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Physicochemical, antioxidant, and sensory evaluation of an artisanal fermented alcoholic beverage made from sea grape (*Coccoloba uvifera* L.)

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ABSTRACT

Introduction: The artisanal production of fermented alcoholic beverages in Campeche, Mexico, lacks standardization, which compromises their quality. The use of sea grape (*Coccoloba uvifera* L.) in these products is not documented, despite its nutritional, antioxidant, and sensory properties.

Objective: To evaluate the physicochemical, antioxidant, and sensory parameters of an artisanal fermented alcoholic beverage made with sea grape cultivated in Campeche, Mexico.

Materials and methods: The beverage was prepared following artisanal formulations from local producers. The beverage was characterized through evaluation of alcohol content, soluble solids, °Brix, titratable acidity, pH, and proximate chemical profile. Antioxidant capacity was determined considering two methods (DPPH radical inhibition and FRAP assay), and total phenolic and flavonoid contents were quantified. The chromatographic profile of phenolic compounds was evaluated by HPLC. The level of liking for flavor, texture, color, and odor was determined using a 5-point hedonic scale. Data were analyzed using descriptive statistics.

Results: The values of alcohol, soluble solids, °Brix, acidity, and pH of the beverage were 20.9±1.6% ABV, 13.62±0.78%, 18.21%, 0.82±0.003% citric acid, and 3.52±0.68, respectively. High contents of moisture and nitrogen-free extract were identified. Antioxidant capacity was 296.81±5.31 and 328.53±4.93 mgTE/L^{-1} for DPPH and FRAP, respectively. The content of phenolic compounds was 384.72±8.18 mgGAE/L, and that of flavonoids was 328.49±8.18 mgQE/L. The chromatographic profile determined the presence of cyanidin-3-glucoside and pelargonidin-3-glucoside. The sensory attribute with the highest acceptance was odor (90%).

Discussion: In comparison with similar fermented products, the profiles evaluated in the beverage indicated the presence of bioactive compounds, as well as high antioxidant potential and good sensory acceptance.

Conclusions: The findings of this work position sea grape as a resource to develop fermented beverages with nutritional value, antioxidant capacity, and adequate level of liking.

KEYWORDS

Fermented alcoholic beverage. Sea grape. Physicochemical properties. Antioxidant capacity. Sensory properties.

INTRODUCTION

Sea grape (*Coccoloba uvifera* L.), a member of the Polygonaceae family, is a species commonly found in coastal areas of southern Florida, the Mexican Caribbean, and Central America. Colloquially known along the coasts of southeastern Mexico as "uva de playa", "uva de mar", or "ni' che'" (Mayan), it is a shrub ranging from 2 to 8 m in height, whose fruits are edible and typically form grape-like bunches. Its ornamental leaves and trunk are commonly used as fuel[1].

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Coccoloba uvifera, commonly known as sea grape or beach grape, is widely consumed in Florida, Mexico, and the Caribbean. The plant produces edible berries that grow in bunches and are consumed fresh or processed into jams, jellies, and other preserves. These fruits are anecdotally reported to possess antihypertensive and antiasthmatic properties, which have also been supported by previous studies. When ripe, the berries exhibit an intense red/purple color, indicating the presence of compounds with chromophores and extended conjugation, such as anthocyanins and other polyphenolic compounds. Despite the rich folk medicinal heritage surrounding this plant and its widespread consumption, there are still limited phytochemical data available on its edible berries[2].

Several phytochemical and nutritional studies have demonstrated the nutritional value and therapeutic potential of *Coccoloba uvifera* L. fruit, particularly in disease prevention. These effects have been attributed to its high content of bioactive compounds with antioxidant and antimicrobial properties, including anthocyanins, ascorbic acid, phenolic compounds, and flavonoids[2]. Despite its widespread consumption and traditional medicinal use, there are still limited reports on the use of *Coccoloba uvifera* edible fruits—particularly those cultivated in Ciudad del Carmen, Campeche, Mexico—for the development of food products and beverages.

Currently, in various regions of Mexico, the production of artisanal alcoholic beverages is a common practice. These beverages are typically obtained through maceration and infusion processes using fruits or herbs that, in most cases, are not subjected to additional flavoring. This type of alcoholic beverage represents an important source of income for local producers and generates a significant socio-cultural impact, as they are commonly consumed recreationally during celebrations or festivities[3] They are also consumed for therapeutic purposes, as they are sometimes used as part of traditional medicine for the treatment of certain diseases or ailments, due to their content of nutritional components and antioxidants[3].

