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Physicochemical, sensory and microbiological evaluation of mixed nectar from *Opuntia ficus-indica* and *Oxalis corniculate*

Evaluación fisicoquímica, sensorial y microbiológica de néctar mixto de *Opuntia ficus-indica* y *Oxalis corniculata*

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ABSTRACT

The growing demand for processed foods with fewer synthetic additives justifies the development of functional beverages with natural ingredients such as tuna (*Opuntia ficus-indica* (L.) Mill.) and chulco (*Oxalis corniculata* L.). Therefore, the aim of this study was to formulate a mixed nectar and evaluate its physicochemical composition, sensory acceptance, and microbiological quality. Four formulations were prepared by varying the proportion of tuna pulp (20–41%) and chulco juice (4–25%), using hydrolyzed passion fruit peel flour as a replacement for carboxymethylcellulose. Sensory evaluation was performed using a 9-point hedonic scale and ANOVA analysis (P<0.05) applied to 100 consumers, in addition to determining physicochemical parameters and shelf life at 20 and 5 °C. The results showed that treatment T3 (34% tuna and 11% chulco) had the highest acceptability (7.5/9), with high vitamin C content, total phenols, and antioxidant capacity. It also exhibited adequate microbiological stability, with a shelf life of three months at 20 °C and four months at 5 °C. In conclusion, T3 nectar is a functional product with good sensory acceptance and microbiological stability, using high Andean ingredients and a natural thickener, which represents a technological alternative to reduce artificial additives in processed beverages.

RESUMEN

Palabras clave:
Capacidad antioxidante
Bebida funcional
Análisis sensorial

La creciente demanda de alimentos procesados con menos aditivos sintéticos justifica el desarrollo de bebidas funcionales con ingredientes naturales como la tuna (*Opuntia ficus-indica* (L.) Mill.) y el chulco (*Oxalis corniculata* L.). Por ello, el objetivo de este estudio fue formular un néctar mixto y evaluar su composición fisicoquímica, aceptación sensorial y calidad microbiológica. Se elaboraron cuatro formulaciones variando la proporción de pulpa de tuna (20–41%) y jugo de chulco (4–25%), empleando harina hidrolizada de cáscara de maracuyá en reemplazo de carboximetilcelulosa. La evaluación sensorial se realizó mediante una escala hedónica de 9 puntos y análisis ANOVA (P<0,05) aplicado a 100 consumidores, además de la determinación de parámetros fisicoquímicos y vida útil a 20 y 5 °C. Los resultados mostraron que el tratamiento T3 (34% de tuna y 11% de chulco) obtuvo la mayor aceptabilidad (7,5/9), con contenido de vitamina C, fenoles totales y capacidad antioxidante. Asimismo, presentó una adecuada estabilidad microbiológica, con vida útil de tres meses a 20 °C y cuatro meses a 5 °C. En conclusión, el néctar T3 constituye un producto funcional con buena aceptación sensorial y estabilidad microbiológica, utilizando insumos altoandinos y un espesante natural, lo que representa una alternativa tecnológica para reducir aditivos artificiales en bebidas procesadas.

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The National Institute of Quality of Peru (INACAL 2022) defines nectars as non-fermented but fermentable beverages prepared from water and fruit pulp in defined proportions. On the global stage, the rising interest in natural, health-oriented beverages situates fruit-based nectars and functional drinks as a major segment of the non-alcoholic beverage industry, aligning with shifting dietary patterns and preventive-health priorities worldwide. Indeed, the global functional beverages market-which includes fortified juices, botanical drinks, plant-based formulations, antioxidant-rich nectars, and more-was estimated at tens of billions of USD in 2024 and is projected to grow at a compound annual growth rate of approximately 4.9 to 7% over the coming decade, depending on the source (Global Growth Insights 2025). Functional beverages constitute a category of functional foods, recognized for their supply of nutrients, bioactive compounds, and potential anti-diabetic and antihypertensive properties (Kumari et al. 2025).

