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DEVELOPMENT OF A REDUCED SUGAR MANGO BEVERAGE: EFFECT OF SUCRALOSE AND CARBOXYMETHYLCELLULOSE CONCENTRATIONS ON SENSORY ACCEPTABILITY

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ABSTRACT

Excessive sugar consumption is associated with a range of health risks, including obesity, type 2 diabetes and cardiovascular diseases. In response, many countries have implemented policies to regulate products that are high in sugar. In Peru, Law No. 30021, the “Ley de promoción de la alimentación saludable para niños, niñas y adolescentes” (Law for the Promotion of Healthy Eating for Children and Adolescents) mandates front-of-pack warning labels on beverages containing 5 g or more of sugar per 100 mL. The present study aimed to develop a reduced-sugar mango-based beverage that aligns with the national nutritional regulations while maintaining sensory acceptability. Six formulations (F1 - F6) of mango-based beverage were formulated using mango pulp, sugar, carboxymethylcellulose (CMC), citric acid, potassium sorbate and sucralose, while varying the concentration of sucralose and CMC. A multilevel factorial experimental design was used to evaluate the effect of the two food additives: sucralose ($0.136 - 0.138 \text{ g L}^{-1}$) and CMC ($2.60 - 2.90 \text{ g L}^{-1}$) on sensory acceptability, focusing on appearance, taste and texture, as well as purchase intention. A sample of commercial mango-based beverage (control) was also evaluated in the sensory analysis. Sensory evaluation was conducted using a 9-point hedonic scale, and the data were analyzed through response surface methodology (RSM). Results showed a higher preference for formulations with lower concentrations of both sucralose and CMC. The optimal formulation containing 2.6 g L^{-1} of CMC and 0.137 g L^{-1} of sucralose, was determined by Response Surface Methodology (RSM) and corresponds to formulation F3. This formulation delivered 23.04 kcal per 100 mL, a total soluble solids (TSS) value of 5.00 ± 0.02 °Brix and a total sugar content of 4.45 g per 100 mL, well below the threshold established by Peruvian legislation for high-sugar warning labeling. No significant differences ($p > 0.05$) were observed in taste and texture, indicating that the formulated beverages were sensorially comparable. However, a significant difference in appearance was noted between F1-F6 and the commercial sample, mainly attributed to color ($\Delta E = 35.31$), suggesting the need for further improvements to enhance visual appeal and market competitiveness. These findings indicate that Sucralose, CMC and their interactions did not significantly affect the appearance, taste, or texture of the product, while purchase intent was negatively affected by the CMC content. The developed formulation complies with national regulatory standards, in other words, it does not require a front-of-pack warning label.

Key words: beverage, mango, sucralose, carboxymethylcellulose, sensory evaluation, appearance, taste, texture

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INTRODUCTION

High intake of added sugar contributes not only to weight gain but also has become a major driver of non-communicable diseases (NCDs), including obesity, type 2 diabetes, and cardiovascular conditions. Over the past decades, the prevalence of these diseases has risen at an alarming rate, turning them into a global public health crisis [1]. Despite growing awareness of these risks, the demand for sugar-rich foods and beverages remains high. Consumers continue to favor sweet-tasting products, fueling the widespread consumption of carbonated drinks, processed fruit juices and energy drinks [2,3]. This persistent preference for sweetness poses a significant challenge to public health efforts aimed at reducing sugar intake, highlighting the need for alternatives of sugar in food and beverage formulation.

To address this issue, many countries have implemented regulations to inform consumers about sugar content and promote healthier dietary choices. In Peru, the Law N° 30021 mandates that beverages containing ≥ 5 g of sugar per 100 mL display a "High in Sugar" claim [4]. In response, sweeteners have gained attention as effective alternatives, allowing for partial or complete sugar replacement while maintaining sweetness and reducing caloric intake [5].

