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Original Article

Sucrose-substituted and protein-enriched peanut milk ice cream for elderly: Chemical, physical and sensory properties

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Abstract

A peanut milk (PM) ice cream was developed for the elderly with addition of pea protein isolate (PPI, 2%, 3%, and 4%). The 4% PPI achieved the highest protein content (5.31%), with significantly enhanced total solids and viscosity, as well as reduced overrun compared to the lower protein levels ($p<0.05$). Acceptance testing among elders ($n=50$) showed that the 4% PPI sample gained the highest flavor (7.4±1.4) and overall liking scores (8.09±0.7). Furthermore, replacing 12% sucrose of the PM ice cream with 0.68% monk fruit extract + 11.75% inulin (MF+I), 0.03% stevia + 12.37% inulin (S+I), or 6.2% fructose + 6.2% inulin (F+I) showed that F+I was most similar to the control in physical properties and received the highest mouthfeel (7.5±1.3) and overall liking (7.5±1.4) scores. Additionally, all mixes exhibited pseudoplastic flow. The PPI and F+I combination produced a good source of protein and reduced-sugar PM ice cream suitable for elderly consumers.

Keywords: elderly acceptability, inulin, pea protein isolate, peanut milk ice cream, sweetener

1. Introduction

Thailand has become a completely aging society (Tejativaddhana, Chyakhamfoo, & Vo, 2022) and will reach "super-aged" status by 2031, with 28% of the population over 65 years old (Kantachote & Wiroonsri, 2023). Aging typically leads to muscle loss (sarcopenia), decreased bone density, reduced immune function, digestive issues, and loss of appetite, which can be worsened by inadequate protein intake (Bauer *et al*., 2013). Additionally, high sugar consumption in elderly is related to immediate and long-term health issues, including elevated triglycerides, cholesterol, joint inflammation, and metabolic problems (DiNicolantonio, Lucan, & O'Keefe, 2015).

Ice cream is considered a potential nutritional vehicle for the elderly in hospitals and care facilities (Spence, 2019). It also offers emotional comfort and promotes social interaction, enhancing overall quality of life (Drewnowski & Evans, 2001). However, ice cream designed for the elderly must have appropriate levels of fat, sugar, protein, and essential nutrients to support their health (Houston, Nicklas, & Zizza, 2009).

Plant-based milk is a suitable option for addressing fat concerns, as it is free from cholesterol and contains healthy unsaturated fats. Peanuts (*Arachis hypogaea*) are rich in protein (~25–28 g/100 g), essential fatty acids, and bioactive compounds that provide several health benefits such as lowering cholesterol, supporting weight management, and exhibiting anticancer properties (Rafiq & Ghosh, 2017; Toomer, 2017). Although, the protein content of peanut milk is reduced due to dilution during aqueous extraction, typically ranging from 2.0%-3.3% (Jain, Yadav, Rajput, & Bhatt, 2011; Sakthi, Meenakshi, Kanchana, & Vellaikumar, 2019), it can still be comparable to that of cow's milk (3.0%-3.5%) (Lajnaf, Feki, Attia, Ayadi, & Masmoudi, 2022). Additionally, replacing sucrose with alternative sweeteners may also help lower the risk of chronic diseases, making ice creams a health-promoting option. Ozdemir, Dagddemir, Ozdemir, and Sagdic (2008) found that ice cream for diabetic patients made with maltitol, sorbitol, and high fructose corn syrup had lower viscosity, overrun, and three times less glucose than the sucrose control. Stevia substitution reduced viscosity and increased overrun and melting rate while improving sensory acceptance (Alizadeh, Lalabadi, & Kheirouvris, 2014).

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Additionally, Fuangpaiboon and Kijroongrojana (2015) developed low glycemic index coconut milk ice cream with a blend of 4% erythritol, 7% inulin, and 21.5% fructose, which showed similar physical, thermal, and sensory properties to the control (12% sucrose).

Substituting non-fat dry milk or skimmed milk powder with soy protein concentrate (Dervisoglu, Yazici, F, & Aydemir, 2005), soy protein isolate (Akesowan, 2009), or pea protein isolate (Guler-Akin, Avkan, & Akin, 2021) improved ice cream viscosity, melting, and hardness, though higher amounts negatively impacted overrun and sensory properties.

