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Development of a Potentially Functional Beverage Based on Whey, Mango, and Andean Foods

Malpartida, R. J. [1]; Yata, L. E. [1]; Rodríguez, N. [1]; Reategui, C. Y. [1]; Tocto, L. [1]

[1] *Universidad Nacional Autónoma Altoandina de Tarma, Departamento de Ingeniería Agroindustrial, Acobamba, Perú*

Editor

Gustavo González-Neves
Universidad de la República, Facultad de Agronomía, Montevideo, Uruguay

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Correspondence

Laumer Tocto
75422522@unaat.edu.pe

Abstract

The growing demand for functional and sustainable foods has driven the development of formulations that valorize food by-products and promote nutrition that transcends basic requirements, providing bioactive compounds with potential health benefits. This study developed and characterized a potentially functional beverage made from whey, mango (*Mangifera indica* L.), quinoa (*Chenopodium quinoa*), and chicuro (*Stangea henrici*). Using a completely randomized design, three formulations with varying concentrations of quinoa (2, 4, and 6%) and chicuro (6, 4, and 2%) were evaluated, keeping the proportions of whey (52.57%) and mango (39.43%) constant. The physicochemical profile, micronutrient and bioactive compound content, and antioxidant capacity were analyzed for each formulation. With a higher incorporation of quinoa (T1, 6%), the highest values were obtained for protein (2.92 g/100 mL), vitamin A (36.8 mcg/100 mL), vitamin C (90.4 mg/100 mL), calcium (146.7 mg/100 mL), potassium (801.3 mg/100 mL), total phenolic content (6550.2 mg GAE/100 g), flavonoids (370 mg QE/100 g), and antioxidant capacity (2062.5 µmol TE/100 g). In conclusion, we successfully developed a potentially functional and sustainable beverage with an improved nutritional and bioactive profile that aligns with current consumer trends.

Keywords: milk drink, quinoa, bioactive compounds, antioxidants, functional food

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Desarrollo de una bebida potencialmente funcional a base de lactosuero, mango y alimentos andinos

Resumen

La creciente demanda de alimentos funcionales y sostenibles ha impulsado el desarrollo de formulaciones que valorizan subproductos alimentarios y promueven una nutrición que trasciende los requerimientos básicos, aportando compuestos bioactivos con potencial beneficio para la salud. Este estudio desarrolló y caracterizó una bebida potencialmente funcional a partir de lactosuero, mango (*Mangifera indica* L.), quinua (*Chenopodium quinoa*) y chicuro (*Stangea henrici*). Mediante un diseño completamente al azar, se evaluaron tres formulaciones con concentraciones variables de quinua (2, 4 y 6%) y chicuro (6, 4 y 2%), manteniendo constantes las proporciones de lactosuero (52,57%) y mango (39,43%). En cada formulación se analizó el perfil fisicoquímico, el contenido de micronutrientes y compuestos bioactivos, así como la capacidad antioxidante. Con una mayor incorporación de quinoa (T1, 6%), se obtuvieron los valores más altos de proteína (2,92 g/100 mL), vitamina A (36,8 mcg/100 mL), vitamina C (90,4 mg/100 mL), calcio (146,7 mg/100 mL), potasio (801,3 mg/100 mL), contenido total fenólico (6550,2 mg GAE/100 g), flavonoides (370 mg QE/100 g) y capacidad antioxidante (2062,5 µmol TE/100 g). En conclusión, se logró desarrollar una bebida potencialmente funcional y sostenible, con un perfil nutricional y bioactivo mejorado, que se alinea con las tendencias actuales de consumo.

