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The effect of soya curd substitution for milk on physical and sensory properties of vanilla gelato product

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Abstract: The investigation was aimed to evaluate the physical (total solids, melting rate, viscosity, and overrun) and sensory properties of vanilla gelato (VG) made by substituting soya curd (SC) for milk. Samples were VG without SC (F_0) and with SC, i.e. 25% (F_1), 50% (F_2), and 75% (F_3). Each sample criterion consisted of 5 repetitions (n = 20). Results showed that F_3 possessed the lowest total solids, viscosity, and overrun while its melting rate was the highest among other SC substitution levels ($P < 0.05$). The sensory test delineated that F_3 had a less soft texture, although its aroma and flavour were not different from others ($P < 0.05$). Thus, the greater portion of SC substitution for milk in the VGmaking process would substantially affect the physical properties of its final product in which the total solids, viscosity, and overrun were lower while the melting rate was higher. Substituting SC for milk in VG did not affect the sensory properties, except the texture. The higher SC amount used for milk substitution would result in VG with a less soft texture. SC at a certain level of substitution was potentially expected as an innovation of the phyto-gelato product, namely soy gelato.

Keywords: dairy alternative; frozen dessert; organoleptic; attributes; plant-based formulation; textural quality

Gelato is a type of ice cream originating from Italy and now it is widely spreading in Indonesia. The development of the gelato industry has significantly increased ice cream consumption in Indonesia by approximately 20% per year due to the factors such as climate, urban lifestyle, and effective marketing strategies (Wijaya et al. 2023). While gelato and ice cream are both popular frozen desserts, they differ significantly in their composition and production methods. Gelato typically has lower fat content which contributes to its denser texture and richer flavour profile (Sukma and Jariyah 2022). It also has a lower overrun (air incorporation), resulting in a denser and creamier texture (Rinaldi et al. 2014), and contains fewer emulsifiers compared to traditional ice cream (Segall and Goff 2002). The sensory properties of gelato, such as taste, texture, and aroma, are often enhanced by the use of natural ingredients and lower fat content, which can improve consumer acceptability. Gelato has a lower fat content because it is made with milk as the primary ingredient, unlike ice cream, which is made with heavy cream (Goff and Hartel 2013).

Although gelato is milk-based, it still has high calorie content despite being a popular treat. Furthermore, lactose, which is present in cow's milk, can be harmful to certain individuals, particularly young children. A significant percentage of the global population suffers from lactose intolerance, a common condition in which the body is unable to digest lactose due to decreased lactase activity (Szilagyi and Ishayek 2018). All dairy products, including cheese, butter, milk-based candies, chocolate, and other dairy

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products, can trigger allergic reactions in individuals with milk allergies. For those with dairy allergies and lactose intolerance, soy milk serves as a viable alternative. Soy milk is a plant-based beverage that contains fewer calories and has protein content comparable to that of cow's milk, without the presence of casein. Compared to cow's milk, soy milk provides higher amounts of some nutrients such as folate, vitamin B12, and iron, while being lower in fat (Collard and McCormick 2021). According to Collard and McCormick (2021), soy milk contains approximately twice the amount of folate and vitamin B12 and half the fat of cow's milk. Due to its nutritional benefits, soy milk is commonly consumed by vegetarians and individuals with dairy allergies. Despite not being derived from animals, soy milk gets its name from its milky, white appearance. In comparison with cow's milk, soya curd offers additional nutritional benefits. Soya curd is rich in plant-based proteins, contains little to no cholesterol, and is an excellent source of higher quality amino acids, calcium and iron (Li et al. 2020). Although soy protein offers a plant-based alternative, it does not possess the same biological value as milk protein. Milk protein contains a more complete amino acid profile and has higher digestibility, which can influence the functional properties and nutritional outcomes of gelato formulations (Li et al. 2020). To meet the dietary needs of consumers, soy milk has emerged as a popular substitute for cow's milk in various food products, including ice cream and gelato (Bueno et al. 2018). A promising alternative to cow's milk in gelato production, soy-based gelato is made using soybean protein concentrate and water-soluble extract, resulting in unique characteristics related to protein content, solubility, viscosity, melting point, overrun, and acceptance (Savio et al. 2018). However, its application in gelato production has not been extensively explored. While existing research suggests promising acceptance of soy milk in ice cream, limited data are available on the physical characteristics that determine the final product quality.

