ORIGINAL ARTICLE

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Effect of Citric Acid and Brine Pre-Treatment on Deodorization of Green Banana Flour

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ABSTRACT

Background: Green banana flour (GBF) is a nutrient-dense ingredient, rich in resistant starch, fiber, and bioactive compounds, making it particularly suitable for gluten-free products. However, its distinct raw and earthy flavor limits its broader application in foods. While pre-treatments with citric acid and brine have been proposed for deodorization, their efficacy and their impact on the flour's functional and nutritional properties remain insufficiently characterized.

Aims: This study aimed to evaluate the efficacy of citric acid and brine pre-treatments for deodorizing green banana flour and to analyze their effects on its key functional and nutritional properties.

Methods: Peeled and sliced green bananas were subjected to one of three pre-treatments: immersion in a 5% citric acid solution, 5% brine solution, or no treatment (control). The resulting flours were analyzed for their sensory attributes, functional, and nutritional properties. Data were analyzed using ANOVA, and means were compared with the Least Significant Difference (LSD) test at a significance level of $p < 0.05$.

Results: Sensory evaluation revealed a significant reduction in undesirable flavors in the treated flours compared to the control ($p < 0.05$), confirming the deodorizing efficacy of both pre-treatments. Functionally, both treatments significantly reduced the water holding capacity ($p < 0.05$) but had no significant effect on swelling power or solubility ($p > 0.05$). Nutritionally, the protein content was significantly reduced from 4.87% in the control to 3.92 % and 2.83% in the citric acid- and brine-treated flours, respectively ($p < 0.05$).

Conclusions: Pre-treatment with citric acid or brine effectively deodorizes green banana flour. However, these treatments also adversely affect certain functional and nutritional properties, particularly water holding capacity and protein content. These trade-offs must be considered for its application in food product development.

Keywords: Green Banana Flour; Deodorization, Pre-Treatment, Swelling Power, Solubility, Value Addition, Food Security.

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1 INTRODUCTION

Banana (*Musa* species.) is a globally significant plant species, widely consumed as fruit and, in various regions, serving as a critical staple food commodity (Bakare *et al.*, 2017). Globally, bananas rank as the fourth most important food crop, providing indispensable food, nutrition, and income security for over 70 million individuals across Africa (Castillo & Fuller, 2016; Olufemi, 2024). In this continent, bananas are widely consumed fresh and processed into chips, beer and flour, but value addition remains limited (Mudyazvivi & Maunze, 2010).

The annual worldwide production of bananas is approximately 60 million tonnes, a volume comparable to that of grapes and citrus fruit production (FAOSTAT, 2019). Production is highly favored by its relatively by low labor requirement, minimal need for soil preparation, and limited weeding (FAOSTAT, 2019).

Green banana flour is derived from unripe *Musa* species fruit through a sequential process involving peeling, slicing, drying, grinding and sieving, which may be executed manually or mechanically (Cândido *et al.*, 2023). Typically, the process exhibits a low yield, with an input of 8–10 kg of fresh banana required to produce 1 kg of final flour (Jiang *et al.*, 2004).

Interest in GBF production has increased due to its notable content of resistant starch, dietary fiber, and bioactive phenolic compounds. These components have demonstrated potential to improve glycemic response and confer antioxidant benefits for enhanced public health (Juarez-Garcia *et al.*, 2006; Tribess *et al.*, 2009). This functional composition has positioned GBF as a popular ingredient among consumers seeking gluten-free alternatives and those with celiac disease. Furthermore, GBF exhibits superior thickening efficacy compared to conventional wheat flour, requiring a lower quantity during baking or pasting applications (Sarawong *et al*., 2014). However, a significant limitation to its wider adoption is the undesirable, mild raw banana and earthy off-flavor that can be imparted to final food products upon cooking (Cândido *et al*., 2023).

Green bananas are particularly susceptible to enzymatic browning during both processing and storage (Alam *et al*., 2023). This reaction is catalyzed by polyphenol oxidase (PPO), which oxidizes phenolic compounds into quinones, that subsequently polymerize to form dark pigments (Luo & Tao, 2003). This chemical change detrimentally affects sensory attributes, including appearance, taste, odor, and texture (Dotto *et al*., 2019). The rate depends of browning is dependent on factors such as PPO and phenolic content, pH, oxygen availability, and temperature (Komthong *et al*., 2006).

