



## Application guide for the preparation of juices based on traditional fruits in Peru

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### ABSTRACT

Given the absence of practical laboratory guides for fruit juice processing, this study aimed to implement a didactic guide for the production of juices derived from traditional Peruvian fruits as a strategy to bridge the gap between theoretical knowledge and practical application in food engineering education. A quantitative approach with an interactive instructional design was employed, enabling students to perform the complete nectar production process while applying both thermal pasteurization and ultrasound-assisted preservation techniques. Subsequently, the effects of these preservation methods on product quality were evaluated.

The results demonstrated that ultrasound treatment (45°C for 15 min) provided significantly greater preservation of total polyphenols (33.59 mg GAE/100 g) compared with conventional pasteurization (23.35 mg GAE/100 g). Vitamin C content remained high under both treatments, with pasteurization at 80°C for 20 min showing the highest value (44.25 mg/100 mL). Physicochemical parameters, including pH, soluble solids (°Brix), titratable acidity, and viscosity, remained stable throughout the study, although ultrasound treatment exhibited superior viscosity retention. From a microbiological perspective, both preservation methods ensured product safety throughout 42 days of storage, complying with the requirements established by the Peruvian Technical Standard.

The findings indicate that the proposed guide constitutes an effective educational tool for strengthening students' competencies in critical analysis, decision-making, and innovation. By exposing learners to real experimental results, the guide facilitates a deeper understanding of the advantages offered by emerging food preservation technologies compared with conventional processing methods.

**Keywords:** pasteurization; food engineering education; ultrasound technology; polyphenols; traditional fruits.

### 1. Introduction

Food Engineering education currently faces the challenge of moving beyond traditional teaching models in which encyclopedic learning and one-way knowledge transmission continue to characterize classroom practice. For decades, the learning process has largely revolved around the accumulation of theoretical information, memorization of facts, and repetition of concepts presented in textbooks or delivered by instructors through lecture-based approaches. Although traditional higher education facilitates the transmission of knowledge, it has been criticized for promoting passive learning and memorization rather than fostering critical thinking, active engagement, and the practical application of knowledge (Bhardwaj, 2025). While mastery of theoretical foundations is essential for professional training, reliance on this approach as the primary teaching strategy often creates a disconnect between theory and practice.

According to Seery (2024), the gap between theoretical content and practical activities limits students' understanding because instruction centered exclusively on theory, without opportunities for real-world application, hinders knowledge transfer and the development of experimental skills. Consequently, students may become capable of describing theoretical processes while lacking the practical competencies required to make decisions and solve real problems. This theory–practice gap is particularly evident in Food Engineering, where students understand the theoretical aspects of food-processing operations but frequently encounter difficulties when performing laboratory activities. Questions such as how juice is extracted from a traditional fruit or how processing parameters should be adjusted when raw materials vary according to their origin often remain unanswered.

These issues are frequently overlooked in educational models that prioritize decontextualized theoretical instruction. Mundy and Boitumelo (2024) reported that many traditional university laboratories lack contextual relevance and rely on fragmented procedures that fail to promote meaningful learning or establish connections between theory, practice, and real-world applications. Likewise, Postareff et al. (2024) found that educational approaches emphasizing the applicability of knowledge in authentic contexts

are associated with higher teaching quality and improved learning outcomes than traditional theory-centered approaches.

Within Food Engineering education, the lack of laboratory teaching materials represents a critical challenge. Due to the traditionally restricted dissemination of food and beverage processing knowledge, laboratory guides addressing industrial food-processing operations are scarce. Hendrix (2021, p. 1) noted that “the lack of an official curriculum and standardized instructional guides for food science and technology education contributes to uncertainty among students and instructors regarding how specific industrial processes and applied processing techniques should be addressed.” As a result, students may struggle to develop autonomous learning skills and acquire the competencies required to address professional challenges effectively.

In Peru, this issue acquires additional relevance because the country possesses a remarkable diversity of fruits with significant agro-industrial potential. Many of these fruits remain classified as non-traditional crops and are largely excluded from productive chains and educational programs. Consequently, training innovative food engineers requires a pedagogical approach that goes beyond teaching the technical characteristics of traditional fruits. Students must develop competencies related to the handling, processing, and innovation of industrial juice-production processes based on the fruit diversity available across different regions of the country.