Among the various sweeteners available, sucralose (E955) is one of the most widely used non-caloric options. Recognized as Generally Recognized as Safe (GRAS) by the FDA [7], sucralose is approximately 600 times sweeter than sucrose and provides a similar flavor profile, making it a suitable sugar substitute [7]. Additionally, its chemical stability across different temperatures and pH levels enhances its applicability in various food and beverage formulations [8]. However, sugar reduction affects not only sweetness but also other sensory properties such as mouthfeel, viscosity and overall acceptability [9]. To counterbalance these textural changes, hydrocolloids like carboxymethylcellulose (CMC) are commonly used as texturizing and stabilizing agents. Carboxymethylcellulose improves viscosity and mouthfeel, helping maintain the desirable sensory characteristics of reduced-sugar formulations [10]. Given the increasing demand for healthier beverage options, developing formulations that balance sugar reduction with sensory acceptability is essential.

Among the diverse range of fruit-based beverages, mango (*Mangifera indica* L.) stands out due to its rich sensory profile and high nutritional value. Moreover, mango (*Mangifera indica* L.) is a tropical fruit that is widely cultivated, in Peru, making it a leading producer in Latin America [11]. Considering these factors, this study aimed to develop a mango-based beverage that meets Peruvian regulatory standards while maintaining consumer acceptance.



MATERIALS AND METHODS

Materials

Fresh “Edward” mangoes and white sugar were purchased from a local supermarket. A commercial mango-based beverage, that is widely distributed in markets, was also acquired for comparative purposes. According to its label, it contained water, mango juice and pulp (15%), sugar, carboxymethylcellulose, citric acid, vitamins C, A and D, natural mango flavoring, sucralose, acesulfame K and ammonium sulfite caramel color. Food-grade additives used in the beverage formulation — sucralose (E955), carboxymethylcellulose (E466), potassium sorbate (E202), and citric acid (E330) — were purchased from a food-grade ingredient supplier.

Methods

Fruit treatment

Mangoes were selected, discarding those with physical defects. The fruits were washed and disinfected using a 0.1% sodium hypochlorite solution as indicated in previous studies [12]. They were then blanched for 5–10 minutes until their internal temperature reached 75°C to inactivate enzymes, reduce microbial load, preserve color, and soften the fruit [13].

Mango pulp preparation and characterization

Mango pulp was manually extracted and blended using a high-speed blender. pH was determined with a potentiometer (LaquaTwin, HORIBA®). Titratable acidity was also determined and expressed as citric acid percentage. Moreover, ripeness index was calculated as the ratio of soluble solids to titratable acidity.

Beverage preparation

A multilevel factorial experimental design with one replicate was employed in this study. Table 1 presents the complete set of formulations generated using the statistical software STATGRAPHICS Centurion 19 (trial version).

The processing steps of the beverage are illustrated in Figure 1. Mango pulp was mixed with sugar, sucralose, potassium sorbate, CMC and citric acid (Table 2). To standardize the formulation, the total soluble solids content (TSS) of the mango pulp was first measured, as it varies depending on the fruit’s ripeness. The amount of mango pulp used was then adjusted accordingly to maintain the final mixture at 5° Brix.

The mixture was homogenized for three minutes in a high-speed blender, then pasteurized in a microwave oven (MS2596DIR, LG) until 90°C. The beverage was then cooled to 68°C, bottled in 300 mL polyethylene terephthalate (PET) containers,



and sealed using a vacuum-inducing thermal shock at 4°C. Samples were refrigerated until sensory analysis.

