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DEVELOPMENT OF A PRODUCTION PROCESS FOR CARBONATED BANANA BEVERAGE USING AN ENZYMATIC METHOD

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Abstract – *This study aims to develop a production process for a carbonated banana beverage with enhanced sensory and nutritional quality, meeting consumer demand and increasing the value of bananas. The research focuses on optimizing enzymatic treatment using pectinase to improve juice yield and reduce viscosity. Sensory evaluation was used to determine the optimal mixing ratios of banana juice, syrup, and citric acid meeting consumer acceptance. The effects of cooling temperature and CO_2 saturation time on carbonation levels were investigated to ensure adequate CO_2 retention in the final product. Vitamin C stability during storage under different conditions was also assessed to evaluate nutritional preservation. Results showed that pectinase treatment significantly increased juice yield and reduced viscosity, improving process efficiency. An optimal formulation with balanced sweetness, acidity, and flavor was identified based on sensory preferences, corresponding to the blending ratio of 5:95:0.2 (syrup: banana juice: citric acid), which received the highest average sensory score of 5.45. Lower cooling temperatures and longer CO_2 saturation times improved carbonation levels. These findings provide practical insights into key processing factors that influence the quality and shelf life of carbonated banana beverages. The developed process offers a promising approach for producing value-added fruit-based drinks, supporting product diversification and the utilization of bananas in the beverage industry.*

Keywords: carbonated banana beverage, CO_2 saturation, juice yield, pectinase, sensory evaluation, vitamin C stability.

I. INTRODUCTION

Vietnam ranks among the leading countries in banana cultivation, with plantations spanning from the northern to the southern regions. Bananas serve not only as a staple fruit for domestic consumption but also as a significant agricultural export. According to the Ministry of Agriculture and Rural Development of Vietnam [1], Vietnam maintains over 130,000 hectares of banana cultivation, yielding approximately 2.1 million tons annually. Notably, the Mekong Delta contributes 35,278.9 hectares, producing around 478,877.3 tons per year [1].

Bananas are valued for their accessibility and nutritional richness. They are excellent sources of essential vitamins such as C, B1, B2, and E, and contain bioactive compounds including polyphenols and antioxidants [2]. These nutrients support digestive health, strengthen the immune system, improve cardiovascular function, and promote skin health [3]. Given the important health benefits of these nutrients, particularly vitamin C, which plays a crucial role in antioxidant activity and immune support, this study will specifically examine the retention of vitamin C in carbonated banana beverages during storage to assess the product's nutritional stability over time.

Although bananas have been widely utilized in food processing, such as dried banana snacks, banana-based cakes, and smoothies, their application in the beverage industry, particularly in carbonated drinks, remains underdeveloped. Meanwhile, the global beverage market continues to expand, with an increasing variety of fruit-based carbonated beverages, including those made from

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apples, grapes, and pineapples. As highlighted by Panwar et al. [4], leveraging tropical fruits for beverage production not only contributes to product diversification but also enhances the economic value of agricultural outputs and minimizes post-harvest losses.

A critical technology in carbonated beverage production is carbon dioxide (CO_2) saturation. This process enhances flavor, imparts a refreshing sensation, and extends product shelf life by inhibiting the growth of spoilage microorganisms [5]. Moreover, CO_2 plays a role in maintaining product stability by reducing vitamin degradation and preserving nutritional quality during storage [6].

Despite the abundant availability and nutritional benefits of bananas, their potential use in carbonated beverage formulations, particularly regarding the stability of sensitive nutrients such as vitamin C during storage, has been underexplored. This knowledge gap highlights the need for scientific investigation to support product development efforts that are both health-oriented and economically viable. Therefore, this study aims to investigate the retention of vitamin C in carbonated banana beverages during storage under controlled conditions. Specifically, it seeks to answer two main research questions: 1) How does storage time and temperature affect the vitamin C content in carbonated banana beverages? 2) To what extent does CO_2 saturation contribute to vitamin C stability in these beverages?

