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Research Article

Evaluation of the Influence of the Incorporation of Soursop (*Annona muricata*) Juice on the Quality and Stability of a Fermented Yogurt

Moriken Sangare[1, *], Mamady Diawara[2], Aissatou Yaye Diallo[1], Yawa Rosaline Millimono[2]

[1]Department of Food Technology and Control, Higher Institute of Sciences and Veterinary Medicine of Dalaba, Dalaba, Guinea

[2]Guinean Agronomic Research Institute (IRAG), Kaloum Peninsula, Conakry, Guinea

Abstract

Yogurt is one of the most widely consumed fermented dairy products worldwide. This study aimed to produce yogurts with an enhanced nutritional profile. This study evaluated the influence of incorporating soursop (*Annona muricata*) juice on the quality and stability of fermented yogurt by comparing a control sample without juice and three formulations enriched at 10%, 15%, and 20%. Microbiological analyses confirmed the absence of total and fecal coliforms, staphylococci, and sulfite-reducing anaerobes, while total aerobic mesophilic flora remained well below international standards (6–560 CFU/mL). Physicochemical parameters varied significantly depending on the level of incorporation: titratable acidity increased from 1.81% (control) to 3.49% (20%), pH ranged between 4.03 and 4.10, dry matter content varied from 31.80% to 33.72%, protein content rose from 6.26% (control) to 12.58% (20%), carbohydrates decreased from 26.72% to 23.62%, fat content ranged from 0.17% (control) to 2.85% (10%), and total ash content varied between 0.41% and 2.05%. Sensory evaluation revealed higher acceptability for yogurts containing 10% and 15% juice, with improved aroma and texture, while the 20% formulation showed increased acidity and altered texture. Overall, the incorporation of soursop juice enhanced the nutritional profile and sensory qualities of yogurt while maintaining compliance with microbiological standards, positioning soursop-enriched yogurt as a promising innovation to diversify local fermented dairy products and meet consumer expectations for natural and health-oriented foods.

Keywords

Evaluation, Yogurt, Quality, Soursop Juice (*Annona muricata*), Incorporation

1. Introduction

Yogurt is one of the most widely consumed fermented dairy products worldwide, produced by lactic acid bacteria, namely *Streptococcus thermophilus* and *Lactobacillus delbrueckii subsp. bulgaricus*. During yogurt production, these bacteria generate lactic acid, which lowers the pH and induces coagulation of milk proteins. Yogurt is an important source of high-

*Correspondence: Moriken Sangare (morikens@yahoo.fr)

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biological-value proteins and provides essential minerals such as calcium, phosphorus, and potassium, as well as B-group vitamins, particularly B6 and B12. It also offers specific nutritional advantages for individuals with lactose intolerance, as its fermentation process allows the consumption of dairy nutrients while reducing the discomfort associated with hypolactasia. Moreover, the intake of fermented dairy products enriched with probiotic bacteria has been linked to various health-promoting effects [1]. Their metabolites, including carbonyl compounds, volatile and non-volatile acids, and exopolysaccharides, strongly influence yogurt quality [2]. In general, fermented foods are of major importance globally, as their organoleptic, nutritional, and shelf-life characteristics are significantly improved compared to raw materials [3]. In recent years, markets have been flooded with yogurts available in multiple forms, including plain, flavored, mixed with fruit pulp, or whole and sliced fruits added by consumers themselves [3]. Yogurt-based beverages, non-alcoholic liquid yogurts, frozen yogurts in various flavors, and yogurt ice bars are also commercially available. The development and formulation of new products are essential to meet consumer nutritional and sensory expectations, as well as to support diversification within the food industry. Over the past decades, physicians worldwide have reported a decline in global health, reduced life expectancy, diminished work capacity, and weakened resistance to infections. A healthy diet is considered the most appropriate solution to these issues, which compels the dairy industry to continuously design new yogurt formulations. These formulations must meet consumer demands for natural products with low sugar and fat content, free from preservatives, while maintaining desirable flavor perception, which largely determines product acceptability [4]. Yogurt is often supplemented with fruits to enhance its sensory quality and health benefits. Among these fruits, soursop (Annona muricata) is notable for its antimicrobial, anti-inflammatory, and potentially anticancer properties, although the latter remain under scientific investigation. Research has highlighted the presence of bioactive compounds, particularly acetogenins, which may exert therapeutic effects [5]. During the last quarter of the previous century, global yogurt production and consumption increased substantially, reaching 14.9 million tons annually. Today, more than 30% of the world's population consumes yogurt regularly, with an estimated per capita annual consumption of 2.1 kg. In 2018, global yogurt sales generated approximately €78 billion, compared to €62 billion in 2013 [5].

