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Effects of organic acids on the characteristics of *Musa troglodytarum* L. banana puree

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Abstract

Organic acids play a critical role in preventing enzymatic browning and maintaining the quality of fruit-based products. This study investigated the effects of different organic acid additions (citric and ascorbic acid) on the physicochemical and sensory properties of *Musa troglodytarum* L. banana puree. The banana puree was prepared by dry heat treatment of the unpeeled fruit and mashing the peeled fruit, followed by the addition of 0.25% citric or ascorbic acid at varying concentrations of 0.025% and 0.05%. Moisture, ash, fiber content, pH, total carotenoid, total sugar color, and sensory attributes were evaluated using standardized methods. The results indicated that ascorbic acid, particularly at a 0.05% concentration, significantly improved moisture retention, smoothness, brightness, and visual appeal, while also inhibiting enzymatic browning. Citric acid effectively lowered the pH but caused a greater reduction in carotenoid content. Sensory evaluations showed that 0.05% ascorbic acid-treated puree had the highest consumer preference, particularly for its uniformity of colour, texture, and balanced sourness. This study highlighted the importance of acidulant selection for enhancing the quality and consumer acceptability of banana-based products.

1. Introduction

Bananas, highly valued for their global popularity, are cultivated in over 130 tropical and subtropical countries, offering a wide variety of types, each with unique attributes (Singh *et al*., 2017). Among these, *M. troglodytarum*, locally known as pisang tongka langit in Maluku, Indonesia, stands out for its erect bunches, vibrant color, and distinctive flavor. Notably, *M. troglodytarum* bananas have a yellow to orange-colored pulp, indicative of their richness in beta-carotene, a precursor of vitamin A and a potent antioxidant. Studies show that the beta-carotene content of the banana varies, with elongated, cone-shaped bananas containing 52.76 to 55.33 mg/100 g, and shorter, round-shaped bananas ranging from 22.31 to 37.12 mg/100 g (Hiariej *et al.*, 2021).This high beta-carotene content positions *M. troglodytarum* as a valuable raw material for manufacturing processed food products like banana puree.

Banana puree, a soft, creamy paste made from ground and blended bananas, is widely used in food products due to its extended shelf life compared to raw fruit. It is a key ingredient in baby food, juices, dairy products, and baked goods (Ditchfield *et al*., 2004; Yap *et al*., 2017; Pandita, 2018). The global market for banana puree has seen significant growth, with projections forecasting an annual growth rate of 4.8% from 2017 to 2027 (Pandita, 2018). However, the quality of banana puree is influenced by various factors, including the use of organic acids during processing, which can significantly affect its sensory and nutritional attributes. Understanding how organic acid addition affects *M. troglodytarum* banana puree is crucial for optimizing its production and ensuring consumer acceptance.

Organic acids in foods, known for their preservative properties and ability to prevent enzymatic browning, have been studied in various fruits such as pear puree (Zhou *et al*., 2018), banana smoothies (Wang *et al*., 2014), banana puree (Zou *et al.*, 2023), and peach puree processed with high-pressure treatments (Guerrero-Beltran *et al*., 2005). Citric acid, for example, is commonly used to lower pH and inhibit enzymatic browning, which preserves the color and appearance of fruit purees (Chaisakdanugull *et al.*, 2007). Ascorbic acid, meanwhile, is widely recognized for its antioxidant properties, which can prevent oxidation and extend the shelf life of food products (Baldwin *et al*., 2008; Gallo *et*

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al., 2021). While these acids have shown unique effects on the sensory and physicochemical properties of other fruit purees, the specific impact on *M. troglodytarum* banana puree remains underexplored.

Although research has extensively covered various banana species, such as *Musa cavendish* and *Musa acuminata*, which are more commonly studied, there is limited understanding of how acidification affects *M. troglodytarum*. Studies by Forena *et al*. (2024) emphasize the importance of bioactive compounds in bananas, yet they largely focus on more widely cultivated species. Additionally, previous research has highlighted the role of ripeness, heat treatment, and fermentation on banana puree properties (Dash and Rai, 2016; Gallo *et al*., 2021), but these studies mostly concern other banana types.

Given the distinct genetic and biochemical profiles of different banana species (Li *et al*., 2013), it is essential to investigate how organic acids specifically affect *M. troglodytarum*. Citric and ascorbic acids were selected for this study due to their ability to influence pH, inhibit browning, and potentially enhance texture and flavor. By controlling acid levels, it may be possible to optimize both the sensory and nutritional properties of *M. troglodytarum* puree.

The primary objective of this research is to evaluate the effects of citric and ascorbic acids on the quality of *M. troglodytarum* banana puree. This study aims to assess how these acids impact the puree's sensory and physicochemical properties and determine the optimal acid addition to enhance both sensory appeal and nutritional quality. By addressing these objectives, this research seeks to contribute to the improvement of processing techniques for *M. troglodytarum*, thereby promoting its use in the food industry.

2. Materials and methods

2.1 Materials

Short *M. troglodytarum* bananas were harvested from Siwang village in Ambon Island, Moluccas, Indonesia. The degree of maturity of the bananas was determined by the colour of the fruit flesh by using an egg yolk colour chart based on the method described by Englberger *et al*. (2006). The banana used in this study, with the maturity of 10 days after harvest, matching the egg yolk color number 10 (Figure 1).

2.2 Banana puree production

Unpeeled *M. troglodytarum* bananas, deemed mature at 10 days post-harvest, were selected based on pulp color indicators. The bananas, each with similar dimensions, were then subjected to dry heat treatment. Unpeeled bananas were placed in a Restoline Roller Grill Oven Convection FC 380 (France) at 200°C for 2.5 min on one side, followed by an additional 2.5 min on the other side total of 5 min.