The present study aimed to implement an application guide for the preparation of juices based on traditional fruits in Peru. Rather than functioning as a recipe manual, the guide was designed as a bridge between theory and practice, enabling students to apply scientific principles in laboratory settings and make informed decisions during food-processing operations. Specifically, noni (*Morinda citrifolia*), star fruit (*Averrhoa carambola*), and tamarillo or tree tomato (*Solanum betaceum*) were selected because they are representative fruits of the region and provide an opportunity to contextualize learning within the local environment.

## 2. Method

This study adopted a quantitative approach and followed an interactive research design. According to Hurtado (2000, p. 353), interactive research is understood as one that “involves an intervention process that proposes and applies structured designs, plans, and actions with the purpose of modifying a given situation; that is, interactive research integrates models, designs, and plans within its methodological development.” In this study, an application guide for the preparation of juices based on traditional fruits in Peru was implemented. The guide was divided into the following sections: learning objectives, materials and equipment, execution instructions, application questions, and an evaluation rubric.

## 3. Results

The present application guide was developed to strengthen the relationship between theory and practice in Food Engineering education. Rather than being structured as a recipe manual, it was designed as an instructional tool to guide students in decision-making during juice processing while promoting critical analysis, interpretation of results, and comparison of preservation technologies.

### Practical Objectives

#### General Objective

- To apply scientific principles for the production and preservation of juices derived from traditional Peruvian fruits by comparing thermal processing and emerging technologies.

#### Specific Objectives

- To extract juice from selected fruits using technical processing criteria.
- To determine physicochemical parameters, including pH, °Brix, acidity, and viscosity.
- To apply thermal pasteurization and ultrasound as preservation methods.
- To analyze the impact of each process on product quality.

### Materials and Equipment

- Raw Materials
- Ripe noni (*Morinda citrifolia*)
- Ripe star fruit (*Averrhoa carambola*)
- Ripe tamarillo (*Solanum betaceum*)

### Equipment

- Analytical balance
- Blender or pulper
- Refractometer
- pH meter

- Thermometer
- Water bath or pasteurizer
- Ultrasound equipment
- Glassware
- Filters or sieves
- Competencies to Be Developed
- Application of Food Engineering principles
- Real-time decision-making
- Critical analysis of industrial processes
- Evaluation of physicochemical and microbiological quality
- Innovation and process improvement capabilities

### **Instructions**

The detailed instructions for each stage of the production process of a beverage based on noni, star fruit, and tamarillo are presented below. The procedure was carried out using a total fruit sample of 120 kg (60 kg of noni, 30 kg of star fruit, and 30 kg of tamarillo). Each step should be followed sequentially to ensure proper implementation of the procedure.

#### **Phase 1. Raw Material Reception**

Noni (*Morinda citrifolia*), star fruit (*Averrhoa carambola*), and tamarillo (*Solanum betaceum*) fruits were obtained from the local market or from the National University Pedro Ruiz Gallo (Lambayeque, Peru). Fruits were selected in fresh condition and suitable for processing.

#### **Phase 2. Selection and Initial Cleaning**

The fruits were manually sorted, and those showing insect damage, signs of deterioration, or any sanitary defects were discarded. Selected fruits were washed with distilled water to remove surface dirt and soil residues.

#### **Phase 3. Fruit Weighing**

Each fruit type was weighed separately to verify the initial quantities:

Noni: 60 kg

Star fruit: 30 kg

Tamarillo: 30 kg

The exact weights were recorded for subsequent calculations.

#### **Phase 4. Washing with Pasteurized Cold Water**

The fruits were immersed in previously pasteurized cold water (water heated to pasteurization temperature and subsequently cooled) to provide additional sanitation. Care was taken to avoid damaging the fruit skin.

#### **Phase 5. Manual Peeling and Seed Removal**

The fruits were manually peeled.

For fruits containing seeds, such as star fruit and tamarillo, manual seed removal was performed to separate the seeds from the pulp. Noni fruits required additional treatment during subsequent stages.