There is a growing trend toward the consumption of foods that provide benefits beyond basic nutrition, along with the development of fruit-based beverages with enhanced nutritional quality to promote consumer health (Quispe-Herrera et al. 2022). In the food industry, additives such as thickeners (e.g., carboxymethylcellulose in nectars) are commonly employed to improve product consistency (OMS 2023). However, systemic allergic reactions have been reported following exposure to carboxymethylcellulose in pharmaceutical formulations and in certain foods containing this additive (Townsend et al. 2021).

Foods such as prickly pear (*Opuntia ficus-indica* (L.) Mill.), chulco (*Oxalis corniculata* L.), and hydrolyzed passion fruit peel flour (*Passiflora edulis* Sims) represent promising raw materials for producing functional nectars due to their content of bioactive compounds. Red prickly pear, rich in polyphenols (phenolic acids, flavonoids, flavanols, and bioflavonoids), pyridine, betalains, and coumarins, exhibits significant antidiabetic, antioxidant, and antihypercholesterolemic properties (Mehta et al. 2025).

Passion fruit peel, a by-product of the agribusiness sector, is noteworthy for its soluble dietary fiber, polyphenols, and antioxidant activity (Chuqui-Diestra and Paucar-Menacho 2021). Hydrolysis enhances its functional potential by depolymerizing pectins, releasing low-molecular-weight fractions with prebiotic effects that modulate the intestinal microbiota, contribute to cholesterol reduction, and serve as a natural alternative to conventional thickeners, emulsifiers, and stabilizers (Patel and Maheshwari 2024).

Oxalis corniculata L. (chulco) is an herbaceous plant native to the inter-Andean valleys. It is noteworthy for its content of phenolic acids and flavonoids, which exhibit antioxidant activity, inhibit lipid peroxidation, and protect plasmid DNA from oxidative damage (Bharti et al. 2024).

The combination of fruits and vegetables in nectar formulations provides a broad spectrum of nutrients, including vitamins, minerals, and antioxidants, while also offering a diversity of flavors that is of significant interest to the food industry (Heredia et al. 2021; Loyola et al. 2019). Within this framework, there is a growing need to develop nectars with enhanced nutritional potential that minimize the use of synthetic additives such as citric acid, carboxymethylcellulose, and artificial colorants.

Despite the growing interest in the development of functional beverages based on natural ingredients, there are limitations in the standardization of raw materials, microbiological control, and the optimization of physicochemical and sensory properties in mixed nectars. In the case of prickly pear (*Opuntia ficus-indica* (L.) Mill.) and creeping wood sorrel (*Oxalis corniculata* L.), variability in their chemical composition and the limited research on their combined application hinder the ability to ensure product stability, safety, and sensory acceptance. In this context, a research gap is identified in the formulation of mixed nectars incorporating both ingredients, with a comprehensive evaluation of their physicochemical, microbiological, and sensory quality.

Therefore, the aim of this study was to evaluate the effect of different proportions of nopal pulp (*Opuntia ficus-indica* (L) Mill, 20–41% w/w) and chulco stems (*Oxalis corniculata* L., 4–25% w/w) on the sensory acceptability of a nectar among university students, as well as the physicochemical and microbiological composition and shelf life of the sample with the highest overall acceptance.

MATERIALS AND METHODS

Raw material procurement

Red prickly pear fruits were sourced from Yanasara

(Curgos, La Libertad, Peru). The chulco plant (red stem variety) was collected from Munmalca and Coigobamba, located in the districts of Sarín and Huamachuco, respectively, with an average plant height of 60 cm. Passion fruit (*Passiflora edulis* Sims) was obtained from the village of El Convento, in the district of Chugay, and all raw materials were obtained in their fresh state and at commercial maturity. Potassium sorbate, used as a preservative, was purchased from a commercial supplier.

