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DEVELOPMENT AND QUALITY EVALUATION OF PLANT-BASED NON-DAIRY ICE CREAM USING SOY MILK WITH VARYING STABILIZER CONCENTRATIONS

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Abstract
Lactose intolerance affects approximately 75% of the global population, driving consumer demand for plant-based dairy alternatives. This study aimed to develop a non-dairy ice cream using 100% soy milk as a complete substitute for cow milk and to evaluate the effect of different stabilizer concentrations (0.1%, 0.2%, and 0.3%) on the physicochemical, physical, and sensory properties. Soy milk was prepared from soybeans by soaking, grinding, filtration, and boiling. Four treatments were formulated: T_0 *(control, cow milk with standard stabilizer),* T_1 *(100% soy milk + 0.1% stabilizer),* T_2 *(100% soy milk + 0.2% stabilizer), and* T_3 *(100% soy milk + 0.3% stabilizer). The ice cream samples were analyzed for fat, protein, moisture, ash, total solids, pH, overrun, meltdown time, and sensory attributes (color, taste, texture, aroma, overall acceptability) using a 7-point hedonic scale. Results showed that soy milk ice creams had significantly lower fat (6.8–7.2% vs. 10.5% in control) but comparable protein (3.5–3.8%). Moisture content was higher (64.0–66.5% vs. 62.0%), while ash content was slightly lower (0.65–0.67% vs. 0.70%). Overrun decreased with increasing stabilizer (70% in* T_0 *to 50% in* T_3*), whereas meltdown time increased (35 min in* T_1 *to 48 min in* T_3*). Sensory evaluation revealed that* T_3 *(0.3% stabilizer) received the highest scores among soy-based treatments for taste (7.8), texture (8.2), aroma (7.8), and overall acceptability (8.0), though all soy treatments scored lower than the dairy control. The study concludes that 100% soy milk can successfully replace cow milk in ice cream, and 0.3% stabilizer yields the best overall quality among the tested formulations.*

1. INTRODUCTION

Lactose intolerance and cow milk protein allergy affect about 75% of the world's population, leading to a growing demand for plant-based dairy alternatives (Rangel et al., 2016). The global market for plant-based dairy substitutes is expanding rapidly, with an expected increase from 7.4% to over 18.5% by 2023 (Pandalaneni et al., 2024). Consumers choose plant-based products for health, environmental sustainability, and ethical reasons (Alcorta et al., 2021). Among plant-based milks, soy milk is particularly promising because it contains high-quality protein (about 3.5%), a balanced amino acid profile, no lactose or cholesterol, and bioactive isoflavones that offer health benefits (Kundu et al., 2018; Olías et al., 2023).

Ice cream is a complex frozen dessert that requires stable emulsions, proper air incorporation, and controlled ice crystallization. Replacing dairy milk with plant milk poses challenges in texture, overrun, melting behavior, and sensory acceptance (McClements & Grossmann, 2022). Stabilizers play a key role in improving mix viscosity, preventing ice crystal growth, and enhancing melting resistance (Bahramparvar & Mazaheri Tehrani, 2011). Previous studies have explored partial substitution of dairy milk with soy milk (up to 50%), but limited information is available on formulations using 100% soy milk with varying stabilizer levels.

2. MATERIALS AND METHODS

2.1 Raw Materials

Soybeans, sugar, cream, skim milk powder, stabilizer/emulsifier (Cremadon, a commercial blend of mono-/diglycerides and stabilizers), vanilla flavor, and distilled water were purchased from local markets in Faisalabad, Pakistan. All ingredients were of food grade.

2.2 Preparation of Soy Milk

Soybeans were washed, weighed, and soaked in tap water for 18 hours at room temperature. The soaked beans were rinsed, drained, and ground with water in a 1:7 (w/v) ratio using a laboratory blender. The slurry was filtered through a muslin cloth, and the filtrate (soy milk) was boiled for 10 minutes to denature anti-nutritional factors and improve flavor. The composition of the prepared soy milk is presented in Table 1.

