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ORIGINAL ARTICLE

Rheological behavior of hydrocolloid blends as stabilizers for ice cream formulation

Comportamiento reológico de mezclas de hidrocoloides como estabilizantes para la formulación de helado

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Abstract Ice cream formulation relies on stabilizers that guarantee texture, creaminess, and structural stability during processing and storage. The objective of this study was to evaluate the rheological behavior of gelatin, guar gum, and xanthan gum blends in milk and cream ice cream. A mixture design was employed, with variable proportions of gelatin (10–20%), guar gum (50–75%), and xanthan gum (10–20%), to measure apparent viscosity and flow time using a Brookfield viscometer and a 10 mL pipette at 20 °C. Results indicated that guar gum provided the greatest increase in viscosity in both mixes. At the same time, gelatin exhibited a moderate effect, particularly in the cream mix, where its performance was comparable to that of xanthan gum. The optimal blend (16.2% gelatin, 67.9% guar gum, 15.9% xanthan gum) yielded viscosities of 50.8 mPa·s (milk) and 47.3 mPa·s (cream). It was concluded that the proposed formulation strikes a balance between rheological performance, sensory acceptability, and low ingredient cost.

Keywords hydrocolloids, rheology, ice cream, stabilizers, viscosity.

Resumen La formulación de helados depende de estabilizantes que aseguren textura, cremosidad y estabilidad durante el procesamiento y almacenamiento. El objetivo del estudio fue evaluar el comportamiento reológico de mezclas de gelatina, goma guar y goma xantana en helados de leche y de crema. Se empleó un diseño experimental de mezcla con proporciones variables de gelatina (10–20 %), goma guar (50–75 %) y xantana (10–20 %), y se midieron viscosidad aparente y tiempo de descarga mediante viscosímetro Brookfield y pipeta de 10 mL a 20 °C. Los resultados mostraron que la goma guar aportó el mayor incremento de viscosidad en ambas mezclas, mientras que la gelatina contribuyó de forma moderada, especialmente en la mezcla crema, donde su efecto fue comparable al de la xantana. La formulación óptima (16,2 % gelatina, 67,9 % goma guar, 15,9 % xantana) generó viscosidades de 50,8 mPa·s (leche) y 47,3 mPa·s (crema). Se concluyó que la combinación propuesta equilibra rendimiento reológico, aceptabilidad sensorial y bajo costo de ingredientes.

Palabras clave gomas hidratantes, reología, helado, estabilizantes, viscosidad.

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PUBLIS EDITORIAL

Introduction

The incorporation of additives in the food industry aims to enhance critical product attributes, including color, flavor, texture, and shelf life, thereby ensuring consumer satisfaction and overall quality. Among these, stabilizers play a key role in ice cream manufacturing, as they directly influence the rheological behavior of the mix, its viscosity, gel formation, and structural stability (Soukoulis et al., 2008; Saha & Bhattacharya, 2010).

In Cuba, ice cream production relies on commercial stabilizers from various sources, with variable presentations and uneven supply. Well-known brands often use proprietary blends of hydrocolloids to achieve specific functional properties, which complicates product consistency (Saha & Bhattacharya, 2010). Faced with stability issues or supplier changes, domestic ice cream parlors have resorted to different combinations of stabilizers.

Detailed knowledge of the composition and viscometric properties of gums such as guar, xanthan, and gelatin is key to predicting their performance in ice cream mixes and ensuring production consistency. Guar- and xanthan-based stabilizers have demonstrated synergies in viscosity and melt strength, with formulations that significantly reduce meltdown rates (Soukoulis et al., 2008; Liu et al., 2023). Furthermore, thermo-rheological oscillation tests have validated the relationship between elastic (G') and viscous (G") moduli and sensory attributes such as creaminess and firmness (Milliatti & Lannes, 2018).

Although some Cuban studies have evaluated stabilizer blends using viscometric techniques, demonstrating their predictive capacity during freezing (Fatemeh et al., 2016; Rodríguez et al., 2016), systematic information on specific combinations with defined proportions is still lacking. Therefore, the present study aimed to evaluate the rheological behavior of blends of guar gum, xanthan gum, and gelatin in milk and cream ice creams, to optimize a formulation that combines technical performance, sensory quality, and economic viability.

Methodology

The following raw materials were used in the research: whole milk powder, guar gum, xanthan gum, commercial gelatin (340º Bloom), lacto-350 vegetable fat, refined sugar, and glycerol monostearate. Physicochemical analyses were performed according to NC-ISO 7328 (2004) for fat in ice cream mixes, NC-ISO 3728 (2000) for total solids, and an estimate for non-fat solids. The density of the mixtures was measured using a DMA 35 densitometer.