Methodology

The raw materials (prickly pear pulp and chulco stems), whole and hydrolyzed passion fruit peel flour, as well as the most widely consumed commercial nectar, were subjected to physicochemical analysis. The parameters evaluated included free lipids, ash, moisture, pH, soluble solids, titratable acidity, reducing sugars, vitamin C (2,6-dichlorophenolindophenol) (FSSAI 2016), crude fiber (INACAL 2001), total proteins (ISO 5983, Kjeldahl), antioxidant capacity (Plank et al. 2012) and total phenols (Folin–Ciocalteu method, using gallic acid as standard). The density of the raw materials and of the most acceptable nectar formulation was determined by pycnometry. Table 1 summarizes the percentage composition of the four nectar formulations.

Table 1. Experimental design of the four nectar formulations.

Components		Formulation (%) (w/w)			
		T1	T2	T3	T4
Variables	Prickly pear pulp	20	27	34	41
	Chulco stem juice	25	18	11	4
Constants	Hydrolyzed passion fruit peel flour	1.0	1.0	1.0	1.0
	White sugar	8.96	8.96	8.96	8.96
	Potassium sorbate	0.04	0.04	0.04	0.04
	Still table water *	45	45	45	45
Total		100	100	100	100

*2 mg 100 mL^{-1} sodium and pH of 7.7

Prickly pear pulp preparation

Ripe prickly pears with a pH of 5.40–5.81 and soluble solids ranging from 10 to 14 °Brix were selected. The fruits were washed with water and disinfected in a 50-ppm sodium hypochlorite solution for 10 min. They were then boiled for 2 min to inactivate enzymes, reduce microbial load, and improve texture. The peel was removed, and the endocarp was blanched at 85 °C for 1 min. The pulping was carried out using a high-speed laboratory homogenizer (Whiteline 600 W, 3,000 rpm for 20 s), ensuring that the seeds were not crushed; subsequently they were separated using a sieve with a mesh size $\leq$2 mm.

Chulco juice extraction

Reddish-pink stems were selected, exhibiting an approximate pH of 3, as measured using a digital pH meter (MILWAUKEE brand, model MW150). The stems were washed and disinfected in a 70-ppm sodium hypochlorite solution for 10 min, then blanched at 85 °C for 3 min. They were subsequently crushed in a blender (3,000 rpm for 60 s) and sieved through a mesh screen with a pore size $\leq$1 mm.

Preparation of hydrolyzed passion fruit peel flour

Passion fruits with a pulp soluble solids content of 12–14 °Brix were used. The peels were disinfected in a 50 ppm NaClO solution for 10 min and cut into pieces of approximately 2×1 cm to facilitate blanching (85 °C for 30 s). The pieces were dehydrated in a convective-air oven at 50 °C for 72 h with an airflow of 0.5 m s^{-1}, then ground and sieved through a mesh $\leq$1 mm.

Hydrolysis was carried out using the enzyme Pectinex Ultra SPL at a concentration of 2% (w/w) relative to passion fruit peel flour, with 0.075 mL of enzyme added per gram of flour. The mixture was incubated at 50 °C for 24 h. Enzymatic activity was inactivated by cooling to

1 °C. The hydrolyzed material was then dried in an oven at 50 °C for 72 h, ground, and sieved (≤ 1 mm) to obtain flour with a uniform particle size. Figure 1 illustrates the process for nectar production.