Furthermore, while the chemical analysis of the basic composition of gelato variants, such as proteins, fats, dry matter, and nutritional value, could provide additional insights, this study focuses primarily on the physical and sensory characteristics of the formulated gelato. Previous research has extensively documented the fundamental composition of plant-based gelato ingredients (Savio et al. 2018; Li et al. 2020; Ng et al. 2024); thus, this study prioritises the formulation innovation and its impact on gelato quality. However, recognising the importance of chemical analysis in providing a more comprehensive understanding of the nutritional and structural aspects of the product, future studies should consider incorporating such analyses to enhance the product evaluation. This study investigates the potential of soya curd – created by coagulating soy milk with acids such as lemon juice or vinegar – as an alternative to cow's milk in gelato production. The objective is to develop high-quality plant-based gelato, including soy gelato, and to contribute to innovation in the frozen dessert industry.

MATERIAL AND METHODS

Preparation of soya curd (SC)

The preparation of SC followed the methodology described by Meyer (2016). Soybeans were washed thoroughly and soaked for 6 h until the epidermis was separated from the beans. The soaked soybeans were then blended and strained to obtain soy milk. The soy milk was heated to boiling, with pandan leaves added for flavour. The temperature was then lowered to 60 °C before adding a 5% vinegar coagulant. The coagulation process was allowed to proceed for 10 min to form curd, after which the mixture was filtered to separate the curd from the whey. After coagulation, the soya curd was transferred into fine-mesh cheesecloth to separate the whey. The curd was then subjected to manual pressing by applying uniform pressure using a weighted object for a specific duration. This process facilitated the removal of excess moisture while preventing excessive dehydration, ensuring a consistent texture and dry matter content. The controlled pressing method helped standardise the curd composition, which is crucial for maintaining uniformity in the final gelato formulation. The resulting soya curd was blended until it reached a smooth and creamy texture. The use of soya curd instead of liquid soy milk was chosen to provide a more stable texture in gelato, preventing excessive iciness and ensuring a creamier mouthfeel.

Preparation of gelato

Gelato was prepared following the procedure outlined by Goff and Hartel (2013). In this study, only a partial replacement of cow's milk with soya curd was implemented to maintain the desirable texture and flavour profile typically associated with dairy-based gelato. No complete replacement was performed to prevent potential alterations in the gelato

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structural integrity and sensory attributes, leading to undesirable changes in mouthfeel and overall acceptability. The partial substitution approach allows for an evaluation of the effect of soya curd on the physical and sensory properties of gelato while still ensuring that the product retains its characteristic creaminess and appeal.

The gelato formulation was divided into four variants with varying ratios of cow's milk and SC compositions, as detailed in Table 1. F_0 served as the control (0% soya curd), while F_1, F_2 and F_3 incorporated 25, 50 and 75% substitution of cow's milk with soya curd, respectively. Importantly, the substitution was calculated based on the dry matter content of soya curd rather than on a volumetric basis. This adjustment ensured consistency in total solids across all treatment groups and minimised discrepancies caused by the higher moisture content in soya curd. By standardising the solids content, the formulations allowed for a more reliable comparison of the effects of soya curd on gelato quality.

Each formulation consisted of milk (fully or partially substituted by SC), whipped cream, egg yolk, and sugar. These ingredients were blended and heated to 80 °C for 30 s, then cooled to 60 °C before tempering with a mixture of egg yolks and sugar. The mixture was then reheated to 70 °C for 2 min, then strained through a fine sieve into a bowl, covered, and chilled in the fridge at 4 °C for several hours or overnight. The chilled mixture was then processed in an ice cream maker for 30 min, producing a soft and dense gelato. Finally, the gelato was stored in a freezer to achieve a firmer texture before serving.