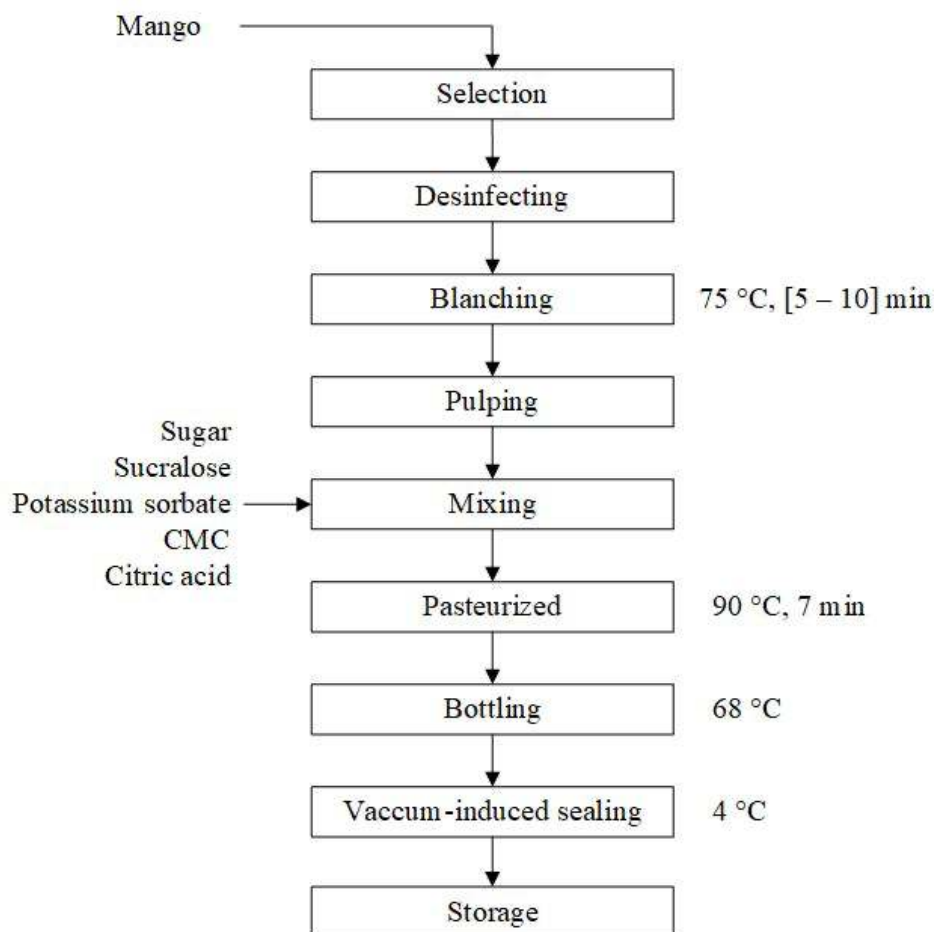


Figure 1: Schematic diagram of the mango - based beverage preparation process

Sensory Evaluation

The sensory evaluation was conducted by ninety-eight untrained panelists. All participants provided informed consent for their participation before the start of the test. Each sample (30 mL at 20°C) was presented monadically in 80 mL polypropylene cups, which were randomly labeled with three-digit codes, following the methodology described by Yoon *et al.* [17]. The panelists assessed the sensory acceptability of the six experimental samples (F1 – F6) and a sample of the commercial beverage using a 9-point hedonic scale to evaluate the attributes of appearance, taste and texture. The scale ranged from 1, representing “I don’t like it at all” and 9, representing “I like it very much”, as described by Guedes *et al.* [18]. Furthermore, purchase intention was assessed using a 5-point scale, where 1 represented “I would surely not buy it”, 3 represented “I would maybe buy it”, and 5 represented “I would surely buy it”, based on the approach outlined by Palma-Morales *et al.* [19].

Data Processing

Sensory analysis results were subjected to analysis of variance (ANOVA) followed by multiple comparison tests. Optimization was performed using Response Surface Methodology (RSM) with STATGRAPHICS Centurion 19 (trial version), aiming to maximize purchase intention and sensory attributes, including appearance, taste and texture.

Physicochemical, colorimetric and proximate Analysis

Optimal formulation based on the results of the sensory analysis was characterized based on the following physicochemical parameters: density, which was measured using a pycnometer following the method described by Talens [17], TSS (°Brix) using a refractometer, and pH were also determined. Moreover, viscosity was evaluated according to the guidelines specified by Aristizábal and Sánchez [18].