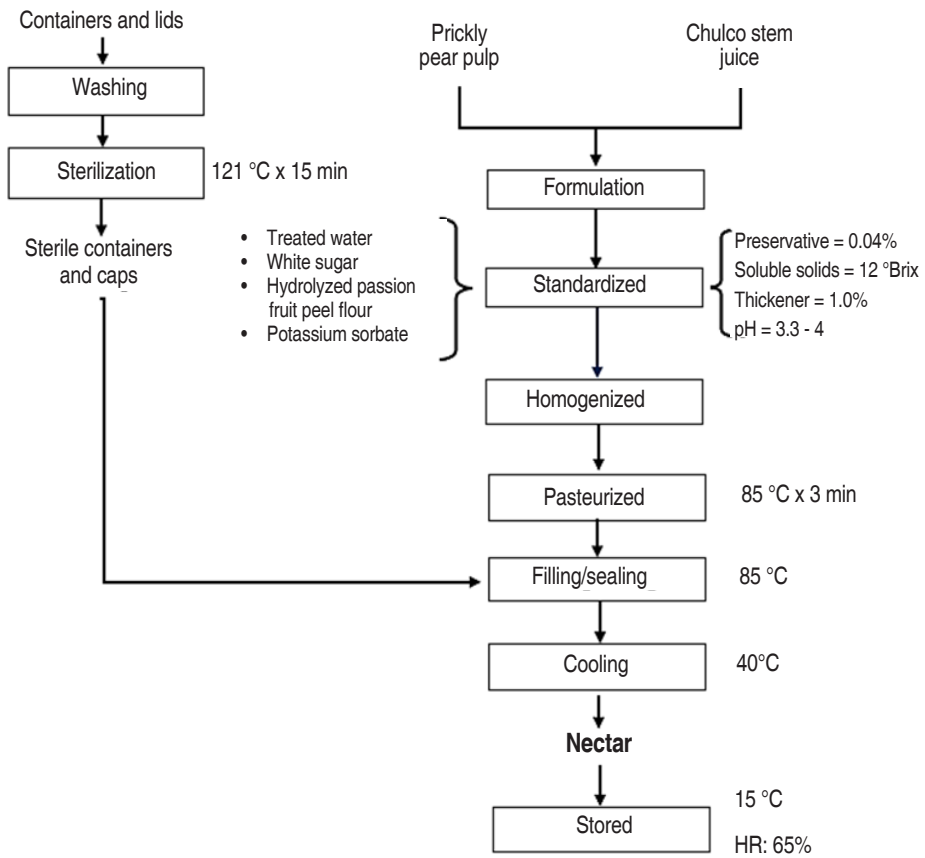


Figure 1. Process flow for nectar production.

Statistical techniques

For the physicochemical characterization of the raw materials, a descriptive analysis was performed (mean ± standard deviation).

For sensory evaluation, a nine-point hedonic scale (1 = extremely disliked to 9 = extremely like) was used to assess the organoleptic attributes of color, odor, taste, consistency, and overall acceptability. The study was carried out at the Universidad Nacional de Trujillo with the participation of 100 students, all of whom provided informed consent. Analysis of variance (ANOVA) was performed to determine significant differences among the four treatments for each sensory attribute. In addition, Fisher's Least Significant Difference (LSD) test was applied to compare treatment means. Statistical analyses were conducted using R software, with a significance level set at 5%.

RESULTS AND DISCUSSION

Table 2 shows the physicochemical analysis of prickly pear pulp, showing a moisture content in the range of 79.0–91.0% (Martins et al. 2023; Aparicio-Fernández et al. 2017). Soluble solids were slightly higher than the range of 12.3–13.7 °Brix reported by Martins et al. (2023), but consistent with the parameters described for the red variety by Aparicio-Fernández et al. (2017). The ash content was close to the 1.0% reported by Martins et al. (2023), while the density (1.0479–1.0543 g cm^{-3}) fell within the range reported by the same authors. No free lipids were detected, and only a low content of reducing sugars was

observed. In contrast, Martins et al. (2023) reported lipid fractions ranging from 0.12 to 0.15% and reducing sugar values between 8 and 14%.

The antioxidant capacity of prickly pear was higher than the 22.42% DPPH reported by Torres-Bojórquez et al. (2020). The fiber content fell within the range of 1.4–4.8%, while the protein content exceeded the 0.5% reported by Martins et al. (2023). The acidity was higher than the 0.52% reported by Aparicio-Fernández et al. (2017). The pH was within the range of 5.0–6.9 described by Martins et al. (2023) and Aparicio-Fernández et al. (2017). Total carbohydrates were lower than the range of 14–20% reported by Martins et al. (2023). The total phenolic content was comparable to the orange, white, and purple varieties, which range from 3.69 to 4.08 mg g^{-1}. Isorhamnetin-3-rutinoside, along with smaller amounts of isorhamnetin-3-glucoside, rutin, and kaempferol-3-rutinoside, have been identified as major phenolic compounds (Enciso et al. 2021).