The demand for functional foods is steadily increasing, supported by a growing body of scientific evidence. In this context, considerable research has focused on enhancing the sensory and functional properties of yogurt. Given the potential health risks associated with synthetic additives, recent efforts have shifted toward the use of natural ingredients considered safer for improving the nutritional quality of yogurt. Among these natural ingredients, soursop (Annona muricata) has attracted particular interest.

Soursop, a member of the Annonaceae family, is notably rich in bioactive compounds, especially annonaceous acetogenins polyketide-derived molecules reported to exhibit potential anticancer properties [1]. Its juicy and aromatic pulp is also an important source of potassium, fructose, and vitamins C, B1, and B2 [1, 6]. Despite its recognized nutritional value, soursop remains underutilized in Guinea. The fruit is characterized by a creamy, aromatic pulp highly appreciated for its distinctive flavor [7]. Soursop pulp typically contains 80–81% moisture, about 1% protein, and approximately 18% carbohydrates [8]. It is traditionally used in the preparation of juices, syrups, jams, and jellies. However, the fruit is highly perishable at full maturity: it softens rapidly, becomes spongy, is highly susceptible to fungal spoilage, and deteriorates within a few days, which limits its consumption in fresh form [1].

In Guinea, particularly in the prefecture of Dalaba, the only type of yogurt produced is artisanal yogurt flavored with synthetic aromas, sold by street vendors and in certain service stations and shops. Within this context, the development of new, healthier yogurts enriched with local products remains a major challenge. Therefore, this study was conducted to evaluate the impact of incorporating soursop juice on the physicochemical, microbiological, and sensory quality of yogurt. This work aims to contribute to dietary diversification and improve consumer well-being through innovative fermented dairy products.

2. Materials and Methods

2.1. Presentation of the Study Area

This study was conducted in the Urban Commune of Dalaba, located 355 km from the Guinean capital Conakry and 55 km from the regional headquarters of Mamou. Yogurt production and sensory evaluation were carried out at the Food Technology Laboratory of the Higher Institute of Veterinary Sciences and Medicine of Dalaba (Republic of Guinea). Physicochemical and microbiological analyses were performed at the laboratories of the National Office for Quality Control, located in the Urban Commune of Matoto in Conakry (Republic of Guinea).

2.2. Materials Used

Table 1 presents the various technical and laboratory equipment used during the implementation of the field activities.

Table 1. List and quantity of equipment used.

N°	Description	Quantity
1	Volumetric flasks	3
2	Analytical balances	2
3	Extraction devices	1
4	Erlenmeyer flasks	5
5	Petri dishes	36
6	Mixer	1
7	Ovens	5
8	Dehydrators	4
9	Crucible	4
10	Mold oven	1
11	Soxhlet apparatus	2
12	Heating mantle	1
13	Round-bottom flask	1
14	Beakers	5
15	Graduated cylinders	1
16	Bec bunsen	1
17	Blender	1
18	Water bath	1
19	Refrigerator at 4°C	1
20	Colony counter	1
21	pH meter	1
22	Digestor/Mineralization unit	1
23	Spatula	1
24	Graduated burette	1
25	Fume hood	1
26	Extraction tube	
27	Beatmer	1
28	Sieve	1
29	Stainless steel knife	3
30	Recording sheet	22

Table 2. Culture media and chemicals used.

Germ count	Culture media	Incubation temperature	Incubation time	Standards
Total Aerobic Mesophilic Flora	Plate Count Agar	30	24-72	5.105CFU/g
Total and Fecal Coliforms	Deoxycholate Lactose Agar	37-44	24 -48	103CFU/g
Sulfite-Reducing Anaerobe	Baird Parker Agar	46	24	102CFU/g

Germ count	Culture media	Incubation temperature	Incubation time	Standards
Staphylococcus aureus	Baird Parker Agar	37-44	24-48	102CFU/g

The culture media used, as well as the temperatures and incubation time for counting germs in our samples, are shown in Table 2.