The scope of the study encompasses the formulation of carbonated beverages using ripe banana pulp, carbonation at a standardized pressure, storage under two temperature conditions, and periodic measurement of vitamin C content, CO_2 concentration, and relevant physicochemical parameters. The paper first reviews previous studies, followed by a detailed description of the beverage preparation process and analytical techniques employed in the Materials and Methods section. The Results and Discussion section presents the findings and examines the influence of carbonation and storage conditions on vitamin C retention. Finally, the Conclusion highlights the key outcomes and discusses their implications for product development and future research.

II. LITERATURE REVIEW

The application of pectinase enzymes in fruit juice processing has been extensively studied for its ability to improve extraction efficiency, reduce viscosity, and enhance the overall sensory quality of juice products. According to Koyu et al. [6], the application of pectinase can increase juice yield by up to 85%. It also significantly reduces the viscosity of the pulp, which facilitates the filtration process and contributes to the stabilization of the final product. In addition, the enzymatic hydrolysis process affects key quality parameters such as vitamin C content, pH, and Brix value. According to Omeje et al. [7], pectinase not only enhances the efficiency of juice extraction but also plays a role in preserving key nutritional components, particularly vitamin C. Nevertheless, the enzymatic treatment must be carefully controlled, as excessive hydrolysis can lead to the oxidation of vitamin C and destabilization of pH and Brix levels, which are vital for product quality and shelf stability.

The pH of the beverage significantly decreased as the storage period increased. This decline in pH was observed regardless of sugar concentration or storage temperature. After 90 days of refrigerated storage at 5^oC, the pH values recorded were 4.067, 4.000, and 3.850 across the respective samples. The study further confirmed that the decrease in pH was consistent over time, irrespective of storage conditions. The lowest pH value, 3.660, was found in the sample containing 1.25% sugar stored under ambient conditions, after 90 days. Yadav et al. [8] reported similar findings in a study on banana and sapota beverages stored at various temperatures for 180 days.

The formulation of the beverage, specifically the ratio of banana juice, sugar syrup, and citric acid, is a determining factor in defining its sensory attributes. Attaining the ideal harmony of sweetness, acidity, and overall flavor is crucial in the development of fruit-based beverages, as it plays a key role in meeting consumer preferences

and ensuring product appeal [9]. It has been shown that adding citric acid at concentrations ranging from 0.1% to 0.3% effectively stabilizes pH levels, reduces the degradation of vitamin C, and imparts a subtle tartness that enhances the beverage's refreshing quality [10, 11]. It is suggested that a sugar concentration within the range of 8–12% Brix is ideal for maintaining a balanced sweetness while preserving the light and refreshing nature expected of carbonated fruit beverages. Excessive sweetness can mask natural fruit flavors and reduce the perceived freshness.

The observed increase in acidity can be attributed to the presence of CO_2, citric acid, and other acidifying agents intentionally incorporated during beverage formulation. This trend is consistent with the findings of Ilamaran et al. [12], who reported a rise in acidity in banana and sapota beverages stored under both ambient (35–36^{o}C) and refrigerated (3–5^{o}C) conditions. These acidulants are commonly added not only to enhance flavor and taste but also to serve as preservatives, contribute antioxidant benefits, and improve the overall aroma of the beverage. Each batch of juice was carbonated to three different levels of CO_2 content, 2.5, 3.0, and 3.5 gas-to-liquid volumes. Sensory preference panels were conducted by keeping either the titratable acidity or the carbonation level constant while varying the other parameter. Although the overall preference did not show many statistically significant differences, the product with 0.75% titratable acidity and a low carbonation level was generally favored [13].

Formulation development must be guided by both sensory evaluation and physicochemical analysis, incorporating parameters such as pH, Brix, color, aroma, flavor, and product stability during storage. The integration of these assessments is essential for identifying an optimal formulation that meets both quality standards and consumer expectations.

Carbonation, achieved through CO_2 saturation, is a key process in the production of carbonated beverages. It not only imparts the characteristic effervescence and refreshing sensation but also serves as a microbial control mechanism. The antimicrobial effects of CO_2 have been emphasized, with findings showing its ability to suppress the growth of spoilage microorganisms, thereby improving the microbiological stability of the final product [13].