Table 2. Physicochemical characteristics of prickly pear pulp and chulco stem juice.

Indicator	Raw material values	
	Prickly pear pulp	Chulco stem juice
Humidity (%)	82.23±0.14	91.13±0.60
Soluble solids (°Brix)	13.78±0.06	1.74±0.13
Ashes (%)	1.31±0.18	5.35±0.02
Density (g cm^{-3})	1.05±0.0011	1.01±0.001
Free lipids (%)	ND	ND
Reducing sugar (%)*	1.45±0.25	0.10±0.01
Antioxidant capacity (%)	76.30±0.92	78.56±0.27
Fiber (%)	1.68±0.21	1.47±0.12
Proteins (%)	2.92±0.20	1.38±0.18
Vitamin C (mg 100 mL^{-1})	14.8±0.16	1.83±0.26
Total phenols (mg 100 mL^{-1})	3.43±0.21	6.81±0.19
Acidity (% citric acid)	0.63±0.08	2.06±0.07
pH	5.78±0.01	2.32±0.03
Total carbohydrates (%) (difference)**	13.54	2.14

Mean values of three determinations ± standard deviation, *Glucose equivalent, **(100-moisture-protein-lipids-ash), ND = Not Detectable.

The juice from *Oxalis corniculata* L. stems had a relatively high ash content compared to prickly pear, indirectly indicating the presence of minerals. Badwaik et al. (2011) reported the presence of sodium (1.12%), magnesium (0.25%), potassium (2.17%), and calcium (2.5%). Its antioxidant capacity (78.56%) reflects a strong ability to scavenge free radicals, while its high acidity (2.06%) resulted in a low pH (2.32), favoring the microbiological stability of the nectar. However, the juice contained low levels of soluble solids (1.74 °Brix), reducing sugars (0.10%), fiber (1.47%), protein (1.38%), and carbohydrates (2.14%). These values are comparable to those reported by Badwaik et al. (2011), who also documented a high vitamin C content (125 mg 100 g^{-1}), high moisture (92.3%), and a low carbohydrate level (1.36%) in *Oxalis corniculate* L. Regarding antioxidant capacity, the phenolic content was 6.81 mg 100 mL^{-1}, whereas Badwaik et al. (2011) reported 30 mg L^{-1}. Additional studies indicate that O. *corniculata* L. possesses anti-inflammatory properties, highlighting its potential as a functional ingredient in the food and nutraceutical industries (Kumari et al. 2025).

Table 3 shows the physicochemical analyses of passion fruit peel flour (whole and hydrolyzed), which was used as a thickening agent in the nectar. The hydrolyzed flour showed a lower moisture content (6.01%) compared to the whole flour (7.13%), likely due to the release of poorly

soluble and hygroscopic compounds during pectinase hydrolysis. This value was also lower than the 11.25% reported by Chuqui-Diestra and Paucar-Menacho (2021). Minimal differences were observed in ash and protein contents (5.92 and 5.88 g 100 g^{-1}, respectively), both of which were close to the 5.14% reported by Chuqui-Diestra and Paucar-Menacho (2021). Reducing sugars increased from 1.03% in whole flour to 1.23% in hydrolyzed flour, attributable to the enzymatic breakdown of polysaccharides by pectinase. An increase in titratable acidity (2.97%) was also observed, which corresponded to a lower pH (4.12) in hydrolyzed flour. Chuqui-Diestra and Paucar-Menacho (2021) reported a high dietary fiber content (63.88%) and strong antioxidant activity (1520.49 µmol ET 100 g^{-1}), both of which enhance rheological properties and support its use as an effective substitute for commercial thickeners and gelling agents. Furthermore, the incorporation of passion fruit peel into food formulations has been associated with anti-inflammatory, antiperspirant, and antidiabetic properties (Patel and Maheshwari 2024).

Table 3. Physicochemical characteristics of whole and hydrolyzed passion fruit peel flour.