Control strategies for enzymatic browning in fresh produce and derived products involve targeting these influencing factors (Jiang *et al*., 2004). Control methods are broadly categorized as physical (e.g., blanching, or oxygen reduction) and chemical (e.g., the use of chelating agents, acidifiers and antioxidants that inhibit PPO activity) (Grimm *et al*., 2012). Implementing value addition processes for GBF, such as deodorization, is therefore crucial for promoting its utilization, preventing deterioration, and mitigating significant post-harvest losses (Afzal *et al*., 2022; Choudhury *et al*., 2019; Zou *et al*., 2022).

Prior investigations into GBF have primarily focused on characterizing its basic product attributes (Alkarkhi *et al*., 2011; Menezes *et al*., 2011; Rodríguez-Ambriz *et al*., 2008) and assessing its direct application in food systems, such as ice cream production (Yangilar, 2015). Comparative studies on drying methods have shown that freeze-drying preserves higher levels of protein, fat, ash, and fiber, whereas hot air drying tend to increase GBF moisture content and water-holding capacity (Taskin, 2025).

An Indian evaluating three banana varieties noted that chemical treatments with calcium chloride and ascorbic acid resulted in the highest flour recovery (31.95%), while inherent varietal differences significantly influenced moisture, sugar composition, and titratable acidity (Gadhave *et al*., 2023). Conversely, a related study reported that high steam-blanching temperatures reduced GBF yield, although blanching for 10–20 minutes with 0.25% potassium metabisulphite enhanced water-holding capacity and improved the content of protein, fat, and minerals (Deng *et al*., 2019). Further analysis of modified GBF indicated that pre-gelatinization diminished color quality, pasting ability, and solubility, yet significantly improved the flour's oil absorption and swelling capacity when compared to native and annealed samples (Kunyanee *et al*., 2024).

Despite the demonstrated potential of GBF as a functional ingredient, its widespread industrial adoption remains constrained by undesirable off-odors that negatively impact consumer acceptance. While various deodorization techniques have been explored for other plant-based flours (Bakare *et al*., 2017; Plunkett, 1913), limited research exists on the use of citric acid and brine treatments specifically for odor reduction in GBF. Furthermore, the implications of these treatments on the flour's functional and nutritional properties remain inadequately explored, highlighting a research gap in optimizing deodorization to improve both sensory quality and nutrition for wider food applications.

Therefore, the current study was designed to rigorously examine the effectiveness of citric acid and brine in deodorizing GBF and assessed their impact on its functional and nutritional properties. This research is crucial for optimizing a simple deodorization method, thereby promoting the broader utilization of GBF in the food industry, adding value to banana products, reducing post-harvest losses, and ultimately supporting food and nutrition security initiatives.

2 Material and Methods

2.1 Study Area and Description

The study utilized green bananas sourced from Samanga and Makandi farms, both situated within the Honde Valley in Zimbabwe (18°29′48.40″S and 32°51′11.52″E). This location is approximately 130 km from the city of Mutare. The Honde Valley falls within Agro-ecological Region 1, which is characterized by the highest precipitation levels in Zimbabwe. These favorable climatic conditions support the area's substantial bananas production, which is estimated to range between 27000 – 30000 tonnes annually (FAOSTAT, 2019). The specific cultivar used for all experiments was the Cavendish variety. All subsequent processing of the GBF treatments and the required laboratory analysis were conducted at the University of Zimbabwe, specifically within the Department of Nutrition Dietetics and Food Sciences laboratory in Harare.

2.2 Experimental Design

A total of three GBF treatments were evaluated: (1) **Control GBF**: Flour produced without any additive treatment; (2) **5% Citric Acid GBF**: Flour produced following immersion in a 5% citric acid solution; (3) **5% Brine GBF:** Flour produced following immersion in a 5% brine solution.

For each treatment condition, three independent production units were generated. Samples were collected from each of these treatment units in triplicate for analysis. The collected samples were then subjected to analyses to determine their organoleptic properties, water-holding capacity, swelling power, solubility, and protein content. The specific preparation method for all samples is delineated in Section 2.3

2.3 Preparation of Green Banana Flour

Raw green bananas were first de-fingered to separate individual fruits and were then manually washed in cold water. The fruits were hand-peeled and immediately soaked in clean, cold water for approximately five minutes, ensuring complete immersion to minimize enzymatic browning. The peeled bananas were immediately and manually sliced into cylindrical pieces, approximately 2 mm thickness, using a stainless-steel knife (Saw Power Blades, Zimbabwe). These slices were then re-immersed in the same cold water. Following the soaking period, the sliced bananas were drained, spread onto perforated trays, and air-dried for five minutes to remove surface moisture. The banana slices were subsequently dried in a convection oven (Lab design Engineering, South Africa) at a controlled temperature of 55°C for 24 hours. The resulting dried pieces were milled in a high-speed blender, sieved through a 250 μm mesh, and the resulting flour was sealed in labelled, airtight polythene bags before being stored in a cool, dry environment (Figure 1).