The efficiency of CO_2 dissolution is significantly influenced by cooling temperature. Specifically, lowering the temperature from 10^{o}C to 4^{o}C can increase CO_2 solubility by 30–40%, resulting in higher carbonation levels and better retention of effervescence upon opening [14]. This highlights the broader impact of storage temperature on both CO_2 solubility and the sensory attributes of carbonated beverages. Cooler storage conditions (4–8^{o}C) promote CO_2 retention, which in turn helps maintain carbonation, acidity, and the refreshing mouthfeel typical of such products. In contrast, higher storage temperatures accelerate CO_2 loss, leading to decreased carbonation, elevated pH, and diminished sensory appeal by Masoumi et al. [15]. While low temperatures are beneficial, excessively prolonged CO_2 saturation during processing may cause pH imbalances and negatively affect sensory characteristics. Therefore, establishing optimal parameters, particularly maintaining cooling temperatures between 4–8^{o}C and limiting saturation time to 2–5 minutes, is essential to achieving effective carbonation while preserving overall product quality.

Storage conditions also play a crucial role in preserving carbonated banana beverages, particularly regarding maintaining vitamin C content, pH, Brix, and CO_2 retention. Vitamin C is sensitive to oxidative degradation, especially under exposure to light and oxygen. It was reported that fruit juices stored at 4^{o}C preserved more than 85% of their vitamin C content after four weeks, while those kept at 25^{o}C experienced losses of over 50% in just two weeks [16].

In addition to nutritional degradation, elevated storage temperatures accelerate the loss of dissolved CO_2, diminishing the beverage's effervescence and overall sensory appeal. It was emphasized that storing the product in cool conditions (4–8^{o}C) and shielding it from light and air is vital

for preserving its quality and extending its shelf life [11].

Based on a thorough review of existing literature, this study develops a carbonated banana beverage that not only enhances the utilization of locally available bananas but also meets consumer expectations in terms of sensory quality, nutritional value, and product stability. Specifically, the research aims to optimize the enzymatic extraction process using pectinase to improve juice yield and reduce viscosity; identify a balanced formulation of banana juice, syrup, and citric acid for optimal taste; determine appropriate carbonation conditions based on temperature and saturation time; and evaluate the influence of storage conditions on key quality parameters such as pH, Brix, vitamin C content, and CO_2 retention. These objectives are grounded in practical needs for reducing post-harvest losses, increasing the value of agricultural products, and contributing to the diversification of fruit-based beverages in the market.

III. MATERIALS AND METHODS

A. Materials and equipment

Cavendish bananas (Viba Food brand) were procured from the Co.opmart supermarket (Tra Vinh, Vietnam). Bananas were selected for uniform size and appearance to ensure consistency in processing. Before enzymatic hydrolysis, the fruits were stored under ambient conditions at a temperature of 30 ± 2^oC.

The pectinase enzyme used in this study was in powder form, with a declared enzymatic activity of 20,000 U/g. The enzyme exhibited optimal activity within a pH range of 7.5–8.5 and at a temperature range of 40–50^{o}C. This enzyme preparation was sourced from Phuongtram Agricultural Product & Chemical Trading Co., Ltd (Ho Chi Minh City, Vietnam).

A precision-controlled incubation chamber (Memmert, Germany) was employed for temperature-dependent processes. The chamber had a total capacity of 100 liters and was equipped with a proportional-integral-derivative control system. The unit allowed temperature settings from 5^{o}C to 65^{o}C, with a maximum tray surface temperature of 67^{o}C and a temperature accuracy of $\pm0.1^oC$, ensuring precise thermal control during enzymatic treatments.

Carbonation was carried out using a CO_2 saturation system (GEA, Germany) designed for small-scale beverage processing. The system featured an integrated CO_2 concentration sensor, a working volume of 40 liters, and a CO_2 reservoir containing 25 kg of compressed gas. Operating under a pressure range of 2–6 bar, the system delivered a carbonation rate between 2.5 and 5.0 g CO_2/L, providing the required gas levels for the development of carbonated beverages.