Indicator	Unit	Passion fruit peel flour	
		Whole	Hydrolyzed
Humidity	%	7.13±0.21	6.01±0.10
Ashes	g 100 g^{-1}	6.22±0.13	6.41±0.15
Proteins	g 100 g^{-1}	5.92±0.18	5.88±0.18
Free lipids	g 100 g^{-1}	0.54±0.08	0.59±0.06
Reducing sugar*	%	1.03±0.01	1.23±0.28
Acidity (citric acid)	%	1.74±0.15	2.97±0.09
pH	value	4.48±0.01	4.12±0.01

Mean values of three determinations ± standard deviation, *glucose equivalent.

Replacing carboxymethylcellulose with hydrolyzed passion fruit peel flour represents a sustainable alternative in nectar production, as it aligns with a circular economy approach that promotes the use of agro-industrial waste. This strategy allows for the valorization of byproducts with thickening and stabilizing properties. Furthermore, it contributes to reducing the use of synthetic additives, the consumption of which can be associated with adverse reactions in sensitive consumers, thus fostering the development of more natural, safer beverages that are in line with current trends in the food industry.

In Table 4, treatment T3 (34% prickly pear pulp and 11% chulco stem juice) received the highest scores for color, flavor, and overall acceptability. In contrast, treatment T4 (41% prickly pear pulp and 4% chulco stem juice) achieved the highest score for aroma. Treatment T2 (27% prickly pear pulp and 18% chulco stem juice) obtained the highest

Table 4. Mean hedonic scores for the sensory attributes of the four nectar treatments.

Organoleptic attribute	Scores from 1 to 9 for each treatment (T)			
	T1 ± SD	T2 ± SD	T3 ± SD	T4 ± SD
Color	6.71±1.32^{a}	7.14±1.39^{b}	7.63±1.02^{c}	7.63±1.10^{c}
Smell	6.20±1.63^{a}	6.81±1.34^{b}	6.94±1.45^{b}	7.04±1.36^{b}
Flavor	6.74±1.26^{a}	6.88±1.11^{a}	7.47±1.36^{b}	7.27±1.24^{b}
Consistency	5.67±1.56^{a}	6.68±1.26^{b}	6.55±1.70^{b}	6.65±1.34^{b}
General acceptability	6.79±1.20^{a}	6.93±1.06^{ab}	7.53±1.09^{c}	7.23±1.06^{bc}

T: treatment, SD: standard deviation. Different superscript letters (a, b, and C) indicate significant differences among treatments for each sensory attribute.

score for consistency, whereas treatment T1 (20% prickly pear pulp and 25% chulco stem juice) received the lowest scores across all sensory attributes.

On a 9-point hedonic scale, treatment T3 achieved an overall acceptability score of 7.53, comparable to the 7.28 reported for a mango–plum-based nectar (Cordova et al. 2023) and to the score of 7.21 obtained in the evaluation of a carrot–orange nectar (Loyola et al. 2019). Statistically, the consistency of treatments T2, T3, and T4 did not differ significantly.

In Table 5, the most acceptable nectar (T3) had a moisture content of 83.12%, a value close to the 83.80% reported for *Passiflora tripartita Kunth* nectar (Neyra and Sosa 2021). The ash content was relatively high (1.04%) compared with the 0.20% reported for P. *tripartita* Kunth nectar (Neyra and Sosa 2021), but lower than the 1.7% found by Ticsihua and Orejon (2022) in a functional beverage based on white prickly pear and goldenberry. The absence of lipids in this type of product is not nutritionally relevant, given the composition of the raw materials used (Martins et al. 2023).

Table 5. Physicochemical characteristics of nectar (T3) with the highest acceptability overall.