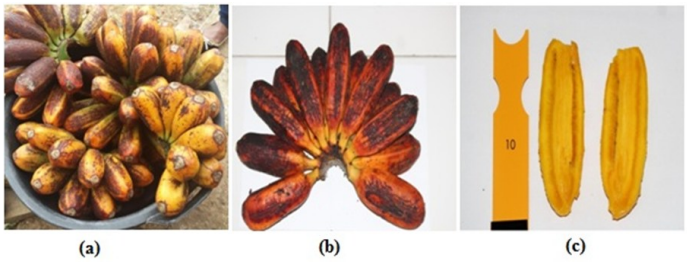


Figure 1. The samples of *M. troglodytarum* bananas right after harvest (a) and 10 days after harvest, which was used in puree making (b and c).

Bananas underwent a 2-minute immersion in an ice bath before being peeled. The pulps were then mashed through stainless steel sieves, with the 80-mesh size, to obtain the puree. Organic acid treatments, including no acid, 0.25% citric acid, 0.025% ascorbic acid, and 0.05% ascorbic acid, were added to 100 g banana puree through rigorous manual mixing. Replicates, totaling three for statistical validity, were employed. A control group comprising fresh pulp was included for baseline comparison. The puree was then packed in a vacuum-sealed plastic bag using a vacuum sealer (ANVS01-US00, Anova Culinary, China) and stored in a refrigerator at 4°C for 2 days pending further analyses.

2.3 Moisture content

The moisture content was determined following the methods outlined by the AOAC Official Method 925.10.

2.4 Ash content

The ash content was determined according to the methods outlined by the AOAC Official Method 923.03.

2.5 Fiber content

The fiber content was determined following the methods described by the AOAC Official Method 962.09.

2.6 Total carotenoid content

Approximately 2 g of banana puree sample was placed in an Erlenmeyer flask, followed by the addition of 5 g of KOH and 10% ethanol up to 50 mL. The mixture was then refluxed at 70-80°C for 30 min in a water bath. After cooling, the sample underwent filtration using filter paper, and the resulting precipitate was washed with 20 mL of hot 95% ethanol before another filtration. The Erlenmeyer flask was rinsed with 30 mL of ether, and the filtrate was combined. This combined filtrate was then subjected to extraction using

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a separatory funnel, with 50 mL of distilled water and 10 mL of saturated NaCl solution. The layers of ethanol and distilled water were discarded, and the remaining mixture was re-extracted with 25 mL of ether. The ether solution, containing beta-carotene, was combined with the ether solution from the previous filtration. This combined solution was washed successively with 50 mL of distilled water, 20 mL of ether, and 10 mL of saturated NaCl. Subsequently, all layers of distilled water were discarded. The resulting extract was transferred into a 25 mL volumetric flask through filtration, and anhydrous Na_2SO_4 powder was added. The solution was then saturated with an ether solution. The absorbance of the sample was measured at a wavelength of 450 nm (UV 2600i Spectrophotometer, Shimadzu, Japan). The total carotene content in the samples was determined based on the standard curve of total carotene (Sigma-Aldrich).

2.7 pH

The pH of the samples was measured using a calibrated pH meter (HI 221, Hanna Instrument, USA). The pH meter was first calibrated with standard buffer solutions (pH 4.0, 7.0, and 10.0). After calibration, the electrode was rinsed with distilled water and dried. It was then immersed in the puree sample, and the pH reading was recorded once stabilized. The electrode was rinsed with distilled water between measurements to ensure accuracy.

2.8 Total sugar

The total sugar content was determined using the Lane-Eynon titration method (AOAC Official Method 925.35B). The sample was clarified with lead acetate and filtered. A measured volume of the filtrate was diluted with distilled water. The solution was titrated with Fehling's solution (a combination of Fehling's A and B) using methylene blue as an indicator. The titration was conducted by gradually adding the sample solution to the boiling Fehling's solution until the blue color completely disappeared, indicating the reduction of all copper (II) ions.

$$\text{Total sugar}(\%)=\left(\frac{\text{Volume of fehling (mL)}\times\text{N Fehling Solution}\times\text{weight of sugar}}{\text{Volume of sample (mL)}}\right)\times 100$$

2.9 Color measurement

The puree's color was assessed using a Minolta Colorimeter (CM 508i, Minolta Corp, Japan). The measurements were taken in CIE-Lab format, where L indicates brightness ranging from black (0) to white (100), a represents the scale from green to red (-80 to +80), and b ranges from blue to yellow (-80 to +80). Before each measurement, the device was calibrated using black and white reference tiles. The color of the puree was measured at three randomly selected points on the packaging.

2.10 Hedonic characteristics

A hedonic sensory analysis of banana puree derived from roasted *M. troglodytarum* fruit with varying acid concentrations was conducted with a panel of 30 semi-trained individuals. The study aimed to evaluate the liking of sensory attributes, including appearance, brightness, uniformity, smoothness, consistency, thickness, sweetness, sourness, and overall flavor. The samples included four variations: no acid, 0.25% citric acid, 0.025% ascorbic acid, and 0.05% ascorbic acid. Each panelist was provided with a randomized order of samples to mitigate order effects. Panelists rated each sensory attribute on a 7-point hedonic scale, where 1 indicated the least favorable perception and 7 the most favorable. The liking of each attribute was determined as follows: appearance was assessed based on visual appeal, while brightness referred to the luminance of the puree. Uniformity evaluated the homogeneity of the texture, and smoothness measured the fineness of the puree. Consistency and thickness were judged on the viscosity and density, respectively. Sweetness and sourness ratings captured the intensity of these tastes, and the overall flavor represented the integrated perception of all attributes. The data collection involved panelists tasting each sample and recording their ratings on individual score sheets. The mean scores for each attribute across all panelists and samples were calculated to determine the impact of different acid concentrations on the preference for sensory properties of the banana puree.