Table 1: Composition of prepared soy milk

Constituent	Value (%)
Moisture	88.0 ± 0.5
Ash	0.5 ± 0.02
Fat	2.5 ± 0.3
Protein	3.5 ± 0.2
Total solids	12.0 ± 0.6
Acidity	0.15 ± 0.01
pH	6.5 ± 0.05

2.3 Ice Cream Formulation

Four treatments were prepared as shown in Table 2. The control (T_0) was made from cow milk (100%) with standard stabilizer. All plant-based treatments used 100% soy milk with different stabilizer concentrations. The basic ice cream mix formulation (per 0.5 L) is given in Table 3.

Table 2: Treatment plan

Treatment	Milk type	Stabilizer concentration (%)	Description
T_0 (control)	Cow milk	Standard	Dairy-based control
T_1	Soy milk	0.1	Non-dairy
T_2	Soy milk	0.2	Non-dairy
T_3	Soy milk	0.3	Non-dairy

Table 3: Formulation of ice cream mixture (per 0.5 L)

Ingredient	Quantity
Soy milk (or cow milk in control)	300 mL
Cream	62.5 mL
Sugar	75 g
Skim milk powder	60 g
Stabilizer/emulsifier	2.5 g (adjusted to 0.1-0.3%)
Vanilla flavor	0.1%
Color	0.1%

2.4 Ice Cream Preparation

The ice cream mix was prepared by weighing all ingredients according to the treatment plan. The mixture was pasteurized at 80°C for 15 minutes to ensure microbial safety and then homogenized at 15 bar pressure using a laboratory homogenizer. After homogenization, the mix was aged at 4°C overnight (12–14 hours) to allow stabilizer hydration and fat crystallization. The aged mix was frozen and whipped in an ice cream maker (batch freezer) for 10–15 minutes until a semi-solid consistency was achieved. The partially frozen ice cream was filled into 100 g cups, hardened at −30°C for 24 hours, and stored at −18°C for further analysis. A flow diagram of the process is presented in **Figure 1** (adapted from the thesis).