Palabras clave: bebida láctea, quinua, compuestos bioactivos, antioxidantes, alimento funcional

Desenvolvimento de uma bebida potencialmente funcional à base de soro de leite, manga e alimentos andinos

Resumo

A crescente procura por alimentos funcionais e sustentáveis impulsionou o desenvolvimento de formulações que valorizam subprodutos alimentares e promovem uma nutrição que transcende as necessidades básicas, fornecendo compostos bioativos com potenciais benefícios para a saúde. Este estudo desenvolveu e caracterizou uma bebida potencialmente funcional à base de soro de leite, manga (*Mangifera indica* L.), quinoa (*Chenopodium quinoa*) e chicuro (*Stangea henrici*). Através de um desenho completamente aleatório, foram avaliadas três formulações com concentrações variáveis de quinoa (2, 4 e 6%) e chicuro (6, 4 e 2%), mantendo constantes as proporções de soro de leite (52,57%) e manga (39,43%). Em cada formulação, analisou-se o perfil físico-químico, o teor de micronutrientes e compostos bioativos, bem como a capacidade antioxidante. Com uma maior incorporação de quinoa (T1, 6%), foram obtidos os valores mais elevados de proteína (2,92 g/100 mL), vitamina A (36,8 mcg/100 mL), vitamina C (90,4 mg/100 mL), cálcio (146,7 mg/100 mL), potássio (801,3 mg/100 mL), teor fenólico total (6550,2 mg GAE/100 g), flavonoides (370 mg QE/100 g) e capacidade antioxidante (2062,5 µmol TE/100 g). Em conclusão, conseguiu-se desenvolver uma bebida potencialmente funcional e sustentável, com um perfil nutricional e bioativo aprimorado, que está em sintonia com as tendências atuais de consumo.

Palavras-chave: bebida láctea, quinoa, compostos bioativos, antioxidantes, alimento funcional

1. Introduction

Currently, the growing trend toward functional foods and beverages reflects global interest in products that provide health benefits beyond basic nutrition (De La Fuente et al., 2025). This interest responds to greater consumer awareness of chronic diseases associated with diet, such as obesity, cardiovascular disorders, and type 2 diabetes. According to the World Health Organization (2025), around 2.5 billion adults were overweight in 2022, of whom 890 million were obese. To address this challenge, there is a continuing need to develop products that incorporate ingredients and by-products with bioactive properties that enhance their functional value and nutritional quality (Arias-Palma et al., 2021).

In this context, a wide range of functional beverages has been consolidated, of which more than 40% are dairy beverages such as whey. This demonstrates its potential as a matrix for the development of new functional

products (Ahmed et al., 2023). Whey, a liquid by-product obtained after the precipitation of casein during cheese production (Agualongo et al., 2022), contains proteins rich in essential amino acids with high bioavailability (Naik et al., 2023). These proteins stand out as precursors of biologically active peptides, capable of exerting various beneficial physiological effects (Sumny & Kempka, 2025).

However, the potential of whey is limited by its organoleptic characteristics, such as its distinctive smell and taste (Michiu et al., 2024). An effective strategy to overcome this limitation is to mix it with fruit, which significantly improves its sensory appeal (Saleem et al., 2025). Recent studies have shown that beverages made from whey and Andean fruits such as aguaymanto (Physalis peruviana L.) and tumbo (Passiflora mollissima), or tropical fruits such as mango, have high nutritional and functional value (Chagua et al., 2023) and are well accepted in terms of sensory properties (Ahmed et al., 2023). Mango is a fruit rich in nutrients and bioactive compounds (Ahmed et al., 2023), such as phenolic acids and carotenoids, which exhibit antioxidant activity (Yahia et al., 2023).

To further enhance the functionality of these beverages, the incorporation of pseudocereals and Andean roots represents an innovative opportunity. Quinoa, a pseudocereal noted for its high protein content and balanced amino acid profile (Gaur et al., 2025), provides bioactive compounds such as phytosterols and phenolics (Villacrés et al., 2022). For its part, chicuro (*Stangea henrici*) is of interest for its nutritional value and potential as a source of fructooligosaccharides, prebiotic compounds, and minerals (Malpartida Yapias, 2022). In addition, these raw materials provide essential vitamins and minerals; for example, mango is an important source of vitamins A and C (Ahmed et al., 2023), while whey provides calcium and B vitamins (Naik et al., 2023). Complementarily, quinoa and chicory contain minerals such as iron, magnesium, and zinc, contributing to the nutritional value of the functional beverage (Gaur et al., 2025). The inclusion of these ingredients can improve protein quality, increase the concentration of bioactive secondary metabolites (Li et al., 2025), and enhance the metabolic benefits of the final product (Vajdovich et al., 2025).