The chemicals used during the laboratory work consisted of copper sulfate, 95% alcohol, NaOH (0.1N and 0.40%), a color indicator (phenolphthalein), petroleum ether, concentrated sulfuric acid, sodium sulfate, and buffered peptone water. All of these reagents were of analytical grade.

2.3. Sample Preparation

The samples used, consisting of 3 kg of powdered milk and 1 kg of soursop (Annona muricata L.), were purchased at the market in the city of Dalaba. Initially, a visual inspection was carried out to ensure the raw materials were of good quality. The sorted and purchased products were then placed in a thoroughly washed and dried cooler and transported to the food processing workshop for juice production. The powdered milk (LP brand) was also carefully protected and placed in bags to prevent any contact with the outside environment before being transported to the workshop for yogurt production. It is worth noting that when purchasing the milk, its organoleptic characteristics, including color, odor, and physical appearance, were taken into account to ensure high-quality milk.

2.4. Microbiological Analyses of Raw Materials (Milk and Soursop)

The quality of the final product being directly dependent on that of the raw materials, a microbiological assessment of milk and soursop was carried out in the microbiology laboratory of the National Quality Control Office in Matoto, Conakry. This assessment focused on the enumeration of Total Aerobic Mesophilic Flora (TAMF), Total Coliforms (TC) and Fecal Coliforms (FC), Staphylococci, and Sulfite-Reducing Anaerobes (SRA). The enumerations were performed on selective and differential culture media, following a sequence of standardized procedures and in accordance with the manufacturer's technical recommendations:

2.4.1. Preparation of the Stock Suspension

Preparation of the stock suspension was carried out in accordance with AFNOR standard NF V08‑010 (March 1996). A 25 g portion of yogurt was transferred into a sterile flask and diluted with 225 mL of sterile physiological saline. The mixture was aseptically homogenized and then allowed to stand for 30 minutes at room temperature to enable the revivification of microorganisms. The resulting mixture constituted the stock suspension.

2.4.2. Preparation of Decimal Dilutions

From the stock suspension, decimal dilutions were prepared in accordance with standard NF EN ISO 6887-1. Sterile test tubes were arranged in a rack, and 9 mL of sterile distilled water were dispensed into each tube. Successive 1 mL transfers from the stock suspension were then performed, with homogenization at each step. This procedure was repeated until the desired decimal dilution was obtained. Finally, 1 mL of the last dilution was withdrawn and discarded.

2.4.3. Enumeration of Total Aerobic Mesophilic Flora

The principle of this method is to enumerate the Total Aerobic Mesophilic Flora (TAMF) on Plate Count Agar, in accordance with standard NF EN ISO 4833-1. The procedure involves aseptically transferring 1 mL of each dilution (10^{-5}, 10^{-6}, 10^{-7}) into sterile Petri dishes, followed by the addition of 15 mL of Plate Count Agar (PCA). The contents are then homogenized by gently rotating the plates. After solidification of the medium, the plates are incubated at 30 °C for 72 hours. Colony reading focuses on red colonies with a diameter equal to or greater than 0.5 mm after 24 hours of incubation.

2.4.4. Staphylococcus Enumeration

The enumeration of Staphylococcus spp. was performed according to method NF EN 6888-1, using Baird-Parker agar as the selective culture medium. The protocol involved dissolving 60 g of dehydrated medium in 1 L of distilled water. The mixture was gradually brought to a boil with continuous agitation and maintained at boiling until complete dissolution. It was then dispensed into tubes at 9 mL per tube and sterilized in an autoclave at 121 °C for 15 minutes. After sterilization, the medium was kept in a molten state in a water bath until use. Once cooled to 45–50 °C, 5 mL of sterile egg-yolk tellurite emulsion was added to 100 mL of medium, followed by thorough homogenization. The supplemented medium was poured into sterile Petri dishes and allowed to solidify on a cold surface. The plates were subsequently dried in an incubator with the lids slightly open. For colony reading, characteristic colonies of coagulase-positive Staphylococcus appear as black or grey colonies-reflecting the reduction of tellurite to telluride—surrounded by a clear halo resulting from proteolysis within the opaque zone.