However, research on plant-based ice cream for elderly consumers is limited. This study aimed to formulate protein-fortified PM ice cream and replace sucrose with natural alternative sweeteners that would meet the consumer acceptability.

2. Materials and Methods

2.1 Preparation of protein supplemented peanut milk (PM) ice cream

The liquid ingredients contained 74.8% PM, 10% coconut milk [Thai Agri Foods, Thailand], and 0.2% vanilla extract [Greenhill Co., Ltd., Thailand]. The dry ingredients consisted of 2, 3, or 4% PPI [Bright Infinity Co., Ltd., Thailand], 12.4% sugar, 0.2% guar gum [Chemipan Co., Ltd., Thailand], and 0.2% mono-diglyceride [Value Industrial Product Co., Ltd., Thailand]). From our preliminary study, 2% milk solid-not fat in the formulation was replaced with 2% PPI, which was used as the control. The ice cream was prepared as presented in Figure 1.

2.3 Preparation of sucrose-substituted PM ice cream

The PM and ice creams were prepared according to Figure 1, except that extraction time of the PM was increased to 4 min, in order to make the protein content reach ~3%. The control and sucrose substitution samples were formulated to gain a similar sweetness at 12.4% sucrose equivalent **(**SE**)** as shown in Table 1.

2.4 Analyses

2.4.1 Rheological properties

Rheological characteristics of the ice cream mix were measured with a rotational rheometer (DHR-2, TA Instruments, USA) using a cup and bob geometry at 4 °C. A logarithmic flow sweep and apparent viscosity determination were performed at a shear rate of 100 to 1 s^{-1} and 50 s^{-1}, respectively. The flow behavior was described by the Oswald-de Waele power-law model (Fuangpaiboon & Kijroongrojana, 2015).

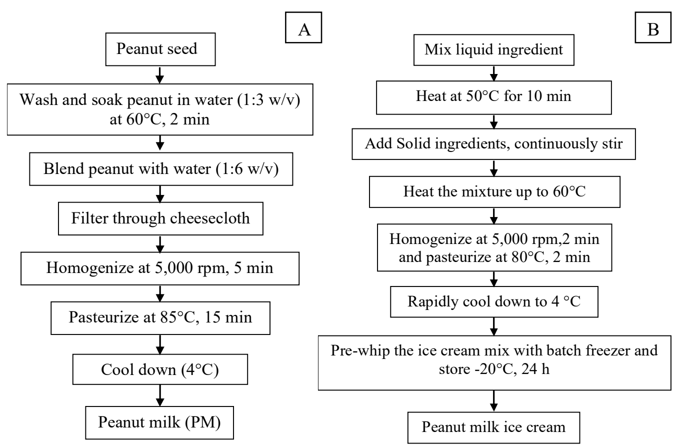

Figure 1. Flow diagram of PM (A), and ice cream production (B)

Table 1. Formulations of PM ice creams with different sweetener blends

Ingredient	Control	MF+I	SV+I	F+I
PM	73	73.2	73.2	73.2
Coconut milk	10	10	10	10
Pea protein isolate	4	4	4	4
Sucrose	12.4	-	-	-
Monk fruit extract (MF)	-	0.65	-	-
Stevia (S)	-	-	0.031	-
Fructose (F)	-	-	-	6.2
Inulin (I) (DP=10)	-	11.75	12.369	6.2
Guar gum	0.2	-	-	-
Mono-diglycerides	0.2	0.2	0.2	0.2
Vanilla extract	0.2	0.2	0.2	0.2

2.4.2 Overrun

Overrun was calculated with the following formula (Whelan, Vega, Kerry, & Goff, 2008):

$$\% \text{ Overrun} = [(\text{weight of mix} - \text{weight of ice cream}) \times 100] / \text{weight of ice cream}$$

2.4.3 Hardness

Ice cream hardness was measured as the peak force during 10 mm penetration by a cylindrical probe (SMSP/6) into the center of a sample tempered at 26±2 °C, 1 min at 2 mm/s using a texture analyzer (Soukoulis, Rontogianni, & Tzia, 2010).