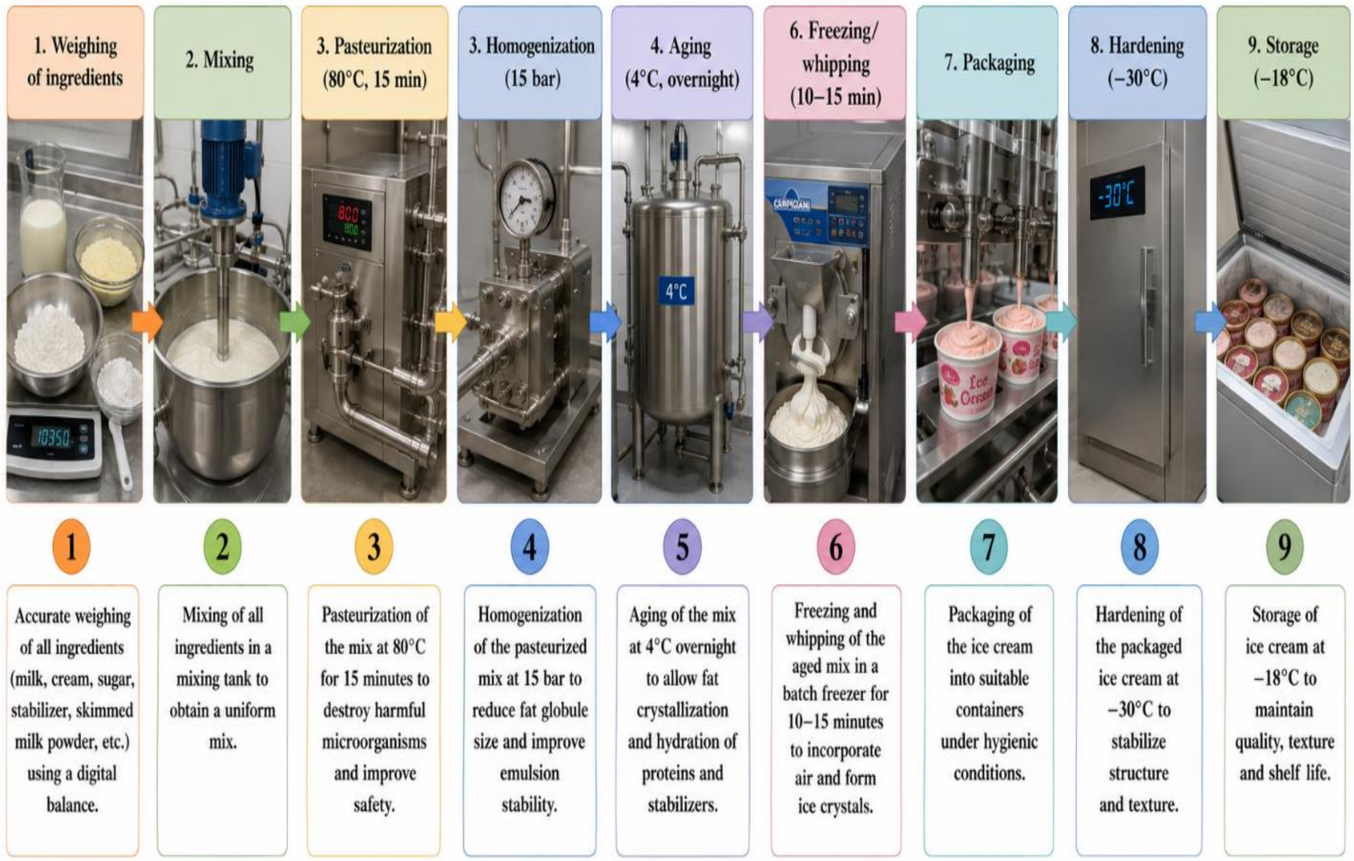

Figure 1: Flow sheet of ice cream preparation

2.5 Physicochemical Analysis

All analyses were performed in triplicate.

- **Fat content:** Determined by the Gerber method according to AOAC (2016). **Protein content:** Kjeldahl method (N × 6.25) (AOAC, 2016).
- **Moisture content:** Oven drying at 105°C to constant weight (AOAC, 2016).
- **Ash content:** Muffle furnace incineration at 550°C (AOAC, 2016).
- **Total solids:** Gravimetric method (AOAC, 2016).
- **pH:** Measured with a digital pH meter after melting the ice cream (AOAC, 2012).

2.6 Physical Properties

Overrun: Calculated as the percentage increase in volume due to air incorporation. Equal volumes of unfrozen mix and frozen ice cream were weighed, and overrun (%) = (weight of mix – weight of ice cream) / weight of ice cream × 100 (Jana et al., 2016).

Meltdown time: A 50 g ice cream sample was placed on a metal mesh screen at 37°C, and the time until the first drip appeared was recorded (Umar, 2015).

2.7 Sensory Evaluation

Fifteen semi-trained panelists (staff and students of the Department of Food Science and Technology) evaluated the ice cream samples using a 7-point hedonic scale (1 = dislike very much, 7 = like very much) for color, taste, texture, aroma, and overall acceptability (Abdullah et al., 2003). Samples were served in random order with three-digit codes at room temperature, and panelists rinsed their mouths with water between samples.

2.8 Statistical Analysis
Data were analyzed by one-way analysis of variance (ANOVA) using Statistics 8.1 software. Significant differences between treatment means were determined by Duncan's multiple range test at a significance level of $p < 0.05$.

3. RESULTS AND DISCUSSION
3.1 Physicochemical Properties
3.1.1 Fat Content
Fat content was significantly lower ($p < 0.05$) in all soy milk-based ice creams compared to the control (Table 4). The control (cow milk) had the highest fat (10.5%), while soy milk treatments ranged from 6.8% (T_3) to 7.2% (T_1). This reduction is attributed to the lower fat content of soy milk (2.5%) compared to cow milk (3.5%) and cream (30%) used in the formulation. Similar results were reported by Aboulfazli et al. (2016) and Pereira et al. (2011), who observed a decrease in fat when soy milk replaced dairy milk. The lower fat content offers a potential advantage for consumers seeking reduced saturated fat intake.