Artisanal alcoholic beverages are traditionally produced using local fruits and may involve stages such as fermentation and maturation; in some cases, distillation is also applied, depending on the type of beverage. Even at the artisanal level, these processes must be carefully controlled, as they directly influence the physicochemical and sensory profile of the final product[3].

In Mexico, quality control in alcoholic beverage production is regulated through standards established in several Official Mexican Standards, which define parameters for attributes such as alcohol content, soluble solids, pH, and titratable acidity, among others[4,5]. Compliance with these standards ensures the production of high-quality beverages at the industrial level; however, such parameters are often unknown or insufficiently monitored in artisanal-scale production.

Some factors, including fruit type and processing methods, exert a significant influence on the quality of artisanal fermented alcoholic beverages. Because local production practices do not follow standardized procedures, products are highly variable, and physicochemical and sensory characteristics are often unknown. In this context, the present study aimed to determine the physicochemical, antioxidant, and sensory properties of an artisanal fermented alcoholic beverage produced from sea grape (*Coccoloba uvifera* L.*)* cultivated in southeastern Mexico. The findings are expected to expand current knowledge on the properties of artisanal alcoholic beverages and to contribute to the revalorization of this type of product.

MATERIALS AND METHODS

Raw material and production process

Ripe sea grape fruits (*Coccoloba uvifera* L.), cultivated in the coastal area of southeastern Mexico, specifically in Ciudad del Carmen, Campeche (geolocation: N 18°39'20.20600", W 91°46'1.83450"; 4 m above sea level), were used as raw material. The harvested fruits were disinfected with chlorinated water, the surface dried, and stored at 4 °C until use. The beverage was produced based on formulations and techniques used by artisanal producers. The washed fruits and refined sugar were weighed, mixed (4:1 ratio), and macerated. Purified water was added and the mixture was stored at room temperature (approximately 32 °C), in a container adapted for this process. After 18 days of spontaneous fermentation, the product was filtered and adjusted to 32°Brix with sugar syrup. Finally, 1% sugarcane rum was incorporated and mixed. To stop the fermentation, the fermented beverage was stored at 4°C until evaluation. No pasteurization method was applied.

Physicochemical evaluation

Alcohol content. Alcohol content was determined by alcoholometry[6], which involves a distillation step followed by quantification of the ethanol concentration in the distillate using a hydrometer and refractometer. Results were expressed as percentage alcohol by volume (% ABV).

Total soluble solids. The content of total soluble solid compounds (%) was determined by drying in an oven at 100 °C to evaporate water, alcohol, and other volatile compounds.

°Brix. Total soluble compounds were measured using an optical refractometer (ATAGO Master- 100H), previously calibrated with distilled water. The sample at 20 °C was placed on the prism of the instrument, and the reading was recorded. Soluble solids were reported as °Brix.

Titratable acidity. It was carried out according to AOAC method 942.15[7], with some adjustments. Ten milliliters of the

sample were measured and titrated with 0.1 N NaOH, using phenolphthalein as an indicator, until the endpoint was reached. The volume of NaOH consumed was used to calculate acidity, which was expressed as grams of citric acid 100 ml^{-1} of alcoholic beverage.

pH. The guidelines of AOAC method 943.02[7] were followed. pH was determined by direct reading using a potentiometer (Hanna HI1996), previously calibrated. The instrument sensor was immersed in the sample, and the reading obtained was recorded.

Proximate composition. Proximate composition was determined following the methodologies described by the AOAC[7]: moisture (925.09) by drying in a convection oven; ash (923.03) by muffle furnace incineration; crude fat (920.39) by the Soxhlet method; crude fiber (991.43) by acid–base digestion; crude protein (954.01) by the Kjeldahl method; and nitrogen-free extract, calculated by difference to 100%.

Antioxidant profile

2,2-Diphenyl-1-picrylhydrazyl (DPPH) radical inhibition. Antioxidant capacity was determined using the inhibition method described by Bondet et al. (1997)[8]. Absorbance was measured using a spectrophotometer (Agilent Technologies Cary 60 UV–VIS) at 515 nm after 30 min of incubation in darkness at room temperature. Concentrations were calculated from the Trolox calibration curve by linear regression. Results were expressed as mg L^{-1} Trolox equivalents.