The bioactive compounds present in this type of formulation have been associated with the prevention and control of chronic noncommunicable diseases, such as diabetes (Carvalho et al., 2023), obesity (Wen et al., 2025), and cardiovascular diseases (Scarcelli et al., 2025). Its mechanism of action includes, among other things, high antioxidant activity that helps neutralize reactive oxygen species, reducing oxidative stress (Saleem et al., 2025) and, consequently, cellular damage associated with the development of various chronic diseases (Abdo et al., 2022).

In this context, the present study sought to develop and characterize a potentially functional beverage made from whey, mango, quinoa, and chicuro. This approach not only responds to global health trends but also promotes sustainability by valorizing dairy industry by-products and incorporating local Andean ingredients, thereby fostering innovation in the food industry.

2. Materials and Methods

2.1 Procurement of Raw Materials

The whey was obtained in August 2025 from the company Agroindustrias Sagrada Familia S.R.L., located in the province of Tarma, Junín, Peru. The whey was collected immediately after cheese production and stored under refrigeration until use. Chicuro roots (*Stangea henrici*), at physiological maturity, were hand-harvested in August 2025 from wild populations in the district of Paccha, province of Yauli, Junín, Peru, at 3,990 m.a.s.l. Quinoa flour (white Junín variety) and fresh mangoes (Kent variety) were purchased at the Megaproyecto market in Tarma, Junín, Peru, from the same commercial lot to ensure the uniformity of the raw materials used. All samples were transported to the Institute for Research in High Andean Technologies at UNAAT for subsequent use.

2.2 Sample Preparation

The whey was pasteurized at 70 °C for 30 min and then filtered through cheesecloth to remove impurities. The chicuro roots were washed, peeled by hand, and blanched at 71 °C for 3 min. The pulp was then processed in an Oster blender (model BLSTKAG-BPB-0535) for 2 minutes, using a material-to-water ratio of 1:0.5 (w/v). The resulting homogenate was filtered through cheesecloth to obtain the juice. The fresh mangoes were washed, and then the skins and seeds were removed. The resulting pulp was processed in an Oster blender (model BLSTKAG-BPB-0535) using a 1:1 mango-to-water ratio (w/v); the homogenized mixture was then filtered through cheesecloth to obtain the juice. Finally, all raw materials were characterized physicochemically (Table 1) according to the procedures described in sections 2.4 and 2.5.

Table 1. Physicochemical composition of raw materials

Components	Whey	Chicuro	White quinoa	Mango pulp
Moisture (%)	93.86 ± 0.01	87.4 ± 0.05	6.79 ± 0.15	77.11 ± 0.20
Protein (%)	2.55 ± 0.09	0.58 ± 0.01	13.40 ± 0.06	1.29 ± 0.00
Fat (%)	0.25 ± 0.05	0.04 ± 0.17	5.21 ± 0.02	0.09 ± 0.01
Ash (%)	0.69 ± 0.09	0.47 ± 0.05	2.48 ± 0.01	0.69 ± 0.21
TSS (°Brix)	14.2 ± 0.10	13 ± 0.02	1.05 ± 0.05	19.5 ± 0.25
pH	6.30 ± 0.02	6.94 ± 0.01	6.5 ± 0.18	4.27 ± 0.06

2.3 Formulation and Preparation of the Potentially Functional Beverage

Whey, quinoa flour, and chicuro and mango pulps were mixed according to the proportions established for each treatment (Table 2). Each formulation was prepared in triplicate. The mixtures were adjusted with sucrose until the desired total soluble solids were achieved (Njoroge et al., 2025). Subsequently, the mixtures were pasteurized at 80 °C for 15 min and finally hot-filled at 55 °C into airtight polyethylene terephthalate (PET) bottles and stored under refrigeration until analysis.

Table 2. Formulation of a potentially functional beverage based on whey, quinoa flour, and mango and chicuro pulp

Components	Formulations		
	T1	T2	T3
Whey	52.57%	52.577%	52.57%
Quinoa flour	6%	4%	2%
Mango pulp	39.43%	39.43%	39.43%
Chicuro pulp	2%	4%	6%

The formulations were adjusted to 12.5 °Brix by adding sucrose at concentrations of 1.086%, 1.006%, and 0.914% (w/v) for T1, T2, and T3, respectively.