B. Experimental procedure

Banana samples (100 g each) were homogenized with water at a 1:1 ratio. The enzymatic hydrolysis was conducted at 40^{o}C with enzyme concentrations of 0.2%, 0.3%, and 0.4%, and incubation times of 15, 30, 45, and 60 minutes. The hydrolysis process was monitored at 15-minute intervals to assess changes over time. In addition to the enzyme-treated samples, a control sample (referred to as the 0% enzyme or untreated sample) was included in the experiment to serve as a baseline for comparison. This control underwent the same homogenization and incubation conditions (40^{o}C, same time intervals) but without the addition of pectinase. By comparing the control with the enzyme-treated samples, the study was able to demonstrate the impact of enzymatic hydrolysis on juice yield, viscosity, and quality parameters. The inclusion of this control allowed for a more accurate assessment of each enzyme concentration's effectiveness and supported the conclusion that 0.4% was the most suitable for further development. Although the results indicated that 0.4% enzyme concentration yielded the best outcomes, the conclusion may initially appear unconvincing, as higher concentrations such as 0.5% were not tested. However, the selection of 0.4% was based on preliminary exploratory experiments that examined a range of enzyme concentrations. These trials revealed that increases beyond 0.4% resulted in diminishing re-

turns in terms of juice yield and viscosity reduction. Moreover, the 0.4% level provided optimal performance when multiple factors were considered, including extraction efficiency, processing time, enzyme cost, and potential effects on flavor and stability. Therefore, 0.4% was determined to be the most efficient and practical concentration under the experimental conditions.

The blending ratios of banana juice, sugar syrup, and citric acid were investigated to identify a formulation that aligns with consumer preferences. The effects of cooling temperature and CO_2 saturation time were examined at 5^oC, 10^oC, and 15^oC for durations of 3, 4, and 5 minutes to determine optimal carbonation conditions.

Storage trials were conducted to evaluate the effects on pH, Brix, and viscosity of the hydrolyzed juice, as well as vitamin C content after carbonation.

Kinematic viscosity (ν) was calculated as the ratio between dynamic viscosity (μ) and the density (ρ) of the liquid, presented in Formula (1).

$$\nu = \frac{\mu}{\rho} \quad (1)$$

Where: ν (Nu, Kinematic viscosity) – unit: m^2/s or centistokes (cSt); 1 cSt = 10^{-6} m^2/s; μ (Mu, Dynamic Viscosity) – unit: Pa·s (Pascal-seconds) or centipoise (cP); 1 cP = 10^{-3} Pa·s; ρ (Rho, Density) – unit: kg/m^3 [17].

Viscosity measurements were conducted using an Ostwald viscometer (capillary viscometer), a widely used method based on the flow time of a liquid through a capillary tube [18]. The kinematic viscosity can also be calculated using Formula (2) when using a calibrated viscometer.

$$\nu = K \cdot t \quad (2)$$

Where: K is the viscometer constant (determined through calibration); t is the flow time of the liquid through the capillary tube (in seconds).

DCPIP titration method

Vitamin C content was determined using the DCPIP titration method. The concentration of Vitamin C is calculated based on the volume of DCPIP consumed, using the following Formula (3).

$$C_{\text{Vitamin C}} = \frac{V_{\text{DCPIP}} \times C_{\text{DCPIP}} \times M}{V_{\text{sample}}} \quad (3)$$

Where: $C_{VitaminC}$ – concentration of Vitamin C in the sample (mg/mL or mg/100 mL); V_{DCPIP} – volume of DCPIP solution consumed in the reaction with Vitamin C in the sample (mL); C_{DCPIP} – concentration of the DCPIP solution (mol/L); M – molecular weight of Vitamin C (176.12 g/mol); V_{sample} – volume of the sample used for titration (mL).

