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Investigation of Technological Parameters for Stabilizing the Quality of Banana (*Musa spp*) Milk

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Abstract

Musa ABB. is one of the most common banana cultivars in Vietnam, yet it is mainly consumed as fresh fruit, leading to high postharvest losses and low economic efficiency. Banana milk is a promising product for deep processing due to its high sensory and nutritional value. However, the product often suffers from phase separation and serum release during storage because of the inherent instability of the suspension system. This study aimed to determine technological solutions for stabilizing the quality of plantain milk through the use of food additives and high-pressure homogenization. The results indicated that the addition of 0.2% pectin combined with homogenization at 170 MPa significantly improved product homogeneity, minimized phase separation, and maintained sensory quality after one month of storage. The findings contribute to the development of a sustainable processing technology for plantain milk, enhancing the value of Musa ABB fruit.

Keywords: Banana Milk, Stabilizer, Homogenizer Pressure, Additives

1. Introduction

Banana (*Musa spp*.) is one of the most important fruit crops in Vietnam, with a cultivation area of approximately 147,134 ha, accounting for 19% of the total fruit-growing area, and an annual production of 2.64 million tons (FAO, 2023) [1]. Among the various cultivars, plantain (Musa ABB) is widely grown in the northern mountainous regions, north-central areas, and the central highlands due to its broad adaptability and desirable sensory qualities [2]. Despite its potential, plantain is predominantly consumed fresh, which leads to a risk of oversupply and substantial postharvest losses, estimated at 25-50% [3].

Banana milk, produced from a blend of ripe banana purée and milk, is a novel value-added product with high sensory appeal and rich nutritional composition. Bananas provide easily digestible carbohydrates, potassium, vitamin C, and vitamin B6, while milk is an important source of proteins and lipids, making banana milk a potential energy-dense beverage that supports digestion and post-exercise recovery [4]. While fruit-based milk beverages are relatively common, banana milk remains a new category, particularly when made from Musa ABB plantain. One of the major challenges in producing plantain milk is the occurrence of phase separation and serum release during storage. This instability is characteristic of suspension systems and is frequently observed in fruit-milk beverages, negatively affecting sensory quality and consumer acceptance [5]. To address this, technological interventions are required, particularly the use of stabilizing agents such as pectin, carboxymethyl cellulose (CMC), and xanthan gum, hydrocolloids known to enhance viscosity, improve water retention, and increase dispersion stability [6]. This study was conducted to determine suitable technological parameters for stabilizing the quality of plantain milk products. The findings aim to contribute to the optimization of processing technology, improve product quality, and promote the sustainable development of the Musa ABB value chain.

2. Material and methods

2.1 Material

The plantain milk was formulated using the following main ingredients: 14% plantain purée, 10% whole milk powder, and granulated sugar. The plantain purée was prepared from ripe Musa ABB (GL3-2 cultivar) fruits. The final product was adjusted to a total soluble solids (TSS) content of 12%.

2.2 Experimental Design

Selection of stabilizer type and concentration: Banana milk formulations were prepared by blending the base mixture and subsequently adding one of the following stabilizers at specified concentrations: carboxymethyl cellulose (CMC) at 0.02%, 0.03%, and 0.04%; xanthan gum at 0.02%, 0.03%, and 0.04%; and pectin at 0.10%, 0.20%, and 0.30%. A control formulation without stabilizer was also included. After addition of stabilizers, the banana milk was bottled and pasteurized at 115 °C (15 min heating time, 15 min holding time). The products were analyzed for nutritional composition and evaluated for sensory quality immediately after processing and after one month of storage at ambient temperature, in order to determine the most suitable stabilizer type and concentration.

Determination of high-pressure homogenization conditions: In parallel with stabilizer supplementation, high-pressure homogenization was investigated as an additional method to improve product stability and texture. Banana milk mixtures were homogenized at pressures of 150, 170, 190, and 210 MPa; a control sample without homogenization was included. Following homogenization, samples were processed as in Experiment 1 (bottling and pasteurization at 115 °C). Sensory quality was assessed immediately after processing and monitored over one month of ambient storage to determine the optimal homogenization pressure for stability and quality retention.

