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Crafting Low-Sugar Cosmos Ice Cream: Exploring Diverse Stabilizing Agent Combinations

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ABSTRACT

This research focuses on utilizing *Cosmos caudatus* (also known as ulam raja), a bioactive-rich plant, as the primary functional ingredient in ice cream formulations to develop a healthier dessert option. By following the standard ice cream protocol, two stabilizers (xanthan gum and Arabic gum) were used at different ratios, and CMC served as a positive control for the experiment. To determine the optimal conditions, the finished goods were subjected to physicochemical, overrun, and melting tests, and sensory analysis. The results show that the optimal formulation for a low-sugar *Cosmos caudatus* ice cream (LSCI) was achieved at a ratio of 0.75:0.25 between xanthan gum and Arabic gum. The use of optimal stabilizer formulation in developing LSCI had no significant effect on the pH value. However, the viscosity of the optimal formulation was higher than that of the control formulation. A ratio of 0.75:0.25 resulted in lower hardness, higher firmness, and cohesiveness in the texture profile analysis. In terms of colour, aroma, texture, taste, and overall acceptability, the use of an optimal stabilizer formulation on the LSCI outperformed the control stabilizer formulation in all areas. In conclusion, the study identifies the optimal stabilizer formulation (0.75 xanthan gum, 0.25 Arabic gum) for low-sugar *Cosmos caudatus* ice cream, showcasing improved texture and sensory attributes compared to the CMC control. This underscores the potential of this formulation to enhance both the quality and consumer appeal of healthier ice cream options.

INTRODUCTION

Cosmos caudatus (commonly known as ulam raja or "king's salad") is a traditional medicinal herb widely consumed in Southeast Asia, appreciated for its rich profile of bioactive compounds. Recent studies have identified its high concentrations of ascorbic acid (vitamin C), quercetin, and chlorogenic acid, which contribute to its potent antioxidant and anti-inflammatory properties [1,2,3]. These compounds not only neutralize free radicals and mitigate oxidative stress but also show promise in managing chronic conditions like diabetes and cardiovascular diseases [4]. For instance, quercetin, a flavonoid abundant in *Cosmos caudatus*, has been linked to improved glycemic control and reduced systemic inflammation in clinical trials [1,5]. The growing consumer demand for functional foods that combine health benefits with indulgence presents a unique opportunity to innovate in the dessert sector [6, 7]. Low-sugar ice cream has gained traction among health-conscious consumers, yet many products fail to deliver both sensory appeal and bioactive efficacy [8,9]. Incorporating *Cosmos caudatus* as the primary functional ingredient into ice cream formulations could bridge this gap, offering a dessert that satisfies cravings while providing measurable health advantages, such as antioxidant support and potential metabolic benefits.

This study investigates the role of stabilizers, specifically xanthan gum and Arabic gum, in optimizing the physicochemical and sensory properties of a low-sugar *Cosmos caudatus* ice cream (LSCI). While stabilizers are crucial for texture and shelf life [10], their interaction with bioactive compounds in herbal ingredients remains underexplored. We suggest that a 0.75:0.25 xanthan-Arabic gum blend outperforms conventional carboxymethyl cellulose (CMC) in preserving bioactive integrity, enhancing texture (e.g., firmness, cohesiveness), and improving consumer acceptance. The main objectives highlighted in the study are to develop LSCI with optimized stabilizer formulations and evaluate its physicochemical properties (viscosity, overrun, and melting resistance) as well as sensory acceptability against a CMC control. By addressing these gaps, this research aims to advance the development of functional desserts that align with global trends in preventive healthcare and clean-label consumption.

MATERIALS AND METHODS

Materials

The low-sugar *Cosmos caudatus* ice cream (LSCI) was formulated using Dutch Lady Full Cream UHT milk, butter, honey (as a natural sweetener), egg yolk, skimmed milk powder, and standardized *Cosmos caudatus* powder (Astera Food Sdn. Bhd, Malaysia). Stabilizers included food-grade xanthan gum, Arabic gum, and carboxymethyl cellulose (CMC) (Sigma-Aldrich, ≥95% purity). Creamy vanilla essence (McCormick) was added for flavor enhancement.

Experimental Design

Six formulations were evaluated (**Table 1**): a control with 1.0% CMC and five experimental blends with varying xanthan gum-to-Arabic gum ratios of 0:1.0, 0.25:0.75, 0.5:0.5, 0.75:0.25, and 1.0:0, respectively. The total stabilizer concentration was fixed at 1.0% (w/w) across all formulations to isolate the effects of stabilizer type and ratio.