On the other hand, colorimetric characteristics of the optimal formulation and the commercial sample were assessed using a smartphone camera. The camera was set with the same conditions for consistency as is described by Wardani *et al.* [22]. The images were analyzed by the free software Image-J to determine the color parameters L* - lightness, a* - coloring from red (+a) to green (-a) and b* - coloring in the range from yellow (+b) to blue (-b) according to Feitosa *et al.* [23]. Moreover, the color difference (ΔE) was calculated by using Hunter's equation:

$$\Delta E = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \dots \text{(Eq. 1)}$$

Where ΔL^* is the difference in the lightness, Δa^* is the difference in axis a* of chroma and Δb^* is the difference in axis of b* of chroma [21].

The proximate composition was also analyzed. Fat content by AOAC 920.177, 22nd Ed. (2023) and protein content by AOAC 920.152, 22nd Ed. (2023). Carbohydrate content and total energy were calculated. Additionally, reducing sugars (g/100 mL) and total sugars (g/100 mL) were quantified according to AOAC 923.09, 22nd Ed. (2023) and AOAC 968.28, 22nd Ed. (2023), respectively.

Microbiological Analysis

Mesophilic aerobic bacteria (CFU/mL) were quantified using the standard plate count method. Coliforms (MPN/mL), yeasts (CFU/mL), and molds (CFU/mL) were analyzed following the guidelines established by the International Commission on Microbiological Specifications for Foods (ICMSF, 1983). These analyses were conducted to ensure product safety in compliance with the microbiological quality and food safety criteria outlined in the Peruvian sanitary regulations for food and beverages (NTS N° 071-MINSA/DIGESA-V.01).



RESULTS AND DISCUSSION

Raw material characteristics

In the current study, 1.34 kg of mango pulp was extracted from 2.10 kg of fresh fruit, yielding 64% of the total fruit weight. This percentage is in concordance with previously reported mango processing studies, where pulp yield varies from 40 to 60 % depending on factors such as cultivar and ripeness [22,23]. Furthermore, it aligns with findings by Jeevitha *et al.* [27], who reported that mango by-products (including peel, seed and the pulp attached to both) constitute approximately 35–55% of the total fruit weight.

The TSS of mango pulp was 20.07 ± 0.12 °Brix, exceeding the range of 14 – 18 °Brix previously reported by Owino and Ambuko [25]. This variation could be attributed to the fruit maturity stage, as the breakdown of complex metabolites into simple molecules, such as fructose and glucose, during maturation causes the increase in TSS [25]. The ripening index of fresh mango was 74.63 ± 3.39 , corresponding to approximately 18 days of storage, as reported in the study by Ali *et al.* [29]. From another perspective, the sugar accumulation could be advantageous by potentially allowing a reduction in the amount of pulp required in the beverage formulation while maintaining the desired sweetness.

In the current study, the pH of mango pulp was 4.13 ± 0.07 , while titratable acidity was 0.27 ± 0.01 %. This value was slightly higher compared to the pH of mango purée, which was reported as 3.38 ± 0.3 by Vu *et al.* [30]. However, to enhance both safety and sensory attributes, citric acid was added to the beverage formulation. Lowering the pH to approximately 3.0 creates an additional barrier against pathogenic bacteria while simultaneously enhancing the flavor profile, making the beverage more refreshing and palatable [28].

Effect of Sucralose and CMC concentrations on sensory attributes

The statistical analysis of the samples, considering appearance, taste, texture, and purchase intention, reveals the relationship between the independent variables and the response variables, enabling the identification of an optimal formulation. Figure 2 presents the Pareto diagram, where it was observed that neither CMC nor sucralose concentrations significantly influenced product acceptance (p -value > 0.05). Similar results were reported by Carvalho de Castro *et al.* [32] in a study on the acceptability of a mixed beverage made from hibiscus and coconut water sweetened with stevioside.