#### **Phase 6. Fruit Softening and Noni Juice Exudation**

Peeled noni fruits were subjected to a softening process, either through mechanical methods or mild heat treatment, to facilitate juice release.

The exuded noni juice was collected separately and reserved for the final formulation.

#### **Phase 7. Pulp Extraction of Star Fruit and Tamarillo**

Star fruit and tamarillo fruits were processed using a pulping machine or equivalent manual methods to obtain a homogeneous pulp free of large particles.

#### **Phase 8. Filtration for Seed Residue Removal**

The obtained pulps and noni juice were filtered separately using a fine sieve or filter cloth to remove seed residues and coarse fibers, resulting in refined juice and Pulp fractions.

#### **Phase 9. Combination of Refined Juice and Pulp**

The refined products were blended in the following proportions:

50% noni juice

5% star fruit pulp

25% tamarillo pulp  
The mixture was thoroughly homogenized.

#### **Phase 10. Dilution**

The juice-pulp mixture was diluted with previously pasteurized water cooled to room temperature. The amount of water added depended on the desired concentration and was adjusted to obtain a liquid base suitable for subsequent processing stages.

#### **Phase 11. Filtration**

The diluted mixture was filtered again to remove any remaining solids and ensure a smooth texture.

#### **Phase 12. Addition of Additives**

The following additives were incorporated into the filtered mixture according to the indicated percentages based on total mixture weight:

- Sucrose: 10%
- Carboxymethyl cellulose (CMC): 0.1%
- Potassium sorbate: 0.025%
- The mixture was stirred until complete dissolution was achieved.

#### **Phase 13. Ultrasound Treatment**

The mixture was subjected to ultrasound treatment at a frequency of 50 kHz. Different temperature–time combinations were applied according to the experimental design:

- 35°C for 25 min
- 45°C for 20 min
- 55°C for 15 min

This treatment enhanced the extraction of bioactive compounds and improved product stability.

#### **Phase 14. Pasteurization Treatment**

Thermal pasteurization was carried out under the following conditions:

- 60°C for 20 min
- 75°C for 15 min
- 80°C for 10 min

After pasteurization, the samples were rapidly cooled.

Samples were collected for the determination of total polyphenols and vitamin C content.

Total polyphenols were quantified using the Folin–Ciocalteu colorimetric method (Singleton & Rossi, 1965), adapted according to Muñoz (2017).

Vitamin C content was determined using the 2,6-dichlorophenolindophenol method described by Bazán and Mejía (2023).

In addition, physicochemical and microbiological analyses were performed on all samples.

#### **Phase 15. Storage**

The final product was stored under controlled temperature conditions at:

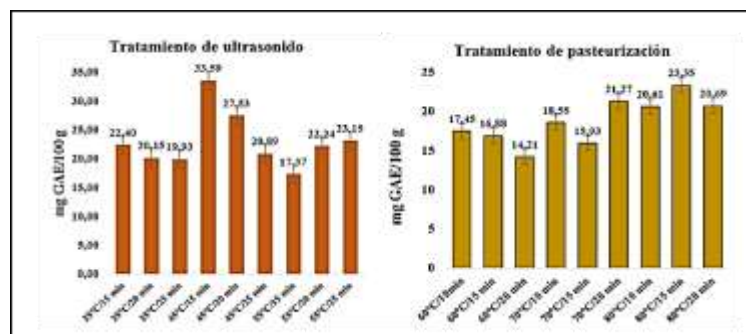
- 10°C
- 27°C
- 37°C

Storage was maintained for up to 42 days, with periodic evaluations conducted to assess product stability.

All experimental conditions and processing data were recorded throughout the study for subsequent analysis.