2.4 Physicochemical Characterization of the Potentially Functional Beverage

The moisture, protein, fat, and ash content were determined using the AOAC standard methods for proximate analysis: 925.10; 991.20; 989.05, and 923. 03 (Acipreste et al., 2025), while the carbohydrate content was calculated by difference.

2.5 Determination of pH, Total Soluble Solids, and Titratable Acidity of the Potentially Functional Beverage

The pH of the samples was determined using a portable pH meter (model HI991001, HANNA®, Peru), which had been previously calibrated with standard buffer solutions of pH 4.0 and 7.0. For the measurement, an aliquot

of the sample was placed in a beaker, and the electrode was immersed until a stable reading was obtained (Karaituma et al., 2025).

Total soluble solids (TSS, °Brix) were determined using a digital refractometer (model HI96801, HANNA®, Peru). To do this, a few drops of the sample were placed on the instrument's prism, and the reading was recorded directly in °Brix. Titratable acidity (TA, %) was determined by acid-base titration. To do this, 10 mL of the sample was diluted with 50 mL of distilled water and titrated with 0.1 N NaOH using phenolphthalein as an indicator until a persistent pink color was observed (Karaituma et al., 2025).

2.6 Determination of Micronutrients in Beverages

For the determination of vitamin A (Method 974.29), vitamin C (Method 985.33), calcium (Method 963.11), and phosphorus (Method 986.24), the procedures described by AOAC International (2005) were followed.

2.7 Total Phenolic Content (TPC)

First, 1 mL of the functional beverage was mixed with 10 mL of methanol; the mixture was stirred at 200 rpm at 20 °C for 30 min; before collecting the supernatant, the mixture was centrifuged at 10,000 rpm. To determine the TPC, a reaction mixture was prepared by combining 0.5 mL of the methanolic extract, 2.5 mL of diluted Folin-Ciocalteu reagent, and 2 mL of a 7.5% calcium carbonate solution. The mixture was incubated for 30 min and its absorbance was measured at 765 nm using a UV–Vis spectrophotometer (Jenway 6715) (Jahangeer et al., 2025). The results were expressed in mg gallic acid equivalents per 100 g (mg GAE/100 g) using a standard gallic acid calibration curve.

2.8 Total Flavonoid Content (TFC)

The TFC of the samples was evaluated using the colorimetric aluminum chloride assay method with slight modifications (Karaituma et al., 2025). The extracts were mixed with 4 mL of distilled water and 0.3 mL of 5% sodium nitrite solution. After 5 min of incubation, 0.3 mL of 10% aluminum chloride solution was added and allowed to incubate for 5 min. Subsequently, 2.0 mL of 1 M sodium hydroxide was added, and the final volume was adjusted to 10 mL with distilled water. The absorbance was measured at 510 nm using a UV-Vis spectrophotometer (Jenway 6715), and the results were expressed as milligrams of quercetin equivalents per 100 g (mg QE/100 g).

2.9 Determination of DPPH Activity

Antioxidant activity was determined using the DPPH method, according to the procedures described by Acipreste et al. (2025). The beverage samples were homogenized with methanol in a 1:2 (w/v) ratio and centrifuged at 4000 rpm for 20 minutes at 4 °C. The supernatant was used for antioxidant analysis using DPPH (0.1 mM in methanol), mixing 0.5 mL of the extract, 1.5 mL of methanol, and 1.0 mL of the DPPH solution. The mixture was incubated in the dark for 30 minutes at 25 °C, and then the absorbance was measured at 517 nm. The results were expressed as µmol Trolox equivalents per 100 g.

2.10 Statistical Analysis

The study was conducted using a completely randomized design; data were stored in Microsoft Excel and analyzed using one-way ANOVA (95% confidence level) with RStudio v4.5.0. Results are expressed as mean ± standard deviation, and significant differences between means were assessed using Tukey's test ($p < 0.05$). In addition, a Pearson correlation analysis was performed to evaluate the relationships between antioxidant activity, TPC, and TFC, considering a significance level of $p < 0.05$.