2.4 Procedure for Deodorization of Green Banana Flour using 5% Citric Acid and 5% Brine

The deodorization procedure involved two chemical pre-treatment methods.

Citric Acid Treatment: De-fingered, washed raw green bananas were manually peeled and immediately immersed in a 5% citric acid solution (Associated Chemicals Enterprise, Roo deport, South Africa) for five mins (Figure 1). The peeled bananas were then manually sliced using a stainless-steel knife (Saw Power Blades, Zimbabwe) into cylindrical pieces of approximately 2 mm thickness and re-immersed in the same 5% citric acid for an additional 30 mins (Figure 1). The citric acid solution was then drained, and the banana slices were thoroughly washed with distilled water to remove residual reagents from the surface. The slices were spread onto

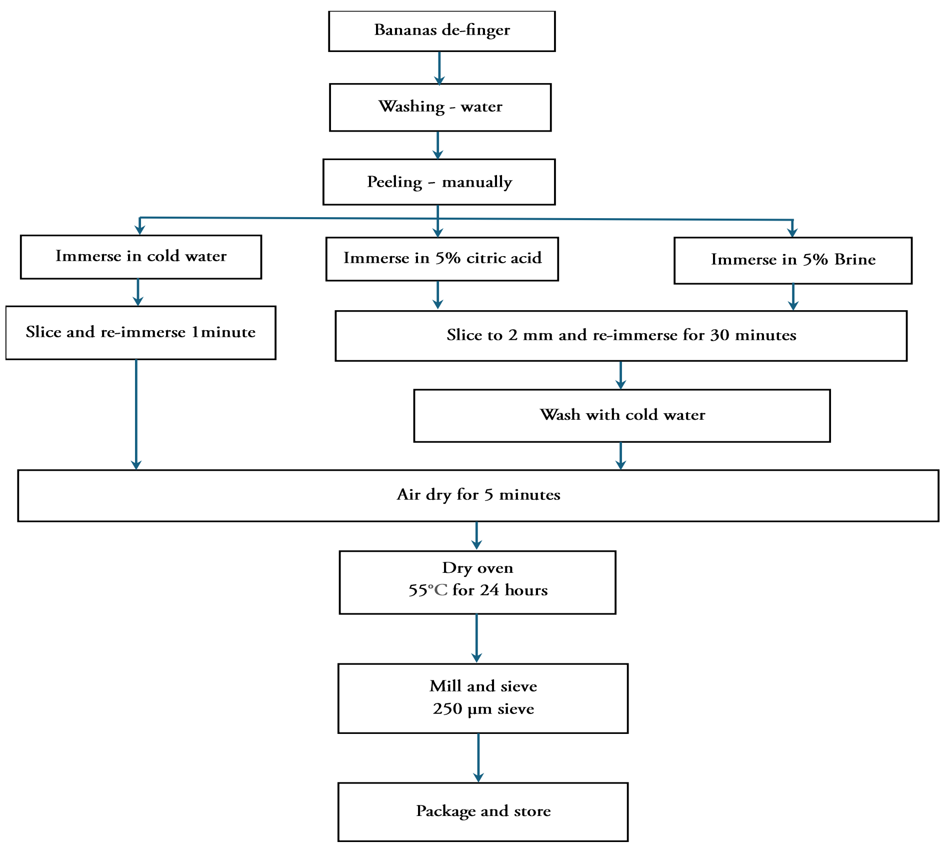

Figure 1. Production of Green banana flour treatments

perforated drying trays, air dried, milled, sieved, and packaged following the same specifications outlined for the control sample (Figure 1).

Brine Treatment: The entire procedure detailed for the citric acid treatment was precisely replicated using a 5% brine solution in place of the citric acid to produce the brine-treated GBF samples.

2.5 Sample Collection and Analysis

Approximately 500 g aliquots were collected from each of the treatment units and analyzed for organoleptic properties, water holding capacity, swelling power, solubility, in addition to nutritional analysis for protein content.