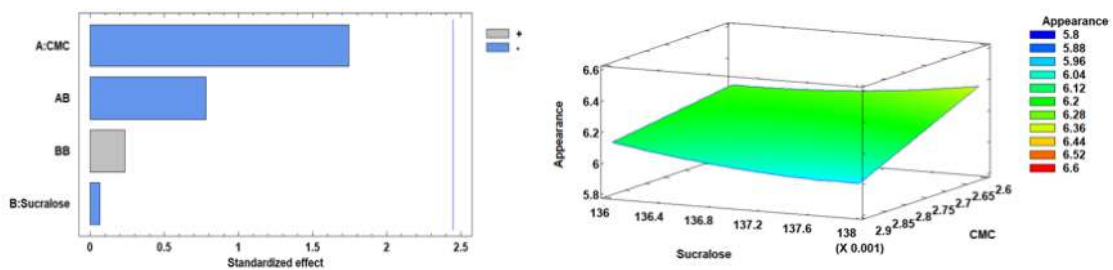
The results showed no significant differences in taste and texture between the experimental samples and the commercial beverage (p -value > 0.05), indicating that the formulated beverages were well accepted with these attributes. Achieving similar



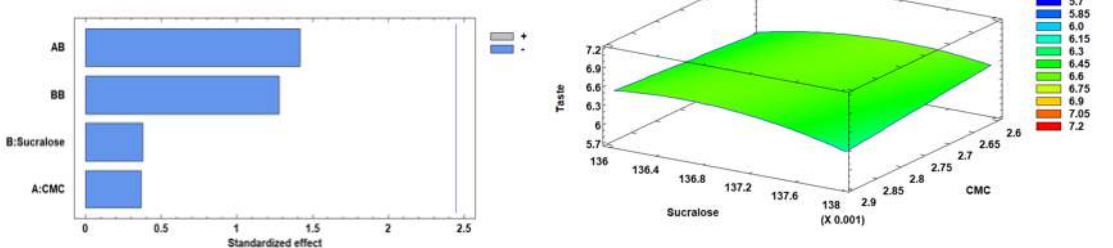
sensory results suggests that the developed formulations have potential for commercial application. Moreover, the purchase intention ratings for all samples, including the commercial beverage, were statistically comparable, indicating a moderate level of consumer acceptance. In contrast, a significant difference was observed in appearance, suggesting that further improvements are necessary for market competitiveness.

Additionally, the combined effect of both factors did not significantly influence the response variable. However, the concentration of CMC had a significant impact on purchase intent, as its effect exceeded the critical statistical limit of the standardized effect.

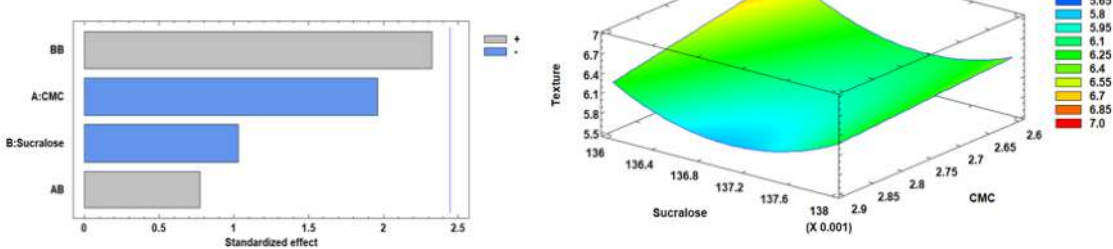
a)



b)



c)