Table 1. Formulation of LSCI.

Stabilizer	Formulation ratio					
	Control	F1	F2	F3	F4	F5
Xanthan gum	0	0	0.25	0.5	0.75	1.0
Arabic gum	0	1.0	0.75	0.5	0.25	0
CMC	1.0	0	0	0	0	0

Ice Cream Production

The ice cream base was prepared by homogenizing all ingredients at 65 °C for 15 min, followed by pasteurization (80 °C, 25 sec) and rapid cooling to 4 °C. The mixture was aged at 4 °C for 24 h to ensure proper hydration of stabilizers. Freezing was performed in a batch freezer (Taylor C709, USA) at −5 °C for 20 min, and the product was hardened at −20 °C until analysis.

Physicochemical Analysis

Viscosity was measured at 10 °C using a rotational rheometer (Brookfield DV3T, spindle 63, 50 rpm). pH was determined with a calibrated pH meter (Jenway 3510, UK). Texture profile analysis (TA.XT Plus, UK) was used to quantify hardness, firmness, and cohesiveness (5-mm cylindrical probe, 1 mm/s, 50% strain). Proximate composition (moisture, protein, fat, fiber, ash) was analyzed via AOAC methods, with carbohydrates calculated by difference.

Sensory Evaluation

Fifty untrained panelists (aged 18–45) evaluated the ice cream using a 9-point hedonic scale (1 = "dislike extremely," 9 = "like extremely") for color, aroma, texture, taste, and overall acceptability. Samples were served in randomized order at −10 °C under white lighting and panelists cleaned their palates with distilled water and unsalted crackers between samples.

Statistical Analysis

Data were analyzed using Minitab® (v21.3.1). One-way ANOVA and paired T-tests compared formulations, with Tukey's HSD test ($p < 0.05$) for post-hoc analysis.

RESULTS AND DISCUSSION

pH Stability and Viscosity Modulation Across Formulations of LSCI Mix

Table 2 presents the pH and viscosity of the low-sugar *Cosmos caudatus* ice cream (LSCI) mix after 24 hours of aging, comparing the control (CMC) and experimental formulations (F1–F5) with varying xanthan gum-to-Arabic gum ratios.

Table 2. pH and Viscosity of LSCI Mix with Different Stabilizer Formulations.

Parameter	Control	F1	F2	F3	F4	F5
pH	6.40 ± 0.02^{a}	6.32 ± 0.03^{ab}	6.38 ± 0.06^{a}	6.35 ± 0.01^{a}	6.34 ± 0.06^{b}	6.35 ± 0.01^{b}
Viscosity (mPa·s)	13.17 ± 0.15^{c}	8.63 ± 0.11^{d}	14.03 ± 029^{b}	14.60 ± 0.17^{a}	14.60 ± 0.17^{a}	14.76 ± 0.21^{a}

Note: Values are expressed as mean ± SD (n = 3). $^{a-d}$ Means with different superscripts were significantly different ($p < 0.05$).

The pH values of all LSCI mixes (6.32–6.40) aligned with the typical range for conventional ice cream (6.2–6.3) [11], indicating that the incorporation of *Cosmos caudatus* and alternative stabilizers did not disrupt the product's acidity balance. The control formulation (CMC) exhibited the highest pH (6.40), while formulations with xanthan-Arabic gum blends showed marginally lower pH (6.32–6.35). This slight reduction may be attributed to the weak acidic nature of xanthan gum [12], though the differences were statistically insignificant ($p > 0.05$) for most formulations. The stability of pH across all samples suggests that the acidic bioactive compounds in *Cosmos caudatus* (i.e., chlorogenic acid) did not significantly alter the mix's acidity, which is critical for maintaining product shelf life and sensory quality.

Based on **Table 2**, the viscosity varied significantly ($p < 0.05$) among formulations, with a clear trend of increasing thickness as xanthan gum content increases (F1–F5). The control (CMC) showed intermediate viscosity (13.17 mPa·s), while F1 (100% Arabic gum) had the lowest viscosity (8.63 mPa·s). In contrast, formulations with ≥50% xanthan gum (F3–F5) achieved the highest viscosity (14.03–14.76 mPa·s), consistent with xanthan gum's strong pseudoplastic behavior and ability to form shear-thinning networks [12,13]. The observed viscosity trends can be attributed to xanthan gum's dominance at higher ratios (F3–F5), where its high molecular weight and helical structure enhanced intermolecular interactions, significantly increasing flow resistance [4].