2.6 Sensory Evaluation

2.6.1 Triangle Test

A triangle test was performed to assess sensory differences between the control and treated GBF products, following the procedures outlined in ISO 4120 (2021). A total of 62 panelists, comprising students, lecturers, and staff from the University of Zimbabwe were recruited.

Panelists were simultaneously presented with three samples, each identified by a unique three-digit random code. The serving scheme employed a randomized block design ensuring that each set contained two samples from one treatment and one from the alternative (e.g., two 5% citric acid-treated GBF samples and one control, or two control samples and one 5% brine-treated sample).

Each panelist tasted all three GBF samples and was required to identify the odd sample. A mouth with plain water was mandated before the evaluation of each consecutive sample. Upon correct identification of the odd sample, panelists assessed the degree of difference between the duplicate and the odd sample based on a five-point scale: "None", "Slight", "Moderate", "Much", or "Extreme" in accordance with ISO 6685 (2017). These qualitative data were converted into quantitative scores (None=0, Slight=1, Moderate=2, Much=3, and Extreme=4, and subjected to descriptive statistics analysis to summarize the responses. The statistical significance of difference in the Triangle Test was determined by consulting the binomial table to establish the minimum number of correct judgments required at the 5% probability level.

2.6.2 Flavor Profile Descriptive Analysis

A flavor profile descriptive analysis was carried out utilizing nine semi-trained volunteer panelists recruited from students, lecturers, and staff population. The panelists were tasked with evaluating the intensity of a set of pre-determined aroma and flavor attributes across both the deodorized GBF samples and the control.

2.7 Functional Properties Analysis

2.7.1 Water Holding Capacity (WHC)

Water holding capacity (WHC) was determined using a modified procedure based on the methodology of Yangilar (2015). Approximately 1g of GBF was weighed into a pre-weighed centrifuge tube (Lastmark Laboratory, Zimbabwe) and mixed with 25 mL of distilled water at room temperature. The test tubes were stirred and incubated at 85°C for one hour. Following incubation, the suspension was cooled in an ice bath and centrifuged at 3000 rpm for 20 minutes at room temperature using a centrifuge (Gemmy Industrial Corporation, Taiwan). The supernatant was decanted, and drained for 10 min at a 45° angle before the residue was weighed using a Mettler Toledo balance (Switzerland). Each sample from respective treatments was analyzed in triplicate.

The water holding capacity was calculated as grams of water per gram of green banana flour using Equation 1:

$$WHC = [(weight\ of\ centrifuge\ tube\ with\ sample + water\ retained - weight\ of\ centrifuge\ tube + dry\ sample\ )]/(weight\ of\ dry\ sample)\ \ldots\ldots\ldots (1)$$

2.7.2 Swelling Power

Swelling power was measured following the method derived from De La Torre-Gutiérrez *et al.* (2008). A 1% GBF suspension was prepared using distilled water at room temperature in centrifuge tubes (Lastmark Laboratory, Zimbabwe). This suspension was then heated to 85°C for 30 minutes in a hot water bath, with manual agitation performed intermittently every five minutes. The suspensions were cooled in an ice bath and centrifuged for 15 minutes at 3000 rpm at room temperature using a centrifuge (Gemmy Industrial Corporation, Taiwan). The supernatant was decanted, and the mass of the remaining precipitated residue was measured using a Mettler Toledo balance (Switzerland). Each sample from respective treatments was analyzed in triplicate.

Swelling power was calculated as the mass of the swollen residue per unit mass of the dry sample (g/g) using the Equation 2:

$$Swelling\ power = (weight\ of\ container + precipitated\ residue) - weight\ of\ container\ \ldots\ldots\ldots (2)$$

2.7.3 Solubility

Solubility was determined according to the method described by De La Torre-Gutiérrez *et al.* (2008). The supernatant as described in the swelling procedure was decanted into a pre-weighed evaporator dish (Lastmark Laboratory, Zimbabwe). This solution was subsequently dried in a Lab Design Engineering dryer at 110 °C for approximately two hours until a constant weight was achieved. Each sample was analyzed in triplicate.

