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IMPACT OF GALACTURONIC AND CITRIC ACID TREATMENTS ON THE PHYSICOCHEMICAL PARAMETERS AND SENSORY QUALITY OF TIGER NUT (*Cyperus esculentus* L.) MILK

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ABSTRACT

The increasing demand for plant-based milk alternatives has driven interest in improving the quality and shelf life of tiger nut (*Cyperus esculentus L.*) milk. This study investigated the effects of citric and galacturonic acid treatments on the sensory attributes, pH, and reducing sugar content of tiger nut milk. Citric acid was extracted from ripe sweet oranges via ethanolic immersion and thermal agitation, whereas galacturonic acid was obtained through enzymatic hydrolysis of pectin using pectinase at 40°C for 2 hours. The acids were applied at varying concentrations (0.1–0.5 mg/ml), and the treated samples were evaluated over 120-hours. Sensory evaluation revealed moderate consumer preference, with 60–70% of the panellists rating the colour, flavour, taste, aroma, and overall acceptability. Both acids significantly ($p<0.05$) influenced the physicochemical properties of milk. Higher concentrations (0.3–0.5 mg/ml) induced a pronounced reduction in pH, from an initial value of 6.30 to as low as 2.56 after 120 hours, while simultaneously increasing the reducing sugar content in a dose-dependent manner. Significant differences ($p<0.05$) in reducing sugar levels were observed in samples treated with ≥0.3 mg/mL of Citric and galacturonic acid, whereas lower concentrations had negligible effects on reducing sugar levels. These findings highlight the potential of citric and galacturonic acids as natural acidulants to enhance microbial stability and improve the preservation of tiger nut milk. This study provides a foundation for clean-label, acid-based preservation strategies for plant-based dairy alternatives. Further research is recommended to establish the optimal concentrations for safe and effective application in commercial formulations.

Keywords: Tiger Nut, Citric Acid, Galacturonic Acid, Sensory Properties, pH, Total Reducing Sugar

INTRODUCTION

The increasing demand for affordable and nutritionally alternative plant-based beverages has increased research into milk alternatives, particularly in developing regions where the high cost and limited accessibility of dairy milk pose significant challenges to consumers. This growing interest has led to investigations of novel plant-based sources and innovative processing technologies (Daryani *et al*., 2024; Akansha *et al*., 2025). Among these, *Cyperus esculentus L*., commonly known as tiger nut, has gained attention because of its favourable nutritional profile, which includes dietary fibres, proteins, sugars, minerals, vitamins, and various bioactive phytochemicals which includes alkaloids, saponins, steroids, tapenoids, and glycosides (Abdullahi *et al*., 2022; Abubakar *et al*., 2018; Tasiu *et al*., 2023). Despite its nutritional benefits, tiger nut milk is constrained by its limited shelf life and susceptibility to microbial spoilage, which restrict its scalability and commercialisation (Abubakar *et al*., 2018; Eruteya *et al*., 2024; Zou *et al*., 2025; Abdulrahman *et al*., 2025). Consequently, the development of effective preservation methods is necessary to enhance microbial stability, extend shelf life, and retain sensory and nutritional qualities. Organic acids are widely recognised as promising natural preservatives owing to their broad antimicrobial activity and ability to maintain the quality of tiger nut milk (Abd Rahim, 2025). Citric and galacturonic acids are two prominent acidulants that play significant roles in food formulation and preservation (Hui *et al*., 2025). Citric acid, often derived from citrus or pomegranate peels, has been employed in pectin extraction processes, influencing the yield, structural integrity, and antioxidant properties of the extracted pectin (Iñiguez-Moreno *et al*., 2025; Li *et al*., 2024). Galacturonic acid, a monomer used for pectin hydrolysis, is also utilised in the food industry as a functional acidulant (Iqbal *et al*., 2025). The pH of food systems is an essential factor governing microbial proliferation, enzymatic reactions, flavour perception, and product shelf life (Oladeji *et al*., 2024). Tiger nut milk and its derivatives typically exhibit a mildly acidic pH, ranging from 5.8 to 6.5 (Okafor *et al*., 2018), which supports moderate microbial activity unless controlled through thermal or chemical preservation methods (Banjo and Osumare, 2024). Furthermore, pH modulation directly affects the solubility and perception of flavour compounds, thereby influencing the overall sensory profile of plant-based beverages (Xu and Yin, 2024). Physicochemical and sensory attributes are critical parameters that determine the consumer acceptability of plant-based milk (Abubakar *et al*., 2018; Iranloye *et al*., 2024; Santamarina *et al*., 2025). Notably, the inherent sweetness of tiger nuts is attributed to their substantial content of reducing sugars, such as glucose, fructose, and maltose (Zhang *et al*., 2025), which contribute to their palatability and energy yields. These sugars also have implications for the development of natural sweeteners and low-glycaemic index formulations (Kalahal *et al*., 2024). This study assessed the effects of citric and galacturonic acids on the pH, sensory attributes, and reducing sugar content of tiger nut milk.