The apparent viscosity (mPa·s) was determined using a Brookfield LVT model viscometer with spindle No. 2 at 30 min-1 and 20 ºC, according to an internal control method. The discharge time was also evaluated using a 10 mL pipette at 20 ºC, and the apparent viscosity was calculated using the Alvarado and Aguilera equation (2001), which relates viscosity with density and discharge time. For the experimental design, a mixture design prepared with the Design Expert software was used, where the variables were the proportions of gelatin (10-20%), guar gum (50-75%) and xanthan gum (10-20%), taking as response variables the apparent viscosity (mPa·s) and the discharge time (s).

The generated formulations were structured in a design matrix and prepared according to standard parameters of the ice cream industry. The cost of the raw materials used in the production of the mixes and stabilizers was evaluated. Finally, the data obtained was processed using Design Expert version 6.0.1 to generate statistical models and optimize the mix composition based on its viscosity.

Results and discussion

Table 1 presents the results of the formulations for the stabilizers used in the milk ice cream mixes. The results indicate that the combination of gelatin, guar gum, and xanthan gum has a significant influence on the viscosity and discharge time of the product. Higher percentages of guar gum and xanthan gum were associated with increased viscosity and discharge time (experiments 9, 10, 11, 12, and 13). For example, experiment 9, with 75% guar gum and 15% xanthan gum, showed the highest viscosity (63.7 mPa·s) and the longest discharge time (26.0 s). This behavior is consistent with that reported by Gao et al. (2024), who noted that both guar gum and xanthan gum are hydrocolloids with a high capacity for hydration and formation of viscoelastic networks in aqueous solutions.

With an increasing proportion of gelatin and a decreasing amount of gums, viscosity tends to decrease (experiments 5 and 8), which shortens the discharge time. A similar result was reported by Banerjee and Bhattacharya (2012), who indicated that gelatin provides structure but has a lower thickening effect compared to polysaccharides such as xanthan or guar gums.

Synergistic interactions between these hydrocolloids can enhance the viscosity of the system depending on their relative proportions (Lin et al., 2023). Thus, balanced combinations, such as those in Experiment 10 (12.5% gelatin, 71.25% guar gum, 16.25% xanthan gum), achieve high viscosity (50.0 mPa·s) and long discharge times (24.0 s) without exceeding acceptable sensory limits.

The optimization of hydrocolloid blends must consider their rheological impact and their effect on the stability and sensory acceptability of the final product (Arancibia et al., 2015). The areas richest in guar gum and xanthan (sides close to the vertex B–C) correspond to high viscosity predictions,

Table 1. Values media by formulation for the milk ice cream mixes

Experiment	Gelatin (%)	Guar gum (%)	Xanthan gum (%)	Viscosity (mPa·s)	Download time (s)
1	10	70	20	47.0 (0.5)	20.4 (1.2)
2	10	70	20	42.0 (0.5)	19.7 (1.1)
3	15	75	10	35.5 (1.0)	16.5 (0.5)
4	16.25	71.25	12.5	43.0 (0.5)	19.7 (0.4)
5	17.5	65	17.5	25.0 (0.5)	13.3 (0.3)
6	20	65	15	32.0 (0.5)	16.9 (0.2)
7	20	70	10	30.0 (0.5)	17.1 (0.2)
8	20	70	10	25.0 (0.5)	15.0 (0.0)
9	10	75	15	63.7 (6.5)	26.0 (0.0)
10	12.5	71.25	16.25	50.0 (0.5)	24.0 (0.0)
11	15	67.5	17.5	51.0 (0.5)	22.0 (0.0)
12	20	60	20	51.0 (0.5)	23.4 (0.6)
13	10	75	15	54.0 (0.5)	24.0 (0.0)
14	20	60	20	49.0 (0.5)	22.0 (0.0)

which is evident in the formulation points (experiment 9) that reached values above 60 mPa·s. This trend is consistent with studies that have reported a marked synergistic effect between guar and xanthan, resulting in a drastic increase in the viscosity of aqueous solutions (Soukoulis et al., 2008; Saha & Bhattacharya, 2010).

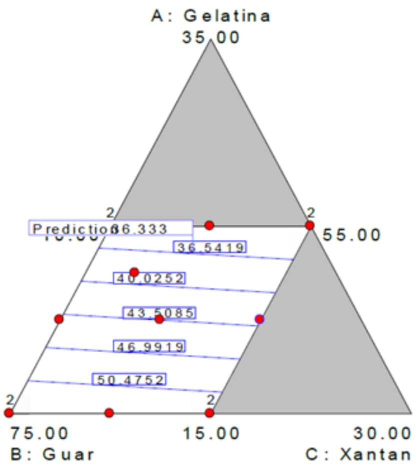

Figure 1. Behavior of the goo in a milk ice cream mix with changes in the relations of the rubber bands.

