrin, 0.96% dextrose monohydrate, 0.38% stabilizer–emulsifier blend, and 0.1% dark chocolate flavor. Liquid ingredients were heated to 50 ± 2°C in a stainless steel pan placed in a water bath. The dry ingredients were weighed and added to the liquid ingredients and then stirred until melted. The mixes were batch pasteurized at 80 ± 2°C for 2 min and then blended for 2 min using a blender (model: W36, Moulinex, France). The ice cream mixes were cooled in an ice bath to 4°C. Following the addition of a dark chocolate flavor, all mixes were aged at 4 ± 2°C for 24 h. The ice cream mixes were transferred into a hard ice cream maker with a compressor (model 48845, UNOLD, Germany). Freezing took 45 min before having 50 g portions filled into plastic cups and hardened at -20 ± 2°C for 24 h before the analyses.

*Table 1* Ice cream mix formulations.

| Levels of fat (% w/w) | Milk with 0% fat (%) | Cream with 35% fat (%) | Fat replacer (%) |
|---|---|---|---|
| 0.4 | 72.24 | 0.84 | 0.25 |
| 2.5 | 67.86 | 5.22 | 1.57 |
| 5.0 | 62.64 | 10.38 | 3.10 |
| 8.5 (Standard formula) | 53.85 | 19.23 | - |

*Physicochemical analysis*

After aging, the pH values of the ice creams mixes were measured using a pH meter (model Lab 855, SI Analytics, Germany). The total soluble solids (TSS) of the ice creams mixes were evaluated using a hand refractometer (model: N1, Atago, Japan), and the viscosity of the ice creams mixes were determined using a viscometer (model: DV-2P R, Anton Paar, Austria) at 10 ± 2°C with a spindle number of R2 and rotation speed of 1,000 rpm, read the value 30 s, after rotated. Fat content was investigated using the Roese-Gottlieb method based on AOAC (2019); method 989.05.

The overrun was measured by comparing the weight of the ice cream mix and ice cream in a fixed-volume container and determined using the formula of Pon *et al.* (2015).

$$Overrun\ (\%) = \frac{weight\ of\ liquid\ ice\ cream - weight\ of\ ice\ cream}{weight\ of\ ice\ cream} \times 100$$

The melting rate was examined according to Liu *et al.* (2018). The ice cream (50 ± 1 g at -20°C) was placed on a wire grid with 250 mm of melting beaker at ambient temperature (25°C). The melting rate was monitored using a thermocouple commencing when the ice cream had a temperature of -10 ± 1°C at 1 cm depth from the ice cream surface. The melting ice cream was weighed every 10 min in 1 h. The weight of the melted ice cream was expressed as a percent of the total weight of the initial ice cream. The recorded data were used to calculate the melting rate (100 g/min)

Texture analysis was conducted at ambient temperature (25°C) using a texture analyzer (Brookfield: CT3, USA), equipped with a 25.4 mm diameter cylindrical probe with (TA11). Ice cream samples were transferred to -10°C, 24 h before analysis. The conditions for analysis were as follows: penetration distance = 10 mm; the movement speed of cylindrical probe before testing, during testing, and after testing was 2.0, 1.0, and 1.0 mm/s respectively. The ice cream, remaining in the plastic cup, was penetrated in two places on its largest smooth surfaces. Hardness was measured as the peak compression force (N) during penetration into the sample.

The color of the ice cream was determined using a color meter (model: XE Pluse, MiniScan, USA). The analysis was repeated three times. The results were reported as an average value in the CIE system, with L*, a*, and b* indicating lightness, redness, and yellowness, respectively.

*Sensory evaluation*

A sensory evaluation of the low-fat chocolate ice cream was performed by 50 untrained-panelists. Ice cream samples were taken from frozen storage (-20°C) 24 h after hardening and promptly offered to the testers. The evaluation focused on color, flavor/taste, smoothness, gumminess, meltability, and overall acceptability. All samples were compared to the control chocolate ice cream (8.5% fat), and the results were recorded as scores ranging from 1 to 9 (9 = like very extremely, 8 = like very much, 7 = like moderately, 6 = like slightly, 5 = neither like nor dislike, 4 = dislike slightly, 3 = dislike moderately, 2 = dislike very much, and 1 = dislike extremely), as prescribed by Phianmongkhol *et al*. (2012).