Table 4: Effect of treatment on fat content (%)

Treatment	Fat (%)
T_0	10.5 ± 0.3^a
T_1	7.2 ± 0.2^b
T_2	7.0 ± 0.2^b
T_3	6.8 ± 0.2^b

Different superscript letters in a column indicate significant difference ($p < 0.05$).

3.1.2 Protein Content
Protein content was highest in the control (3.8%) and slightly lower but not significantly different among soy treatments (3.5–3.7%) (Table 5). Soy milk contains approximately 3.5% protein, similar to cow milk, so the replacement did not drastically alter protein levels. This contrasts with studies using fruit flours or other plant proteins that can increase protein content (Qayyum et al., 2017). The comparable protein content makes soy ice cream a nutritionally adequate alternative.

Table 5: Effect of treatment on protein content (%)

Treatment	Protein (%)
T_0	3.8 ± 0.1^a
T_1	3.5 ± 0.1^b
T_2	3.6 ± 0.1^b
T_3	3.7 ± 0.1^b

3.1.3 pH

The pH decreased significantly ($p < 0.01$) with increasing stabilizer concentration (Table 6). The control had the highest pH (6.6), while T_3 had the lowest (6.2). This indicates slightly higher acidity in soy-based ice creams, possibly due to the slightly lower pH of soy milk (6.5) and the stabilizer type. Santos and Silva (2012) similarly reported a decrease in pH when fat and sugar substitutes were added. The pH values remained within the typical range for ice cream (6–7), so acidity did not negatively affect product stability.

Table 6: Effect of treatment on pH

Treatment	pH
T_0	6.6 ± 0.03^a
T_1	6.4 ± 0.04^b
T_2	6.3 ± 0.02^b
T_3	6.2 ± 0.03^c

3.1.4 Moisture Content

Moisture content was significantly higher ($p < 0.01$) in soy-based ice creams compared to the control (Table 7). T_1 (0.1% stabilizer) had the highest moisture (66.5%), while T_3 (0.3% stabilizer) had 64.0%. The control had only 62.0% moisture. This increase is due to the higher water content of soy milk (88% vs. ~87% in cow milk) and the water-binding capacity of the stabilizers. Yangılar (2015) also reported increased moisture when fruit powders were added, as they compete for free water. Higher moisture content may affect texture and melting behavior.

Table 7: Effect of treatment on moisture content (%)

Treatment	Moisture (%)
T_0	62.0 ± 0.5^c
T_1	66.5 ± 0.4^a
T_2	65.0 ± 0.3^b
T_3	64.0 ± 0.4^b

3.1.5 Ash Content

Ash content (minerals) was slightly lower in soy treatments (0.65–0.67%) compared to the control (0.70%) (Table 8), but the differences were small and statistically significant ($p < 0.05$). Soy milk contains less calcium but more iron than cow milk. The slight decrease in ash is consistent with the replacement of dairy solids (which are higher in calcium) with soy milk. Nasr (2021) also observed increased ash with fruit pulp addition due to higher mineral content, but in this case, the mineral profile shifted rather than decreased dramatically.

Table 8: Effect of treatment on ash content (%)

Treatment	Ash (%)
T_0	0.70 ± 0.02[a]
T_1	0.65 ± 0.02[b]
T_2	0.66 ± 0.01[b]
T_3	0.67 ± 0.02[b]

3.2 Physical Properties

3.2.1 Overrun

Overrun decreased significantly ($p < 0.01$) as stabilizer concentration increased (Table 9). The control had the highest overrun (70%), while T_3 had the lowest (50%). Higher stabilizer concentrations increase the viscosity of the ice cream mix, which reduces the incorporation of air during freezing (Sofjan & Hartel, 2004). Although lower overrun yields a denser product, it can also improve melting resistance. The overrun values obtained are within the range reported for plant-based ice creams (50–70%) by Ng et al. (2024).