Experimental analysis

Physical properties of vanilla gelato. The physical characteristics of gelato were evaluated by measuring total solids, melting rate, viscosity, and overrun. Total solids were determined by drying the sample at 105 °C to constant weight, after which the ratio of the dried sample weight to the initial weight was calculated (Yu et al. 2017). Melting resistance was assessed by freezing 50 g of gelato for 4 h, and then measuring the time required for it to melt at room temperature (Lomolino et al. 2020). Viscosity was measured with a Brookfield DV-E viscometer (AMETEK Inc., USA) at 30 rpm, and results were recorded in Pascal-seconds (Pa·s). Overrun was calculated by comparing the volume and weight of gelato dough before and after the freezing process, with the overrun percentage determined by the weight difference relative to the initial dough weight (Sukma and Jariyah 2022).

Sensory properties of soy gelato. A sensory evaluation was conducted in this study to assess taste, texture, aroma, and overall acceptance (Sousa et al. 2019). This evaluation involved 25 semi-trained panellists who rated the gelato on a scale for each attribute. For taste, the scale was: 1 = unpleasant; 2 = somewhat pleasant; 3 = pleasant; and 4 = very pleasant. For texture, the scale was: 1 = not smooth; 2 = somewhat smooth; 3 = smooth; and 4 = very smooth. For aroma, the scale was: 1 = characteristic of soy; 2 = somewhat milky; 3 = characteristic of milk; and 4 = very milky. Overall preference was rated on a scale of: 1 = dislike; 2 = somewhat like; 3 = like; and 4 = very much like.

RESULTS AND DISCUSSION

Physical properties of soy gelato. The substitution of cow's milk with soya curd in gelato production significantly affects its physical properties, as observed in the variations of total solids, melting rate, viscosity, and overrun. Figure 1A shows that as the percentage of soya curd

Table 1. Formulation of gelato

Composition (%)	Treatment			
	F_0	F_1	F_2	F_3
Milk	68	51	34	17
Whipped cream	6	6	6	6
Egg yolk	10	10	10	10
Sugar	16	16	16	16
Soy curd (adjusted to dry matter equivalent)	0	17	34	51
Total	100	100	100	100

F_0, F_1, F_2 and F_3 – 0, 25, 50, and 75% dry matter-based replacement of milk by soya curd; the substitution of cow's milk with soya curd was calculated based on the dry matter content of soya curd to ensure consistency in total solids

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increases, the total solids content decreases due to its lower fat and protein composition. Figure 1B highlights a progressive increase in melting rate with higher soya curd substitution, likely caused by the protein influence on structure. Figure 1C reveals that viscosity decreases with the addition of soya curd, as cow's milk provides a fuller fat and protein profile, contributing to thickness. Lastly, Figure 1D illustrates a reduction in overrun as the fat content decreases with increased soya curd, limiting air incorporation. These results demonstrate how soya curd impacts the structural and textural characteristics of gelato, which is essential for developing non-dairy alternatives with desirable quality traits.

Based on the results of Figure 1A, F_0 had the highest total solids content, while F_1, F_2, and F_3 exhibited a progressive decrease, suggesting that the increased soya curd substitution lowers total solids content. This reduction is due to soya curd being a soy protein coagulated with low levels of fat, vitamins, minerals, and easily digestible protein. This finding aligns with Li et al. (2020), who noted that the nutritional composition of soya curd is slightly lower compared to other soy products. Total solids encompass all solid components within a food item, including proteins, fats, and carbohydrates, affecting overall texture and stability.