Solubility was calculated as the percentage of soluble solids relative to the initial dry sample mass using Equation 3:

$$Solubility = \left[\frac{(Weight\ of\ solute)}{(Weight\ of\ solution)}\right] x100 \ \ldots\ldots\ldots\ldots (3)$$

Where: $Weight\ of\ solution = Weight\ of\ solute + Weight\ of\ solvent$

2.8 Nutritional Analysis

Protein Determination - Kjeldahl Method

The protein content was determined via the standard Kjeldahl method using a Kjeldahl distiller, following the procedure specified by the AOAC (2023). Approximately 1 g of GBF was accurately weighed into a 1 L Kjeldahl digestion flask (Lastmark Laboratory, Zimbabwe). This was followed by the addition of 8 g copper catalyst tablets (Skylabs, South Africa) and 25 mL of concentrated sulphuric acid (Associated Chemical Enterprise, South Africa). The flask was gently heated on a unit heater in a fume hood until the initial frothing stopped and the sample color turned to a clear pale turquoise color (greenish yellow). Following this clearing phase, the mixture was boiled for an additional 60 minutes to ensure complete digestion.

The flask was allowed to cool to room temperature, and the contents were diluted by the addition of 300 mL of distilled water. For distillation, a 500 mL Erlenmeyer flask containing 50 mL of boric acid with indicator (Fisher Chemicals, UK) was placed on a distillation unit (Japson Selector, India). A 100 mL volume of 40% sodium hydroxide (Associated Chemical Enterprise, South Africa) was introduced down the side of the flask neck and a few pieces of zinc pellets (Skylabs, South Africa) were added. Distillation was initiated with the Kjeldahl tubes positioned on the lower shelf of the unit, and was continued until 150 mL of distillate was collected in the Erlenmeyer flask containing the boric acid solution.

The collected distillate was titrated against 0.098 M sulphuric acid (Associated Chemical Enterprise, South Africa) to a brown endpoint. A reagent blank was used to adjust the sample titer values.

The percentage of nitrogen (N) and the final protein percentage were calculated using the following standard equations:

$$\%\ Nitrogen = \left[\frac{(Vs-Vb)\ x\ 14.007g\ x\ 0.098M}{Weight\ of\ sample\ x\ 1000}\right] x100 \ \ldots\ldots (4)$$

Where: Vs = Volume of acid used in titration for the sample (mL)

Vb = Volume of acid used in titration for the blank (mL)

$$\%Protein = \%N\ x\ 6.25 \ \ldots\ldots\ldots\ldots (5)$$

2.9 Data Analysis

All quantitative data were managed and preliminarily processed using Microsoft Excel software. Further statistical analysis was performed utilizing GenStat statistical software, Version 18. For the triangle test, ANOVA and a two-tailed binomial test for paired preference were applied to determine whether significant differences existed in overall liking and product preference. Data pertaining to the flavor profile, water-holding capacity (WHC), swelling power, solubility, and protein content were analyzed using a one-way Analysis of Variance (ANOVA). Following the determination of significant treatment effects, Tukey's HSD (Honestly Significant Difference) post-hoc test was applied to facilitate the separation of treatment means at the 95% confidence level (α=0.05).

3 RESULTS

3.1 Sensory Differentiation of GBF Treated with Citric Acid and Brine

The Triangle Test results indicated a statistically significant difference between the native (control) and treated GBF samples ($p < 0.05$) (Table 1).

Table 1. Difference Between Native and Treated GBF product (Triangle test)

	Treatment	
Test	5% Citric Acid	5% Brine
Number of panellists	29	33
Correct responses	29	30
Spoiled responses	0	3
Critical number	21	23
***p*-value**	< 0.05	< 0.05

Note: The figures represented are the number of responses from a sensory session. A significance difference will exist if the correct response is equal or greater than the critical number.

Panelists who correctly identified the odd sample proceeded to rate the magnitude of the difference among the GBF treatments (Figure 2). For the GBF treated with 5% citric acid, the majority of panelists (34%) reported a 'much' difference compared to the control. A similarly high proportion of panelists (38%) reported a 'much' difference for the GBF treated with 5% brine when contrasted with the control (Figure 2).