## **Experimental Results**

Figure 1. Polyphenol Quantification in Nectar Subjected to Different Treatments

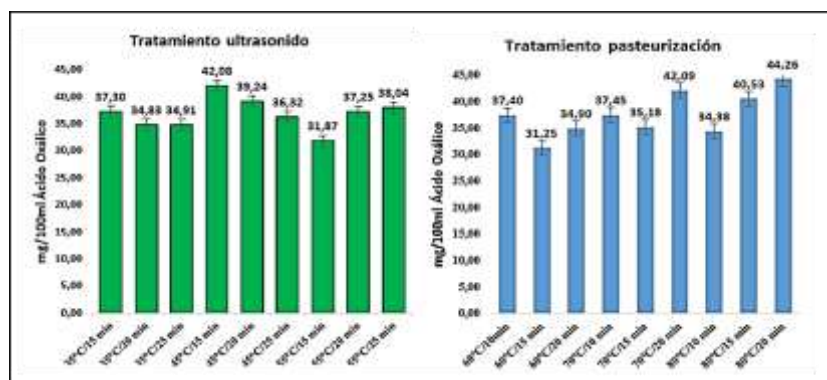


Source: Authors' own elaboration

As shown in Figure 1, the ultrasound treatment with the highest polyphenol content was T4 (45°C/15 min), reaching 33.59 mg GAE/100 g. This result indicates the optimal processing condition for maximizing antioxidant retention in the nectar. In contrast, among the pasteurized samples, treatment T8 (80°C/15 min) exhibited the highest polyphenol content, with 23.35 mg GAE/100 g, followed by treatment T6 (70°C/20 min), with 21.27 mg GAE/100 g. The lowest polyphenol concentration was observed in treatment T3 (60°C/20 min), which yielded 14.21 mg GAE/100 g.

These findings suggest that although pasteurization effectively preserves microbiological quality, it causes an approximate 30% reduction in polyphenol content. Consequently, the results support the potential of non-thermal technologies, particularly controlled ultrasound processing, as superior alternatives to conventional pasteurization for preserving antioxidant compounds.

Figure 2. Vitamin C Quantification in Nectar Subjected to Different Treatments



Source: Authors' own elaboration

Figure 2 shows that the ultrasound treatment with the highest vitamin C content was T4 (45°C/15 min), reaching 42.08 mg/100 mL oxalic acid equivalent. Among the pasteurized samples, treatment T9 (80°C/20 min) exhibited the highest vitamin C concentration, with 44.26 mg/100 mL oxalic acid equivalent, followed by treatment T6 (70°C/20 min), with 42.09 mg/100 mL oxalic acid equivalent.

The lowest vitamin C content was recorded in treatment T2 (60°C/15 min), with 31.25 mg/100 mL oxalic acid equivalent.

These results indicate that pasteurization achieved excellent vitamin C retention, although at the expense of polyphenol preservation. Therefore, while thermal processing may be appropriate for products promoted primarily for their vitamin C content, ultrasound treatment demonstrated comparable vitamin C retention and superior preservation of polyphenolic compounds. These findings highlight the different mechanisms involved in the degradation and stabilization of vitamin C during processing.

Table 1. Physicochemical Characteristics of Nectar Subjected to Pasteurization and Ultrasound Treatments

Physicochemical Characteristics	Pasteurization Treatment			Ultrasound Treatment		
	T1 (60°C/20min)	T2 (70°C/15min)	T3 (80°C/10min)	T1 (35°C/25min)	T2 (45°C/20min)	T3 (55°C/15min)
pH	3,88 ± 0,03	3,88 ± 0,03	3,92 ± 0,02	3,88 ± 0,02	3,91 ± 0,02	3,87 ± 0,03
°Brix	13,81 ± 0,03	13,9 ± 0,01	13,71 ± 00	13,72 ± 0,02	13,74 ± 0,01	13,74 ± 0,01
Acidity (g acid/100g)	0,43 ± 0,01	0,43 ± 0,01	0,41 ± 0,01	0,43 ± 0,01	0,43 ± 0,02	0,43 ± 0,02
Viscosity (mPas)	19,26 ± 0,02	19,18 ± 0,04	19,13 ± 0,01	19,21 ± 0,02	19,23 ± 0,02	19,23 ± 0,02

Source: Authors' own elaboration

The results presented in Table 1 indicate that increasing temperature and reducing processing time during pasteurization resulted in a slight increase in pH and a reduction in acidity. Likewise, °Brix values and viscosity decreased as processing severity increased. In contrast, no substantial differences were observed among the ultrasound treatments. These findings demonstrate that ultrasound processing represents a viable alternative to conventional pasteurization because it preserves the physicochemical characteristics of the product. The stability observed in pH and total soluble solids (°Brix) confirms that the physicochemical identity of the nectar remained unchanged. Furthermore, ultrasound-treated samples exhibited greater viscosity retention than nectar pasteurized at 80°C, suggesting lower degradation of the natural polymeric networks of fruit pectins.