Notably, the 0.75:0.25 xanthan-Arabic gum blend (F4) achieved a viscosity comparable to 100% xanthan gum (F5), demonstrating a synergistic effect that enables cost-effective optimization without sacrificing functionality. These results align with those of Zhao et al. [12], who highlighted the dose-dependent stabilizing efficacy of xanthan gum and the secondary role of Arabic gum in emulsion stabilization, with minimal contributions to thickening. Together, these findings underscore the potential of tailored stabilizer blends to modulate rheological properties in low-sugar ice cream systems while maintaining economic viability.

Texture Characteristics of LSCI

Texture profile analysis revealed important insights into the structural properties of the LSCI formulations. While no statistically significant differences ($p > 0.05$) were observed in hardness values across formulations (**Table 3**), notable trends emerged that justify the discussion. Formulation 2 (0.25:0.75 xanthan gum: Arabic gum ratio) demonstrated the highest mean hardness value (4233 ± 3166 g), while Formulation 5 (1:0 ratio) showed the lowest (804 ± 374 g). This inverse relationship between xanthan gum concentration and hardness may be attributed to the unique rheological properties of xanthan gum, which forms weaker gel networks at higher concentrations compared to Arabic gum. The similar cohesiveness values (0.08-0.18) across all formulations suggest that while hardness was

affected, the fundamental structural integrity of the ice cream remained consistent regardless of stabilizer combination.

Table 3. Texture Profile Analysis of LSCI Produced with Different Stabilizer Formulations.

TPA	Formulation					
	Control	F1	F2	F3	F4	F5
Hardness (g)	1726 ± 1006[a]	2491 ± 812[a]	4233 ± 3166[a]	3474 ± 883[a]	1882 ± 649[a]	804 ± 374[a]
Adhesiveness (g. sec)	-1215 ± 1210[a]	-701 ± 223[a]	-3447 ± 2415[a]	-726 ± 347[a]	-1858 ± 784[a]	-1060 ± 218[a]
Cohesiveness	0.12 ± 0.06[a]	0.09 ± 0.06[a]	0.18 ± 0.13[a]	0.08 ± 0.06[a]	0.08 ± 0.01[a]	0.15 ± 0.05[a]

Note: Values are expressed as mean ± SD, (n = 3). [a-d] Means with different superscripts were significantly different ($p < 0.05$).

Texture Characteristics of the Optimised LSCI

The proximate analysis of the optimal formulation (F4: 0.75:0.25 xanthan-Arabic gum) compared to the control revealed several important compositional characteristics (**Table 4**). Most notably, the optimal formulation exhibited higher moisture content (62.24 ± 0.02%) than the control (51.34 ± 0.02%). This is most likely due to the superior water-binding capacity of the xanthan-Arabic gum combination. The increased moisture retention could also positively impact product quality by reducing ice crystal formation during storage. In addition, protein content showed a slight but potentially meaningful increase from 6.24 ± 0.75% in the control to 6.43 ± 0.23% in the optimal formulation, suggesting better protein retention during processing.

Moreover, the fat content of 10.80 ± 0.20% in the optimal formulation falls within the typical range for premium ice cream and contributes to desirable mouthfeel characteristics [14]. Perhaps most significantly, the carbohydrate content showed a substantial and statistically significant ($p < 0.05$) reduction from 30.06 ± 0.29% in the control to 21.13 ± 0.22% in the optimal formulation, validating the successful development of a lower-sugar product. This reduction, achieved through the use of honey as a sweetener, represents an important nutritional improvement while maintaining the desirable physicochemical properties of the ice cream.

Table 4. Proximate Analysis of LSCI (Control and F4).

Analysis (%)	Formulation	
	Control	F4 (Optimal)
Moisture	51.34 ± 0.02[a]	62.24 ± 0.02[a]
Ash	0.86 ± 0.02[a]	0.83 ± 0.27[a]
Protein	6.24 ± 0.751[a]	6.43 ± 0.225[a]
Fat	10.03 ± 0.42[a]	10.80 ± 0.2[a]
Fiber	1.47 ± 0.78[a]	0.57± 0.74[a]
Carbohydrate	30.06 ± 0.29[a]	21.13 ± 0.22[b]

Note: Values are expressed as mean ± SD (n = 3). [a-d] Means with different superscripts were significantly different ($p < 0.05$).