MATERIALS AND METHODS

Sample collection

Fresh tiger nuts and citrus fruits were sourced from the Kawo Market in the Kaduna North Local Government Area of Kaduna State, Nigeria. Botanist from the Department of Biological Sciences at the Nigerian Defence Academy in Kaduna verified the authenticity of the nuts and fruits and assigned them identification numbers NDA/BIOH/2023/28 and NDA/BIOH/2023/29, respectively.

Samples preparation

The nuts were meticulously sorted to eliminate stones, pebbles, impurities, decaying stems, and fractured tubers before being rinsed with water to remove any adhering soil. The samples were then washed with distilled water. One kilogram (1 kg) of tiger nuts was then measured and immersed in 2 liters of water for 8 h at ambient temperature to soften the fibre content, following the methodology of Asante *et al* (2014). To prepare the slurry, 500 ml of warm distilled water was combined with 1 kg of tiger nuts and blended four times using a sterile Kenwood mixer (Ukwuru and Ogbodo, 2011). Milk and shafts were separated from the tiger nut mash by filtering through a clean sterile cotton towel. The mixture was further strained to achieve a fine consistency. The filtered tiger nut milk was transferred into a clean stainless-steel container, pasteurised in a water bath at 90 °C for 15 min, cooled to 43 °C for 12 h, and subsequently stored in the freezer for future use (Rita, 2009).

Extraction of Citric Acid from Citrus

Citric acid was extracted from citrus fruits by selecting ripe sweet oranges by thoroughly washing them and separating the peels from the flesh. The peels were then cut into small pieces and immersed in 500 mL of 95% ethanol. The mixture was heated at 60°C for 30 min and agitated for 1 h. The solution was then filtered through a 11 cm (110 mm) Whatman filter paper to remove the solid particles. The filtrate was subjected to crystallisation to obtain purified citric acid. The filtrate was cooled to 20°C for 2 hour, and the citric acid crystals were collected, washed several times with cold distilled water, and dried in a desiccator at room temperature for 24 hours. The yield and purity of citric acid were determined using high-performance liquid chromatography (HPLC) (Sanful, 2009).

Extraction of Galacturonic Acid

The extraction of galacturonic acids was carried out according to Begum *et al.* (2018). Citrus peels were collected and thoroughly washed under running tap water to eliminate impurities. They were then dried at room temperature for 72 hours to reduce the moisture content before being ground into a fine powder with a mortar and pestle to enhance the extraction surface area. The powdered citrus peel was enzymatically hydrolysed using pectinase. The enzyme was mixed with the peel powder at a 1:1 ratio (enzyme:peel powder) and incubated at 40°C for 2 hour, maintaining an optimal pH of 5.5 throughout the process. After incubation, the mixture was filtered through 11 cm (110 mm) Whatman filter paper to separate the solid residues from the liquid fraction. The filtrate, which contained galacturonic acid, was further purified. This involved solvent extraction using 500 mL 95% ethanol. The mixture was heated to 60°C for 30 min to facilitate the extraction of Galacturonic acid. The filtrate was then processed through an ion-exchange column to eliminate impurities and concentrate the galacturonic acid. The column was rinsed with 100 mL of distilled water to remove impurities, and galacturonic acid was eluted using 100 mL of 0.5 M sodium hydroxide solution. The eluate was concentrated using a rotary evaporator, and the concentrated galacturonic acid was dried in a desiccator at room temperature for 24 h. The yield was approximately 5 g per 100 g of peel, and the purity of galacturonic acid was determined to be greater than 95% using high-performance liquid chromatography (HPLC) (Begum *et al.,* 2018).