**Table 2. Microbiological Characteristics of Pasteurized Nectar Stored at 27°C for 42 Days.**

Tests	Results	Reference Value
Total coliforms (NMP/ml)	<3	<10
Aerobic mesophilic count (CFU/mL)	<10	<10
Mold count (CFU/mL)	<10	<10
Yeast count (CFU/mL)	<10	32x10 <sup>2</sup>

**Source: Authors' own elaboration**

According to the microbiological results obtained, the nectar samples complied with the Peruvian Technical Standard (NTP) and the microbiological criteria established in Peru for beverages intended for human consumption. Pasteurized nectar stored at ambient temperature (27°C) for 42 days maintained adequate microbiological stability throughout the storage period.

Total coliform counts were below 3 MPN/mL, well under the established limit (<10 MPN/mL), indicating the absence of fecal contamination and confirming the effectiveness of the pasteurization process. Likewise, aerobic mesophilic counts remained below 10 CFU/mL, corresponding to the maximum permissible value.

The low microbial counts suggest that pasteurization effectively reduced the total microbial load, thereby contributing to product stability during storage. Mold and yeast counts also remained below 10 CFU/mL, values considerably lower than the permissible limits. The absence of growth of these spoilage microorganisms is particularly important because molds and yeasts are among the primary causes of deterioration in fruit-based beverages. Overall, these results demonstrate that pasteurization ensured the microbiological stability of the nectar during storage.

**Table 3. Microbiological Characteristics of Ultrasound-Treated Nectar Stored at 27°C for 42 Days**

Test	Results	Reference Value
Total coliforms (MPN/mL)	<3	<10
Aerobic mesophilic count (CFU/mL)	<10	<10
Mold count (CFU/mL)	<10	<10
Yeast count (CFU/mL)	<10	32x10 <sup>2</sup>

**Source: Authors' own elaboration**

Total coliform counts were below 3 MPN/mL, remaining under the established limit (<10 MPN/mL), which indicates the absence of fecal contamination. Aerobic mesophilic counts were also below 10 CFU/mL, corresponding to the permissible limit. This low microbial load reflects the antimicrobial effects associated with ultrasound-induced cavitation, which can damage microbial cell membranes.

Similarly, mold and yeast counts remained below 10 CFU/mL, values considerably lower than the established limits. The inhibition of these microorganisms is particularly relevant because molds and yeasts are among the principal spoilage agents in fruit-based beverages. Overall, the results demonstrate that the selected ultrasound treatment effectively controlled microbial growth and maintained nectar stability during 42 days of storage at 27°C.

### Questions for Analysis

- Which treatment best preserved the sensory characteristics of the nectar?
- Were significant changes observed in pH or total soluble solids (°Brix) among the treatments?
- Which processing method would be more feasible for industrial-scale implementation? Justify your answer.
- Which treatment provided the greatest preservation of bioactive compounds? Support your response with the experimental results obtained.

### Critical Control Points

The following critical control points should be monitored throughout the experimental process:

- Initial fruit quality.

- Pasteurization time and temperature.
- Thermal control during ultrasound treatment.
- Prevention of cross-contamination.
- Proper calibration of analytical and processing equipment.

#### Application Activity

Students are required to:

- Compare the results obtained from the three fruits.
- Determine which fruit exhibits the highest industrial processing yield.
- Propose improvements to the production process.
- Design a basic industrial production line flow diagram.
- Develop evidence-based conclusions from the experimental results.

**Table 4. Evaluation Rubric**

Criterion	Excellent (5)	Good (4)	Fair (3)	Poor (1–2)
<b>Theoretical Understanding</b>	Demonstrates full integration of theoretical concepts and practical application.	Demonstrates partial integration of theory and practice.	Describes concepts without critical analysis.	Merely repeats concepts without understanding.
<b>Technical Execution</b>	Performs procedures accurately and correctly.	Performs procedures with minor errors.	Commits frequent procedural errors.	Demonstrates insufficient knowledge of the procedure.
<b>Results Analysis</b>	Interprets and supports findings using scientific evidence.	Provides a basic explanation of the results.	Demonstrates limited interpretation of findings.	Provides no meaningful analysis.
<b>Decision-Making</b>	Justifies technological choices using scientific criteria.	Provides partial justification for decisions.	Makes decisions without adequate support.	Fails to make or justify decisions.