Indicator	Unit	Values
Ashes	%	1.04±0.11
Total solids	%	16.88±0.06
Soluble solids (°Brix)	°Brix	12.03±0.12
Density	g cm^{-3}	1.052±0.005
Alcohol	°GI	ND
Free lipids	%	ND
Reducing sugar	%	0.481±0.04
Antioxidant capacity	%	79.84±1.37
Fiber	%	0.88±0.12
Proteins	g 100 g^{-1}	2.50±0.21
Vitamin C	mg 100 mL^{-1}	5.54±0.18
Total phenols	mg 100 mL^{-1}	1.98±0.19
Sodium	mg	7.05±0.13
Acidity (Citric acid)	%	0.206±0.021
Hydronium ions	pH	3.89±0.03
Total carbohydrates*	g 100 g^{-1}	13.34
Energy**	kcal 100 g^{-1}	31.50

Mean values of three determinations ± standard deviation, *(100-Protein-lipids-ash-moisture), **By calorimetry, ND = Not Detectable.

The prickly pear pulp contributes soluble solids, viscosity, color, and texture to the formulation. Concentrations below 20% result in an overly diluted product with low sensory acceptance, whereas concentrations above 41% markedly increase viscosity and may lead to phase separation. In contrast, chulco juice functions as an acidifying component, providing natural acidity and aromatic compounds. Inclusion levels below 4% do not induce meaningful changes in acidity, aroma, or flavor, while levels above 25% may produce an excessively acidic or dominant taste, thereby compromising the overall sensory balance of the product.

The reducing sugar content was 0.481%, primarily attributable to the glucose and fructose present in prickly pear juice, as well as to the reducing ends of hydrolyzed pectin derived from passion fruit peel. The fiber content (0.88%) was higher than the 0.05% reported for tumbo serrano nectar (Neyra and Sosa 2021) but lower than the 1.8% found in white prickly pear and aguaymanto nectar (Ticsihua and Orejon 2022). The proposed beverage contained 1.98 mg 100 mL^{-1} of total phenols, a value considerably lower than the 33.9–48.4 mg gallic acid 100 mL^{-1} reported for pitahaya nectar and passion fruit peel flour (Muñoz et al. 2023). The vitamin C content was

5.54 mg 100 mL^{-1}, which is below the 9.90 mg 100 mL^{-1} reported by Neyra and Sosa (2021) for a *Passiflora tripartita* Kunth-based nectar sweetened with honey, and the 20.25 mg 100 g^{-1} reported by Ticsihua and Orejon (2022) for a white prickly pear and aguaymanto nectar. By comparison, Saveboworn et al. (2025) reported a phenolic content of 7.28 mg g^{-1} and an antioxidant activity of 4.04% in a rice bran protein beverage.

The density of the most acceptable nectar was 1.052 g cm^{-3}, slightly higher than the values reported by Muñoz et al. (2023) for nectar formulated with pitahaya pulp and passion fruit peel flour, which ranged between 1.013 and 1.026 g cm^{-3}. The acidity was 0.20%, a value comparable to the 0.21–0.30% reported for nectar at various concentrations of mango–plum pulp (Cordova et al. 2023) and close to the 0.42% observed in a Mocambo cocoa mucilage-based nectar (Arrunátegui-Jácome et al. 2024). The soluble solids content of nectar T3 reached 12.03 °Brix, slightly lower than the 13.5 °Brix reported by Neyra and Sosa (2021), but consistent with the 12.16–13.43 °Brix observed by Muñoz et al. (2023) and the 13 °Brix reported for soursop pulp-based nectar (Heredia et al. 2021).

The nectar exhibited a pH of 3.89, favoring stability and preservation, and aligning with values reported for pitahaya–passion fruit nectars (4.53–4.72; Muñoz et al. 2023) and soursop nectar (4.0; Heredia et al. 2021). Lower values, such as those observed in tumbo serrano (3.603; Neyra and Sosa 2021) and Mocambo cocoa mucilage (3.45; Arrunátegui-Jácome et al. 2024), indicate the variability of acidity in fruit-based beverages. Considering that microbiological stability in juices is generally associated with pH<3.8 (Silva et al. 2015), the formulation falls close to this threshold.