*Statistical analysis*

The means and standard deviations (means ± S.D.) of the data were calculated from independent triplicate determinations of duplicate samples in the same batch. Analysis of variance (ANOVA) was carried out using SPSS software version 23 (SPSS Inc., Chicago, Illinois, USA). Differences among the treatment means were compared using Duncan's multiple range tests ($p \leq 0.05$)

**Results**

*Physicochemical properties*

The results of the physicochemical properties of ice cream samples are shown in Table 2. Using a fat replacer with low-fat chocolate ice cream increased viscosity, especially with SPI in low-fat chocolate ice cream, which showed 428.50–1959.77 cP. By comparison, viscosity in chocolate ice cream with WPI was 347.45–1840.02 cP. The highest viscosity among the samples was observed in the ice cream mix with 5% fat, and the ice cream mixes with SPI had significantly ($p \leq 0.05$) higher viscosity than ice cream mixes with WPI and the standard formula. In the graph of melting rate, the sample with SPI fat replacer in 2.5% fat had the lowest slope (Figure 1). The overrun of the standard formula was 33.34%, which was higher than other reduced fat ice creams ($p \leq 0.05$). In term of a texture profile analysis, the hardness values of all the samples were ranged between 70.25 to 98.68 N. Low-fat chocolate ice cream with SPI was substantially harder than those with WPI. The hardness of 0.4% fat WPI chocolate ice cream was 70.25 N and the value was significantly lower than the standard formula ($p \leq 0.05$).

Regarding the results in Table 3, the results illustrated that ice cream incorporated with fat replacers in 5% fat had a higher TSS than the standard formula, and the difference was statistically significant ($p \leq 0.05$). At 0.4, 2.5, and 8.5% fat (standard), TSS of both WPI and SPI as fat replacers were not statistically different ($p \leq 0.05$). TSS tended to increase when filling the fat replacer. The result of pH measurement in chocolate ice cream showed that samples containing WPI ranged between 6.56 and 6.70, which was lower than the pH of the standard formula ($p \leq 0.05$). The pH of samples with WPI was lower than those of samples with SPI ($p \leq 0.05$).

The color parameters of the low-fat chocolate ice cream are shown in Table 4. The $L^*$ values ranged from 24.95 to 37.33. The standard ice cream resulted in the highest $L^*$ value, and the value was significantly higher than those of the others ($p \leq 0.05$). The a* values of all samples were red (positive), ranged from 9.14 to 10.97. The a* values of samples with WPI and SPI as fat replacers in the 2.5% and 5.0% fat were not significantly different ($p>0.05$). The a* values of 0.4% fat samples with WPI and SPI were significantly different from the other samples ($p \leq 0.05$), with a* values of 10.97 and 10.57, respectively. The b* values of all samples were yellow (positive), ranged from 10.45 to 14.20. The b* values of 0.4% fat samples with WPI and SPI were not different with the standard sample ($p>0.05$). The b* values of the standard formula and 0.4% fat chocolate ice cream with WPI and SPI were 12.45, 12.85, and 12.96, respectively.

*Table 2* The effects of fat replacers and levels of fat on viscosity, overrun, melting rate and hardness of chocolate Ice cream.

| Fat replacer | Levels of fat(%w/w) | Viscosity (cP) | Overrun (%) | Hardness (N) |
|---|---|---|---|---|
| WPI | 0.4 | $347.45 \pm 9.98^{f}$ | $23.69 \pm 0.45^{b}$ | $70.25 \pm 19.73^{b}$ |
| | 2.5 | $393.42 \pm 22.27^{e}$ | $16.37 \pm 2.29^{d}$ | $76.10 \pm 2.45^{ab}$ |
| | 5.0 | $1840.02 \pm 38.55^{b}$ | $14.62 \pm 0.96^{d}$ | $79.52 \pm 8.99^{ab}$ |
| SPI | 0.4 | $428.50 \pm 24.34^{e}$ | $24.41 \pm 2.65^{b}$ | $87.92 \pm 8.75^{ab}$ |
| | 2.5 | $825.23 \pm 48.71^{c}$ | $20.55 \pm 1.62^{c}$ | $90.06 \pm 19.23^{ab}$ |
| | 5.0 | $1959.77 \pm 65.77^{a}$ | $19.38 \pm 2.60^{c}$ | $98.68 \pm 8.54^{a}$ |
| Standard formula | 8.5 | $710.32 \pm 22.47^{d}$ | $33.34 \pm 0.85^{a}$ | $76.45 \pm 11.04^{ab}$ |

Data within column followed by different letters are significantly different ($p \leq 0.05$).