Source: Authors' own elaboration

## 4. Discussion

The implementation of the present application guide generated an experimental dataset comparing two preservation technologies—conventional thermal pasteurization and ultrasound processing—applied to a mixed nectar formulated from non-traditional Peruvian fruits (noni, star fruit, and tamarillo). The following discussion analyzes the significance of these findings, their implications for the food industry, and, most importantly, their educational value within the teaching–learning process of Food Engineering.

#### Impact of Processing Treatments on Bioactive Compounds: Polyphenols and Vitamin C

The results presented in Figures 1 and 2 reveal a differential response of bioactive compounds to the processing treatments applied. These findings allow students to understand that not all components of a food matrix respond equally to technological interventions.

#### Total Polyphenol Analysis

The superior performance of ultrasound treatment T4 (45°C/15 min), which achieved 33.59 mg GAE/100 g, compared with pasteurization treatment T8 (80°C/15 min), which reached 23.35 mg GAE/100 g, supports the hypothesis proposed in the introduction regarding the detrimental effects of thermal processing on heat-sensitive compounds. The approximately 30% reduction in polyphenol content observed in pasteurized samples can be attributed to the thermolabile nature of these compounds. Prolonged exposure to elevated temperatures may disrupt polyphenol structures or promote oxidation reactions, leading to their degradation.

This finding is particularly relevant for the training of future food engineers. Students must understand that when the objective is to develop products with enhanced antioxidant properties, non-thermal technologies such as ultrasound represent a more suitable processing alternative. By analyzing these results, students internalize the concept of process optimization not only from a preservation perspective but also in terms of maintaining the functional properties of foods.

#### Vitamin C Analysis

Figure 2 presents an apparently contrasting behavior. Treatment T9 (pasteurization at 80°C for 20 min) exhibited the highest vitamin C content (44.25 mg/100 mL), surpassing the ultrasound treatments. Nevertheless, ultrasound treatment T4 (45°C/15 min) also demonstrated high vitamin C retention (42.08 mg/100 mL).

This phenomenon may be explained by two mechanisms that students should learn to evaluate critically. First, matrix effects and analytical methodology may influence the results. Although severe heat treatment can degrade vitamin C, it may simultaneously inactivate oxidative enzymes such as ascorbate oxidase, which would otherwise consume vitamin C during storage and analysis. Furthermore, the 2,6-dichlorophenolindophenol method may detect total reducing compounds rather than exclusively ascorbic acid.

Second, heat-assisted extraction may have enhanced the release of vitamin C bound to cellular structures, increasing its availability for quantification.

From a pedagogical perspective, these findings demonstrate that data interpretation is not always straightforward. A higher numerical value does not necessarily indicate a superior process. Instead, results must be evaluated collectively with other quality indicators. In this case, while pasteurization achieved the highest vitamin C concentration, ultrasound processing provided superior preservation of polyphenols while maintaining high vitamin C levels.

Consequently, if the goal is to develop a beverage rich in a broad range of antioxidants, ultrasound treatment T4 represents the most favorable option. Conversely, if the primary marketing claim is based exclusively on vitamin C content, pasteurization at 80°C for 20 min may be acceptable despite the loss of other bioactive compounds.

#### **Physicochemical Stability: An Indicator of Product Identity**

Table 1 provides an example of how Food Engineering evaluates whether a processing technology alters the fundamental characteristics of a product. The results demonstrated remarkable stability in pH, °Brix, and acidity across all treatments.

From a technical perspective, the slight increase in pH and decrease in acidity observed during pasteurization at 80°C may be associated with the precipitation of organic acids or the onset of Maillard reactions, which can subtly modify the equilibrium of the system. In contrast, the minimal variations observed in ultrasound-treated samples suggest that cavitation acts primarily at the cellular and microbial levels without substantially affecting the low-molecular-weight soluble compounds responsible for sweetness and acidity.