Sensory Evaluation

The sensory properties of the tiger nut milk produced in this study, including colour, flavour, taste, aroma, and overall acceptability, were analysed as described by Short *et al.* (2021). The evaluation was conducted using a panel of 10 semi-trained members, categorised into two groups:
Extremely like (A)
Extremely dislike. (B)
The samples were presented to the panellists in white glass cups filled with tiger nut milk.

Determination of pH of the Samples

To determine the pH of tiger nut milk, 5 ml of the tiger nut milk extract was transferred into a clean beaker. The pH meter was calibrated using buffer solutions of pH 4 and 7, and the electrode was rinsed with distilled water prior to immersion in the tiger nut milk sample. The pH readings were recorded using a pH meter. This procedure was replicated for multiple samples of tiger nut milk to ensure the precision of the results. This methodology was adapted from a study by Sharma and Chauhan (2019), who assessed the quality of tiger nut milk derived from various cultivars using various processing methods.

Determination of Total Reducing Sugar of Tiger-nut Milk

To determine the total reducing sugar content in the tiger nut milk extract, the following procedure was used. Tiger nut milk extract (10 ml) was diluted with distilled water in a 100 ml volumetric flask and subsequently filtered using a Whatman filter paper. A 10 ml aliquot of the diluted sample was transferred to a test tube. Subsequently, 10 ml of Fehling's solution was added to the test tube and mixed thoroughly. The mixture was then heated in a boiling water bath for 10 min. After cooling to room temperature, the contents were transferred to a filter paper in a Büchner funnel and washed with distilled water. The filter residue was transferred to a pre-weighed crucible, heated in an oven at 600-700°C for 30 min, and then cooled in a desiccator. The crucible containing the Cu (II) oxide precipitate was weighed. The amount of reducing sugars was calculated from the weight of Cu (II) oxide. This methodology, based on Fehling's method, is widely used to determine the total reducing sugar content in various food samples (Poitevin, 2016).

Experimental Design

In this study, 5 liters of tiger nut milk was used. The initial pH of the sample was determined using a pH meter before dispensing 200 ml each into 11 different conical flasks as test groups. The conical flasks were randomly labelled as Tc, T1, T2…T10. Group 1 (Tc) was the control, and T1-T5 were the test groups for galacturonic acid while T6-T10 were the test groups for citric acid. The test groups were treated with varying concentrations of citric and galacturonic acids, as described below.
Group 1 (Tc): Normal control: No galacturonic acid or citric acid
Group 2(T1): Tiger-nut milk + 0.1mg/ml galacturonic acid
Group 3(T2): Tiger-nut milk + 0.2mg/ml galacturonic acid
Group 4 (T3): Tiger-nut milk + 0.3mg/ml galacturonic acid
Group 5 (T4): Tiger-nut milk + 0.4mg/ml galacturonic acid
Group 6 (T5): Tiger-nut milk + 0.5mg/ml galacturonic acid
Group 7 (T6): Tiger-nut milk + 0.1mg/ml citric acid
Group 8 (T7): Tiger-nut milk + 0.2mg/ml citric acid
Group 9 (T8): Tiger-nut milk + 0.3mg/ml citric acid
Group 10 (T9): Tiger-nut milk + 0.4mg/ml citric acid
Group 11 (T10): Tiger-nut milk + 0.5mg/ml citric acid
The effect of the acids was measured on all the test groups and control by measuring the pH, sensory properties, and reducing sugars after 24 h by taking samples from each group for analysis.