From a nutritional perspective, the nectar provided 2.5% protein, higher than the 0.4% in *Passiflora tripartita* Kunth-based nectar (Neyra and Sosa 2021) but below the 4.65 g 100 mL^{-1} reported for white prickly pear–aguaymanto nectar (Ticsihua and Orejon 2022). Total carbohydrates (13.34%) were lower than the 16.3% observed by Neyra and Sosa (2021). The caloric value (31.50 kcal 100 g^{-1}) was markedly lower than values reported for similar beverages, such as *Passiflora tripartita* Kunth nectar (66.0 kcal 100 mL^{-1}; Neyra and Sosa 2021) and cocona–quinoa drinks (49.3 kcal 100 g^{-1}; Quispe-Herrera et al. 2022), highlighting its potential as a low-calorie alternative.

In terms of sodium, the nectar complied with Peruvian legislation (Law No. 30021), remaining below the regulatory threshold and showing lower concentrations than orange nectar ($\leq$20 mg 100 mL^{-1}) and commercial pineapple juice (15.4 mg 100 mL^{-1}; Rivera et al. 2008). These results position the formulation as a nutritionally competitive product compared to commercial juices, with the advantage of reduced caloric and sodium content, while maintaining acceptable sensory quality.

In Table 6, the microbiological analysis of the nectar stored at temperatures ranging from 0 to 80 °C confirmed the absence of *Pseudomonas aeruginosa* and *Escherichia coli* (<1.10 MPN 100 mL^{-1}), reflecting appropriate hygienic and manufacturing practices during processing. At 40 °C; however, an increase in heterotrophic microorganisms (200 CFU 100 mL^{-1}) was observed, indicating that product stability is maintained below 35 °C, with optimal preservation between 0 and 5 °C. The microbiological evaluation established a shelf life of three months at room temperature (20 °C) and four months under refrigeration (5 °C), in compliance with NTP 203.110:2022.

Table 6. Microbial counts of nectar (T3) with the highest overall acceptability.

Temperature (°C)	Time (hour)	Microbial counts*		
		Pseudomonas aeruginosa **(CFU 100 mL^{-1})**	***Escherichia coli*** **(NPM 100 mL^{-1})**	**Heterotrophic (CFU 100 mL^{-1})**
0	1.0	Absence	<1,1	<1.0
5	1.0	Absence	<1,1	<1.0
35	1.0	Absence	<1,1	10.0
40	1.0	Absence	<1,1	200.0
60	1.0	Absence	<1,1	60.0
80	1.0	Absence	<1,1	2.0

*Mean values of three determinations.

In the statistical evaluation, the analysis of variance (ANOVA) of the four formulations for the attributes of color, aroma, taste, consistency, and overall acceptability yielded calculated F values of 13.27, 6.77, 7.38, 10.69, and 8.88, respectively, compared to a tabular F value of 2.63. This demonstrates that significant differences existed among the four treatments (T1, T2, T3, and T4) for all sensory attributes, with all *P*-values <0.05. Fisher's Least Significant Difference (LSD) test was subsequently applied, grouping treatments into homogeneous subsets identified by the letters "a, b, and c." Significant differences were observed in most organoleptic attributes, confirming that the formulations differ statistically. However, certain treatments showed similarities in specific attributes: color (T3–T4), aroma (T2–T3, T2–T4, T3–T4), taste (T1–T2, T3–T4), consistency (T2–T3, T2–T4, T3–T4), and overall acceptability (T1–T2, T2–T4, T3–T4). These results indicate that some formulations share comparable sensory characteristics.

CONCLUSION

Formulation T3 achieved the highest overall sensory acceptability, exhibiting favorable nutritional attributes, thus confirming the feasibility of developing a low-calorie, functional fruit-based product. Microbiological evaluations verified the stability and safety of the nectar at both room temperature and under refrigeration, meeting current regulatory requirements. The product represents an innovative alternative for the agro-industrial sector by incorporating underutilized Andean plant resources into a stable, nutritious, and sensorially acceptable beverage.

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CONFLICT OF INTERESTS

The corresponding authors declare that they have no conflict of interest.

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