3. Results and Discussion

3.1 Physicochemical Characterization of the Potentially Functional Beverage

The results of the physicochemical characterization (Table 3) reveal that formulation T1 (composed of 6% quinoa flour and 2% chicuro pulp) had the highest values for protein, fat, pH, and total soluble solids, with these differences being statistically significant ($p < 0.05$) compared to T2 and T3.

Table 3. Physicochemical composition of the potentially functional beverage

Physicochemical composition (g/100 mL)	Treatments		
	T1	T2	T3
Moisture	78.45±0.01^a	81.89±0.02^b	79.63±0.03^c
Protein	2.92±0.00^a	2.89±0.01^b	2.63±0.01^c
Fat	0.63±0.01^a	0.60±0.01^b	0.57±0.01^c
Acidity (Exp. Citric acid)	1.52±0.01^a	1.40±0.05^b	1.32±0.01^c
Soluble solids	12.90±0.1^a	12.70±0.02^b	12.55±0.02^c
pH	5.40±0.1^a	5.34±0.04^b	5.07±0.01^c

Subscripts indicate significant differences between treatments ($p < 0.05$).

The protein content of beverage T1 (2.92 g/100 mL) exceeds the maximum reported (1.92%) for fermented whey beverages enriched with aguaymanto and tumbo (Chagua et al., 2023) and beet juice and whey, with a value of 1.07 g/100 mL (Michiu et al., 2024). This increase is attributed to the contribution of quinoa flour, a finding consistent with studies documenting an improvement in protein, fat, and ash content when incorporating this pseudocereal (Li et al., 2025). However, the value obtained is lower than the range of 4.65-4.69 g/100 mL observed in beverages formulated with whey protein isolate with aqueous beet peel extract (Abdo et al., 2022). This disparity is explained by the difference in the protein raw material used; while the present study used liquid whey (2.55 g/100 g), the cited research used protein isolate with a protein content greater than 90%.

For its part, the TSS content of formulation T1 (12.90 °Brix) falls within the range reported for functional milk drinks with whey and beet juice (11.69-14.04 °Brix) (Michiu et al., 2024). However, it is significantly lower than that of mixed whey and mango beverages, whose values range from 17.15 to 18.10 °Brix (Ahmed et al., 2023). This disparity suggests that prioritizing Andean ingredients (quinoa, chicuro) reduces the soluble solids content compared to formulations that use higher proportions of mango to enhance palatability. Since TSS influences sweetness and sensory acceptance, the lower value observed could directly affect the organoleptic perception of the beverage. Finally, pH values ranged from 5.07 to 5.40 and acidity from 1.32 to 1.52%, falling within a slightly acidic range similar to other studies reported on whey-based beverages (Chagua et al., 2023).

3.2 Micronutrient Content of the Potentially Functional Beverage

As shown in Table 4, formulation T1 had the highest concentration of micronutrients, with notable values for vitamin A (36.8 mcg/100 mL), vitamin C (90.4 mg/100 mL), calcium (146.7 mg/100 mL), phosphorus (166.3 mg/100 mL), and potassium (801.3 mg/100 mL). This enriched nutritional profile results from the combination of whey, which retains approximately 55% of the nutrients in milk (Ahmed et al., 2023), with ingredients such as quinoa, known for its high micronutrient density (Li et al., 2025).

Table 4. Vitamin and mineral content of the potentially functional beverage

Micronutrient composition (mg/100 mL)	Treatments		
	T1	T2	T3
Vitamin A (mcg/100 mL)	36.8 ± 0.01[a]	35.1 ± 0.01[b]	29.3± 0.12[c]
Vitamin C*	90.4 ±0.01[a]	89.9 ±0.01[b]	88.2±0.01[c]
Calcium	146.7 ± 0.58[a]	141.3±0.58[b]	135.7±0.61[c]
Phosphorus	166.3 ±0.58[a]	148.9±0.90[b]	140.7±0.01[c]
Potassium	801.3 ±0.58[a]	791.0±0.01[b]	758.0±0.64[c]

*Vitamin C is expressed in mg ascorbic acid/100 mL. Subscripts indicate significant differences between treatments ($p < 0.05$).