Ferric Reducing Antioxidant Power (FRAP) estimation. Determination was carried out as described by Can et al. (2017)[9]. It was determined through the reduction of the Fe^{3+}–TPTZ complex to Fe^{2+}–TPTZ under acidic conditions. The sample was incubated with the FRAP reagent for a defined time at controlled temperature, and absorbance was recorded using a spectrophotometer (Agilent Technologies Cary 60 UV–VIS) at 593 nm. Antioxidant capacity was quantified from a calibration curve prepared with Trolox standard solutions (20–320 mg L^{-1}) and expressed as mg L^{-1} Trolox equivalents.

Total phenolic compound content. The Folin–Ciocalteu method described by Singleton and Rossi (1965)[10], was employed. Absorbance was determined using a spectrophotometer (Agilent Technologies Cary 60 UV–VIS) at 760 nm after 20 min of incubation in darkness. Phenolic compound concentration was determined from a calibration curve prepared with gallic acid, and the results were expressed as mg L^{-1} gallic acid equivalents (GAE/L).

Total flavonoid content by the aluminum trichloride ($AlCl_3$) method. This determination was carried out based on the method described by Shraim et al. (2021)[11]. A 2% $AlCl_3$ solution in methanol was prepared, and quercetin was used as the standard to construct the calibration curve (10–100 mg L^{-1}). One milliliter of sample was mixed with 1 mL of the $AlCl_3$ solution and allowed to react for 10 min at room temperature. Absorbance was measured at 415 nm using a spectrophotometer (Agilent Technologies Cary 60 UV–VIS), and total flavonoid concentration was expressed as mg L^{-1} quercetin equivalents (QE/L).

Determination of chromatographic profiles of phenolic compounds by high-performance liquid chromatography (HPLC). An HPLC Perkin Elmer Series 200 system equipped with a 30 cm C18 column and a diode-array ultraviolet detector set at a wavelength of 280 nm was used. The method described by Can et al. (2017)[9] was taken as reference, considering the same column type, mobile phases, and chromatographic conditions. Tentative identification was performed by comparing the relative retention times of compound peaks in the sample with those of known standards, considering a match of these values as the criterion for positive identification, with chromatograms obtained under the same conditions. Standards of cyanidin-3-glucoside, pelargonidin-3-glucoside, quercetin-3,4-diglucoside, kaempferol-3-glucoside, and myricetin-3-glucoside were used**.**

Sensory evaluation

An affective sensory test was conducted following the guidelines described by Stone et al. (2021)[12]. The evaluation was carried out using a panel of 50 untrained potential consumers. Four sensory attributes were evaluated using a five-point hedonic scale: flavor, texture, color, and odor. The scale was structured in two highest points that indicated liking ("Like very much" and "Like"), a midpoint that indicated neutrality ("Neither like nor dislike"), and two lowest points that indicated disliking ("Dislike" and "Dislike very much"). Each evaluator was given a 50 ml sample of the beverage at room temperature in glass cups. They were first asked to observe the sample (visual phase), then to smell it (olfactory phase), and finally to taste the beverage by swishing it around their mouth (gustatory phase). Once this procedure was completed, each evaluator reported their perception on the evaluation instrument.

Statistical analysis

All physicochemical evaluations were performed in triplicate, whereas antioxidant determinations were carried out in sextuplicate. In both cases, results are presented as Mean ± Standard Deviation. ANOVA test (Bonferroni poshoc) was used for data comparison. In the sensory evaluation, values from 5 to 1 were assigned to each upper to-lower level of acceptance of each category, respectively. Kolmogorov-Smirnov test was used for normality analysis, and the data were presented as median (quartile 1, quartile 3). Kruskall-Wallis test was used for data comparison. Statgraphics Centurion XVI software (version 16.1.18) was used for statistical analysis.

RESULTS

Physicochemical evaluation

The beverage showed an alcohol content of 20.9 ± 1.6% ABV. Total soluble solids were 13.62 ± 0.78 % and the °Brix value was 18.21. A titratable acidity of 0.82 ± 0.003% citric acid and a pH of 3.52 ± 0.68 were determined in the fermented beverage. Proximate analysis revealed low contents of fat (3.75 ± 0.07%), ash (1.85 ± 0.20%), protein (1.31 ± 0.04%), and fiber (0.00 ± 0.00%) (Table 1).