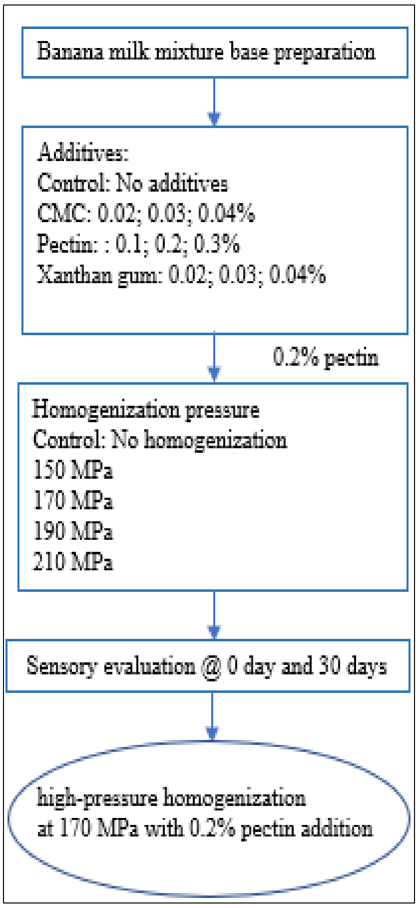

Fig 1: Experimental design

2.3 Analytical analyses

Determination of the total soluble solids (TSS) content: determined by electronic refractometry (refractometry) in accordance with TCVN 4417-87.

Determination of sugar and starch content: according to TCVN 4594-88.

Determination of protein content: according to TCVN 8134:2009 (ISO 937:1978).

Determination of total reducing sugars content: according to TCVN 4594-88.

Determination of lipid content: according to TCVN 6688-3:2007.

Determination of total organic acid content: according to TCVN 5483:2006.

Sensory evaluation method for product quality: hedonic taste test using a 9-point hedonic scale (1 = extremely dislike, 9 = extremely like).

2.4 Statistical Analysis

Statistical hypotheses were tested by analysis of variance (ANOVA), and treatment means were compared using the least significant difference (LSD) test at a significance level of $P < 0.05$.

3. Results

3.1 Additives and concentration on stabilization of banana milk

Table 1 indicate that the addition of stabilizers such as pectin, carboxymethyl cellulose (CMC), and xanthan gum at various concentrations did not significantly affect the key nutritional composition of the plantain milk product.

Table 1: Effect of type and concentration of additives on nutritional composition of banana milk

Additives	Concentration (%)	TSS (°Bx)	Total sugar content (%)	Protein (%)	Lipid (%)	Polysaccharide (%)	Total acid (%)
Control	0	12.0[a]	11.27[a]	2.51[a]	3.09[a]	0.32[a]	0.056[a]
Pectin	0.1	12.0[a]	11.27[a]	2.51[a]	3.09[a]	0.32[a]	0.056[a]
	0.2	12.1[a]	11.27[a]	2.51[a]	3.09[a]	0.32[a]	0.056[a]
	0.3	12.2[a]	11.27[a]	2.51[a]	3.09[a]	0.32[a]	0.056[a]
CMC	0.02	12.0[a]	11.27[a]	2.51[a]	3.09[a]	0.32[a]	0.056[a]
	0.03	12.0[a]	11.27[a]	2.51[a]	3.09[a]	0.32[a]	0.056[a]
	0.04	12.1[a]	11.27[a]	2.51[a]	3.09[a]	0.32[a]	0.056[a]
Xanthan gum	0.02	12.0[a]	11.27[a]	2.51[a]	3.09[a]	0.32[a]	0.056[a]
	0.03	12.0[a]	11.27[a]	2.51[a]	3.09[a]	0.32[a]	0.056[a]
	0.04	12.0[a]	11.27[a]	2.51[a]	3.09[a]	0.32[a]	0.056[a]

Values within the same column followed by the same letter are not significantly different at $\alpha = 0.05$

Specifically, the total sugar, protein, lipid, starch, and total organic acid contents remained comparable to those of the control sample, at 11.27%, 2.51%, 3.09%, 0.32%, and 0.056%, respectively. This finding suggests that the hydrocolloid additives employed in this study primarily function as colloidal stabilizers, possessing negligible nutritional value and contributing minimally to the nutritional profile of the product. A slight increase in total soluble solids (TSS) from 12.0 to 12.2 °Bx was observed with increasing stabilizer concentration, particularly in formulations containing pectin and CMC. This effect is likely attributable to the inherent solids content of the hydrocolloids, which marginally contributes to the overall soluble solids in the system. However, the magnitude of this increase (0.1–0.2 °Bx) is considered negligible in practical terms. These observations are consistent with the findings of Kaur *et al*. (2019) [7] and Rao *et al*. (2015) [8], who reported that stabilizers such as CMC and xanthan gum can improve viscosity and enhance colloidal stability in fruit-milk beverages without inducing substantial changes in the chemical composition of the product.