Viscosity represents a particularly important parameter. The greater viscosity retention observed in ultrasound-treated samples suggests lower degradation of pectins, which are polysaccharides responsible for nectar texture and body. High-temperature pasteurization can hydrolyze these polymeric chains, resulting in reduced viscosity. For students, this finding demonstrates that the choice of processing technology directly affects consumer sensory perception, including mouthfeel and product consistency, which are critical quality attributes in beverages.

#### **Microbiological Effectiveness: Validation of Product Safety**

Tables 2 and 3 provide conclusive evidence regarding the most fundamental requirement of any food-processing operation: product safety and stability.

#### **Comparative Analysis**

Both preservation methods—pasteurization and ultrasound—complied with the requirements established by the Peruvian Technical Standard (NTP). Total coliform counts (<3 MPN/mL), aerobic mesophilic counts (<10 CFU/mL), and mold and yeast counts (<10 CFU/mL) remained within acceptable limits even after 42 days of storage at 27°C.

#### **Significance of the Findings**

This may be the most important outcome of the practical activity from an educational perspective. The results clearly demonstrate that ultrasound is not merely an experimental or secondary alternative but rather a technologically viable method for ensuring microbiological stability. The antimicrobial action of ultrasound is associated with cavitation phenomena that disrupt microbial cell membranes and contribute to microbial inactivation.

By comparing the microbiological performance of both technologies, students can conclude that, from a food safety perspective, pasteurization and ultrasound achieved equivalent outcomes. This understanding broadens their perception of industrial processing technologies and challenges the traditional assumption that heat is the only effective means of microbial control.

#### **Synthesis and Responses to the Application Guide Questions**

The discussion directly addresses the questions proposed in the application guide, demonstrating the effectiveness of the educational tool.

**Which treatment best preserved sensory characteristics?**

Although a formal sensory evaluation was not conducted, viscosity may be considered a useful indicator of texture. Since ultrasound processing achieved greater viscosity retention, it would likely preserve a more natural and desirable mouthfeel. Furthermore, the higher retention of polyphenols may contribute to differences in color and overall sensory profile compared with pasteurized products.

#### **Were significant changes observed in pH or °Brix?**

No substantial changes were detected. However, the slight variations observed under pasteurization conditions indicate that thermal processing may promote concentration effects or acid precipitation, phenomena that were not observed in ultrasound-treated samples.

#### **Which process would be more viable for industrial application?**

Industrial feasibility should be evaluated from a multifactorial perspective. Pasteurization is a mature technology that generally requires lower initial investment but involves higher energy consumption and a quality cost associated with the degradation of bioactive compounds. Ultrasound technology may require greater initial investment; however, it offers opportunities to produce higher-value functional beverages while reducing thermal energy requirements and potentially shortening processing times. These considerations encourage students to perform comprehensive cost–benefit analyses when evaluating industrial alternatives.

#### **Which treatment better preserved bioactive compounds?**

Ultrasound treatment T4 (45°C/15 min) demonstrated superior overall preservation of bioactive compounds, maximizing polyphenol retention while maintaining high vitamin C levels.

#### **Final Reflection: The Educational Value of the Application Guide**

The results obtained through the implementation of this guide fully validate the pedagogical approach proposed in the introduction. Students were not limited to following procedural instructions; instead, they were challenged to interpret real experimental data and develop scientific reasoning.

The activity promoted:

- Critical thinking, by requiring students to explain why ultrasound processing retained more polyphenols and preserved viscosity more effectively.
- Decision-making skills, by encouraging the selection of the most appropriate treatment according to specific quality objectives.
- Systems thinking, by demonstrating that processing technologies affect not only microbial safety but also the nutritional and sensory characteristics of foods.
- Local contextualization, through the use of non-traditional Peruvian fruits, fostering appreciation of biodiversity and encouraging innovation based on local resources.

In conclusion, the application guide proved to be an effective educational tool for transforming the laboratory into a space for knowledge construction. Rather than functioning as a procedural exercise, the laboratory became an environment for investigation, analysis, and process improvement, contributing to the development of food engineers equipped with the competencies required by modern industry.

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