2.11 Quantitative descriptive analysis

To conduct a quantitative descriptive analysis of banana puree derived from roasted *M. troglodytarum* fruit with varying acid concentrations, a panel of 10 trained individuals was utilized. The samples included four variations: no acid, 0.25% citric acid, 0.025% ascorbic acid, and 0.05% ascorbic acid. Each panelist evaluated the samples for specific quality attributes related to color, texture, and taste, which were scored on a 1-7 scale as can be seen in Table 1. Sample preparation involved creating banana puree from dry heat-treated *M. troglodytarum* fruit and dividing it into the four sample variations. Each sample was prepared and stored under identical conditions to ensure consistency. The panelists, who had been trained on the definitions and descriptions of each quality attribute, participated in practice sessions to familiarize themselves with the 7-point scale and ensure consistent scoring. During the evaluation process, the samples were presented to the panelists in a randomized order to avoid order effects. Panelists were provided with standardized evaluation forms to rate each

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Table 1. Quality attributes and definitions.

Quality attribute	Definition	Description	Scale (1-7)
Color			
Appearance	Visual appeal of the puree	General attractiveness and appeal based on initial sight	1 (very poor) to 7 (excellent)
Brightness	Luminance of the puree	The light reflecting property, perceived lightness or darkness	1 (very dark) to 7 (very bright)
Uniformity	Homogeneity of the puree color	Consistency of color throughout the sample	1 (very uneven) to 7 (very even)
Texture			
Smoothness	Finest of the puree	Perceived smoothness to touch and mouth feel	1 (very coarse) to 7 (very smooth)
Consistency	Viscosity of the puree	Thickness or flow behavior of the puree	1 (very thin) to 7 (very thick)
Thickness	Density of the puree	Perceived density when puree is handled or tasted	1 (very watery) to 7 very dense)
Taste			
Sweetness	Intensity of sweet taste	Level of sweetness perceived	1 (not sweet) to 7 (very sweet
Sourness	Intensity of sour taste	Level of sourness perceived	1 (not sour) to 7 (very sour)

attribute on a 1-7 scale, and sufficient time was allowed between samples to cleanse their palate and prevent cross -sample contamination. Data collection involved compiling the score sheets from each panelist and calculating the mean scores for each attribute across all panelists and samples.

2.12 Statistical analysis

The collected data were analyzed using ANOVA for a completely randomized design. Treatments with significant differences ($p < 0.05$) were further evaluated using the Tukey test. All analyses were conducted using MINITAB statistical software, version 17.

3. Results and discussion

3.1 Effects of organic acids on physicochemical properties of Musa troglodytarum banana puree

The moisture content (Table 2) of *M. troglodytarum* banana puree was significantly influenced by the addition of citric and ascorbic acids ($p < 0.01$). The sample without any acid had a moisture content of 73.76%, which did not significantly differ from the sample treated with 0.25% citric acid (73.88%). However, the introduction of ascorbic acid had a more pronounced effect. The puree treated with 0.025% ascorbic acid exhibited the highest moisture content at 74.71%, significantly greater than both the no-acid and citric-acid-treated samples. The sample with 0.05% ascorbic acid also showed a higher moisture content (74.57%) compared to the no-acid sample, but this value was slightly lower than the 0.025% ascorbic acid treatment. These results indicate that ascorbic acid, particularly at a concentration of 0.025%, is more effective in increasing the moisture content of *M. troglodytarum* banana puree.

This increase in moisture content with ascorbic acid can likely be attributed to its hygroscopic nature, which enhances water retention within the puree matrix. Previous studies by Ariyo *et al.* (2021) and Forena *et al*. (2024) have demonstrated similar effects, where acidulants influenced the physicochemical properties of banana products. Additionally, higher moisture content plays a crucial role in the storage stability of banana-based products. Increased hydration can improve texture and reduce drying requirements, as noted by Jaramillo-Garcés *et al*. (2023), which is beneficial for processing steps like drying or incorporation into other food systems (Raikham *et al*., 2015; Razali *et al*., 2020). While citric acid also slightly increased moisture content, its effect was less substantial compared to ascorbic acid. Citric acid is known more for its role in lowering pH and preventing enzymatic browning rather than significantly impacting moisture retention. Thus, ascorbic acid appears to be a more effective agent for improving the water-holding capacity of banana puree. From a practical standpoint, the increased moisture content associated with ascorbic acid, particularly at 0.025%, may be advantageous for applications where freshness, texture, and flavor are critical, such as in fresh food products or baby food. However, for products requiring a longer shelf life or easier storage, a lower moisture content might be preferable. Therefore, the choice of acid and concentration should be aligned with the specific goals of the product being developed. Future studies could further explore how these acid treatments interact with other quality parameters such as texture, flavor, and microbial stability.

The analysis of ash content across the different samples of *M. troglodytarum* banana puree revealed no statistically significant differences ($p > 0.05$) (Table 2). The ash content for the sample without any acid addition

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Table 2. Physicochemical characteristics of *M. troglodytarum* banana puree with different organic acids stored at 4°C for 2 days.