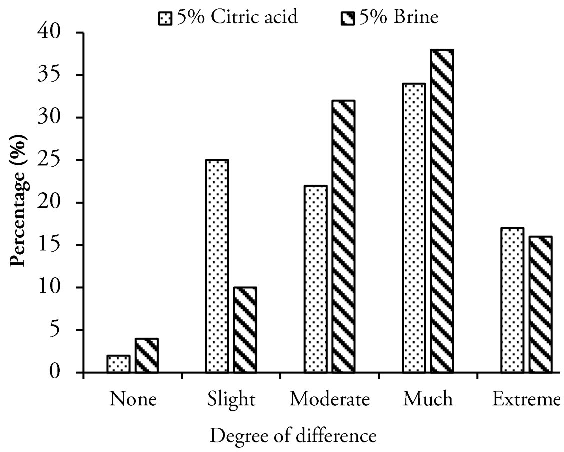

Figure 2. Selection of degree of difference "None", "Slight", "Moderate"," Much", and "Extreme" from the correct responses

3.2 Flavor Profile of the Native, Citric Acid and Brine Treated Cooked green banana product

The Flavor Profile Descriptive Analysis revealed marked differences among the treatments (Figure 3). The native (untreated) green banana flour exhibited a prominent astringency flavor, coupled with discernible notes of rawness and bluntness, when compared to the chemically treated samples.

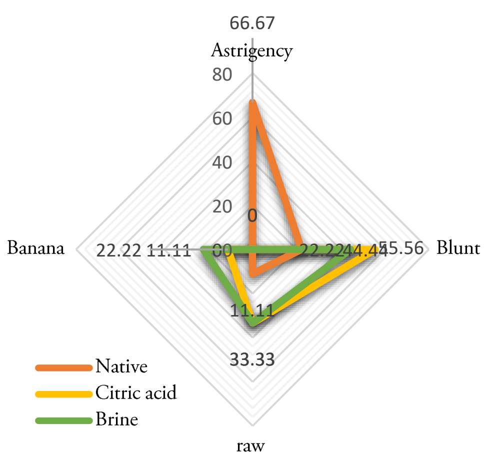

Figure 3. Flavour Profiles of the Native, Citric Acid and Brine Treated Cooked Green Banana Product

Conversely, the scores for desirable banana flavor and undesirable rawness were lowest in the control treatment. The astringency attribute was clearly the dominant sensory characteristic of the native flour. Comparing the treated samples, the citric acid-treated flour displayed a higher intensity of bluntness than the brine-treated flour. Furthermore, banana flavor notes were more distinctly pronounced in the brine-treated product than in the citric acid-treated product. Statistical analysis confirmed that the perceived intensity of the rawness flavor did not differ significantly between the citric acid and brine pre-treatments (Figure 3).

3.3 Functional Properties of the Native, Citric Acid and Brine Treated Cooked Green Banana Flour

Significant differences in the Water Holding Capacity (WHC) were observed across the three treatments ($p < 0.05$). The untreated control sample exhibited the highest WHC at 2.16 g/g dry sample. However, no statistical difference in WHC was recorded between the citric acid and brine-treated green banana flour samples ($p > 0.05$) (Table 2).

In contrast to the WHC findings, the analysis showed no significant difference in the swelling power or solubility between the native control GBF and either of the chemically treated samples ($p > 0.05$) (Table 2).

Table 2. Functional properties of native, citric acid treated, and brine treated GBF treatments

	Parameter		
Treatment	**Water holding capacity (g/g)**	**Swelling power (g/g)**	**Solubility (%)**
Native (Control)	2.16 ± 0.03^{a}	17.70 ± 0.50^{a}	5.95 ± 0.13^{a}
5% Citric Acid	2.09 ± 0.01^{b}	17.79 ± 0.25^{a}	5.79 ± 0.54^{a}
5% Brine	2.09 ± 0.01^{b}	17.71 ± 0.36^{a}	5.63 ± 0.44^{a}
***p*-value**	< 0.05	0.67	0.30

Note: The figures presented are the average values for each treatment. Means within a column were compared using Tukey's test at $p < 0.05$ and different superscript letters indicate statistically significant differences.

3.4 Protein Content of Native, Citric Acid Treated and Brine Treated Green Banana Flour

A statistically significant difference in protein content was recorded among the three GBF treatments ($p < 0.05$) (Table 3). The control treatment had significantly higher protein content than the treated GBF treatments ($p < 0.05$). Protein content was significantly reduced in the treated GBF ($p < 0.05$), with brine treated flour having greater decrease than the citric acid treated flour (Table 3).

Table 3. Protein content of native, citric acid treated, and brine treated GBF

Parameter	
Treatment	**Protein (%)**
Native	4.87 ± 0.12 [a]
5% Citric Acid	3.92 ± 0.51 [b]
5% Brine	2.83 ± 0.07 [c]
***p*-value**	< 0.05

Note: The figures presented are the average values for each treatment. Means within a column were compared using Tukey's test at $p < 0.05$ and different superscript letters indicate statistically significant differences.