The results in Table 2 indicate that the use of different stabilizers at varying concentrations did not significantly alter the perceived color and aroma of banana milk; however, they had a pronounced impact on the product's taste and texture after processing. The control sample (without additives) exhibited the lowest viscosity (80 cP), resulting in slight phase separation and a relatively low sensory texture score (6.8). This suggests that the colloidal structure of the product was insufficiently stabilized, which aligns with the findings of Akkarachaneeyakorn (2015) [9], who reported that fruit milk without hydrocolloids tends to undergo phase separation during storage.

For pectin-supplemented samples, viscosity increased from 118 to 162 cP as concentration rose from 0.1% to 0.3%, with a notable improvement in texture, particularly at 0.2%, where the product exhibited a uniform structure and the highest average texture score (8.40). This suggests that an optimal pectin concentration can form a light gel network, enhancing dispersion stability without imparting excessive thickness. However, at 0.3%, the product became overly thick, with slight declines in both taste (from 8.5 to 8.4) and texture scores (from 8.4 to 7.2), indicating possible consumer rejection of excessive viscosity. These observations are consistent with Sirbu & Gaur (2010) [10], who noted that pectin provides moderate stabilization but may impair palatability if overdosed.

In CMC-supplemented samples, viscosity rose from 127 to 194 cP as concentration increased from 0.02% to 0.04%, but sensory scores for taste and texture declined, particularly at 0.04%, where the product was described as "overly thick" and the texture score dropped to 6.3. This suggests that while CMC effectively increases viscosity, exceeding the optimal threshold may promote uneven gel network formation, leading to undesirable "powdery" or "pasty" mouthfeel, as also reported by Kaur *et al*. (2019) [7].

Xanthan gum addition resulted in the highest viscosities among the three stabilizers (up to 232 cP at 0.04%), but the lowest sensory taste and texture scores, especially at 0.03-0.04%, where excessive stickiness reduced the texture score to 5.0. This excessive viscosity likely contributed to an unpleasant adhesive mouthfeel, lowering consumer acceptability. Such findings are consistent with Funami *et al*. (2008) [11], who reported that high xanthan gum concentrations can cause "stringiness" in beverages, reducing overall quality perception.

Table 2: Effect of type and concentration of additives on sensorial properties of banana milk

Additives	Concentration (%)	Viscosity (cP)	Sensory properties					General evaluation
			Color	Flavor	Taste	Texture	Average score	
Control	0	80	8.3[a]	8.4[a]	8.5[a]	6.8[d]	8.00[c]	Lightly layering
Pectin	0.1	118	8.3[a]	8.4[a]	8.5[a]	7.8[b]	8.25[b]	Uniformity
	0.2	125	8.3[a]	8.4[a]	8.5[a]	8.4[a]	8.40[a]	Uniformity
	0.3	162	8.3[a]	8.4[a]	8.4[a]	7.2[c]	8.08[c]	Homogeneous, slightly thick
CMC	0.02	127	8.3[a]	8.4[a]	8.0[b]	7.5[bc]	8.05[c]	Uniformity
	0.03	150	8.3[a]	8.4[a]	7.5[c]	7.3[c]	7.88[d]	Homogeneous, slightly thick
	0.04	194	8.3[a]	8.4[a]	7.3[cd]	6.3[e]	7.58[e]	Homogeneous, thick
Xanthan gum	0.02	185	8.3[a]	8.4[a]	7.2[cd]	6.0[f]	7.48[f]	Homogeneous, slightly viscous
	0.03	203	8.3[a]	8.4[a]	7.0[d]	5.5[g]	7.30[g]	Uniform, feel the viscosity clearly
	0.04	232	8.3[a]	8.4[a]	6.8[d]	5.0[h]	7.13[h]	Uniform, feel the viscosity clearly

Values within the same column followed by the same letter are not significantly different at $\alpha = 0.05$

Furthermore, the results indicate that changes in taste were largely influenced by texture modifications rather than direct flavor contributions, as pectin, CMC, and xanthan gum are all odorless and tasteless. At high concentrations, their indirect impact, through altering viscosity and mouthfeel, negatively affected flavor perception, particularly in a liquid product such as banana milk. This is corroborated by Funami *et al*. (2008) [11], who found that excessive viscosity in liquid beverages can elicit negative consumer responses.