2.4.4 Melting rate

An 80 g frozen sample was placed on a wire mesh at 26 ± 2 °C, and the melt loss was recorded every 10 min for 120 min. The percentage of mass loss was plotted over time, and the maximum melting rate was defined as the steepest slope of the melting curve (Whelan *et al*. 2008).

2.4.5 Chemical composition

The protein content was assayed using the Kjeldahl method, and Total solids, Total sugar and reducing sugar, and fat content of PM ice cream were determined according to AOAC (2000).

2.4.6 Acceptance test

Acceptance test was performed according to Fuangpaiboon and Kijroongrojana, (2015). The appearance, taste, smell, texture, and overall acceptability of ice cream were judged by 50 panelists aged 60 or older in Songkhla province using a 9-point Hedonic scale. The study received ethical approval from the Health Science Human Research Ethics Committee of Prince of Songkhla University **(**64-039-1-1**)**.

The sucrose-substituted formulation with the highest overall acceptance score was chosen for the proximate analysis according to AOAC (2000).

2.5 Statistical analysis

The entire study used a completely randomized design (CRD), except in the acceptance test, where a randomized complete block design (RCBD) was implemented. Analysis of variance (ANOVA) was applied for all the data. Duncan's multiple range test for mean comparison and Pearson's correlation were performed using the SPSS software (version 28, SPSS Inc., Chicago, IL, USA).

3. Results and Discussion

3.1. Effect of protein addition on PM ice cream quality characteristics

3.1.1 Chemical properties

The components that influenced the protein amount of PM ice cream samples were PPI, PM, and coconut milk contributing 84%, 1.6%, and 1% protein, respectively. PPI provided a significant source of protein that was positively correlated with the concentration ($r = 0.830$, $p < 0.05$) (Figure 2A). As expected, the ice cream fortified with 4% PPI had the highest protein content (5.31%) accounting for 10.6% of Recommended Daily Intake (RDI), and can be classified as "a good source of protein" (U.S. Food and Drug Administration, 2023). However, our preliminary study found that the addition of PPI at levels beyond 4% resulted in gel formation in the mix, which negatively affected the texture of ice cream.

The dry ingredients in the ice cream formulations (17%) made up the majority of the TS (Figure 2B). Furthermore, the solids content is mostly raised by PPI. The 4% PPI sample had the highest total solids ($p<0.05$), while those with 2% and 3% PPI were not different from each other.

3.1.2 Physical properties

The viscosity increased with PPI addition ($p<0.05$) (Figure 3A). The proteins are able to bind water and form a more stable gel matrix (Boye, Azre, & Pletch, 2009). Moreover, the proteins are usually adsorbed at the fat and air interfaces to provide stability, while the rest become concentrated in the serum phase and contribute to higher viscosity (Goff & Hartel, 2012).

The flow behavior of ice cream mixes was characterized by the consistency coefficient (K), which reflects the presence of colloidal particles within the mix. Incorporation of PPI resulted in a higher consistency coefficient (Figure 3B), likely due to its more compact molecular structure that requires greater shear stress to attain an equivalent shear rate.

Flow behavior (n) values of all mixes ranged from 0.60 to 0.72 (Figure 3C) demonstrating the degree of pseudoplasticity of a fluid ($n<1$).

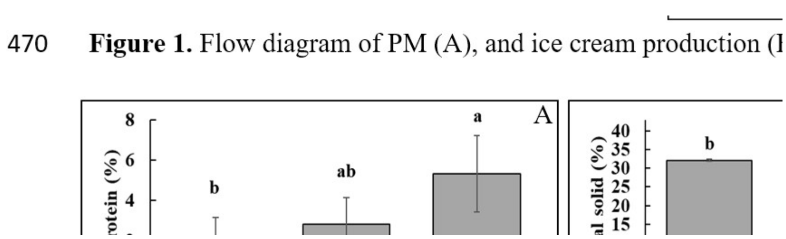

Figure 2. Protein (A), and Total solids content (B) in PM ice cream added with different levels of pea protein isolate. Different letters indicate significant differences ($p < 0.05$). Bar represents standard deviation (n=3).