3.5 Protein Content of Native, Citric Acid Treated and Brine Treated Green Banana Flour

A statistically significant difference in protein content was recorded among the three GBF treatments ($p < 0.05$) (Table 3). The control treatment had significantly higher protein content than the treated GBF treatments ($p < 0.05$). Protein content was significantly reduced in the treated GBF ($p < 0.05$), with brine treated flour having greater decrease than the citric acid treated flour (Table 3).

4 Discussion

4.1 Effect of GBF Treatment on Sensorial Properties

This investigation confirms that the chemical pre-treatment of green bananas with citric acid and brine during flour production significantly alters the final taste and flavor profile. The untreated control exhibited a strong undesirable astringency accompanied by subtle notes of rawness and bluntness. Conversely, the treated samples demonstrated an improved flavor profile, indicating effective deodorization of the flour. The lower perceived intensity of the inherent banana flavor and rawness in the control may be attributable to the dominance of the astringency flavor. This observation aligns with previous findings by Wang *et al.* (2014), which reported a sour astringency, slight bitterness, and a beer-like taste in similar untreated products.

The citric acid treated flour displayed a higher bluntness flavor than brine-treated flour, while the brine-treated product exhibited more pronounced banana flavor notes. This flavor enhancement effect in the brine-treated sample highlights the well-documented role of salt in accentuating flavor perception (Oba *et al.*, 2002). Crucially, the rawness flavor notes did not differ between the two chemical pre-treatments. This outcome suggests that both citric acid and brine treatment effectively influenced the phenolic compounds involved in flavor-contributing reactions that occurs in the green banana such as reduction of enzymatic browning of the bananas which imparts an undesirable flavor to the dried product (Anyasi *et al.*, 2017). Brine, in particular, has been demonstrated to non-competitively inhibit PPOs activity non-competitively in fresh produce, thereby preventing the development of off-flavors (Oba *et al.*, 2002).

Similar results were reported in an Indonesian study by Sondak *et al.* (2018), where the use of calcium hydroxide and citric acid as GBF improvers was explored. The native treatment exhibited an undesired taste and aroma, rejected by 60% of panelists, while the citric acid-treated GBF achieved the highest acceptance for taste and aroma.

4.2 Influence of GBF Treatment on Functional Properties

The chemical pre-treatment of GBF with citric acid and brine consistently led to a reduction in the WHC. Both the citric acid and brine pre-treatment exerted an equivalent effect, reducing the WHC of the —a characteristic that is generally considered undesirable in various food processing applications. WHC constitutes a crucial functional property in baking and food processing, reflecting its ability to absorb and retain water, directly influencing the final texture, volume, and quality of baked products.

The observed WHC for the native banana flour in the present study is comparable to the higher WHC values (2.5 g/g) reported by Rodríguez-Ambriz *et al.* (2008). However, the WHC recorded by Yangilar (2015) for citric acid–treated green banana flour (1.08 g/g dry sample) was lower than the current findings, yet higher than the 0.19 g/g dry sample reported by Singh *et al.* (2017). These variations are likely attributable to differences in the banana cultivar used, among other processing factors (Wibowo *et al.*, 2021). Banana flour yield depends on cultivar type, with higher yields obtained from low-moisture varieties typically preferred for frying (Cândido *et al.*, 2023).

The addition of citric acid in GBF production can lead to a reduction in WHC due to a combination of factors, including pH alteration, starch modification, potential hydrolysis or Maillard reactions, and interactions with other components such as minerals and antioxidants (Alkarkhi *et al.*, 2011). Acid treatment can impair the hydrophobic and hydrophilic capacities of the native GBF (Cândido *et al.*, 2023). Specifically, the reduction in water absorption capacity is reduced due to increased crystalline regions and a decrease in the amorphous region in the starch granules of the GBF (Lawal, 2004). Despite this reduction, the resulting WHC values remain within the effective range for utilizing GBF as a thickener in various liquid and semi liquid food systems (Aurore *et al.*, 2009; Juarez-Garcia *et al.*, 2006; Suntharalingam & Ravindran, 1993). The decrease in WHC following brine treatment is primarily due to the disruption of molecular interactions, osmotic effects, and modifications to protein and mineral properties (Bezerra *et al.*, 2013).