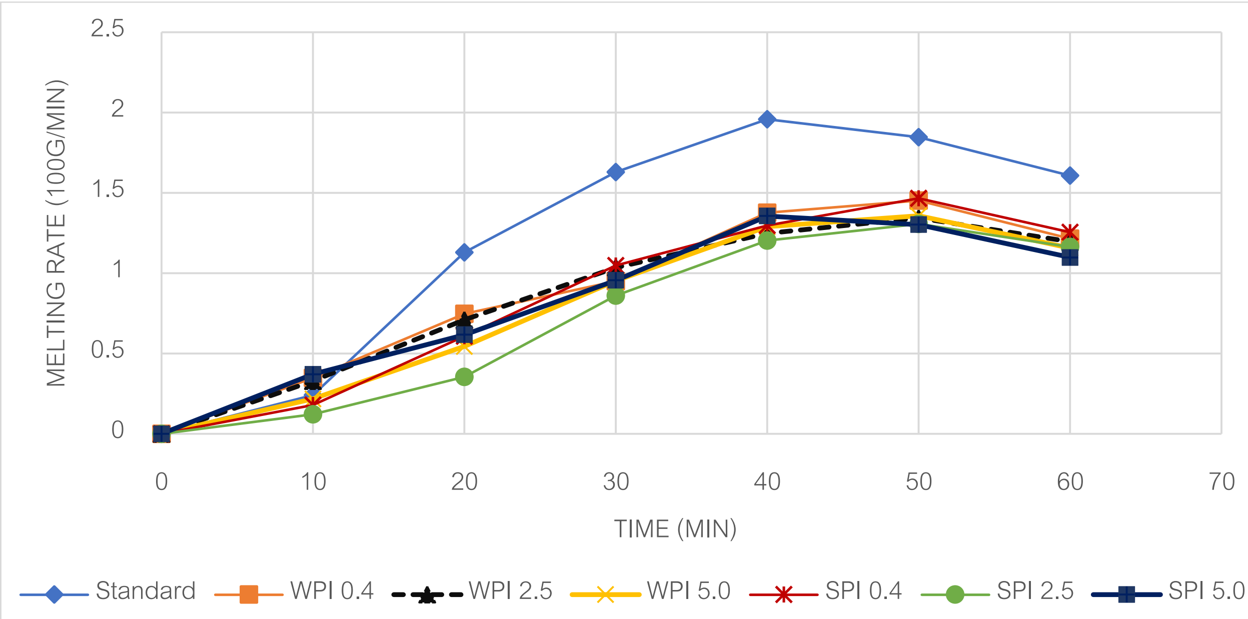


*Figure 1* The melting rate of chocolate ice cream containing fat replacers at three levels of fat.

*Table 3* The effects fat replacers and levels of fat on fat content, total soluble solid and pH of chocolate Ice cream.

| Fat replacer | Levels of fat (%w/w) | Fat content (%) | TSS (%Brix) | pH |
|---|---|---|---|---|
| WPI | 0.4 | 0.59 $\pm$ 0.12[d] | 33.67 $\pm$ 0.52[c] | 6.70 $\pm$ 0.04[b] |
| | 2.5 | 2.53 $\pm$ 0.02[c] | 35.17 $\pm$ 0.41[c] | 6.60 $\pm$ 0.05[c] |
| | 5.0 | 5.05 $\pm$ 0.07[b] | 40.17 $\pm$ 3.49[a] | 6.56 $\pm$ 0.03[c] |
| SPI | 0.4 | 0.57 $\pm$ 0.09[d] | 34.83 $\pm$ 0.75[c] | 6.71 $\pm$ 0.03[b] |
| | 2.5 | 2.69 $\pm$ 0.18[c] | 35.00 $\pm$ 0.63[c] | 6.73 $\pm$ 0.02[ab] |
| | 5.0 | 5.10 $\pm$ 0.07[b] | 36.83 $\pm$ 0.41[b] | 6.75 $\pm$ 0.08[ab] |
| Control | 8.5 | 8.58 $\pm$ 0.02[a] | 34.33 $\pm$ 0.52[c] | 6.78 $\pm$ 0.05[a] |

Data within column followed by different letters are significantly different ($p \leq 0.05$).