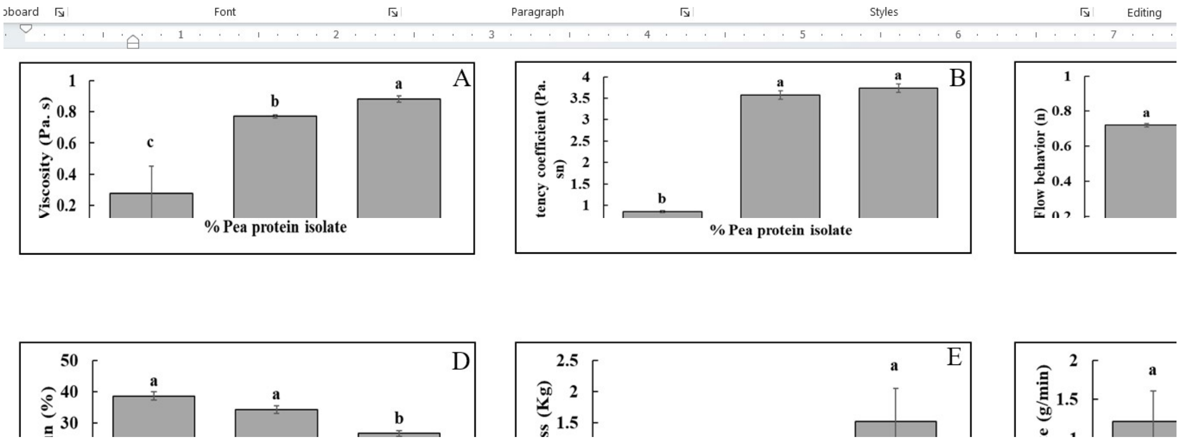

Figure 3. Physical properties of PM ice cream added with different levels of pea protein isolate: (A) Viscosity*, (B) Consistency coefficient*, (C) Flow behavior index*, (D) Overrun*, (E) Hardness**, and (F) Melting rate*. Different letters indicate significant differences ($p < 0.05$). Bar represents standard deviation (*n=3, **n=10).

Figure 3D demonstrates that the samples with 2% PPI had the highest overrun (38.6%) ($p<0.05$). Overrun had a negative correlation with % PPI added, as the very high-viscosity gel matrix may hinder air incorporation during the freezing process (Sivasankari *et al*., 2019).

The hardness of ice creams increased with increasing PPI (Figure 3E) ($p<0.05$), likely due to the protein's high water-holding capacity and the formation of a more rigid structure, resulting in a harder texture (Mutlu, Cooke, & Dimos, 2021). Moreover, Wilbey, Cooke, and Dimos (1998) reported that lower overruns contributed to increased hardness. The results aligned with Akesowan (2009), who found that the addition of soy protein and chickpea flour also increased the ice cream hardness.

The sample with 4% PPI had the lowest melting rate ($p<0.05$), while those with 2% and 3% were not significantly different. Increased mix viscosity likely resulted in a denser, more stable structure that reduced the melting rate (Marshall, Goff, & Hartel, 2012). Similarly, Klahorst (1997) reported a negative correlation between the melting rate and TS 20-40%, as a high solids content enhanced structure and improved melting resistance.

3.1.3 Acceptance test

The acceptance test (Figure 4) showed no significant differences in color, texture, and mouthfeel liking scores across all samples ($p\geq0.05$). Nevertheless, the samples with 4% PPI received the highest flavor and overall liking scores, possibly due to the consumers' preference for the strong nutty flavor of PPI.

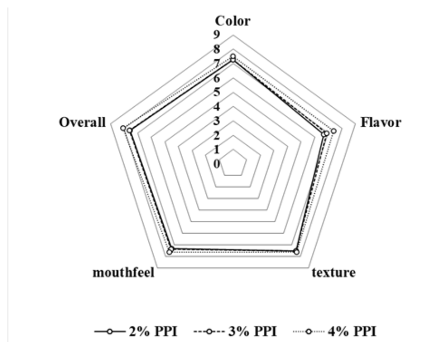

Figure 4. Acceptance scores of the PM ice creams with different levels of pea protein isolate