The regions with a higher proportion of gelatin show lower viscosity predictions, which corroborates the experimental results observed in formulations with higher gelatin content (experiments 5-8). Gelatin contributes to structure but has a lesser thickening effect compared to polysaccharides (Soukoulis et al., 2008).

The prediction curve exhibits behavior that aligns with recent findings on ternary blends, where viscoelastic stability against thermal variations is maximized with high xanthan contents, as described in formulation studies for frozen products (Ramos-Maldonado et al., 2023).

Soukoulis et al. (2008) demonstrated that guar–xanthan combination reduces the melting point in ice cream by increasing phase adhesion and cold mix viscosity. Meanwhile, Saha and Bhattacharya (2010) documented that the synergistic effects between guar and xanthan far exceed the individual contributions of each hydrocolloid in terms of thickening and final texture. It has also been observed that in ternary mixtures with a high percentage of xanthan, the elastic modulus remains more stable against temperature changes, suggesting greater robustness for ice cream stored or subjected to thermal cycling (Ramos-Maldonado et al., 2023).

Formulations with high guar and xanthan gum content were observed to generate high viscosities, were observed to generate high viscosities, which are beneficial for delaying melting and improving texture. An increase in gelatin drastically reduces viscosity, making it suitable for products with a more fluid texture. Balanced combinations with an intermediate composition promote an appropriate viscometric profile without compromising fluidity or thermal stability.

Table 2 shows the variation in apparent viscosity and discharge time when modifying the proportions of gelatin, guar gum, and xanthan in ice cream-type mixtures. Viscosity ranges varied between 28.7 and 60.0 mPa·s, and it was noticed that the results were higher than the viscosity ranges reported by Ruiz (2015) for this type of ice cream.

The high viscosity in formulations with 70–75% guar gum and 15–20% xanthan gum (Experiments 1, 2, 3), with values between 51 and 60 mPa·s and prolonged discharge times (26–28 s) evidences a marked synergistic effect between guar gum and xanthan gum. This effect has been reported by Karaman et al. (2014) and Ramos-Maldonado et al. (2023),

Table 2. Effect of gelatin, guar gum, and xanthan gum concentration on viscosity and discharge time of frozen dairy dessert formulations

Experiment	Gelatin (%)	Guar gum (%)	Xanthan gum (%)	Viscosity (mPa·s)	Discharge time (s)
1	10	70	20	60.0 (0.5)	26.9 (0.1)
2	10	70	20	53.0 (0.5)	28.3 (0.1)
3	15	75	10	51.0 (0.5)	26.0 (0.0)
4	16.25	71.25	12.5	36.0 (0.5)	27.0 (0.0)
5	17.5	65	17.5	35.0 (0.5)	25.0 (0.0)
6	20	65	15	29.0 (0.5)	23.0 (0.0)
7	20	70	10	47.0 (0.5)	26.0 (0.0)
8	20	70	10	41.8 (2.4)	26.3 (0.4)
9	10	75	15	40.0 (3.0)	27.7 (0.6)
10	12.5	71.25	16.25	28.7 (1.5)	26.8 (0.7)
11	15	67.5	17.5	42.7 (0.6)	30.3 (0.2)
12	20	60	20	30.5 (0.5)	27.5 (0.6)
13	10	75	15	40.0 (1.0)	26.8 (2.1)
14	20	60	20	40.0 (2.6)	27.2 (0.3)

who obtained a high viscosity modulus in binary and ternary mixtures of these hydrocolloids.

When gelatin is increased (≥ 17%) in combination with guar and xanthan (Experiments 5, 6, 8), a decrease in viscosity (30–35 mPa·s) and shorter discharge time (23–26 s) are observed, indicating that gelatin contributes less to thickening compared to guar and xanthan gums (Soukoulis et al., 2008; Saha & Bhattacharya, 2010).

Formulas with intermediate compositions (Experiment 4, for example) exhibited moderate viscosity values (~36 mPa·s) and adequate discharge times (~27 s), suggesting a functional balance between rheological stability and process manageability.

Guar and xanthan gums are recognized as the main responsible for the viscometric increase, while gelatin acts as a structuring agent, but with a lesser thickening effect (Soukoulis et al., 2008; Karaman et al., 2014; Ramos-Maldonado et al., 2023). Ramos-Maldonado et al. (2023) observed synergistic interactions in mixtures of guar gum, xanthan, and cellulose, reflected in viscosities higher than those of each polysaccharide separately, especially in the presence of high xanthan content, which coincides with the results of experiments 1–3.

Soukoulis et al. (2008) demonstrated that blends of guar and xanthan gum in ice cream produce greater creaminess and resistance to cold melting due to rheological synergy. In contrast, the addition of gelatin only improves the structure, but not the viscosity.