*Table 4* The effects of fat replacers and levels of fat on color of chocolate ice cream.

| Fat replacer | Levels of fat (%w/w) | L* | a* | b* |
|---|---|---|---|---|
| WPI | 0.4 | 27.55±0.91[d] | 10.97±1.44[a] | 12.85±0.91[bc] |
| | 2.5 | 29.19±0.51[c] | 9.14±0.77[b] | 10.45±1.12[d] |
| | 5.0 | 32.94±1.84[b] | 9.61±0.67[b] | 11.00±0.96[d] |
| SPI | 0.4 | 24.95±1.96[e] | 10.57±0.48[a] | 12.96±0.70[bc] |
| | 2.5 | 27.63±1.79[d] | 9.83±0.37[b] | 13.54±0.84[ab] |
| | 5.0 | 28.02±0.79[cd] | 9.76±0.53[b] | 14.20±0.69[a] |
| Standard formula | 8.5 | 37.33±2.05[a] | 9.34±0.90[b] | 12.45±1.73[c] |

Data within column followed by different letters are significantly different ($p \leq 0.05$).

*Sensory Properties*

Sensory properties of the ice cream samples was performed, as shown in Table 5. The samples with WPI in 2.5 and 5.0% fat had all sensory characteristics close to those of the control sample and no statistically significant differences ($p > 0.05$). The samples with WPI received a smoothness score close to the control sample and greater than the sample with SPI. In terms of the overall acceptance, the standard formula scored the highest at 8.00, which was not different in low-fat ice cream with WPI in 5.0% fat (7.86; $p > 0.05$). The low-fat ice cream with WPI in 0.4, 2.5, and 5.0% fat had overall acceptance scores of 7.08, 7.25, and 7.86, respectively. With SPI, the overall acceptance scores were lower, recorded as 6.67, 6.60, and 5.58, with fat content 0.4, 2.5, and 5.0% respectively.

*Table 5* Sensory evaluation of low-fat chocolate Ice cream mixes and chocolate Ice cream containing fat replacers at three levels of fat.

| Fat replacer | Levels of fat (%w/w) | Color | Flavor | Smoothness | Gumminess | Melting | Overall acceptance |
|---|---|---|---|---|---|---|---|
| WPI | 0.4 | 7.14±1.05[b] | 7.20±1.32[b] | 7.08±1.34[bc] | 6.40±1.65[c] | 7.26±1.23[b] | 7.03±1.40[b] |
| | 2.5 | 7.56±1.16[ab] | 7.55±1.07[ab] | 7.25±0.81[b] | 7.13±1.29[ab] | 7.65±1.08[ab] | 7.67±1.04[a] |
| | 5.0 | 7.69±1.10[a] | 7.56±1.20[ab] | 7.86±1.15[a] | 7.56±1.33[a] | 7.73±1.17[ab] | 7.85±1.11[a] |
| SPI | 0.4 | 7.20±1.18[b] | 7.20±1.36[b] | 6.67±1.32[c] | 6.80±1.36[bc] | 7.20±1.43[b] | 7.03±1.32[b] |
| | 2.5 | 7.06±1.36[b] | 6.36±1.50[c] | 6.60±1.52[c] | 5.71±1.90[d] | 6.13±1.81[c] | 6.02±1.79[c] |
| | 5.0 | 6.47±1.57[c] | 5.71±1.80[d] | 5.58±1.85[d] | 5.27±1.77[d] | 5.24±1.76[d] | 5.22±1.65[d] |
| Standard formula | 8.5 | 8.02±0.94[a] | 7.89±0.96[a] | 8.00±0.91[a] | 7.62±1.26[a] | 7.96±1.04[a] | 8.13±0.79[a] |

Data within column followed by different letters are significantly different ($p \leq 0.05$).