3.2 Effect of sucrose substitution PM ice cream qualities

3.2.1 Chemical properties

TS of the ice cream samples ranged from 28.00 to 31.74 (Figure 5A). The lower TS in samples containing MF and F+I was due to the lower content of solid ingredients in the formulation (Table 1). Moreover, TS is influenced by several factors, such as density and water absorption, solubility, dispersion and sweetener concentration (Akbari, Eskandari, Davoudi, & Nasiri, 2016; Franck, 2002; Guggisberg, Cuthbert-Steven, Piccinali, Bütikofer, & Eberhard, 2009). The role of sweeteners in ice cream production is crucial, influencing both flavor and physical properties (Baer & Baldwin, 1984). Choice of sweetener blend significantly impacted reducing sugar levels ($p<0.05$). Reducing sugar in the sample with F+I was the highest (5.93±0.16%), while those with MF+I (0.86±0.02%) and S+I (0.90±0.01%) were approximately four times lower than the control (sucrose) (3.86±0.07%) ($p<0.05$). This aligned with Fuangpaiboon and Kijroongrojana (2015) who revealed that the coconut ice cream with fructose+inulin had the highest reducing sugar when compared with other sweetener blends (sucrose, erythritol+fructose+inulin, and xylitol+inulin). Reducing sugars such as fructose, glucose, and galactose, possess free aldehyde or ketone groups (Pratt & Cornely, 2013), acting as reducing agents. However, the total sugar content of ice cream added with sweetener blends, mostly from inulin, was slightly lower than the control ($p<0.05$). Quantitative measurement of total sugar involves the oxidation of aldoses to aldonic acids (BeMiller & Huber, 2007). During acid hydrolysis, inulin can be cleaved into D-

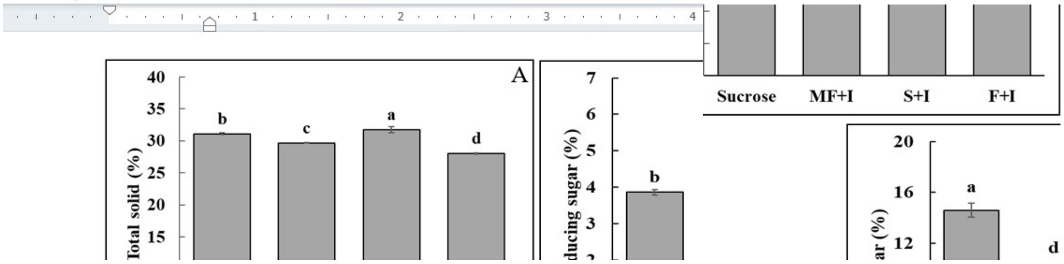

Figure 5. Total solids (A), Reducing sugar (B), and Total sugar (C) of PM ice creams with different sweetener blends. MF: monk fruit extract, S: stevia, F: fructose and I: inulin. Different letters indicate significant differences (p<0.05). Bar represents standard deviation (n=3).

fructose and glucose, classified as a ketose and an aldose, respectively, which both affect total sugar measurement (Fuangpaiboon & Kijroongrojana, 2015). Therefore, the sample with partial replacement of sucrose with a F+I effectively reduced total sugar content by approximately 50%, which can be classified as "reduced-sugar" ice cream (U.S. Food and Drug Administration, 2023). This reduction could lower the postprandial glycemic response compared to sucrose on a per-serving basis, supporting better blood glucose management and reducing the risk of type 2 diabetes (Huang *et al.,* 2023). Inulin further contributes soluble dietary fiber that slows glucose absorption, promotes beneficial gut microbiota, and improves insulin sensitivity (Wang *et al*., 2019; Zhang *et al*., 2020).