Acid treatments	Moisture (%)	Ash (%)	Fiber (%)	pH	Total Carotenoid (ppm)	Total Sugar (%)	Colour L	Colour a	Colour b
No acid	73.76±0.05^{c}	0.56±0.02^{a}	0.78±0.04^{a}	4.86±0.05^{a}	115.34±0.90^{a}	20.77±0.16^{a}	52.66±0.05^{d}	4.34±0.05^{a}	40.71±0.14^{b}
0.25% Citric acid	73.88±0.07^{c}	0.55±0.05^{a}	0.41±0.03^{b}	4.40±0.10^{b}	84.35±0.35^{d}	19.53±0.26^{b}	52.95±0.05^{c}	3.97±0.03^{b}	42.14±0.08^{a}
0.025% Ascorbic acid	74.71±0.02^{a}	0.52±0.04^{a}	0.79±0.05^{a}	4.80±0.20^{a}	94.61±0.65^{c}	19.95±0.19^{b}	55.15±0.05^{a}	3.25±0.06^{c}	38.67±0.18^{d}
0.05% Ascorbic acid	74.57±0.06^{b}	0.50±0.02^{a}	0.50±0.05^{b}	4.76±0.05^{a}	96.58±0.90^{b}	18.48±0.19^{c}	53.84±0.04^{b}	2.41±0.04^{d}	39.81±0.17^{c}

Values are presented as mean±SD. Values with different superscripts in the same column are statistically significantly different at α = 0.05.

Table 3. Hedonic characteristics of *M. troglodytarum* banana puree with different organic acids stored at 4°C for 2 days.

Acid treatments	Appearance	Brightness	Uniformity	Smoothness	Consistency	Thickness	Sweetness	Sourness
No acid	5.47^{c}	5.37^{c}	4.47^{c}	4.67^{c}	5.50^{b}	4.90^{c}	5.83^{a}	5.00^{b}
0.25% Citric acid	6.07^{ab}	6.13^{ab}	4.83^{b}	5.83^{a}	6.13^{a}	6.17^{a}	5.80^{a}	5.80^{a}
0.025% Ascorbic acid	5.80^{bc}	5.77^{bc}	4.80^{b}	5.22^{b}	6.17^{a}	6.13^{a}	5.83^{a}	5.07^{b}
0.05% Ascorbic acid	6.37^{a}	6.20^{a}	5.60^{a}	5.93^{a}	6.23^{a}	5.70^{b}	5.80^{a}	5.70^{a}

Values with different superscripts in the same column are statistically significantly different at α = 0.05.

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was 0.56%, which was comparable to the ash content in the samples treated with 0.25% citric acid (0.55%), 0.025% ascorbic acid (0.52%), and 0.05% ascorbic acid (0.50%). Despite the variations in acid type and concentration, the consistency in ash content suggests that the addition of citric or ascorbic acid, at the concentrations tested, does not significantly alter the mineral composition of the banana puree. This uniformity in ash content across treatments aligns with the general understanding that acidulant addition primarily affects pH and other properties rather than the mineral content, which is more closely related to the inherent composition of the banana itself. The lack of significant differences in ash content underscores the stability of the mineral content in banana puree under varying acid treatments, making it a reliable factor in the formulation of banana-based products.

The fiber content of *M. troglodytarum* banana puree varied significantly across the different samples ($p < 0.01$) (Table 2). The sample without any acid addition had a fiber content of 0.78%, which was comparable to the sample treated with 0.025% ascorbic acid (0.79%). However, significant reductions in fiber content were observed in samples treated with 0.25% citric acid (0.41%) and 0.05% ascorbic acid (0.50%) compared to the control and the sample treated with 0.025% ascorbic acid. This suggests that both citric acid at 0.25% and ascorbic acid at 0.05% negatively impacted fiber content, leading to a decrease in the structural integrity of the dietary fibers. The significant decrease in fiber content in the samples treated with higher concentrations of citric and ascorbic acids can be attributed to acid-induced hydrolysis or solubilization of the fiber matrix. Acidification likely weakens the bonds within the fiber structure, such as pectin or cellulose, causing them to degrade or become more soluble. This phenomenon is consistent with findings from Cherian *et al*. (2008) and Maaloufa *et al*. (2024), who reported that acidulants can disrupt the fiber matrix, reducing its retention. Specifically, acids may break down the pectin framework, which plays a key role in maintaining fiber structure in fruit-based products, leading to a more significant reduction in fiber content. Similar trends have been observed in studies involving other fruit purees where acid treatments have been shown to weaken fiber retention. For example, studies on mango and guava purees (Raikham *et al*., 2015) reported a similar reduction in fiber content when exposed to citric acid, further supporting the idea that certain acid concentrations can alter the structural integrity of dietary fibers across different fruit matrices. These findings emphasize the role of acids in fiber solubilization, particularly in acidic environments where enzymatic activity or pH reduction may exacerbate fiber breakdown. From a practical perspective, these results highlight the importance of optimizing acid concentrations in banana puree formulations to preserve fiber content. Fiber is a valuable nutritional component, and maintaining its integrity is essential for meeting dietary fiber content claims on product labels. At lower concentrations (e.g., 0.025% ascorbic acid), fiber content remained relatively unaffected, suggesting that minimal acid treatment could help retain fiber while achieving other desirable properties such as pH adjustment or browning prevention. However, at higher concentrations of citric or ascorbic acid, a balance must be struck to avoid compromising fiber content while still benefiting from the preservation and sensory improvements that acidulants provide.