Figure 1B shows that the melting rate progressively increased with higher levels of soya curd substitution. F_0 (0% soya curd) exhibited the lowest melting rate, while F_3 (75% soya curd) had the highest. This trend indicates a faster melting process as the proportion of soya curd increases, since a higher melting rate corresponds to a shorter time required for the gelato to melt. This consistent upward trend across treatments suggests that soya curd substitution significantly weakens the gelato melting resistance. The observed increase in melting rate is likely due to structural changes caused by reduced fat content and by the altered protein network introduced by soya curd. Cow's milk, rich in fat and casein proteins, contributes to emulsion stability and stronger fat-protein interactions, which help retain air and water during melting. In contrast, soya curd contains less fat and different types of plant-based proteins that may lack the same emulsifying and stabilising properties. It results in a less stable gelato matrix that melts more

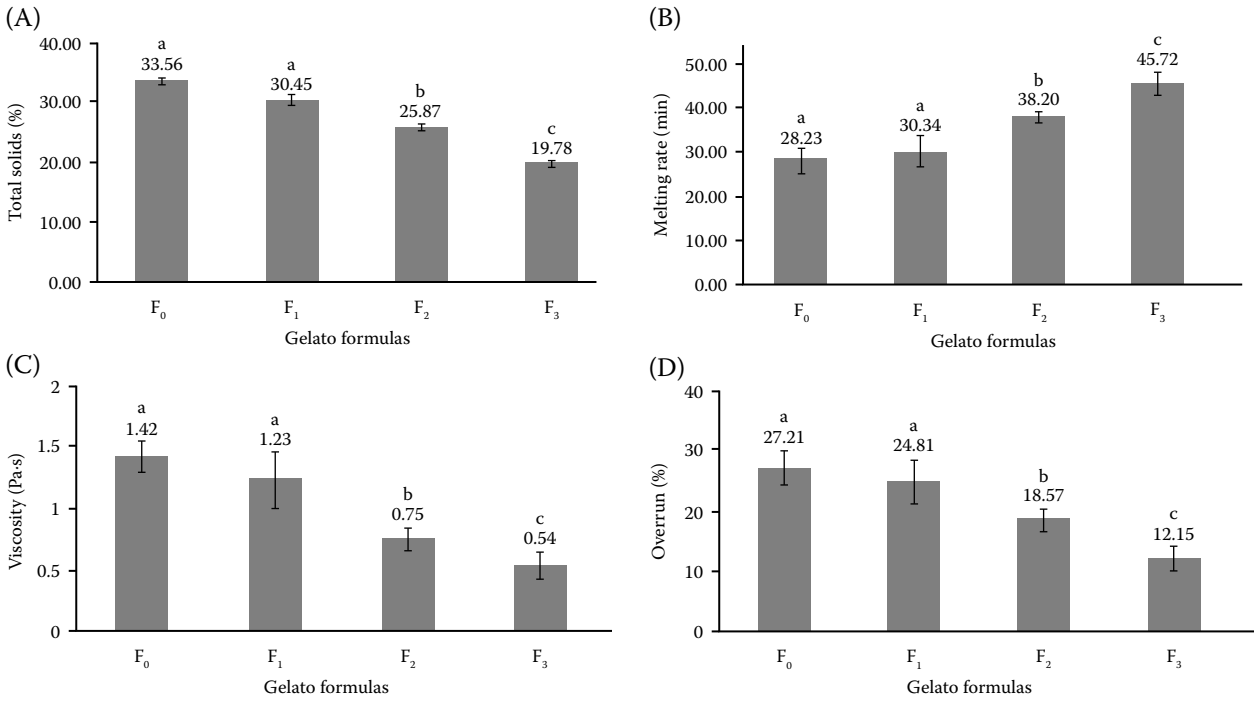

Figure 1. (A) Total solid (%) based on each treatment formula of soy curd substitution; (B) melting rate (min) based on each treatment formula of soy curd substitution; (C) viscosity (Pa·s) based on each treatment formula of soy curd substitution; (D) overrun (%) based on each treatment formula of soy curd substitution

Data were expressed as mean with standard deviation in error bars; F0, F1, F2, and F3 were various gelato formulas consisting of milk substitution by soya curd in 0, 25, 50, and 75% respectively; different lowercase letters above each value indicated significant differences between formulas ($P < 0.05$)

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quickly when exposed to room temperature. These findings are consistent with Daw and Hartel (2015), who reported that lower fat levels lead to faster meltdown in frozen dairy products due to diminished structural support and reduced water-binding capacity.