The vitamin C content of the drink significantly exceeds the values reported in other functional whey-based drinks. For example, mango and carrot drinks contain 9.92 mg/100 mL (Ahmed et al., 2023), citrus and spirulina fermented drinks contain between 6.76 and 6.85 mg/100 g (Elkot et al., 2024), while pomegranate and beetroot concentrates contain 3.5 and 2.6 mg/100 mL, respectively (Saleem et al., 2025). The value found is relevant, given that vitamin C is an important nutrient with antioxidant and free radical defense capabilities, highlighting the functional value of the beverage (Ahmed et al., 2023).

With regard to mineral content, in formulation T1, calcium (146.7 mg/100 mL) and phosphorus (166.3 mg/100 mL) levels exceed those reported in mango whey drinks (Ca: 37.28-41.37 mg/100 mL; P: 46.33-49.86 mg/100 mL) (Ahmed et al., 2023); in particular, the calcium content of the beverage is important for bone health and reducing the risk of hypertension. For its part, the potassium concentration (801.3 mg/100 mL) is approximately five times higher than that recorded in beverages fortified with *Spirulina platensis* (163.95 mg/100 g) (Elkot et al., 2024). This potassium content promotes hydrolytic and electrolytic function, positioning the beverage within the functional and isotonic product segment (Abdo et al., 2022). The superiority of the values found is attributed to quinoa, chicuro, and whey, which are valued for their micronutrient content.

3.3 Bioactive Properties of the Potentially Functional Beverage

The bioactive properties of the beverage, evaluated by total phenolic content (TPC), total flavonoid content (TFC), and antioxidant capacity (AC), demonstrated the functional value of the beverage formulated from whey, mango, quinoa, and chicuro. As shown in Figure 1, formulation T1 exhibited the highest values of TPC (6550.2 mg GAE/100g), TFC (2062.5 mg QE/100g), and AC (370.0 µmol TE/100g), being statistically significant ($p < 0.05$) compared to formulations T2 and T3.

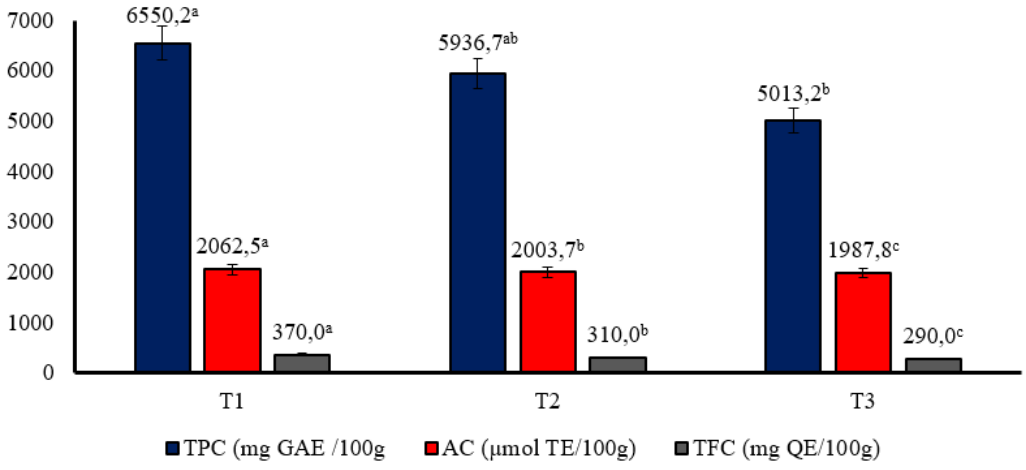

Figure 1. TPC, TFC, and antioxidant capacity (AC) content of the potentially functional beverage

Subscripts indicate significant differences between treatments ($p < 0.05$).

The TPC values of the formulated functional beverage were higher than those reported by Abdo et al. (2022) in whey drinks with beetroot peel (4321 mg GAE/100g) and those reported by Chagua et al. (2023) in a whey drink enriched with aguaymanto and tumbo (343.54 mg/100g). Phenolic compounds are primarily responsible for antioxidant activity, and their considerable concentration in formulation T1 may directly contribute to neutralizing ROS, a key mechanism in the prevention of chronic diseases (Li et al., 2025).