The pH value of *M. troglodytarum* banana puree exhibited significant differences across the various samples ($p < 0.01$) (Table 2). The control sample, which did not receive any acid treatment, had the highest pH value of 4.86. The samples treated with 0.025% ascorbic acid (pH 4.80) and 0.05% ascorbic acid (pH 4.76) also showed considerable differences in pH values; however, these were not significantly different from the control. In contrast, the sample treated with 0.25% citric acid had a significantly lower pH value of 4.40, indicating a stronger acidification effect compared to the other treatments. These findings align with previous research demonstrating that citric acid exerts a more substantial impact on lowering pH due to its higher acidity compared to ascorbic acid, which is typically used for its antioxidant properties rather than its acidifying capacity (Fidina *et al*., 2018; Awad and Alzobaay, 2024). The dissociation of citric acid in solution releases protons, thereby decreasing pH and enhancing the overall acidity of the puree. This ability to lower pH effectively is critical for the preservation and sensory attributes of banana-based products. The pH values across the samples highlight the statistically significant impact of acid type and concentration on the banana puree's acidity. Understanding these variations is essential for optimizing the quality and stability of banana-based food products. The stability of pH in such formulations is crucial, as it can influence microbial stability, enzymatic activity, and overall shelf life (Castañón *et al.*, 1999; Saarniit *et al*., 2023). Therefore, understanding the role of different acids in modifying pH is essential for optimizing the quality and stability of banana-based food products.

The total carotenoid content of *M. troglodytarum* banana puree exhibited significant variation among the different samples ($p < 0.01$) (Table 2). The control sample, which did not receive any acid treatment, had the highest total carotenoid content at 115.34 ppm. The

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sample treated with 0.05% ascorbic acid showed a slightly lower total carotenoid content of 96.58 ppm, which was significantly different from the control. The sample treated with 0.025% ascorbic acid exhibited a total carotenoid content of 94.61 ppm, also significantly lower than the control but higher than the sample treated with 0.25% citric acid, which had the lowest total carotenoid content at 84.35 ppm. These results highlight the significant impact of acid type and concentration on the total carotenoid content in banana puree, with citric acid at 0.25% resulting in the most pronounced reduction. The significant reduction in carotenoid content with citric acid treatment may be attributed to its higher acidity, which can promote degradation of carotenoids more effectively than ascorbic acid, which is primarily recognized for its antioxidant properties rather than its acidifying capacity. Mechanistically, citric acid may enhance the oxidation of carotenoids, leading to their breakdown and loss of nutritional value. This finding aligns with previous research that indicates carotenoids are particularly sensitive to acidification and various factors such as ripening stages, light exposure, and the presence of phenolic compounds, all of which can influence carotenoid stability (Wall, 2006; Zhou *et al*., 2023; Ishikiriyama *et al*., 2024). The interaction of light exposure and phenolic compounds with carotenoids further underscores the complexity of factors affecting their stability in banana-based products. For example, studies have shown that light can accelerate carotenoid degradation, while certain phenolic compounds may either stabilize or destabilize these pigments depending on their concentrations and the surrounding environment (Sundaram *et al.*, 2011; Hu *et al*., 2019). Understanding these interactions is crucial for optimizing carotenoid retention in banana puree, especially in formulations intended for enhanced nutritional value.

From a nutritional perspective, carotenoids are essential for health, providing antioxidant properties and contributing to the prevention of various diseases. The reduction in total carotenoid content in the acid-treated samples suggests a potential decrease in the overall nutritional profile of banana puree. Therefore, it is imperative for food manufacturers to consider the implications of acidification on carotenoid stability when developing banana-based products. To optimize carotenoid retention, it is advisable to minimize the use of strong acid treatments or to explore alternative methods of acidification that may preserve carotenoids more effectively. Additionally, employing lower concentrations of ascorbic acid may help maintain carotenoid levels while still providing some acidifying benefits. Future research should focus on identifying optimal processing conditions that balance acidification with the preservation of carotenoid content, ensuring that *M. troglodytarum* banana puree remains nutritionally beneficial.

The total sugar content of *M. troglodytarum* banana puree showed significant differences across the various treatments ($p < 0.01$) (Table 2). The control sample, which did not undergo any acid treatment, had the highest total sugar content at 20.77%. A slight reduction in sugar content was observed in the sample treated with 0.025% ascorbic acid (19.95%), indicating that ascorbic acid at this concentration had a mild impact on sugar retention. In contrast, the sample treated with 0.25% citric acid exhibited a more pronounced reduction in total sugar content (19.53%), suggesting that citric acid, with its strong acidifying properties, may influence sugar degradation or conversion more effectively than ascorbic acid. The most significant reduction in total sugar content was recorded in the sample treated with 0.05% ascorbic acid (18.48%), which was lower than both the control and citric-acid-treated samples. Although ascorbic acid is primarily known for its antioxidant properties, at higher concentrations, it appears to engage in more complex interactions with enzymes involved in sugar metabolism, such as glycosidases, leading to greater sugar breakdown. This aligns with findings by Gallo *et al*. (2021), who reported that ascorbic acid influences enzymatic browning reactions, which can affect the sugar content in fruit products. Citric acid, known for its acidifying capacity, likely promotes a reduction in pH, which alters enzyme activity within the puree, leading to increased sugar degradation or conversion into other compounds. As noted by Abd El-Wahhab *et al*. (2023), changes in pH can influence the behavior of enzymes such as glycosidases, which play a role in sugar metabolism. This mechanism explains the more significant impact of citric acid on reducing sugar content, as seen in previous studies on acidic environments in fruit products.