Data Analysis
Statistical analyses were performed using the Statistical Product and Service Solutions (SPSS) software (version 21). Statistical differences were evaluated using one-way and two-way analysis of variance (ANOVA), followed by Duncan's Multiple Range Test to detect significant differences among the mean values of different groups. Differences were considered significant at $p < 0.05$ (i.e. at 95% confidence interval).

RESULTS AND DISCUSSION

Sensory Properties of Tiger Nut Milk

Table 1 presents the sensory evaluation results of the tiger nut milk. The findings demonstrated that the product was generally well received by the panellists, with the majority expressing positive feedback on all assessed attributes. The results indicated that over half of the panellists favoured the sensory properties of tiger nut milk. Flavour, taste, and overall acceptability emerged as the most appreciated sensory attributes, each receiving approval from seven of the ten participants. This suggests a strong core sensory appeal in terms of taste and overall experience. In contrast, colour and aroma were favoured by six participants and disfavoured by four, indicating slightly more mixed opinions. Although not rated as highly as flavour and taste, these attributes garnered the majority of preferences. Overall, the results reflect a positive perception of the product's sensory qualities, with favourable responses ranging from 60% to 70% across all evaluated attributes, suggesting that only minor enhancements may be needed to further improve consumer satisfaction.

Table 1: Sensory properties of tiger nut milk

Sensory Properties	Number of people that like (A)	Number of people that dislike (B)
Colour	6	4
Flavor	7	3
Taste	7	3
Aroma	6	4
Acceptability	7	3

Effect of Galacturonic Acid on pH of Tiger Nut Milk

The impact of galacturonic acid on the pH of tigernut milk was monitored over six consecutive days (0–120 hour), with measurements taken at 24-hour intervals (Table 2). The findings indicated no statistically significant difference ($p>0.05$) in the pH values for the groups treated with 0.1, 0.2, and 0.3 mg/ml of galacturonic acid on any day of the study. Nevertheless, a dose-dependent reduction in pH was observed in Galacturonic Acid-treated samples from T1 to T5. Increasing the concentration of galacturonic acid to 0.4 and 0.5 mg/ml led to a significant decrease ($p>0.05$) in the pH of the treated samples compared to the normal control. Furthermore, there was a notable decrease in pH across the group range

Table 2: Effect of galacturonic acid on pH of tiger nut milk

		pH value per time					
	Test groups	**Tc**	**T1**	**T2**	**T3**	**T4**	**T5**
	Conc. of galacturonic of acid (mg/ml)	0.0	0.1	0.2	0.3	0.4	0.5
Day1	0hour	6.30 ± 0.03^{e}	6.25 ± 0.02^{e}	6.18 ± 0.25^{e}	5.85 ± 0.36^{d}	5.62 ± 0.37^{c}	5.48 ± 0.09^{a}
Day2	24hours	6.20 ± 0.10^{e}	6.12 ± 0.34^{d}	5.95 ± 0.29^{d}	5.48 ± 0.18^{c}	5.08 ± 0.67^{b}	4.56 ± 0.45^{a}
Day3	48hours	5.95 ± 0.08^{d}	5.70 ± 0.01^{d}	5.40 ± 0.24^{c}	4.80 ± 0.09^{b}	4.47 ± 0.05^{a}	4.25 ± 0.05^{a}
Day4	72hours	5.70 ± 0.14^{d}	5.48 ± 0.39^{d}	4.85 ± 0.40^{c}	4.20 ± 0.05^{c}	3.88 ± 0.04^{b}	3.29 ± 0.27^{a}
Day5	96hours	5.55 ± 0.26^{c}	5.20 ± 0.03^{d}	4.09 ± 0.02^{c}	3.87 ± 0.26^{b}	3.05 ± 0.09^{a}	2.99 ± 0.45^{a}
Day6	120hours	5.20 ± 0.45^{c}	4.45 ± 0.06^{c}	3.50 ± 0.46^{b}	3.08 ± 0.34^{a}	2.85 ± 0.02^{a}	2.56 ± 0.39^{a}

Values were obtained from triplicate determinations (mean ± standard error of the mean). Values with different superscripts in a column are significantly different ($P<0.05$).