3.2.1 Physical properties

The control exhibited a higher viscosity than the cases with sweetener blends (Figure 6A), mainly due to the presence of guar gum in its formulation. Guar gum, a galactomannan polysaccharide, significantly increases viscosity even at low concentrations due to its molecular structure and weight (440,000 to 650,000 Da) allowing strong molecular interactions. It also exhibits shear-thinning behavior, where the viscosity decreases as the shear rate increases, aiding the smooth processing and texture stability of ice cream (Casas, Mohedano, & García-Ochoa, 2000). Our preliminary study showed that inulin from the sugar blend sample has the ability to form a strong gel matrix. Therefore, adding guar gum to these formulations resulted in over-gelation, which led to an undesirably hard texture and affected the melting properties. As a result, guar gum was intentionally omitted to achieve a balanced and acceptable texture. However, the control sample without guar gum (0.25±0.01 Pa. s) had a higher viscosity than the sweetener blend samples, except for that with F+I. This was due to the crystallization of sucrose and the formation of a more concentrated structure. (Clarke, 2004; Porto, 2025). Inulin addition resulted in gel formation after freezing, due to cryogel formation, polymeric gels formed through radical polymerization in aqueous solutions at zero temperatures. During this process, most of the water freezes, concentrating the dissolved monomers in non-frozen regions where polymerization occurs (Altunbaş, Uygen, Uygen, Akgöl, & Denizl, 2013). For the consistency coefficient, the high-viscosity mixes indicate more *K* (Karaca, Guven, Yasar, Kaya, & Kahvaoglu, 2009). The control had the highest *K* (p<0.05), followed by samples with F+I, S+I, and MF+I. The *n* values of all mixes ranged from 0.65 to 0.91, indicating typical shear thinning behavior (*n*<1). Rheology is affected by many factors including sweetener molecular size, water-holding capacity, the degree of polymerization, and branching of polysaccharides (Marshall, Goff, & Hartel, 2003; Soukoulis *et al*., 2019). Moreover, the presence and concentrations of other components like fats, polysaccharides, and proteins, as well as phenomena such as protein aggregation, fat crystallization, and the coalescence or flocculation of fat droplets also influence the rheological properties (Goff, Davidson, & Cappi, 1994; Nor Hayati, Che Man, Tan, & Nor Aini, 2007; McClements, 1999).

The overrun had a positive correlation with viscosity (r=0.979, p<0.05). In ice cream production, higher mix viscosity helps trap and stabilize air bubbles, resulting in higher overrun during the freezing and whipping process (Clarke, 2004). Thus, the ice cream becomes lighter and more aerated ice cream (Martínez *et al*., 2020). Azari-Anpar, Khomeiri, Ghafouri-Oskuei, and Aghajani (2017) reported also that increased viscosity resulted in higher overrun, which improved the texture and volume of the low-fat ice cream using resistant starch and maltodextrin. Furthermore, Sert, Mercan, and Kilinc (2005) revealed that low-viscosity mixes produced smaller air cells and reduced overrun in buffalo milk ice cream. Moreover, the higher overrun tended to correlate with lower hardness (r=-0.98, p<0.05) (Figure 6E). Increased air incorporation reduced the density, resulting in a soft texture of ice cream (Muse & Hartel, 2004; Sofjan & Hartel, 2004; Wilbey *et al*., 1997).

Additionally, the control sample had the highest melting rate (1.12 g/min) followed by F+I (0.97 g/min), while MF+I and S+I samples showed the lowest rate and did not melt due to gel structure formulation. This effect is stronger in formulations with lower overrun, as seen in the MF+I and S+I samples which had a dense structure. Sofjan & Hartel (2004) revealed that the lower overrun cases melted faster than those with higher overrun. Inulin has been shown to form cryogels in ice cream as described previously (El-Nagar, Clowes, Tudorică, Kuri, & Brennan, 2002). Whelan *et al*. (2008) noted that the melting rate was influenced more by hardness than internal structure. Inulin addition improved texture and stability, resulting in slower melting rates and enhanced structural integrity (Guggisberg, Cuthbert-Steven, Piccinali, Bütikofer, & Eberhard, 2009).