The variations in sugar content among the samples can be attributed to the differing chemical properties of ascorbic and citric acids. Ascorbic acid, as an antioxidant, not only affects browning reactions but also interacts with enzymes involved in sugar breakdown. The more pronounced reduction in sugar content with 0.05% ascorbic acid suggests a stronger interaction with metabolic pathways at higher concentrations, compared to its milder effect at lower concentrations (0.025%). In contrast, citric acid appears to influence sugar degradation primarily through its strong acidification properties, which lower the pH and enhance enzymatic activity associated with sugar metabolism. These results highlight the importance of understanding how different acids interact with sugar components in banana-based products. From a practical standpoint, manufacturers

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should carefully consider the concentration and type of acid used in formulations to balance sugar retention with other desired properties, such as pH control and browning prevention. Lower concentrations of ascorbic acid may be preferable for retaining sugar content, while higher concentrations, although beneficial for antioxidant activity, may result in greater sugar loss. Similarly, citric acid, while effective in reducing pH and enhancing microbial stability, should be used with caution to avoid excessive sugar degradation.

The colorimetric analysis of *M. troglodytarum* banana puree showed significant differences in L (lightness), a (redness), and b (yellowness) values across the different treatments ($p < 0.01$) (Table 2, Figure 2). The control sample, which did not receive any acid treatment, had the lowest L value (52.66), indicating a darker puree. The puree treated with 0.025% ascorbic acid exhibited the highest lightness (L = 55.15), significantly higher than the control and all other treatments. The 0.05% ascorbic acid sample had an L value of 53.84, higher than the control but lower than the 0.025% ascorbic acid sample. The sample treated with 0.25% citric acid had a lightness value of 52.95, slightly higher than the control but significantly lower than the ascorbic acid-treated samples. For the a value, which reflects redness, the control sample had the highest value (4.34), indicating a more pronounced red hue. The sample treated with 0.25% citric acid showed a lower a value of 3.97, followed by the 0.025% ascorbic acid sample (3.25). The 0.05% ascorbic acid sample had the lowest a value (2.41), significantly lower than the other samples, indicating the least red hue. Regarding the b value, which represents yellowness, the sample treated with 0.25% citric acid had the highest b value (42.14), significantly higher than all other samples, suggesting a stronger yellow hue. The control sample had a b value of 40.71, lower than the citric-acid-treated sample but higher than both ascorbic-acid-treated samples. The 0.025% ascorbic acid sample had the lowest b value (38.67), significantly lower than all other samples, while the 0.05% ascorbic acid sample had a b value of 39.81, still lower than the control but higher than the 0.025% ascorbic acid sample.



Figure 2. The resulting *M. troglodytarum* banana puree treated with different organic acids.

The significant differences in L, a, and b values across the samples can be attributed to the distinct effects of ascorbic and citric acids on enzymatic browning and color stabilization. Ascorbic acid, known for its strong antioxidative properties, effectively inhibits polyphenol oxidase (PPO) activity, preventing browning reactions and leading to a lighter color, as reflected in the higher L values in the ascorbic acid-treated samples. This aligns with previous research by Yang *et al*. (2000), which demonstrated that ascorbic acid reduces browning by inhibiting PPO activity, resulting in a brighter product. Citric acid, while also effective at inhibiting browning, influences the color differently, as seen in the lower L values and higher b values. Citric acid's pH-lowering effect may alter the degradation or stabilization of color compounds in the banana puree, affecting both redness and yellowness. This effect can be attributed to the pH-dependent nature of enzymatic reactions and pigment stability, as noted by Abd El-Wahhab *et al*. (2023), who found that citric acid modulates color through its influence on pH, reducing Maillard reaction products that contribute to color changes. The lower a value observed in citric acid-treated samples further suggests that citric acid is less effective at preserving the red hues compared to ascorbic acid. The differences in a and b values between ascorbic- and citric-acid-treated samples highlight the complex interactions between acids and color compounds in banana puree. Ascorbic acid's antioxidative properties likely prevent the degradation of pigments associated with red and yellow hues, while citric acid's stronger acidification alters enzymatic and non-enzymatic reactions that influence these color components. Similar findings have been observed in other fruits, such as apples and peaches, where citric acid has been shown to impact the stability of carotenoids and anthocyanins, leading to changes in redness and yellowness (Wang *et al*., 2014). From a practical standpoint, these results provide valuable insights for food manufacturers seeking to optimize the color of banana-based products. Ascorbic acid, at lower concentrations, can be used to achieve a lighter and more stable color, while citric acid may be preferred for applications where a stronger yellow hue is desired. The choice of acid and its concentration should be carefully managed depending on the desired color attributes, as these acids can significantly influence both the visual appeal and consumer acceptance of the final product.

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3.2 Effects of organic acids on the sensory preference characteristics of Musa troglodytarum banana puree.

The sensory evaluation of *M. troglodytarum* banana puree treated with various acid solutions showed significant differences in several hedonic attributes, including appearance, brightness, uniformity, smoothness, consistency, thickness, sweetness, and sourness (Table 3). These attributes were rated on a 7-point hedonic scale, where 1 indicated the least favorable perception and 7 the most favorable. The analysis revealed that acid treatments had a notable impact on panelist preferences, with certain treatments resulting in more favorable evaluations. For appearance, the puree treated with 0.05% ascorbic acid received the highest favorability score (6.37), indicating that it was the most visually appealing. In contrast, the control sample (5.47) had the lowest appearance score, reflecting a less favorable perception. The puree with 0.25% citric acid (6.07) and 0.025% ascorbic acid (5.80) was moderately well-received, with no significant differences between them, but both were rated more favorably than the control. A similar trend was observed for brightness, where the 0.05% ascorbic acid treatment achieved the highest score (6.20), making it the most favorably perceived in terms of brightness. The 0.25% citric acid treatment followed closely behind (6.13), while the control sample (5.37) was rated significantly lower, indicating a less favorable perception of brightness.