Effect of Citric Acid on pH of Tiger Nut Milk

Table 3 presents the impact of citric acid on the pH levels of tigernut milk, assessed at 24-hour intervals. No statistically significant difference ($p<0.05$) was observed between the pH values of the control group (Tc) and the group (T6) treated with 0.1 mg/ml citric acid from day 1 to 6. Similarly, this pattern was evident in groups T7 and T8, which were treated with 0.2 and 0.3 mg/ml citric acid, respectively. In contrast, groups T9 and T10, treated with 0.4 mg/ml and 0.5 mg/ml citric acid concentrations, exhibited significant differences ($p<0.05$) in pH values. Overall, the findings indicated a decrease in pH values corresponding to an increase in citric acid concentration from day 1 to day 6 for groups (T7, T8, T9, and T10) treated with varying concentrations of citric acid, measured at 24-hour intervals over a time span of 0–120 hour.

Table 3: Effect of citric acid on pH of tiger nut milk

		pH value per time					
	Test group	**Tc**	**T6**	**T7**	**T8**	**T9**	**T10**
	Conc. of citric acid (mg/ml)	0.0	0.1	0.2	0.3	0.4	0.5
Day1	0hour	6.30 ± 0.03^{e}	6.20 ± 0.03^{e}	6.05 ± 0.15^{d}	5.65 ± 0.06^{c}	5.42 ± 0.35^{b}	5.28 ± 0.05^{a}
Day2	24hours	6.20 ± 0.10^{e}	6.00 ± 0.35^{e}	5.80 ± 0.29^{d}	5.38 ± 0.18^{c}	4.95 ± 0.25^{b}	4.30 ± 0.40^{a}
Day3	48hours	5.95 ± 0.08^{d}	5.60 ± 0.01^{d}	5.20 ± 0.24^{c}	4.60 ± 0.29^{b}	4.22 ± 0.05^{a}	4.05 ± 0.15^{a}

Day4	72hours	5.70±0.14^{d}	5.40±0.39^{d}	4.60±0.40^{c}	4.10±0.15^{c}	3.65±0.05^{b}	3.05±0.20^{a}
Day5	96hours	5.55±0.26^{c}	5.10±0.03^{d}	4.02±0.02^{c}	3.65±0.26^{b}	2.95±0.03^{a}	2.75±0.42^{a}
Day6	120hours	5.20±0.45^{c}	4.40±0.06^{c}	3.30±0.46^{b}	3.00±0.34^{a}	2.65±0.02^{a}	2.35±0.33^{a}

Values were obtained from triplicate determinations (mean ± Standard error of the mean). Values with different superscript letters in the columns are significantly different (p<0.05).

Effect of Galacturonic Acid on Total Reducing Sugar in Tiger Nut Milk

The impact of galacturonic acid on the total reducing sugar content in tiger nut milk over 1–6 days, within the timeframe of 0–120 hour, is presented in Table 4. An increase in the total reducing sugar content was noted in the experimental group with increasing concentrations of galacturonic acid. No significant difference (p>0.05) was observed in the total reducing sugar values between the control group (Tc) and the groups (T1 and T2) treated with 0.1 and 0.2 mg/ml concentrations of galacturonic acid from day 1 to day 6, with measurements taken every 24 hours. Conversely, a significant difference (p>0.05) was observed in the total reducing sugar values between the control group (Tc) and the groups (T3, T4, and T5) treated with 0.3, 0.4, and 0.5 mg/ml concentrations of galacturonic acid from days 1 to 6, with measurements taken every 24 hours.