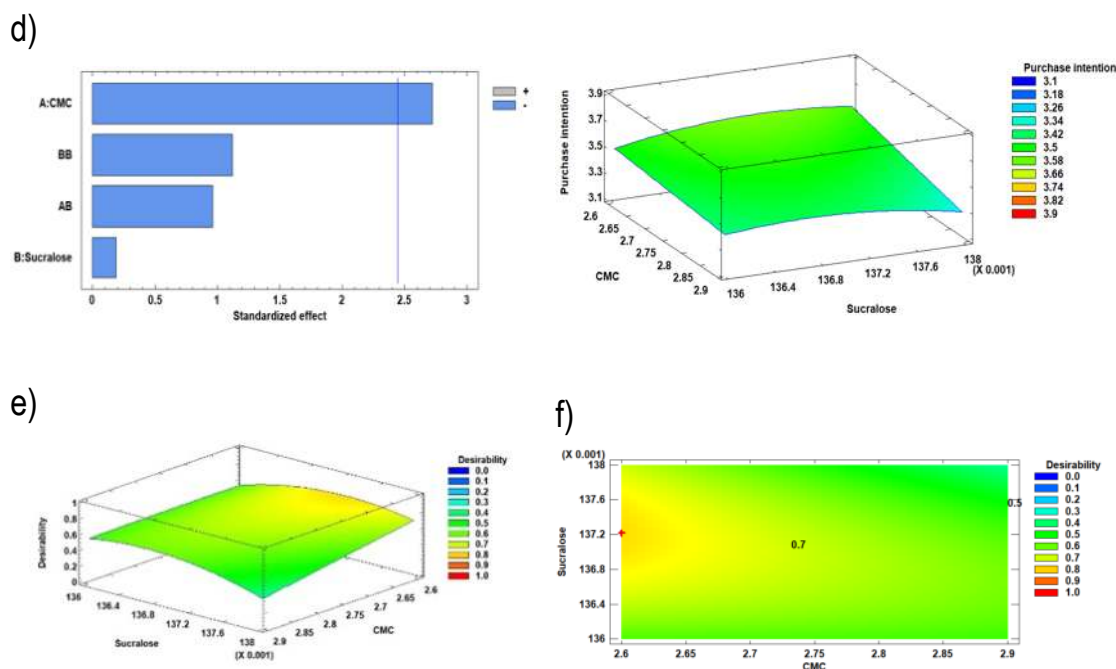


Figure 2: Standardized Pareto diagram and Estimated response surface for a) appearance, b) taste, c) texture, d) purchase intention, respectively, e) Multiple estimated response surface and f) Response surface contour

Regarding the appearance attribute, no significant differences were observed among the designed formulations (F1–F6). However, the commercial sample received a significantly higher rating ($p < 0.05$). In terms of taste, the formulation with the highest concentrations of sucralose and CMC (F6) received the lowest score ($p > 0.05$), whereas formulations F1–F5 were rated similarly and comparable to the commercial sample. For Texture, formulation F4 received the lowest rating ($p < 0.05$), while the remaining formulations exhibited homogeneous results. These findings suggest a preference for lower sucralose concentrations. However, in the case of CMC, the analysis of taste and texture indicates contrasting effects. The multiple optimization analysis was determined based on the RSM for purchase intention, as CMC showed a notable influence in the Pareto diagram. The optimization was performed using the desirability function (with a maximum value of 0.7791). As shown in Figure 2 (e–f), the optimal concentrations were 0.137 g of sucralose and 2.60 g of CMC, corresponding to formulation F3. In this context, consumer preference is influenced by viscosity, as an excessive increase can negatively impact texture acceptance. This effect has been observed in previous studies, where higher concentrations of chia mucilage affected sensory perception [30]. Since mango pulp naturally contains pectin, starch, cellulose and hemicellulose [31] the addition of CMC further enhances viscosity, allowing for better control over

the beverage's texture to achieve a desirable mouthfeel that meets consumer expectations [32].