For uniformity and smoothness, the 0.05% ascorbic acid treatment again resulted in the highest ratings, with scores of 5.60 for uniformity and 5.93 for smoothness, indicating a more favorable texture compared to other treatments. The control sample was rated the least favorably in both attributes, with scores of 4.47 and 4.67, respectively. The acid treatments—0.25% citric acid and 0.025% ascorbic acid—also resulted in higher favorability than the control but were not as positively perceived as the 0.05% ascorbic acid treatment. In terms of consistency and thickness, the acid-treated samples, particularly those treated with citric acid and 0.05% ascorbic acid, were rated significantly more favorably than the control. The highest consistency scores were found in the 0.025% and 0.05% ascorbic acid treatments (6.17 and 6.23, respectively), reflecting the panelists' preference for these textures. The thickness was also rated more favorably for the citric acid and 0.025% ascorbic acid treatments, with scores above 6, compared to the control's less favorable rating of 4.90.

Sweetness perception was consistent across all treatments, with scores ranging from 5.80 to 5.83, indicating no significant differences and suggesting that acid treatments did not alter the favorability of sweetness. However, the sourness attribute showed significant variation, with citric acid (5.80) and 0.05% ascorbic acid (5.70) treatments receiving more favorable ratings than the control (5.00), indicating that the acids positively influenced the sourness perception, enhancing the overall sensory appeal.

Acid treatments, particularly with 0.05% ascorbic acid, improved the favorability of several sensory attributes of *M. troglodytarum* banana puree. The acid-treated samples, especially those treated with ascorbic acid, were generally more preferred by the panelists than the untreated control, reflecting a positive trend in consumer preferences for appearance, texture, and sourness.

3.3 Effects of organic acids on the sensory quality attributes of Musa troglodytarum banana puree

The sensory evaluation of *M. troglodytarum* banana puree treated with various acids revealed significant differences in the degree of the quality attributes, including appearance, brightness, uniformity, smoothness, consistency, thickness, sweetness, and sourness (Figure 3). These attributes were assessed on a 7-point scale, with higher values representing a greater degree of the specific attribute. Values with the same letter indicate that the differences between the treatments were not statistically significant.

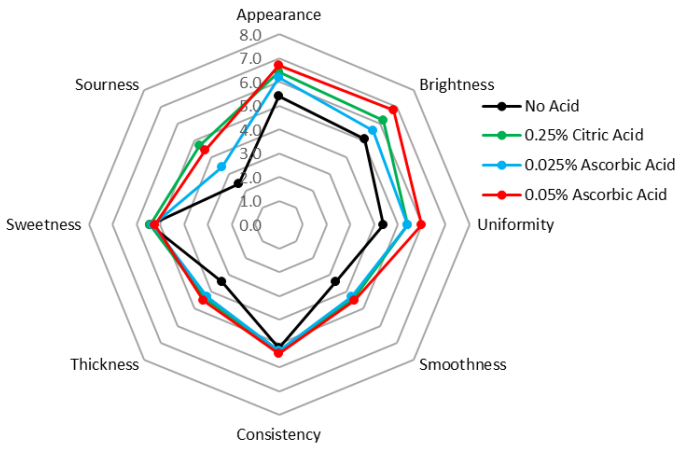


Figure 3. Sensory quality attributes of *M. troglodytarum* banana puree with different organic acids and stored at 4°C for 2 days.

In terms of appearance, the puree treated with 0.05% ascorbic acid had the highest score (6.70), indicating a significantly more visually appealing appearance compared to the other samples. The control puree, without any acid treatment, had the lowest appearance score (5.40), suggesting a less visually appealing product. The citric acid treatment (6.40) and 0.025% ascorbic acid treatment (6.20) showed similar degrees of appearance, with no significant differences between them. For brightness, defined as the light-reflecting property or perceived lightness, the 0.05% ascorbic acid-

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treated puree was rated the brightest (6.80), followed closely by the citric acid treatment (6.20). The control sample was perceived as significantly darker, with a score of 5.10. The 0.025% ascorbic acid treatment also exhibited moderate brightness (5.60), but it was significantly less bright than the 0.05% ascorbic acid-treated puree. Uniformity refers to the homogeneity of the puree's color, and the highest score was again observed in the 0.05% ascorbic acid-treated puree (6.00), indicating the most even color distribution. Both the citric acid and 0.025% ascorbic acid treatments had uniformity scores of 5.40, which were significantly more uniform than the control puree, which had the lowest score (4.40).

The appearance and brightness of the puree were significantly improved by the acid treatments, especially with 0.05% ascorbic acid. This increase in brightness and visual appeal can be explained by the fact that ascorbic acid, known as a powerful antioxidant, likely prevented browning reactions in the banana puree, particularly enzymatic browning. The browning reaction, catalyzed by polyphenol oxidase, is inhibited at lower pH levels, which acids like ascorbic and citric acid provide. Previous studies have reported similar findings, where ascorbic acid effectively maintains the color and brightness of fruit purees by inhibiting enzymatic browning. For example, in apple puree, ascorbic acid significantly improved color retention compared to untreated samples (Kim *et al.*, 2021). The uniformity of the color was also enhanced by the acid treatments. The improved color homogeneity is likely due to the stabilization of pigments and reduction of uneven browning reactions. Similar results were observed in studies on acid-treated apple and peach purees, where acidulants like citric acid improved the visual uniformity by reducing oxidative degradation of the pigments (Wu *et al.*, 2016). Acid-induced changes in texture may also help spread pigments more evenly throughout the puree, further enhancing uniformity.