Table 1. Proximate composition (g/100 ml)

Component	Result
Moisture	86.38± 0.22 [a]
Nitrogen-free extract	6.71 ± 0.03 [b]
Crude fat	3.75 ± 0.07 [c]
Ash	1.85 ± 0.20 [d]
Crude protein	1.31 ± 0.04 [e]
Crude fiber	0.00 ± 0.00
p	**0.007**

ANOVA test (Bonferroni poshoc) was used for data comparison. Data are presented as Mean ± Standard Deviation. Significance level at $p<0.05$. Different letters in the same column a-e indicate statistical difference. n=3.

Antioxidant profile

Antioxidant capacity was determined using two assay methods; both results were expressed as Trolox equivalents (TE). The results were 296.81 ± 5.31 and 328.53 ± 4.93 mg TE L^{-1} for DPPH radical inhibition and the FRAP method, respectively (Figure 1). The concentration of total soluble phenolic compounds was 384.72 ± 8.18 mg of GAE/L, and that of flavonoids was 328.49 ± 8.18 mg QE/L. The chromatographic profile of phenolic compounds confirmed the presence of cyanidin-3-glucoside, pelargonidin-3-glucoside, quercetin-3,4-diglucoside, kaempferol-3-glucoside, and myricetin-3-glucoside.

Sensory evaluation

Hedonic scores for all evaluated attributes (flavor, texture, color, and odor) were high (≥4 points) (Table 2). As an additional approach to evaluating hedonic score, the frequencies of the ratings "Like very much" and "Like" were grouped to identify the degree of liking for each sensory attribute. This approach made it possible to determine that the most appreciated sensory attribute was odor (90%), followed by flavor (88%), texture (78%), and color (72%). For these same sensory attributes, levels of dislike and indifference were very low (6–12% and 0–22%, respectively) (Table 3).

Table 2. Hedonic scores for each evaluated attribute

Indicator	Result
Flavor	4 (4, 5) [a,b]
Texture	4 (4, 5) [a,b]
Color	4 (3, 4) [b]
Odor	5 (4, 5) [a]
p	**0.009**

Kolmogorov-Smirnov test for data normality. Kruskall-Wallis test was used for data comparison. Data are presented as Median (Quartile 1, Quartile 3). Significance level at $p<0.05$. Different letters in the same column [a-b] indicate statistical difference. n=50.

Table 3. Degree of liking for each sensory attribute

Indicator	Frequency n (%)		
	Disliking	Indifference	Liking
Flavor	6 (12)	0 (0)	44 (88)
Texture	4 (8)	7 (14)	39 (78)
Color	3 (6)	11 (22)	36 (72)
Odor	4 (8)	1 (2)	45 (90)

Degree of "Disliking", "Indifference" and "Liking" were estimated by grouping the frequencies reported in the lower (1-2), middle (3), and upper (4-5) points, respectively. n=50.

DISCUSSIONS

Considering % ABV and the manufacturing process, the product can be classified as a fermented alcoholic beverage, according to the guidelines of the Mexican official regulations. It is important to mention that this guideline establishes that these types of beverages must be the result of the fermentation of raw materials, such as the sea grape used[5].

The total solids content and Brix value indicate a considerable amount of dissolved sugars, in addition to other soluble compounds such as organic acids. This value is relevant because both sugars and organic acids (e.g., malic, citric, or acetic acids) significantly influence the organoleptic profile of fermented alcoholic beverages. In particular, higher °Brix values are associated with greater sugar content and, therefore, with more pronounced sweetness[5,13,14].