Table 9: Effect of treatment on overrun (%)

Treatment	**Overrun (%)**
T_0	70.0 ± 1.5[a]
T_1	60.0 ± 1.2[b]
T_2	55.0 ± 1.3[c]
T_3	50.0 ± 1.1[d]

3.2.2 Meltdown Time

Meltdown time (time to first drip at 37°C) was longest for T_3 (48 min), followed by the control (45 min), then T_2 (40 min) and T_1 (35 min) (Table 10). This indicates that higher stabilizer concentrations significantly improve melting resistance. Stabilizers bind free water, increase the viscosity of the unfrozen phase, and create a more stable network that delays collapse (Hartel et al., 2003). Soy proteins also contribute to water binding and structural integrity (Singh et al., 2008). The improved meltdown resistance is a notable advantage of soy-based ice creams.

Table 10: Effect of treatment on meltdown time (min)

Treatment	Meltdown time (min)
T_0	45 ± 2^c
T_1	35 ± 1^a
T_2	40 ± 1^b
T_3	48 ± 2^c

3.3 Sensory Evaluation

Sensory scores for all attributes are summarized in Table 11. The control (cow milk ice cream) consistently received the highest scores for color (8.5), taste (8.6), texture (8.7), aroma (8.5), and overall acceptability (8.6). Among the soy-based treatments, T_3 (0.3% stabilizer) scored highest for taste (7.8), texture (8.2), aroma (7.8), and overall acceptability (8.0). T_1 (0.1% stabilizer) had the lowest scores. The beany flavor typical of soy was more noticeable at lower stabilizer concentrations; higher stabilizer likely improved mouthfeel and masked off-flavors to some extent. These results agree with Homayouni et al. (2021), who found that 50% soy substitution was acceptable, and with Ng et al. (2024), who reported that plant-based ice creams generally score lower than dairy controls.

Table 11: Sensory scores of ice cream treatments (7-point hedonic scale, mean ± SD)

Treatment	Color	Taste	Texture	Aroma	Overall acceptability
T_0	8.5 ± 0.2^a	8.6 ± 0.3^a	8.7 ± 0.2^a	8.5 ± 0.3^a	8.6 ± 0.2^a
T_1	7.5 ± 0.3^b	7.0 ± 0.4^c	7.2 ± 0.3^c	7.4 ± 0.2^b	7.2 ± 0.3^c
T_2	7.8 ± 0.2^b	7.5 ± 0.3^b	7.8 ± 0.2^b	7.6 ± 0.3^b	7.7 ± 0.2^b
T_3	8.0 ± 0.3^b	7.8 ± 0.2^b	8.2 ± 0.3^b	7.8 ± 0.2^b	8.0 ± 0.3^b

Different superscripts within a column indicate significant differences ($p < 0.05$).

4. CONCLUSION

This study successfully developed a non-dairy ice cream using 100% soy milk as a complete substitute for cow milk. The addition of stabilizers (0.1–0.3%) significantly affected the physicochemical, physical, and sensory properties of the soy milk ice cream. Key findings include:

- Soy milk ice cream had lower fat content (6.8–7.2% vs. 10.5% in control) but comparable protein (3.5–3.8%), making it a lower-fat, lactose-free alternative.
- Moisture content increased (64–66.5%), while ash content slightly decreased.
- Overrun decreased with higher stabilizer (70% in control to 50% in T_3), producing a denser product.
- Meltdown resistance improved with higher stabilizer, with T_3 showing the longest

meltdown time (48 min), even exceeding the control (45 min).

- Sensory evaluation revealed that T_3 (0.3% stabilizer) was the best among soy treatments for taste (7.8), texture (8.2), and overall acceptability (8.0), although all soy samples scored lower than the dairy control.

Practical implications: Soy milk can be used as a complete replacement for cow milk in ice cream production. A stabilizer concentration of 0.3% is recommended for the best balance of texture, melting resistance, and sensory acceptance. The product is suitable for lactose-intolerant individuals, vegans, and consumers seeking plant-based functional foods.

Recommendations for future research:

- Incorporate natural flavorings (vanilla, chocolate, fruit purees) to mask the beany taste of soy.
- Evaluate longer storage stability (up to 6 months) and probiotic incorporation.
- Fortify with calcium, vitamin D, and vitamin B12 to match the nutritional profile of dairy ice cream.
- Explore blends of soy milk with other plant milks (coconut, oat, almond) to improve sensory properties.

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