It is also important to clarify the terminology related to melting behaviour**.** Treatment F_0 exhibits the lowest melting rate, which corresponds to a lower melting point due to its higher fat content and stable structural matrix. Conversely, formulations with higher soya curd substitution (F_1 to F_3) show higher melting rates, associated with higher melting points. It may be attributed to the presence of more protein interactions in soya curd, which initially provide thermal resistance. However, due to the lower fat content, the structural integrity of the gelato is compromised, and once destabilised, it melts more rapidly. Thus, although the melting point may be slightly elevated due to protein content, the overall melting behaviour reflects a faster melting process due to the weaker fat-based structural support.

The viscosity test results, displayed in Figure 1C, indicate that F_0 has the highest viscosity due to its complete profile of fats, proteins, and carbohydrates. These results align with Tvorogova et al. (2022), who reported that whey protein concentrates and hydrolysates, when partially replacing non-fat milk solids in ice cream, affect the dynamic viscosity, beatability, thermal stability, and dispersion of air phase and ice crystals. The viscosity of ice cream mixture increased due to the presence of fat, protein, and other components in milk, enhancing total solids. Additionally, egg yolks, which contain lecithin, act as natural emulsifiers that further contribute to viscosity. Compared to commercial stabilisers or emulsifiers, egg yolks are considered a healthier alternative.

Figure 1D shows that overrun decreased progressively as the percentage of soya curd substitution increased. F_0 (0% soya curd) had the highest overrun, while F_3 (75% soya curd) exhibited the lowest. This decline in overrun can be attributed to the reduction in fat content, which limits the gelato ability to incorporate and retain air during the freezing process. Fat plays a critical role in air entrapment by stabilising air bubbles and forming a cohesive structure in the frozen matrix (Goff and Hartel 2013; Cheng et al. 2020).

Soya curd contains less fat and different emulsifying proteins compared to cow's milk, which may reduce its capacity to stabilise air cells during churning. Consequently, as the soya curd content increases, the formulation becomes less efficient at incorporating air, resulting in lower overrun values. Lower overrun also contributes to a denser product, which may influence the perceived mouthfeel and creaminess of the gelato (Savio et al. 2018). During freezing, the weight of the gelato remains constant, but the volume increases due to air incorporation. It results in a decrease in specific (relative) density. Understanding this dynamic is essential for evaluating the structural quality of frozen desserts (Goff and Hartel 2013). A well-balanced overrun contributes to desirable texture and melting characteristics, whereas excessively low overrun may produce a heavy, less palatable product.

Sensory properties of products. The sensory evaluation of soy gelato formulations reveals significant differences in taste, texture, aroma, and overall preference based on the level of soya curd substitution. As indicated in Table 2, the gelato made entirely from cow's milk (F_0) received the highest scores across all parameters, while increasing the soya curd content in F_1, F_2, and F_3 led to a decline in sensory attributes. Notably, F_1, with 25% soya curd, maintained similar sensory scores to F_0, indicating an acceptable flavour profile. However, higher levels of soya curd in F_2 and F_3 resulted in more pronounced beany flavours and a reduction in creaminess, though all formulations remained within an acceptable range for panellists.

Based on the research findings, treatment F_0 received the highest scores in all sensory parameters, followed by F_1, F_2, and F_3 in descending order. There was no significant difference between F_0 and F_1, suggesting that a 25% soya curd substitution does not significantly alter sensory attributes. However, treatments F_2 and F_3, containing 50 and 75% soya curd, respectively, exhibited a notable decline in sensory scores. Treatment F_0, composed entirely of cow's milk without any soya curd, was rated highest for its pleasant and milky taste, smoothest texture, and the most pronounced milky aroma. It can be attributed to the natural sweetness of lactose and the characteristic slightly salty taste contributed by chlorides, citrates, and other minerals present in cow's milk. Cow's milk is generally perceived as creamier and more viscous, whereas soy milk is often described as more astringent with distinct beany flavour (Wan et al. 2022). Additionally, the high fat content in cow's milk enhances the gelato smooth texture and intensifies its milky flavour.