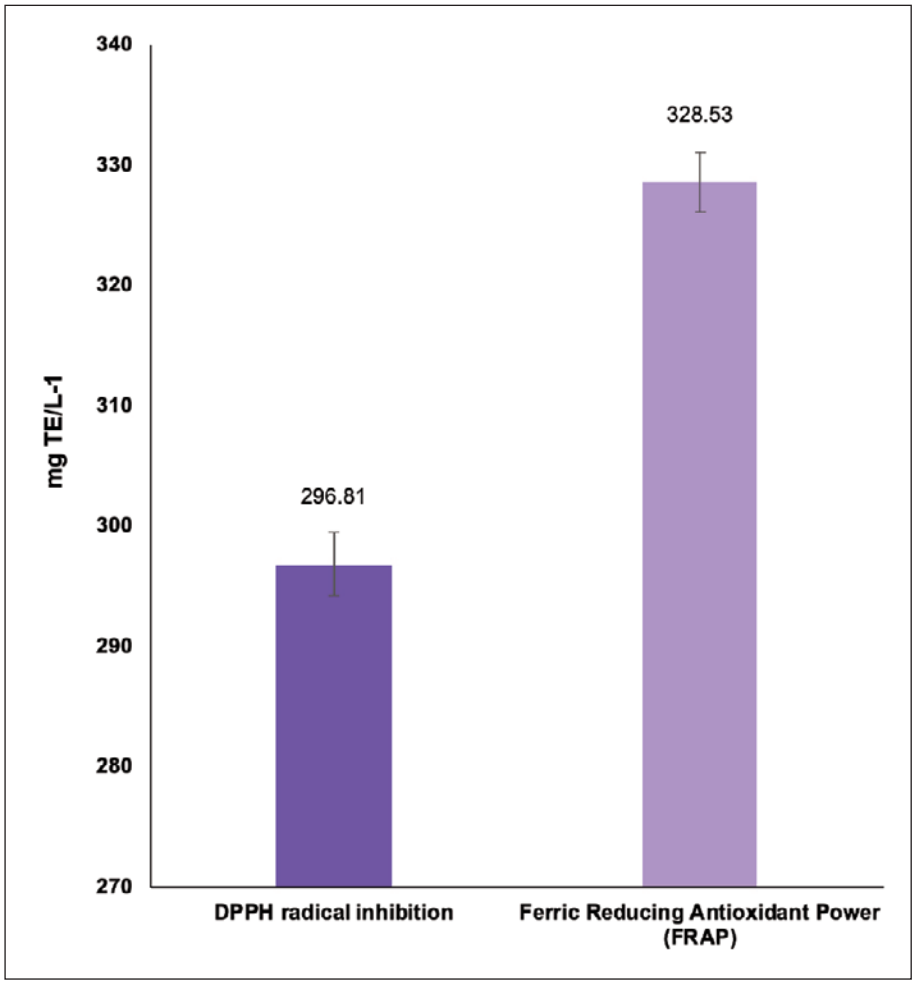

Figure 1. Antioxidant capacity expressed as Trolox equivalents (TE)

In terms of acidity and pH, the results were similar to those obtained in fermented alcoholic beverages produced from other plant sources, such as soursop (*Annona muricata*)[13], tree tomato (*Solanum betaceum*)[14], and coffee (*Coffea arabica* L.)[15]. It has been documented that the acidity of fermented alcoholic beverages is mainly due to the formation of organic acids during the fermentation process and the intrinsic acids of the fruits. In particular, the presence of compounds such as citric, lactic, malic, and succinic acids is essential, as their absence would result in products with poor flavor, as well as increased susceptibility to microbial contamination[16].

Proximate analysis revealed low contents of fat, ash, protein, and fiber, due to the nature of the product as a fruit-based fermented beverage. Similar moisture and nitrogen-free extract contents were also observed when compared with those of other fermented alcoholic beverages derived from plant-based products, such as beetroot[17], banana, and pineapple[18] (Table 1).

The antioxidant capacity values (Figure 1) fall within the range reported for artisanal alcoholic beverages produced from various fermented macerated fruits (70.084–1,729.57 mg TE L^{-1}), corresponding to a moderate level of antioxidant capacity in fruit-based alcoholic beverages[16,19,20]. The wide range of antioxidant power in this type of beverage can be attributed to several key factors, such as the content of bioactive compounds, fruit species, degree of ripeness, fermentation protocols used, and the presence of seeds or peels during maceration, among others[20]. While it is important to recognize the antioxidant capacity of the developed beverage, its alcohol content (20.9 ± 1.6% ABV) can be harmful if consumed frequently and in excess.

Specifically, several studies have related the antioxidant activity of fruits to their content of bioactive compounds, such as phenolic compounds and flavonoids[20]. Therefore, consuming foods and beverages containing redox-active compounds may protect cells from oxidative stress damage and thus reduce the risk of various degenerative diseases associated with this stress. In this regard, the concentration of total soluble phenolic compounds in the alcoholic beverage was 384.72 ± 8.18 mg GAE/L, and that of flavonoids was 328.49 ± 8.18 mg QE/L, indicating that these compounds constitute a significant fraction contributing to its antioxidant activity.