Saha and Bhattacharya (2010) reviewed the function of hydrocolloids in the food industry, highlighting that guar and xanthan are more potent thickening agents than gelatin in aqueous solutions, especially under low temperature and shear conditions, which is reflected in formulas with lower gelatin content.

The mean viscosity and discharge time values for the optimal milk and cream ice cream formulations show significant differences, reflecting the influence of mix composition on rheological properties and processing behavior. The cream mix had a higher viscosity (46.3 mPa·s) compared to the milk mix (34.2 mPa·s), as well as a longer discharge time (26.3 s *vs*. 20.5 s).

These results are consistent with previous studies, which indicate that the fat and total solids content in ice cream mixes increases viscosity due to a greater interaction between the particles and the liquid matrix (Goff & Hartel, 2013). The fat in the cream mix acts as a resistance to flow agent, resulting in longer discharge times, a phenomenon described by Adapa et al. (2000), who found that mixes with higher fat content exhibit increased viscosity and greater storage stability.

Viscosity directly influences the texture and mouthfeel of the final product. A longer discharge time, associated with higher viscosity, can result in a denser and creamier mix, desirable characteristics in premium ice creams (Marshall et al., 2003). However, it is essential to control these parameters to prevent the mix from becoming too viscous, which could make it challenging to handle and freeze. Furthermore, studies such as those by Ranaweera et al. (2022) indicate that the addition of stabilizing hydrocolloids can significantly modify viscosity and discharge time, suggesting that the optimal formulation should balance the amount of fat and stabilizers to achieve adequate functional and sensory properties.

The difference in viscosity and discharge time between the milk and cream blends is primarily attributable to the fat and total solids composition, with direct effects on ice cream processing and quality. These results are consistent with the existing scientific literature and provide valuable information for optimizing formulation. During experimentation with the optimal formulations, a definitive conclusion could not be reached because the viscosities did not meet initial expectations. For this reason, the two response variables corresponding to the experiments with the milk ice cream and cream ice cream blends were optimized to obtain a single stabilizer formulation applicable to both blends.

As a result of this optimization, a formulation composed of 16.2% gelatin, 67.9% guar gum, and 15.9% xanthan gum was obtained, which generated viscosities of 50.8 mPa·s for the milk ice cream mixture and 47.3 mPa·s for the cream ice cream mixture. This optimal formulation is consistent with the results obtained in Experiment 11, which presented viscosities of 51.0 mPa·s for the milk ice cream mixture and 42.7 mPa·s for the cream ice cream mixture. The viscosity values, both generated by the model and obtained in Experiment 11, are within the established restriction interval for both mixtures.

Based on these results, the optimal stabilizer blend was determined to be composed of gelatin (16.2%), guar gum (67.9%), and xanthan gum (15.9%). Although gelatin could have been excluded due to its low gelling power, its presence contributes to the formation of a stable foam that gives the ice cream a greater sensation of creaminess, especially in low-fat milk ice creams. Furthermore, gelatin delays freezing and prevents the formation of large ice crystals, which improves the final texture of the ice cream. It also decreases surface tension at the liquid-air interface, strengthening air retention (overrun) during the freezing process, which is key to the product's structure and quality (Gelco, 2013).

Conclusions

The viscosities of the different formulations were determined, and it was observed that gelatin, as a stabilizer, contributed little to the increase in viscosity in the milk ice cream mix. In contrast, it showed a stabilizing power similar to that of xanthan gum in the cream ice cream mix. On the other hand, guar gum was the stabilizer that demonstrated the greatest effect for both types of mixes. The optimal formulation for both mixes was composed primarily of gelatin, with guar gum in a majority proportion and xanthan gum in a smaller proportion, achieving adequate viscosities for each type of mix. Furthermore, the cost of the proposed formulation was low, implying a minimal contribution to the total cost per liter in both types of mixes.

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Conflicts of interest

The authors declare that they have no conflicts of interest.

Author contributions

Conceptualization: Yan Aldana, Aldo E. Hernández. **Data curation:** Yan Aldana, Migdalia Fojo. **Formal analysis:** Yan Aldana, Migdalia Fojo, Juan González. **Research:** Yan Aldana, Migdalia Fojo, Aldo E. Hernández, Juan González. **Methodology:** Aldo E. Hernández, Juan González. **Supervision:** Aldo E. Hernández. **Validation:** Aldo E. Hernández, Juan González. **Visualization:** Yan Aldana, Migdalia Fojo. **Writing-original draft:** Yan Aldana, Migdalia Fojo. **Writing-review & editing:** Yan Aldana, Migdalia Fojo, Aldo E. Hernández, Juan González.

Data availability statement

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Statement on the use of AI

The authors acknowledge the use of generative AI and AI-assisted technologies to improve the readability and clarity of the article.

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