## Discussion

This study explored the effect of fat replacers on the quality characteristics of low-fat chocolate ice cream by comparing the use of WPI and SPI as fat replacers. In term of physicochemical properties, the viscosity rate tended to increase when the fat recipe was soared. This is similar to the findings by Akesowan (2009) and Phianmongkhol *et al*. (2012), who found that using soy protein and whey protein as fat replacers led to a pronounced increase in the viscosity of dairy ice cream product. This may be explained as water-binding property of WPI and SPI with liquid components to form a gel-like network to modify the rheology of the ice cream. The properties of WPI and SPI, both of which are highly water-absorbing, viscous, and melt resistant. Taha *et al*. (2019) revealed that the adsorbed protein at the oil/water interface of SPI emulsion was higher than WPI emulsion. Thus, SPI could absorb water and form gel better than WPI, thus the viscosity of samples incorporated with SPI were higher than WPI (Table 2). Furthermore, we found that increasing the fat content in the formula, which increases viscosity. Akin *et al*. (2007) reported that fat helps to increase the amount of solid in ice cream mixture and improve mix viscosity, air incorporation, body, texture, and melting properties. When fat content was higher, the level of viscosity increased. This increased viscosity could have been the primary reason for decreased whipping abilities.

Overrun in ice cream is mainly the functionality of milk proteins, emulsifiers, and to certain extent milk fat (Sharma *et al*., 2017). A high overrun is related to high foam expansion and foam stability. The viscosity in ice cream must be appropriate for a good overrun. Too much or too viscosity does not yield good ice cream products. The results of the overrun are summarized in Table 2. Highest overrun was observed for the standard formula ice cream. Using WPI and SPI as fat replacers in low-fat ice cream decreased overrun values. Overrun values for samples with WPI were lower than SPI samples ($P \leq 0.05$). Mahdian and Karazhian, (2013) stated that surfactants like milk protein and some emulsifiers as well as stabilizers improved whipping trait and decreased the size of air cells where fat and other emulsifiers had negative effect on overrun because the foam volume depends on protein concentration. According to the results of the study, at the same fat level, the overrun was higher with SPI than with WPI as a fat replacer. Overrun is the percentage of ice cream that is air incorporated into the product as it expands during the freezing process. It is an important indicator that affects the melting behavior, structure, texture, and sensory properties of ice cream (Yan *et al.*, 2021). Hatipoğlu and Türkoğlu (2020), concluded that the overrun tends to decrease when increasing the fat value. Sharma *et al.* (2017) revealed that the lower overrun was correlated with the increased viscosity. The ingredient of ice cream with more fat may result in slower fluid movement. Furthermore, fat may absorb the protein on the ice cream surface: more fat volume results in increased absorption of protein. More fat also results in increased viscosity (Akin *et al.*, 2007). Decreasing the fat content has an impact on expanding the melting rate due to the fat becoming gauze with surrounding bubbles, thereby increasing the melting resistance (Yan *et al.*, 2021). When the viscosity increases in mixed ice cream, it can reduce the melting rate (Herald *et al*., 2008). Increasing the viscosity may improve the ice cream with a smooth texture. Warren and Hartel (2018) found that fat affects viscosity. Therefore, using ingredients with a higher fat content may result in higher viscosity and slow melting. Using whey protein in ice cream may reduce viscosity and result in lower resistance to melting (Balthazar *et al*., 2017).

Many studies have shown that the hardness of ice cream is affected by many factors, such as fat content, TSS, viscosity of ice cream mix, overrun, bubble size, and distribution, but the main influencing factor is the gas-holding capacity of ice cream (Akalin *et al*., 2008; Rossa *et al*., 2012). Akbari *et al*. (2019) reported that the hardness of ice cream is inversely related to fat content because fat reduction decreases the overrun and increases the formation of ice crystals. In this study, SPI as a fat replacer could increase hardness to a higher extent compared to WPI and the standard formula because SPI has a higher water-absorbing ability. Thus, more effort will be needed to deform low-fat ice cream with SPI compared to the standard sample. The hardness of ice cream is related to overrun—that is, when the overrun is low, hardness increases in ice cream (Yan *et al*., 2021).