Empirical formula for determining CO_2 content in carbonated beverages

Based on practical studies in the beverage industry, the concentration of dissolved CO_2 is typically expressed as a function of saturation temperature and pressure [19], presented in Formula (4).

$$V_{CO_2} = \frac{P_{CO_2} \times 100}{T_H + C} \quad (4)$$

Where: V_{CO_2} – concentration of dissolved CO_2 (g/L or mL CO_2 per 100 mL of beverage); P_{CO_2} – CO_2 saturation pressure (psi or atm); T_H – beverage temperature (^oC); C – empirical correction factor (typically ranging from 1.2 to 1.5 depending on the type of beverage).

IV. RESULTS AND DISCUSSION

The experimental results demonstrated that the extraction yield of Cavendish banana juice was relatively high, with notable variations observed across different pectinase concentrations and hydrolysis durations. Specifically, the yield increased progressively from 87.4% at 0.2% enzyme concentration to 92.3% at 0.4%, under an optimal hydrolysis time of 60 minutes. These findings align with those of Ilamaran [12] who reported similar improvements in juice recovery when using pectinase in banana and sapota beverages, achieving up to 90% yield under enzymatic treatment. The observed increase is attributed to the ability of pectinase to degrade

cell wall polysaccharides, thereby releasing more juice from the pulp matrix and reducing viscosity, which facilitates filtration and improves process efficiency [6, 9]. Such data reinforce the efficacy of enzymatic pretreatment in enhancing extraction performance in tropical fruit-based beverage production.

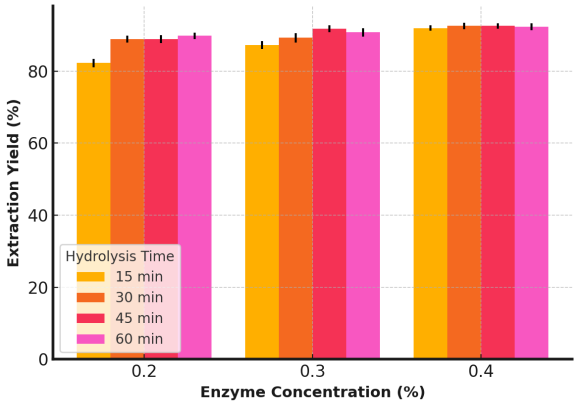

Fig. 1: Extraction yield as affected by hydrolysis time and enzyme concentration

Regarding the effect of enzyme concentration, the extraction yield increased progressively with higher pectinase concentrations when hydrolysis was conducted for 60 minutes. Specifically, the yield was 87.4% at 0.2%, 90.1% at 0.3%, and reached a maximum of 92.3% at 0.4% (Figure 1). These results clearly demonstrate the significant role of pectinase in enhancing banana juice extraction efficiency. Each incremental increase in enzyme concentration led to an improvement in yield, with 0.4% identified as the optimal concentration under the experimental conditions at a hydrolysis time of 60 minutes. However, further increases in enzyme concentration should be carefully considered with cost-effectiveness and potential impacts on the sensory and physicochemical properties of the final product [20].

In terms of hydrolysis time, the lowest juice yield was recorded at 15 minutes (83.44%), while the highest yield was achieved at 60 minutes (87.08%) using a pectinase concentration of 0.2%. However, statistical analysis indicated that the differences among the 30-, 45-, and 60-minute intervals were not significant, suggesting that extending the hydrolysis time beyond 30 minutes does not markedly improve extraction efficiency under this enzyme concentration [21].

These findings are consistent with the study by Lind [21], in which pectinase was shown to effectively break down pectin structures, reduce viscosity, and enhance juice extraction, thereby optimizing raw material processing in the food industry. Therefore, selecting an appropriate enzyme concentration and hydrolysis time is a critical factor in improving extraction yield and the quality of banana juice used in carbonated beverage production.