With regard to TFC, it followed the same linearity as TPC with values ranging from 290 to 370 mg QE/100g; these values are within the range reported by Jahangeer et al. (2025) in a functional beverage made from mango juice, pumpkin, and defatted pomegranate seed extract (308 mg QE/100 mL), and are significantly higher than those reported by Saleem et al. (2025) for a beet, pomegranate, carrot, and whey beverage (13.3 mg QE/100 mL). Flavonoids are a class of phenolic compounds that are essential for defending against cellular damage. These compounds act as powerful antioxidants due to their chemical structure, which allows them to donate hydrogen or electrons to neutralize free radicals (Li et al., 2025). The disparity in the data found with some authors could be due to the incorporation of chicuro and quinoa in the drink; in the latter, up to 102 types of flavonoids have been reported with concentrations around 68.16 mg QE/100 g (Bhinder & Singh, 2025; Qian et al., 2023).

Finally, antioxidant capacity ranged from 1,987 to 2,062.5 µmol TE/100 g as the percentage of quinoa increased (2-6%). A positive correlation was observed between antioxidant capacity and the values of TFC (r = 1.00) and TPC (r = 0.91), demonstrating the contribution of these bioactive compounds to the beverage's antioxidant potential. The antioxidant capacity of the beverage exceeded the 101.25 µmol TE/100 mL reported by Saleem et al. (2025) in a whey drink with pomegranate concentrate, but was lower than the 9,036 µmol/100 g observed by Fernández et al. (2024) in a soursop drink with inulin and whey powder. High antioxidant activity is essential, not only to protect cells, but also to extend the shelf life of functional beverages (Li et al., 2025). In addition, the interaction between polyphenols and whey proteins leads to the formation of conjugates (Acipreste et al., 2025), which can enhance antioxidant capacity and improve product stability (Fernández et al., 2024).

3.4 Implications, Limitations, and Future Prospects of the Study

This study demonstrates the potential for valorizing whey by incorporating it into a potentially functional beverage enriched with mango and Andean foods, thereby contributing to circular economy strategies and the sustainable use of agro-industrial by-products. Furthermore, the inclusion of quinoa and chicuro improved the beverage's nutritional and bioactive profile, particularly in terms of phenolic compounds, flavonoids, and antioxidant capacity attributes associated with potential health benefits.

However, although the results obtained demonstrate significant functional potential, further studies are needed to evaluate the bioavailability and stability of the bioactive compounds present in the beverage, as well as in vitro and in vivo studies to identify and confirm their bioactivity and potential physiological effects on human health (Aispuro et al., 2025; Vila et al., 2025). Furthermore, future research should include sensory analyses, physicochemical stability during storage (including sedimentation, phase separation, and color changes), microbiological evaluations, shelf-life studies, and validation of packaging systems, in order to strengthen the technological and commercial viability of the developed beverage, in line with the growing market for potentially functional beverages (Vajdovich et al., 2025).

4. Conclusions

In conclusion, the study aimed to develop a potentially functional beverage using agri-food waste (whey) and tropical fruits (mango), enriched with quinoa and chicuro pulp, resulting in a sustainable beverage tailored to

current consumer trends. It was found that a higher incorporation of quinoa (T1, 6%) improved the physicochemical profile (protein), the micronutrient content (vitamins A and C, calcium, phosphorus, and potassium), as well as the bioactive and antioxidant properties of the beverage. The high values for total phenolic content (6550.2 mg GAE/100 g), flavonoids (370 mg QE/100 g), and antioxidant capacity (2062.5 µmol TE/100 g) demonstrate the potential of the developed formulation. These findings align with a circular economy approach aimed at valorizing dairy by-products and local Andean ingredients in the development of potentially functional beverages. However, sensory evaluations and shelf-life studies are still required; these aspects should be addressed in future research, along with stability and bioactivity studies using in vitro and in vivo assays, in order to validate its functional potential.

Transparency of Data

Available data: The entire data set that supports the results of this study was published in the article itself.

Author Contribution Statement

	RJM	LEY	NR	CYR	LT
Conceptualization	■				
Formal analysis		■		■	
Investigation			■	■	■
Methodology		■			■
Validation	■		■		
Visualization				■	■
Writing – original draft	■	■		■	■
Writing – review and editing		■	■		

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