In terms of smoothness, which measures the perceived texture of the puree, the 0.05% ascorbic acid treatment had the highest score (4.50), indicating the finest and smoothest texture. The control puree had the lowest smoothness score (3.40), suggesting a coarser texture. The citric acid and 0.025% ascorbic acid treatments were rated similarly (4.40 and 4.30, respectively), with no significant differences between them. The consistency of the puree, representing its viscosity and flow behavior, was rated highest in the 0.05% ascorbic acid-treated sample (5.40). The control and other acid-treated samples had similar scores around 5.20–5.30, showing little variation in perceived thickness or viscosity between these treatments. For thickness, the 0.05% ascorbic acid-treated puree again achieved the highest score (4.50), indicating a denser texture, while the control puree was rated the lowest (3.40), indicating a thinner, more watery texture. The citric acid and 0.025% ascorbic acid treatments produced similarly dense purees, with no significant differences between them. In terms of smoothness, consistency, and thickness, the acid-treated samples, especially those treated with 0.05% ascorbic acid, exhibited greater viscosity and density than the control. This can be attributed to the effect of acids on the pectin and starch structure within the puree. Acids are known to induce pectin gelation and may alter starch gelatinization, increase viscosity and produce a denser texture. For example, studies on mango and guava purees have shown that acid treatments can enhance the gelation of pectin, leading to smoother and thicker textures (Jamsazzadeh Kermani *et al*., 2015; Patel *et al.*, 2016; Makroo *et al.*, 2019), consistent with the results observed in the banana puree. Moreover, the slight increase in moisture retention in acid-treated samples may contribute to a perception of greater smoothness and thickness, as water binds with the starches and pectins more effectively.

Regarding sweetness, all samples had similar scores, ranging from 5.20 to 5.40, with no significant differences among the treatments. This indicates that the acid treatments did not noticeably alter the sweetness perception of the puree. Finally, sourness was most intense in the citric acid-treated puree, which had the highest score (4.70), followed by the 0.05% ascorbic acid treatment (4.40). The control sample had the lowest sourness score (2.40), indicating that the acid treatments, particularly citric acid, significantly enhanced the sour taste of the puree compared to the untreated sample. Overall, these results show that the acid treatments, especially with 0.05% ascorbic acid, significantly influenced the degree of key quality attributes such as appearance, brightness, smoothness, and sourness, making the treated purees more uniform, dense, and brighter compared to the control sample. For sweetness, the sensory scores remained consistent across treatments, with no significant changes. This suggests that the acids did not drastically impact the perceived sweetness of the puree, possibly because the acid concentrations were not high enough to overpower the natural sugars in the banana. This result is in line with previous research, where mild acid treatments were found to have minimal effects on the sweetness perception of fruit purees (García-Parra *et al*., 2011; Mahmood *et al.*, 2012), as the inherent sweetness from sugars like glucose and fructose remains dominant unless very strong acids or high concentrations are used. On the other hand, sourness was significantly enhanced by the citric acid and 0.05%

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ascorbic acid treatments, as expected. Both citric and ascorbic acids are organic acids that lower the pH of the puree, intensifying the sour taste (Fidina *et al.*, 2018; Awad and Alzobaay, 2024). Citric acid, being a stronger acid than ascorbic acid, led to the highest sourness scores, which aligns with its known role in enhancing the sour profile in fruit products. Similar results have been observed in acid-treated citrus juices and fruit beverages, where citric acid significantly enhanced the sourness perception (Junge *et al.*, 2022).

4. Conclusion

The addition of citric and ascorbic acids significantly affects the physicochemical and sensory properties of *M. troglodytarum* banana puree. Among the acid treatments tested, ascorbic acid at 0.05% concentration proved to be the most effective in enhancing the sensory appeal, particularly in terms of appearance, brightness, smoothness, and overall texture. Ascorbic acid inhibited enzymatic browning more effectively than citric acid, contributing to the puree's lighter color, smoother texture, and improved consumer acceptance. This acid concentration also maintained higher moisture content, contributing to a creamier texture, which is crucial for applications in baby food and other ready-to-eat products. While citric acid demonstrated superior acidification properties, leading to a significant reduction in pH, it was less effective in preserving the color and nutritional integrity of the banana puree. Specifically, citric acid at 0.25% caused a greater reduction in carotenoid content compared to ascorbic acid, which is an essential nutrient due to its provitamin A activity. Therefore, while citric acid can be useful for extending shelf life and reducing microbial activity, its impact on nutritional degradation must be carefully managed, particularly in products intended to retain high nutritional value. The sensory evaluation confirmed that the puree treated with 0.05% ascorbic acid was the most preferred by panelists, reflecting a positive consumer response to its uniformity, consistency, and balanced sourness. Citric acid treatment, while effective in enhancing sourness and acidity, was not highly rated for texture and appearance.

These findings underscore the importance of organic acid selection and concentration when processing *M. troglodytarum* banana puree. Ascorbic acid, especially at lower concentrations, offers a balanced solution for maintaining both sensory and nutritional quality, making it a superior choice for product formulations aimed at enhancing consumer appeal. Citric acid, on the other hand, may be better suited for applications requiring stronger acidification and preservation, but should be used cautiously to prevent nutrient loss. Future research should explore the combined use of acidulants with other preservation methods, such as high-pressure processing, to optimize both the sensory attributes and shelf-life stability of banana-based products. Additionally, expanding the study to include other banana cultivars could provide further insights into how different varieties respond to acid treatments, paving the way for broader applications in the food industry.

Conflict of interest

The authors declare no conflict of interest.

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