Physicochemical, colorimetric and microbiological characteristics properties

The optimal formulation (F3) exhibited a viscosity of 54.4 cP at 24.7 °C, indicating a consistency classified as nectar-like [33]. This viscosity is significant not only for the sensory experience, particularly in terms of mouthfeel, but also for product stability. The inclusion of carboxymethyl cellulose (CMC) likely contributed to this desirable texture, ensuring a smooth appearance. However, according to Giridharaprasad *et al.* [37], higher viscosity can negatively impact physical stability, suggesting a sensory acceptability to achieve the optimal viscosity for both texture and stability of the final product.

The physicochemical properties of the F3 formulation and a commercial mango beverage were compared (Table 3). The carbohydrate content of F3 was 5.72 g/100 mL, which was notably higher than that of the commercial product (3.84 g/100 mL). In terms of energy value, F3 provided 23.04 kcal/100 mL, compared to 15.50 kcal/100 mL in the commercial counterpart. Although slightly higher, both beverages are classified as low-calorie, as their energy values fall within the range of 10–84 kcal/100 mL [35]. Both samples contained negligible amounts of fat (0.00 g/100 mL), while protein content was very low in both cases—0.04 g/100 mL for F3 and undetectable in the commercial sample—values that are typical for fruit-based drinks [36].

The pH value of F3 was 2.87 ± 0.02 , slightly more acidic than that of the commercial beverage (3.40 ± 0.02). These values are suitable for inhibiting the growth of spoilage microorganisms. As reported by Lim *et al.* [40], beverages with a pH below 5 create an unfavorable environment for the survival of many pathogens, including yeasts, molds, and acid-tolerant bacteria, thus contributing to extended shelf-life and microbiological safety. Moreover, F3 formulation revealed a TSS content of 5.00 ± 0.02 °Brix, a total sugar content and reducing sugar of 4.45 g/100 mL and 0.61 g/100 mL, respectively. These values confirm its classification as a low-sugar beverage in accordance with the Peruvian Law No. 30021 [4], which mandates that beverages containing 5 g or more of sugar per 100 mL must carry a front-of-pack warning label stating: “Avoid excessive consumption.” Since the sugar content in this formulation falls below this threshold, it is exempt from such labeling. In contrast, the commercial beverage had 4.30 ± 0.00 °Brix, this low value compared with the experimental formulation, reduced the mouthfeel.

On the other hand, differences in appearance could be attributed to color, as indicated by the Commission Internationale de L'Eclairage (CIELAB) and from chromatic parameters L^* , a^* , b^* , color difference (ΔE^*) parameter was calculated



(Table 4). According to García *et al.* [24], ΔE^* values greater than 3.00 are perceptible to the human eye, allowing consumers to distinguish variations in color. In this case, the more intense yellow hue of the commercial beverage can be attributed to the presence of ammonium sulfite caramel colorant in its formulation, as it is shown in Figure 3. This visual distinction may have influenced consumers' perception of the product's appearance, potentially affecting overall acceptance.

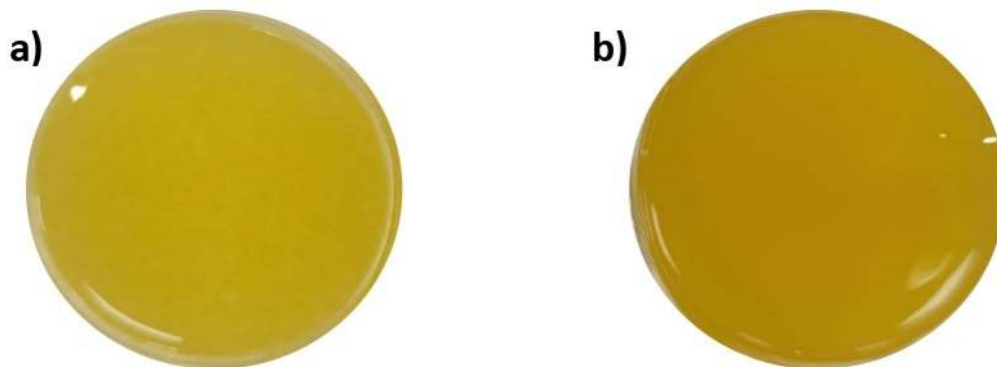


Figure 3: Samples of a) optimal formulation mango-based beverage and b) commercial mango-based beverage