Table 3 demonstrates that the supplementation of hydrocolloids such as pectin, CMC, and xanthan gum had a marked influence on viscosity, physical stability, and sensory quality of Cavendish banana milk after one month of storage at ambient temperature. Specifically, the sample containing 0.2% pectin exhibited a viscosity of 113 cP and achieved the highest average sensory score (8.18), with only slight phase separation. This indicates that pectin is capable of forming a light gel structure, effectively retaining water while maintaining product homogeneity during storage. These findings are consistent with data previously reported [12], who demonstrated that pectin improves the stability of fruit-based dairy products through its ability to interact with proteins and form a water-retentive gel network. At a higher pectin concentration (0.3%), viscosity increased to 130 cP; however, more pronounced syneresis and phase separation were observed. This phenomenon can be explained by the syneresis mechanism, the contraction of the gel network when polysaccharide concentration exceeds the optimal threshold, resulting in water expulsion [13]. Therefore, the addition of pectin requires a balance between viscosity and system stability.

Similarly, for CMC and xanthan gum, increasing concentrations led to higher viscosity but also to greater water separation, more visible phase separation, and a decline in sensory taste scores. This reflects the fact that although these hydrocolloids can markedly increase viscosity, they may not sufficiently maintain long-term stability of the system. Such trends align with the observations of Morris (2009) [14], who noted that certain hydrocolloids tend to alter gel structure in a way that increases viscosity while reducing homogeneity. Notably, xanthan gum at 0.04% yielded the highest viscosity (139 cP) but the lowest sensory score and exhibited clear water separation, indicating that high viscosity does not necessarily equate to better physical stability. These results support the established principle that, in liquid food systems, the stabilizing effect of hydrocolloids depends not only on viscosity but also on their water-holding capacity and interactions with other system components (proteins, sugars).

Overall, the findings indicate that pectin at a concentration of 0.2% is the most effective stabilizer for improving the physical stability of Cavendish banana milk. However, relying solely on additive supplementation is not sufficient for optimal stability. Instead, a combination of chemical (hydrocolloid addition) and mechanical (homogenization) approaches is recommended to enhance both physical stability and sensory quality during processing.

Table 3: Effect of type and concentration of additives on sensorial properties of banana milk after 1 month of storage

Additives	Concentration (%)	Viscosity (cP)	Sensory properties					General evaluation
			Color	Flavor	Taste	Texture	Average score	
Control	0	57	8.1ᵃ	8.4ᵃ	7.5ᶜ	4.3ᵉ	7.13ᵈ	Clear stratification & sedimentation
Pectin	0.1	103	8.2ᵃ	8.4ᵃ	8.1ᵇ	6.0ᵇ	7.70ᵇ	Multiple layers
	0.2	113	8.2ᵃ	8.4ᵃ	8.4ᵃ	7.6ᵃ	8.18ᵃ	Light layering
	0.3	130	8.2ᵃ	8.4ᵃ	7.3ᶜᵈ	5.5ᶜ	7.38ᶜ	Layering, dewatering.
CMC	0.02	99	8.2ᵃ	8.4ᵃ	7.3ᶜᵈ	5.0ᵈ	7.25ᶜᵈ	Multiple layers
	0.03	105	8.2ᵃ	8.4ᵃ	7.3 ᶜᵈ	4.5ᵉ	7.13ᵈ	Multiple layers
	0.04	132	8.2ᵃ	8.4ᵃ	7.0ᵈ	4.5ᵉ	7.05ᵉ	Layering, water separation, viscosity
Xanthan gum	0.02	120	8.2ᵃ	8.4ᵃ	7.0ᵈ	4.5ᵉ	7.05ᵉ	Layering, water separation
	0.03	128	8.2ᵃ	8.4ᵃ	7.0ᵈ	4.5ᵉ	7.05ᵉ	Layering, water separation clearly
	0.04	139	8.2ᵃ	8.4ᵃ	6.5ᵉ	4.5ᵉ	6.93ᵉ	Layering, water separation

Values within the same column followed by the same letter are not significantly different at $\alpha = 0.05$

3.2 Homogenization mode for banana milk stabilization

Banana milk was mixed and supplemented with pectin at a concentration of 0.2%, then homogenized at different pressure levels (150 - 210 MPa). The homogenized samples were bottled in 250 ml white glass bottles, pasteurized and evaluated for quality immediately after processing as well as after 1 month of storage at room temperature. The results in Tables 4 demonstrate that homogenization pressure significantly influenced the quality parameters of banana milk supplemented with 0.2% pectin, both immediately after processing and following one month of storage at ambient temperature. Immediately after formulation, increasing homogenization pressure from 0 MPa to 210 MPa led to a marked increase in viscosity from 125 cP to 185 cP, accompanied by a slight but consistent rise in sensory state scores from 8.4 to 8.6. This trend reflects the effectiveness of high-pressure homogenization in reducing particle size and enhancing interactions between phases in the dispersed system—particularly between pectin, milk proteins, and soluble solids from banana puree. As reported previously by McClements (2005) [15] and Funami *et al*. (2012) [12], high pressure promotes more uniform dispersion of particles, resulting in a finer microstructure and improved colloidal stability. However, after one month of storage, the viscosity of all samples declined compared to their initial values, regardless of homogenization treatment. This reduction can be attributed to structural destabilization of the emulsion or suspension system over time.