Table 4: Effect of galacturonic acid on total reducing sugar in tiger-nut milk

		Total reducing sugar					
	Test group	**Tc**	**T1**	**T2**	**T3**	**T4**	**T5**
	Conc. of galacturonic acid (mg/ml)	0.0	0.1	0.2	0.3	0.4	0.5
Day1	0hour	3.20±0.54^{e}	3.20±0.54^{e}	3.20±0.55^{e}	3.20±0.55^{e}	3.20±0.55^{e}	3.20±0.54^{e}
Day2	24hours	3.05±0.10^{e}	3.07±0.34^{e}	3.10±0.29^{d}	3.13±0.18^{d}	3.15±0.65^{c}	3.16±0.46^{c}
Day3	48hours	2.65±0.08^{d}	2.80±0.01^{d}	2.90±0.25^{d}	3.03±0.09^{b}	3.10±0.05^{c}	3.12±0.07^{c}
Day4	72hours	2.40±0.14^{d}	2.56±0.39^{d}	2.70±0.40^{c}	2.90±0.05^{c}	3.02±0.04^{b}	3.07±0.27^{b}
Day5	96hours	2.15±0.28^{d}	2.35±0.03^{d}	2.48±0.023^{c}	2.67±0.28^{b}	2.95±0.09^{a}	2.96±0.45^{a}
Day6	120hours	2.10±0.46^{c}	2.20±0.08^{c}	2.22±0.46^{c}	2.48±0.30^{b}	2.60±0.03^{a}	2.70±0.30^{a}

Values were obtained from triplicate determinations (mean ± Standard error of the mean). Values with different superscript letters in a column are significantly different (P<0.05).

Effect of Citric Acid on Total Reducing Sugar in Tiger Nut Milk

Table 5 presents the impact of citric acid on the total reducing sugar content in tiger nut milk over a period from day 1 to 6 within a timeframe of 0–120 hours. The findings indicate no statistically significant difference (p>0.05) in the total reducing sugar values between the control group (Tc) and the groups T6 and T7, which were treated with 0.1 and 0.2 mg/ml citric acid, respectively, from day 1 to day 6, with measurements taken every 24 hours. Conversely, a statistically significant difference (p>0.05) was observed in the total reducing sugar values between the control group (Tc) and the groups T8, T9, and T10, which were treated with 0.3, 0.4, and 0.5 mg/ml concentrations of galacturonic acid, respectively, from day 1 to 6, with measurements taken every 24 hours.

Table 5: Effect of citric acid on total reducing sugar in Tiger-nut milk

		Total reducing sugar					
	Test group	**Tc**	**T6**	**T7**	**T8**	**T9**	**T9**
	Conc. of citric acid (mg/ml)	**0.0**	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**
Day1	0hour	3.20±0.54^{e}	3.20±0.54^{e}	3.20±0.35^{e}	3.20±0.45^{e}	3.20±0.45^{e}	3.20±0.52^{e}
Day2	24hours	3.05±0.10^{e}	3.08±0.34^{e}	3.12±0.29^{d}	3.15±0.18^{c}	3.16±0.65^{c}	3.18±0.26^{c}
Day3	48 hours	2.65±0.08^{d}	2.88±0.01^{d}	2.94±0.25^{d}	3.06±0.09^{b}	3.13±0.05^{c}	3.15±0.17^{c}
Day4	72 hours	2.40±0.14^{d}	2.60±0.39^{d}	2.76±0.40^{c}	2.96±0.05^{c}	3.06±0.04^{b}	3.10±0.17^{b}
Day5	96 hours	2.15±0.28^{d}	2.39±0.03^{d}	2.58±0.02^{c}	2.72±0.28^{b}	2.96±0.09^{a}	3.04±0.35^{a}
Day6	120 hours	2.10±0.46^{c}	2.20±0.18^{c}	2.28±0.26^{c}	2.52±0.32^{b}	2.68±0.02^{a}	2.75±0.40^{a}

Values were obtained from triplicate determinations (mean ± Standard error of the mean). Values differing in a column of different subscripts are significantly different (P<0.05).

Discussion

Tiger nuts are widely consumed as a nutritious food source by humans and animals in Africa, Europe and America. An assessment of the sensory attributes of tiger nut milk revealed no statistically significant differences (p>0.05) between the milk samples treated with citric and galacturonic acids and the control group in terms of colour, flavour, aroma, and overall acceptability. This indicates that the addition of citric and galacturonic acids did not significantly influence (p>0.05) or modify the sensory characteristics of tiger nut milk. These results are consistent with that of Adejuyitan *et al*. (2019), who reported that preservatives did not alter the sensory properties of tiger nut milk. However, the samples treated with galacturonic acid exhibited enhanced taste with increasing concentrations of the acid.