According to microbiological analysis, the results confirmed that the beverage met safety standards and was suitable for human consumption. The levels of coliforms, mesophilic aerobes, molds and yeasts were coliforms < 3, mesophilic aerobes < 10, molds and yeasts < 1, all of them below the Maximum Permissible Limits established by Peruvian regulations for non-carbonated beverages [38]. These findings indicate that the beverage meets the necessary microbiological standards for quality and hygiene, ensuring that it is free from harmful microbial contamination. For instance, the low coliform count suggests that proper hygienic practices were maintained throughout the beverage's production process [39]. In the case of molds and yeasts, the undetectable levels underscore the effectiveness of both thermal (pasteurization) and non-thermal methods, such as the addition of potassium sorbate, in preventing the growth of these microorganisms [40].

CONCLUSION AND RECOMMENDATIONS FOR DEVELOPMENT

According to the results, neither CMC (2.60 - 2.90 g L⁻¹) nor sucralose (0.136 - 0.138.g L⁻¹) concentrations had a significant effect on texture, appearance or taste. However, CMC concentration had a significant negative effect on purchase intent. The optimal formulation was determined as 2.6 g L⁻¹ of CMC and 0.137 g L⁻¹ of sucralose, corresponding to formulation F3. When compared to the commercial beverage, no significant differences were observed in terms of texture and taste. However, improvements in appearance may be necessary to better align the experimental formulation with the commercial beverage. Notably, this study

developed a sensorially acceptable beverage comparable to a commercial product while achieving a significant reduction in sugar content. In line with Peruvian regulations, the final product meets the criteria to be classified as “free from high sugar content” labeling, reinforcing its potential as a marketable low-sugar beverage.

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Table 1: Multilevel factorial experimental design with one replicate

	CMC	Sucralose
1	2.6	0.136
1	2.9	0.136
1	2.6	0.137
1	2.9	0.137
1	2.6	0.138
1	2.9	0.138
2	2.6	0.136
2	2.9	0.136
2	2.6	0.137
2	2.9	0.137
2	2.6	0.138
2	2.9	0.138

Note. Both sucralose and CMC were modified following a multilevel factorial design. Two levels were used for CMC, while three levels were used for sucralose

Table 2: Formulation compositions for 1000 mL of reduced-sugar mango beverage



Formulation	F1	F2	F3	F4	F5	F6
Mango pulp (g)	67.56	67.56	67.56	67.56	67.56	67.56
Sugar (g)	30	30	30	30	30	30
CMC (g)	2.60	2.90	2.60	2.90	2.60	2.90
Citric acid (g)	2.30	2.30	2.30	2.30	2.30	2.30
Potassium sorbate (g)	0.25	0.25	0.25	0.25	0.25	0.25
Sucralose (g)	0.136	0.136	0.137	0.137	0.138	0.138



Table 3: Proximate analysis and physicochemical comparison between F3 and commercial beverage

Characteristic	F3	Commercial beverage
Carbohydrates (g/100ml)	5.72	3.84
Total energy (kcal/100ml)	23.04	15.50
Fat (g/100ml)	0.00	0.00
Protein (g/100ml)	0.04	0.00
pH	2.87 ± 0.02	3.40 ± 0.02
TSS (°Brix)	5.00 ± 0.02	4.30 ± 0.00

Table 4: Colorimetric characteristics of F3 and commercial beverage

Sample		L*	a*	b*	ΔE
F3		67.09 ± 1.45	2.45 ± 0.65	54.04 ± 0.88	
Commercial beverage		62.42 ± 3.06	7.70 ± 0.13	52.20 ± 1.91	35.31

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