In contrast, F_1, F_2, and F_3 exhibited progressively lower taste scores, corresponding with the increased presence of beany flavour and diminished milky aroma as the percentage of soya curd increased. Soya curd, made by the coagulation of soy protein, introduces off-flavours due to its volatile carbonyl compounds. The addition of acid coagulants to soy milk lowers its pH,

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Table 2. Evaluation on the sensory characteristic and hedonic of soya gelato

Sensory parameters	Gelato formulas				Criteria scales (1–4)
	F_0	F_1	F_2	F_3	
Taste	3.47 ± 0.46^{a}	3.31 ± 0.56^{a}	3.26 ± 0.61^{a}	3.08 ± 0.57^{b}	beany – milky flavor
Texture	3.52 ± 0.62^{a}	3.02 ± 0.18^{a}	2.71 ± 0.72^{b}	2.58 ± 0.86^{bc}	unspoonable – spoonable
Aroma	3.38 ± 0.47	3.31 ± 0.73	3.11 ± 0.55	3.01 ± 0.44	not milky – milky
Hedonic	3.62 ± 0.51^{a}	3.49 ± 0.69^{ab}	3.18 ± 0.68^{bc}	3.02 ± 0.76^{c}	unpreferable – preferable

Data was expressed as mean ± standard deviation (SD); F_0, F_1, F_2 and F_3 – 0, 25, 50, and 75% dry matter-based replacement of milk by soya curd; $^{a, b, c}$ superscripts showed significant differences between formulas ($P < 0.05$)

leading to protein aggregation and increased hydrophobicity, which contributes to undesirable flavours. This phenomenon, along with protein denaturation in soy milk, can trap flavour compounds and free amino acids, further leading to off flavours (Guo et al. 2019). The beany flavour of soya curd is primarily attributed to the oxidation of polyunsaturated fatty acids, such as linoleic acid, catalysed by the enzyme lipoxygenase when soybeans are exposed to air. This finding aligns with Yu et al. (2017), who reported that enzymatic oxidation is a major factor limiting the sensory appeal of soy-based products. Treatment F_3, containing the highest proportion of soya curd (75%), exhibited the coarsest texture and the weakest milky aroma due to its lower fat content and higher protein concentration. Goff and Hartel (2013) emphasised that fat is essential for achieving a creamy and smooth gelato texture.

The texture scores for F_1, F_2, and F_3 progressively decreased, indicating a softer texture with increasing soya curd content. This decline can be attributed to the reduction of total solids, as decreasing milk content and increasing soya curd lead to lower fat and nutrient levels. While soya curd is high in protein, it is relatively low in fat and other essential components that contribute to gelato creaminess and smooth mouthfeel (Chen et al. 2019). Regarding the aroma, no significant differences were detected between treatments, as milk remained a common ingredient in all formulations, thereby contributing to a milky aroma. However, the higher fat content in F_0 enhanced its milky aroma, whereas F_3, with the highest soya curd content, had the lowest aroma score due to the dominance of beany flavour.

As the proportion of soya curd increased, sensory parameter scores declined due to the presence of off-flavour compounds and the lower nutritional content of soya curd, which undergoes extensive processing. These factors may have affected the panellists' acceptance. A previous study also reported that increasing the soymilk content in cow's milk yogurt resulted in higher scores of textures, body, appearance, flavour, and acidity compared to yogurt made entirely from cow's milk (Abdulqadr et al. 2022). However, despite the observed differences, all sensory parameters remained within an acceptable range, ensuring that all formulations were still palatable to the panellists.

CONCLUSION

This study demonstrates that increasing substitution of cow's milk with soya curd in gelato formulations leads to lower total solids, viscosity, and overrun, along with a faster melting rate and reduced sensory quality. The decline in flavour and texture is consistent with the known properties of soy-based ingredients, where beany notes and reduced fat content typically lower the consumer preference. A 25% substitution maintained acceptable quality, but higher levels negatively impacted structure and palatability. Thus, soya curd can be used as a partial milk alternative, but the careful formulation is needed to balance nutritional and sensory outcomes.

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