3.2.3 Acceptance test

The acceptance test (Figure 7) showed no significant differences in color, flavor, and texture liking

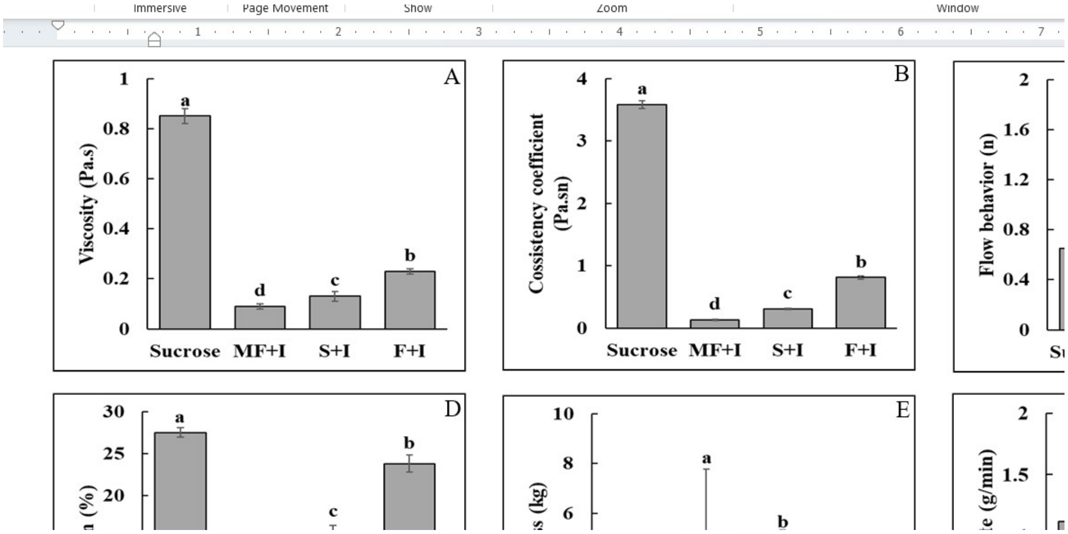

Figure 6. Physical properties of PM ice creams with different sweetener blends: (A) Viscosity*, (B) Consistency coefficient*, (C) Flow behavior index*, (D) Overrun*, (E) Hardness**, and (F) Melting rate*. MF: monk fruit extract, S: stevia, F: fructose and I: inulin. Different letters indicate significant differences (p<0.05). Bar represents standard deviation (*n=3, **n=10).

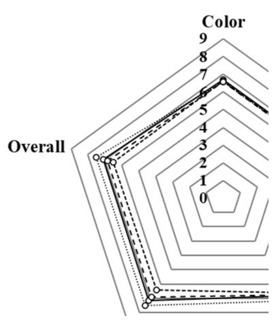

Figure 7. Acceptance scores (n=50) of the PM ice creams with different sweetener blends

scores for the ice creams made with different sweetener blends ($p \geq 0.05$). Despite the different hardnesses of the samples observed (Figure 6E), the texture liking score was unaffected. However, significant differences were found in mouthfeel and overall liking scores ($p<0.05$). F+I and MF+I samples had similar scores to the control, while S+I was scored the lowest ($p<0.05$). High inulin content could increase mouth coating and reduce the sweetness (Fuangpaiboon & Kijroongrojana, 2015), while stevia can produce a cooling sensation that may be undesirable in creamy products (Prakash, Dubois, Clos, Wilkens, & Fosdick, 2008).

3.2.4 Proximate composition of the final product

The proximate analysis of the F+I PM ice cream showed 7.62% protein, 10.66% fat, 10.76% carbohydrate, 0.56% ash, and 70.47% moisture, providing 168.59 kcal per 100 g. The ice cream qualifies as a "good source of protein" under Food Labeling guidelines (U.S. Food and Drug Administration, 2023.) It provides ~15% of the daily protein and fat requirements and ~8% of the daily energy requirement (2000 kcal) for an elderly individual (WHO, 2004), indicating the ice cream's suitability for elderly.

4. Conclusions

This study demonstrated that fortifying ice cream with PPI effectively enhances its protein content for elderly consumers. The 4% PPI formulation achieved the highest flavor and overall liking scores. Additionally, replacing sucrose with F+I formulation reduced total sugar by 50% compared to the control, maintained desirable physical characteristics, and received the highest acceptance scores from elderly panelists. According to the Food labeling regulations, this combination can be classified as a good source of protein and reduced-sugar ice cream suitable for elderly consumers without compromising sensory quality.

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Author Contributions

Nattakorn Promvikorn: Investigation, Formal analysis, Writing - Original draft. Kongkarn Kijroongrojana: Conceptuation, Methodology, Supervision, Writing - Reviewing and Editing.

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