The combination of these results suggests that the 0.75:0.25 xanthan-Arabic gum stabilizer blend represents an optimal formulation for LSCI, providing balanced textural properties while achieving important nutritional targets. The ability to reduce sugar content without compromising texture or stability is particularly noteworthy, as sugar reduction in frozen desserts typically presents significant technical challenges. These findings have important implications for the development of functional ice cream products that meet consumer demands for both health benefits and sensory quality.

Sensory Evaluation of the Newly Developed LSCI

The sensory evaluation of the newly developed LSCI formulations yielded important insights into consumer acceptability (**Fig. 1**). Both the control (CMC-stabilized) and optimal (0.75:0.25 xanthan-Arabic gum) formulations received comparable scores across all sensory attributes, with no statistically significant differences ($p > 0.05$) observed for color, aroma, texture, taste, or overall acceptance. This demonstrates that the modified stabilizer system successfully maintained the desirable sensory profile of the product despite significant formulation changes.

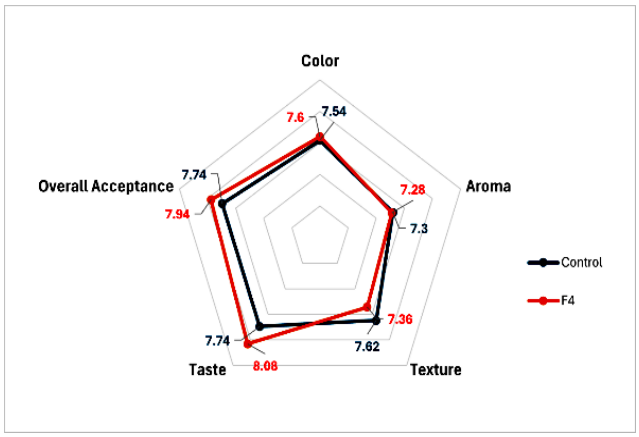

Fig. 1. Sensory Evaluation of LSCI (Control & F4).

Notably, the optimal formulation achieved marginally higher scores for taste (8.08 ± 1.03) and overall acceptance (7.94 ± 1.02) compared to the control (7.74 ± 1.18 and 7.74 ± 1.21, respectively), suggesting potential flavor enhancement from the xanthan-Arabic gum combination. The control formulation showed a slightly higher texture score (7.62 ± 1.22 vs. 7.36 ± 1.54), which correlates with its higher carbohydrate content (30.06 ± 0.29%) compared to the optimal formulation (21.13 ± 0.22%). This relationship between carbohydrate content and texture perception is well-documented in frozen desserts, where sugars contribute significantly to mouthfeel and structural properties.

The absence of significant differences in aroma (7.30 ± 1.50 vs. 7.28 ± 1.34) and color (7.54 ± 1.33 vs. 7.60 ± 1.39) scores between formulations indicates that the stabilizer modification did not adversely affect these important quality attributes. These results are particularly encouraging as they demonstrate that the nutritional improvements achieved through carbohydrate reduction and protein retention did not compromise the product's sensory appeal [11]. The overall high acceptability scores (all above 7 on the 9-point hedonic scale) for both formulations suggest strong market potential for this functional ice cream product.

CONCLUSION

This study successfully developed a low-sugar *Cosmos caudatus* ice cream (LSCI) using optimized stabilizer formulations, demonstrating that a 0.75:0.25 xanthan-Arabic gum blend achieved comparable physicochemical and sensory properties to the CMC control while offering nutritional advantages. Key findings revealed that higher xanthan gum content reduced hardness but maintained viscosity, and the optimal formulation significantly lowered carbohydrate content (21.13 ± 0.22%) without compromising texture or flavor. The sensory evaluation confirmed high consumer acceptability (scores >7/9) for both formulations, with the optimal blend showing marginally improved taste and overall acceptance. The successful retention of protein (6.43 ± 0.23%) and fat (10.80 ±

0.20%) highlights the potential of this formulation as a functional, reduced-sugar dessert that aligns with health-conscious consumer demands. These results position *Cosmos caudatus* as a viable bioactive ingredient for innovative ice cream products, combining metabolic health benefits with sensory appeal.

CONFLICT OF INTEREST

The authors have declared that no conflict of interest exists.

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ETHICS STATEMENT

The University Research Ethics Committee granted ethical approval for the involvement of human subjects (sensorial analysis) in this study, with reference number JKEUPM-2024-1303, on 13 March 2024.

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