The pH value of tiger nut milk (Tc) in this study was 6.30, which is consistent with the 6.5-6.8 range reported by Wakil *et al*. (2014). This slight variation may be attributed to environmental factors influencing tiger nut growth. There was no significant difference in the effect of citric and galacturonic acid on the pH of the control and test groups at 0.1 and 0.2 mg/ml (T2, T3, T6, and T7) concentrations during the initial three days of the experiment. However, a slight variation in pH was observed after the third day. The non-significant difference ($p>0.05$) between the pH values of the treated groups (T2, T3, T6, and T7) with 0.1 mg/ml and 0.2 mg/ml concentrations of citric and galacturonic acid, respectively, compared to the control group, suggests that both acids did not significantly affect the tiger nut milk at these concentrations. Nevertheless, a significant difference in the effect of citric and galacturonic acid on pH was observed at higher concentrations (T3, T4, T5, T8, T9, and T10) in the test groups from 0–120 hours.

The observed significant difference ($p<0.05$) between the groups (T9 and T10) treated with 0.4 mg/ml and 0.5 mg/ml citric acid concentrations, as compared to the control group, can likely be attributed to the increased citric acid concentration. This finding is consistent with the results of David *et al*. (2020), who reported that higher citric acid levels in tiger nut milk tended to alter the pH. Furthermore, the pH of the test group containing galacturonic acid was slightly higher than that of the test group containing citric acid at the same concentration, corroborating the findings of Ke *et al*. (2017), who demonstrated that citric acid has a lower pH than galacturonic acid.

The total reducing sugar content varied with changes in citric and galacturonic acid concentrations. No statistically significant difference ($p > 0.05$) was observed in the total reducing sugar values for the groups (T1 and T2) treated with 0.1 mg/ml and 0.2 mg/ml of galacturonic acid compared to the control group (Tc). This indicates that galacturonic acid at these concentrations did not influence the total reducing sugar content of tiger nut milk. A similar observation was reported by Abiodun *et al*. (2019), who noted that employing galacturonic acid at varying concentrations as a milk preservative yielded diverse outcomes in terms of total reducing sugar content. However, a significant difference ($p > 0.05$) was observed between the groups (T3, T4, and T5) treated with 0.3 mg/ml, 0.4 mg/ml, and 0.5 mg/ml concentrations of galacturonic acid and the control group (Tc), suggesting that galacturonic acid affects total reducing sugar at these concentrations. A consistent increase in total reducing sugar was observed across the groups as the acid concentration increased, although it decreased from 0 h to 120 hours. This can be attributed to the hydrolytic action of the acid on starch, which produces more reducing sugars as the concentration increases.

The statistically insignificant difference ($p > 0.05$) in total reducing sugar values between the groups (T6 and T7) treated with 0.1 mg/ml and 0.2 mg/ml of citric acid and the control group (Tc) may be attributed to the minimal amount of citric acid used, which might not significantly affect the total reducing sugar content in tiger nut milk. Murti *et al*. (2020) similarly observed that varying concentrations of citric acid as a milk preservative produced different outcomes for total reducing sugar content. Conversely, the statistically significant difference ($p > 0.05$) observed between the groups (T8, T9, and T10) treated with 0.3, 0.4, and 0.5 mg/ml citric acid and the control group (Tc) indicates that citric acid affects total reducing sugar at these concentrations

CONCLUSION

Evaluation of the sensory properties indicated that a substantial proportion of the 10-member panel demonstrated a marked preference for the tiger nut milk produced. At a concentration of 0.1 mg/ml, neither galacturonic acid nor citric acid affected the pH values and total reducing sugar in comparison to the control group (Tc). However, at 0.2, 0.3, 0.4, and 0.5 mg/ml, both citric and galacturonic acid significantly influenced the pH values and total reducing sugar relative to the control group (Tc). The study concluded that the treatment of tiger nut milk with citric and galacturonic acids enhanced its shelf life, indicating their potential as preservative agents in tiger nut milk.

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