TSS tended to increase when the fat replacers were added. The increase in TSS affected the ice cream texture. Higher content of TSS resulted in the softer ice cream (Akbari *et al*., 2019). Furthermore, Dervisoglu *et al*. (2005) found that ice cream with low TSS increases the melting rate more than that with high TSS because with low TSS, there is less water absorption, which increases free water and consequently the ice content. Ice cream with more free water melts faster (Pon *et al*., 2015). The pH of samples with WPI was lower than those of samples with SPI ($p \leq 0.05$). However, WPI originates from the acid sedimentation method, which affects the pH of liquid ice cream. When the ratio increased, the pH also decreased.

Samples with fat replacers had significantly lower lightness (L*) than the standard sample. The ice cream was influenced by the yellowness of WPI and SPI. The ice cream color was darker or had a lower *L** value due to the inclusion of fat replacer. In particular, the SPI fat replacer, which was dark yellow, led to a significantly different L* value compared to the sample with WPI ($p \leq 0.05$). According to Dervisoglu *et al*. (2005), filling strawberry ice cream with SPC resulted in lower physical, chemical, and sensory properties than in the control sample.

In term of sensory evaluation, using WPI as a fat replacer were more acceptable than those using SPI. With increased SPI on low-fat chocolate ice cream, the color scores were clearly reduced because SPI conferred a darker yellow than WPI. The dark yellow of SPI affected the ice cream sensory evaluation, resulting in low scores. WPI flavor is similar to milk flavor. We found that with SPI as a fat replacer, the chocolate flavor score also decreased and was lower in the most-liked score due to the SPI flavor sample overshadowing the chocolate flavor. The low-fat chocolate ice cream using WPI as a fat replacer had an increased score with increasing fat content because fat increased the flavor of the ice cream. This finding was similar to the report by Hatipoğlu and Türkoğlu (2020), who found that vanilla-flavored ice cream with increased fat content received better flavor scores. According to Balthazar *et al.* (2017), fat improves ice cream flavor as it melts in the mouth. This is also different with various fat amounts. Most flavoring agents are good at melting in the mouth and evaporate into the olfactory system. Less fat is not suitable as a flavoring agent and evaporates quickly. Hence, low-fat ice cream had lower flavoring agents and lower flavor scores. However, WPI has functional groups such as disulfide bonds, which can absorb water and reduce free water in ice cream. Furthermore, viscosity prevents crystal nuclei movement in ice cream, which becomes a small ice crystal, thereby increasing smoothness (Balthazar *et al.*, 2017). SPI can absorb and create a gel, which decreases free water, resulting in a coarse texture and more pressure than WPI and control sample. These properties result in lower smoothness scores, reduced fat, and a coarse texture in ice cream. The samples with WPI received a smoothness score close to the control sample and greater than the sample with SPI. Thus, WPI resulted in an improved ice cream texture. The gumminess and melting in the mouth were correlated. Therefore, the scores of these sensory variables tended in the same direction. When the viscosity of ice cream increased, it seemed to become gummy, with decreased melting in the mouth, which is considered one of the defects in ice cream (Espinoza *et al*., 2020).

In this study, using WPI as a fat replacer increased fat volume and resulted in a higher overall acceptance score than ice cream with low-fat content. Using SPI as a fat replacer yielded samples with more fat content and lower scores than a low-fat sample due to more fat and more soy protein. The results of the sensory evaluation showed that SPI affected the overall acceptance scores, with more SPI resulting in lower, smoothness, color, flavor, pleasure, viscosity, and melting in the mouth scores. The results of physicochemical and sensory measurements of WPI and SPI in 0.4, 2.5, and 5.0% low-fat chocolate ice cream and compared with standard formula (8.5% fat) showed that the values with WPI in 2.5 and 5.0% fat ice cream samples were close to the control sample.

## Conclusion

Using SPI as a fat replacer in ice cream affected viscosity, overrun, color, hardness, and pH, which tended to be higher than using WPI as a fat replacer. Using WPI as a fat replacer in chocolate ice cream resulted in a smoother texture and slower melt compared to ice cream added with SPI and standard formula. Ice cream with 2.5 and 5% fat with WPI as a fat replacer showed the similar sensory characteristics to the standard sample. Therefore, the 2.5% fat chocolate ice cream with WPI had the greatest potential to develop low-fat chocolate ice cream products with physicochemical and sensory properties closest to the control sample and acceptable by the customers.

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