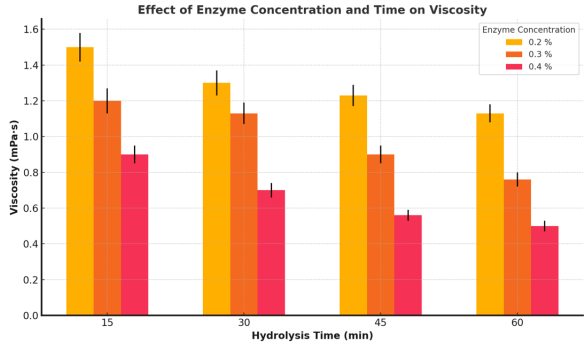

Fig. 2: Viscosity of banana extract

Statistical results (Figure 2) indicated that the viscosity of banana extract decreased with increasing pectinase concentration and hydrolysis time. Specifically, the lowest viscosity (0.5 mPa·s) was recorded at an enzyme concentration of 0.4% and a hydrolysis time of 60 minutes, whereas the highest viscosity (1.5 mPa·s) was observed at 0.2% enzyme concentration and 15 minutes of hydrolysis. This variation highlights the crucial role of pectinase in degrading pectin, one of the primary contributors to high viscosity in fruit extracts [20].

Based on the combined findings of extraction yield and extract viscosity, the study identified the optimal hydrolysis condition as 0.4% pectinase concentration and 60 minutes of hydrolysis. Under these conditions, the highest extraction yield was obtained while maintaining low

viscosity, thereby enhancing extract quality and providing a solid basis for the development of carbonated banana beverages [21].

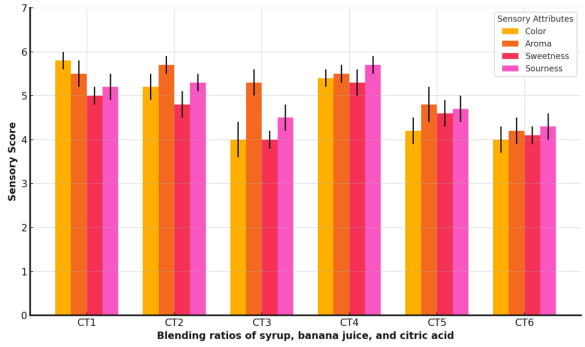

Fig. 3: Consumer preference survey

In this study, sensory evaluation was conducted to assess consumer acceptance of the formulated carbonated banana beverages. Four sensory attributes were evaluated, including color, aroma, sweetness, and sourness. Specifically, color referred to the visual appeal and consistency of the product's appearance, while aroma related to the perceived intensity and pleasantness of the smell. Sweetness and sourness were assessed to determine the balance of taste, reflecting the perceived levels of sugar and acidity, respectively.

All evaluations were performed by a trained panel using a 7-point hedonic scale, ranging from 1 = 'dislike extremely' to 7 = 'like extremely'. Each panelist independently scored all samples, and the results were analyzed to compare sensory performance among different blending ratios of syrup, banana juice, and citric acid. Standard deviation values were also included to reflect variability in panelist responses.

Statistical results from the sensory evaluation (Figure 3) indicated that consumer preference varied significantly depending on the blending ratio of syrup, banana juice, and citric acid. The formulation with the lowest score was the 15:85:0.2 ratio (syrup: banana juice: citric acid), which received an average score of 4.32. In contrast, the highest score of 5.45 was recorded for the 5:95:0.2 formulation. This difference reflects the influence of syrup content on sweetness and overall flavor, where excessive syrup may overpower the characteristic taste of banana juice [22].

Although the CT4 formulation obtained the highest score for flavor, its color score was slightly lower than that of CT1. Nevertheless, the difference in color scores between CT4 and CT1 was not statistically significant, indicating that the visual quality of CT4 remained within acceptable limits. Considering the overall sensory evaluation, including color, aroma, sweetness, and sourness, the CT4 formulation (5:95:0.2; syrup:banana juice:citric acid) was deemed the most suitable, offering superior sensory characteristics and reflecting strong consumer acceptance [23].

Following these findings, the 5:95:0.2 formulation (syrup: banana juice: citric acid) was selected for further physicochemical analysis and quality monitoring during storage to ensure product stability and feasibility in practical production.