Table 4: Effect of homogenizing on quality of banana milk with 0.2% pectin as additive

Pressure MPa	Viscosity cP		Sensory properties score									
			Color		Flavor		Taste		Texture		Average score	
	0 day	30 days	0 day	30 days	0 day	30 days	0 day	30 days	0 day	30 days	0 day	30 days
0	125	113	8.3^{a}	8.3^{a}	8.4^{a}	8.4^{a}	8.5^{a}	8.3^{b}	8.4^{b}	7.6^{b}	8.40^{a}	8.15^{b}
150	142	128	8.3^{a}	8.3^{a}	8.4^{a}	8.4^{a}	8.5^{a}	8.3^{b}	8.4^{b}	7.8^{b}	8.40^{a}	8.20^{bc}
170	150	135	8.3^{a}	8.3^{a}	8.4^{a}	8.4^{a}	8.5^{a}	8.5^{a}	8.6^{a}	8.5^{a}	8.45^{a}	8.43^{a}
190	169	152	8.3^{a}	8.3^{a}	8.4^{a}	8.4^{a}	8.5^{a}	8.5^{a}	8.6^{a}	8.4^{a}	8.45^{a}	8.40^{a}
210	185	167	8.3^{a}	8.3^{a}	8.4^{a}	8.4^{a}	8.5^{a}	8.5^{a}	8.6^{a}	8.4^{a}	8.45^{a}	8.40^{a}

Values within the same column followed by the same letter are not significantly different at $\alpha = 0.05$

According to Gharibzahedi & Chronakis (2021) [16], molecular rearrangements, micro-syneresis, and partial phase separation during storage can loosen the colloidal network, causing the system to become less viscous. This phenomenon is common in plant-based or pectin–protein systems stored under non-optimal thermal and pH conditions. Notably, samples without homogenization and those homogenized at 150 MPa exhibited slight phase separation after storage, accompanied by lower sensory state scores (7.6-7.8). This indicates insufficient stability of the dispersed system at lower pressures. Mechanistically, inadequate homogenization fails to fully disrupt aggregates of protein–pectin complexes or particulate solids from banana puree (starch, fibers, etc.), leading to uneven distribution in the liquid phase. As noted by Thakur *et al.* (1997) [17] and Donsì *et al*. (2010) [18], larger particles tend to settle under gravity while the lighter phase (water and free pectin) rises, causing stratification. Conversely, samples homogenized at pressures ≥170 MPa maintained uniformity and relatively high viscosity after storage (135-167 cP), with sensory scores of 8.4-8.5. These results suggest that higher homogenization pressures facilitated the formation of a robust gel-like network capable of maintaining phase integrity and preventing separation during storage [19]. This stabilizing effect of high-pressure homogenization is consistent with previous findings by Donsì *et al*. (2010) [18] and Mun *et al*. (2009) [20]. It is also noteworthy that increasing homogenization pressure from 190 MPa to 210 MPa further increased viscosity but did not yield a proportional improvement in sensory scores. This suggests that a sensory threshold may have been reached at around 190 MPa, beyond which additional pressure only increases energy costs without delivering substantial product quality benefits.

4. Conclusions

This study demonstrates that the combination of 0.2% pectin supplementation and high-pressure homogenization effectively enhances the stability of banana milk. Homogenization pressure significantly influenced product viscosity, physical stability, and sensory quality both immediately after processing and after one month of storage at ambient temperature. Pressures of 170 MPa or higher resulted in a uniform, homogeneous system with minimal phase separation and water release, maintaining desirable viscosity and sensory scores during storage. In contrast, lower pressures (≤150 MPa) failed to provide sufficient dispersion of particulate matter, leading to reduced stability and visible separation. Notably, increasing homogenization pressure beyond 190 MPa yielded only marginal improvements in physical properties without corresponding sensory benefits, suggesting 170 MPa as the optimal condition for balancing product quality and energy efficiency. Overall, high-pressure homogenization at 170 MPa combined with 0.2% pectin addition is recommended as an effective approach to producing stable, high-quality banana milk.

5. Conflicts of Interest

The authors have no conflicts of interest.

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