In contrast, the swelling power and solubility of the GBF were not significantly affected by either the citric acid or brine treatments, averaging 17.73 g/g (dry basis) and 5.79%, respectively. An identical study conducted in India recorded lower swelling power of unripe banana flour in the range of 8.30–12.76 g/g dry sample at 80°C (Singh *et al.,* 2017). Post-harvest, the metabolism of the banana continues, some modifications will occur on physicochemical characteristics of the bananas and, consequently, on the corresponding GBF (Martín Lorenzo *et al.*, 2024).

Generally, swelling power increases with temperature, and when heated above the gelatinization range, hydrogen bonds which stabilizes the double helices are disrupted thereby affecting the gel network (Tester & Karkalas, 1996). The swelling power and solubility of flour are attributed to the amylopectin structure and amylose content; respectively therefore the indifference of the swelling power and solubility could be the inability of the treatments to alter the amylopectin structures and the amylose content of the flour starch (Tribess *et al.,* 2009).

Previous studies on enhancement of GBF through physical modification reported that pre-gelatinization (PBF) increases the swelling power, while annealing leads to a reduction (Kunyanee *et al.,* 2024), highlighting that the differences in swelling power are largely attributed to distinct interactions between the amorphous and crystalline starch chains (Ma *et al.*, 2022). The formation of weak hydrogen bonds during the pre-gelatinization process, coupled with the decrease in intermolecular forces, contributes to this variation (Tester & Karkalas, 1996).

4.3 Effect of Citric Acid and Brine on Protein Content

The application of both citric acid and brine pre-treatments resulted in a measurable decline in the protein content. This reduction was more pronounced in the brine treated flour than the citric acid treated flour. The protein content observed in the current study was lower than values reported for chemically treated unripe banana flour samples from Nigeria (ranging from 4.64 ± 0.06 to 5.46 ± 0.00 %) Bakare *et al.* (2017). In all instances, the protein content of the banana flour remains significantly lower than that of conventional wheat flour which ranges from 11% to 12% (Bezerra *et al.*, 2013).

Protein content is a key factor for flour selection in baking, as higher levels improve bread-making by increasing water absorption, extending mixing time, and yielding more robust dough (Bakare *et al.*, 2017). Given the low protein content of GBF, its primary application is often optimized as a thickening agent in liquid and semi-liquid food such as ice cream fruit juices and smoothies. Consequently, existing literature advocates for strategies such as optimizing the GBF application in different product formulations (Martín Lorenzo *et al.*, 2024; Paucean *et al.*, 2016; Vernaza *et al.*, 2011) or blending the flour with other raw materials such as legumes or banana peels, to achieve a higher and more complete protein profile (Dotto *et al.*, 2019; Kumar *et al.*, 2019). While banana peels have been shown to contain higher protein content than banana pulp (Castelo-Branco *et al.*, 2017; Sardá *et al.*, 2016), the incorporation of the peel alone may not significantly alter the total protein content of the final whole flour compared to pulp flour (Bezerra *et al.*, 2013). In comparison to wheat flour, GBF has lower protein content and presents low biological value (Bakare *et al.*, 2017; Bezerra *et al.*, 2013). However, GBF is valued for its high content of other key nutrients and functional components, including ash, fiber, and resistant starch (Kumar *et al.,* 2019; Vernaza *et al.*, 2011). The slight decline in protein content following treatment can influence the rate of hydration and surface charge of the flour, which therefore affects gelatinization and the swelling power (Nwokocha & Williams, 2011). However, protein content of GBF has been reported to be of low biological value. Given the amino acid profile and the limiting amino acids (lysine), this can be resolved by blending the flour with other vegetable protein sources such as legumes and cereals during processing (Rezende *et al.*, 2017).

5 Conclusions

This study demonstrates that pre-treatment of green banana with a 5% citric acid or a 5% brine solution is an effective strategy in deodorizing GBF, with the citric acid treatment showing superior sensory profile. Both treatments were found to alter key functional properties such as significantly reducing the water absorption capacity, swelling power, bulk density and pasting characteristics, which could impact the flour's suitability for various food applications. Both treatments decreased the water-holding capacity but had no effect on the swelling power or solubility of the flour.

The concomitant decline in protein content represents a compromise on the flour's nutritional quality.

Despite the marginal reduction in protein, the use of citric acid and brine as pre-treatments is highly recommended for flour processors, as it enhances product acceptability and promotes the wider utilization of GBF. The adoption of these practices could contribute to reducing postharvest losses, while supporting food and nutrition security. Future studies should focus on optimizing the concentration and immersion time to maximize deodorization effectiveness while preserving functional properties and assess the use of deodorized flours in diverse food products to evaluate performance and market potential.

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