Table 1: pH, Brix, and vitamin C values of carbonated banana beverage

Parameter	Result
pH	3.7
Brix	12
Vitamin C (mg/100 mL)	7.43

As shown in Table 1, the beverage exhibits a pH of 3.7, a Brix value of 12, and a vitamin C concentration of 7.43 mg/100 mL. These values were then compared to established standards to assess product suitability. According to the Codex Alimentarius [20], an optimal pH of approximately 3.7 is recommended to stabilize flavor and inhibit microbial growth [21]. In terms of sweetness, a Brix level of 12^{o}Bx is considered ideal, providing a balanced sweetness without being overpowering [22]. However, the vitamin C content of 7.43 mg/100 mL found in the product remains relatively low from a nutritional standpoint when compared to other fortified beverages [7]. This indicates a possible requirement

for modifying the formulation or incorporating functional ingredients to improve the nutritional quality and functional properties of carbonated banana beverages.

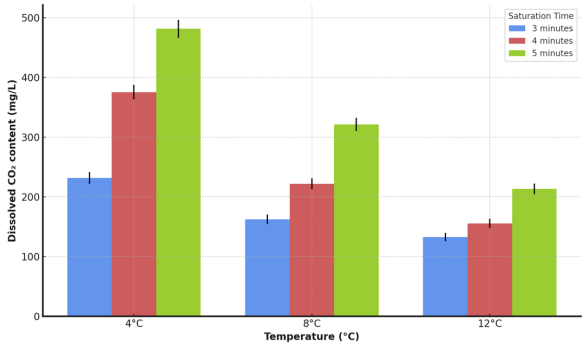

Fig. 4: Consumer preference survey

The concentration of dissolved CO_2 in carbonated beverages is significantly influenced by both cooling temperature and duration. As illustrated in Figure 4, lower cooling temperatures and longer chilling times enhance CO_2 solubility. Specifically, at 5^oC, increasing the cooling time from three to five minutes raised the dissolved CO_2 content from 231.67 mg% to a peak of 481.33 mg%. In contrast, when the cooling temperature was increased to 10^oC and 15^oC, the CO_2 content decreased notably across the same cooling durations. The results align with the findings of Lind [21], which demonstrated that decreasing the temperature enhances the solubility of CO_2 by lowering the molecular energy of water, thus promoting more efficient gas absorption. It is emphasized that maintaining the carbonation process within a cooling range of 4–6^oC, with an appropriate saturation time, is critical to achieving optimal CO_2 retention in carbonated beverages [23].

V. CONCLUSION

This study successfully identified appropriate parameters for enzymatic extraction and formulation to develop a carbonated banana beverage with desirable sensory and nutritional qualities. The use of 0.4% pectinase and a hydrolysis duration of 60 minutes yielded a maximum juice recovery rate of 92.3%, alongside a notable reduction in viscosity to 0.5 mPa·s – both critical factors for efficient processing and product consistency.

Sensory evaluation indicated that the beverage formulation comprising a syrup:banana juice:citric acid ratio of 5:95:0.2 delivered the most favorable organoleptic profile, achieving balance in sweetness, acidity, and overall flavor. The final product met key physicochemical benchmarks, including a pH of 3.7, a soluble solids content of 12°Bx, and a vitamin C concentration of approximately 7.43 mg/100 mL, thereby ensuring nutritional value and product stability over time.

Furthermore, the study confirmed that carbonation efficiency is significantly influenced by temperature and saturation time. The study confirmed that lower cooling temperatures, particularly at 5^oC, combined with extended chilling durations up to five minutes, significantly enhanced the solubility and retention of CO_2 in carbonated banana beverages. Under these optimal conditions, the highest dissolved CO_2 content reached 481.33 mg%, nearly twice that observed at elevated temperatures. This carbonation level also corresponded with superior sensory quality. These results highlight the importance of precise temperature and time control during carbonation and provide a scientific basis for optimizing processing parameters in the commercial production of carbonated banana beverages. Moreover, the findings support ongoing efforts to diversify fruit-based beverages through the valorization of underutilized tropical fruits like bananas.

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