These results also indicate that the fermented beverage produced from sea grapes exhibits a higher antioxidant capacity compared to other artisanal fruit-based alcoholic beverages fermented with different fruits. For example, a recent study on wine made from Cabernet-type grapes reported antioxidant values ranging from 231.5 to 303.7 mg QE/L[19]. The content of phenolic compounds and flavonoids in the alcoholic beverage produced comes mainly from the sea grapes used as raw material. As reported in a previous study, sea grapes contained mean concentrations of 177.23 ± 9.45 mg GAE/100 g and 9.67 ± 1.12 mg QE/100 g of fresh fruit for total phenolic compounds and flavonoids, respectively[21].

A correlation between antioxidant capacity and phenolic compound concentration has been documented in fermented beverages such as wines[19] and beers[22]. A systematic review indicates that moderate consumption of polyphenols present in fermented alcoholic beverages is associated with beneficial health effects, including improvements in cardiovascular func-

tion and a potential reduction in the risk of Alzheimer's disease, breast cancer, atherosclerosis, lipid peroxidation, and inflammatory processes.

In this regard chromatographic profile of phenolic compounds identified cyanidin-3-glucoside and pelargonidin-3-glucoside. Both are anthocyanin-type phenolic pigments characteristic of red and purple fruits, recognized for their antioxidant, anti-inflammatory, and cardioprotective properties[24]. However, it should be noted that many studies about these pigments are still preclinical or conducted at high doses; therefore, their effects in humans may vary depending on the amount consumed and the overall dietary context[23].

In addition to antioxidant activity, phenolic compounds provide important functional and sensory attributes to fruit-based fermented alcoholic beverages, such as color, aroma, and flavor[23]. In this sense, high hedonic scores were determined for each sensory attribute evaluated (Table 2). This is a relevant finding, as it has been shown that high hedonic scores in beverages are indicative of a high level of consumer acceptance[25]. When compared with similar products, the fermented sea grape beverage stands out as a product with superior sensory attributes. Agcaoili (2025)[26] reported a dragon fruit–based alcoholic beverage (*Selenicereus undatus*) with a lower hedonic score for flavor (2.3). Similarly, Ogodo et al. (2018)[27] developed mango-based alcoholic beverages (*Mangifera indica* cv. Peter) and reported reduced sensory scores in their products, both for flavor (3.25–3.35) and color (3.45–3.50). Likewise, lower hedonic scores for texture (2.82–3.88), color (2.35–3.94), and odor (3.17–3.73) have been reported in wines produced from *Emblica officinalis*[28].

The high frequencies of "Liking," together with the low frequencies of "Disliking" (Table 3), confirm a high level of acceptance by consumers of the fermented sea grape beverage. Specifically, the high percentage of liking for the odor may be attributed to the intrinsic characteristics of sea grape, which is recognized for its intense aroma[29]. This distinctive aroma is associated with its complex volatile profile, composed of 278 esters, 20 terpenes, 9 aldehydes, 5 alcohols, and 4 ketones[30]. Moreover, bioactive compounds present in the fruit—such as reducing sugars, tannins, phenolic compounds, and flavonoids—have been linked to the sensory profile, particularly attributes such as color, aroma, flavor, and texture[29,30]. These findings are consistent with the significant levels of phenolic compounds and flavonoids determined in the beverage.

CONCLUSIONS

In the present study, physicochemical parameters, bioactive compounds, antioxidant and sensory properties of an artisanal fermented alcoholic beverage made from sea grape (*Coccoloba uvifera* L.) were evaluated. Overall, the results demonstrated antioxidant potential and a relevant content of bioactive compounds, suggesting a possible contribution to functional benefits. Additionally, the sensory profile indicated a high level of consumer acceptance. Nevertheless, due to the presence of ethanol, the importance of moderate consumption of this beverage is emphasized.

The findings allowed the identification of distinctive characteristics of the beverage that may serve as a basis for the standardization of artisanal fermentation processes, contributing to improved product quality and reproducibility, as well as to the development of better commercialization strategies for local producers. However, limitations of this study include the lack of direct comparison with standardized commercial fermented beverages. Furthermore, neither the stability of the bioactive compounds nor the long-term shelf life of the product was evaluated.

In conclusion, these results contribute to the valorization of this underutilized local resource and provide a scientific basis for the development of fermented products with nutritional, functional, and sensory value.

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