2.4.5. Enumeration of Fecal and Total Coliforms

The enumeration of fecal and total coliforms was performed according to ISO 21148: 2017. The method consists of quantifying coliforms capable of growing on DLA medium after incubation at 44 °C (fecal coliforms) and 37 °C (total coliforms) for 24 to 48 hours. The procedure began with dissolving 42.5 g of dehydrated medium in 1 L of distilled water, followed by gradual heating to boiling with continuous stirring until complete dissolution. The medium was then cooled to 45–50 °C. From the stock suspension and its successive decimal dilutions, 1 mL aliquots were transferred into sterile Petri dishes. Approximately 12 mL of medium were added, homogenized, and allowed to solidify on a cold surface. A second layer of about 4 mL of medium was then poured and left to solidify. The plates were incubated at 44 °C for fecal coliforms and at 37 °C for total coliforms for 24 to 48 hours. For colony reading, coliforms appear as red colonies with a diameter equal to or greater than 0.5 mm after 24 hours of incubation.

2.4.6. Enumeration of Sulfite-reducing Anaerobic Bacteria

The enumeration of sulfite-reducing anaerobes (SRA) was carried out using liver-meat (LM) culture medium in tubes. A volume of 20 mL of LM medium, previously melted and cooled in a water bath, was dispensed into a sterile tube, after which 1 mL of the stock suspension at a 10^{-1} concentration was added and the mixture homogenized. Following homogenization and solidification, the tubes were incubated under anaerobic conditions at 46 °C for 24 hours. Characteristic black colonies of SRA subsequently appeared within the incubation tubes.

The microbial load in the samples was then calculated using the following formula:

$$Ng = \frac{\Sigma\ c}{V\ (n1\ +\ 0.1\ n2)\ d}$$

Ng: number of microorganisms per gram of product

ΣC: sum of characteristic colonies counted on the two selected plates

V: volume of inoculum applied to each plate (in mL)

d: dilution factor corresponding to the first selected dilution

n1: number of plates retained at the first selected dilution

n2: number of plates retained at the second selected dilution

2.5. Production of Soursop Juice

Production of soursop juice began following the microbiological analysis of the fruit (*Annona muricata L.*). Ripe soursop fruits were thoroughly washed with tap water to remove surface impurities. Each fruit was then manually peeled, cut, and deseeded. A second weighing was performed to determine the pulp yield. The extracted pulp was pressed through a sieve to collect the juice in a stainless-steel container. The resulting juice was pasteurized at 85°C for 2 minutes, cooled, and stored at +4 °C until its use in yogurt production.

2.6. Production of Yogurt

Four yogurt formulations were developed at pilot scale in the food technology workshop of the Higher Institute of Sciences and Veterinary Medicine of Dalaba. The first formulation (control yogurt) consisted of 1000 g of powdered milk and 6000 mL of water. The second formulation, designated F10, contained 1000 g of powdered milk, 600 mL of soursop juice, and 5400 mL of water. The third formulation (F15) was composed of 1000 g of powdered milk, 900 mL of soursop juice, and 5100 mL of water. The fourth formulation (F20) included 1000 g of powdered milk, 1200 mL of soursop juice, and 4800 mL of water. Additional ingredients (Table 3) were subsequently incorporated into these formulations.

The process began with a visual inspection to verify that all ingredients (powdered milk, soursop juice, and lactic starter cultures) met quality and food-safety requirements. Each ingredient was then weighed to ensure accurate formulation, using an electronic balance to obtain precise measurements. The powdered milk was subsequently reconstituted by mixing it with water until a uniform consistency was achieved, ensuring proper dispersion of fat and facilitating its behavior during subsequent processing steps.

Table 3. *Processing parameters used in yogurt manufacturing.*

Ingredients	Formulations			
	Control	F10	F15	F20
Powdered milk (g)	1000	1000	1000	1000
Soursop juice (mL)	-	600	900	1200
Water (mL)	6000	5400	5100	4800
Lactic starter cultures	25 g of plain yogurt	25 g of plain yogurt	25 g of plain yogurt	25 g of plain yogurt

Ingredients	Formulations			
	Control	F10	F15	F20
Sugar (g)	500	500	500	500

Control: 1000 g of powdered milk and 6000 mL of water; F10: 1000 g of powdered milk, 600 mL of soursop juice, and 5400 mL of water; F15: 1000 g of powdered milk, 900 mL of soursop juice, and 5100 mL of water; F20: 1000 g of powdered milk, 1200 mL of soursop juice, and 4800 mL of water

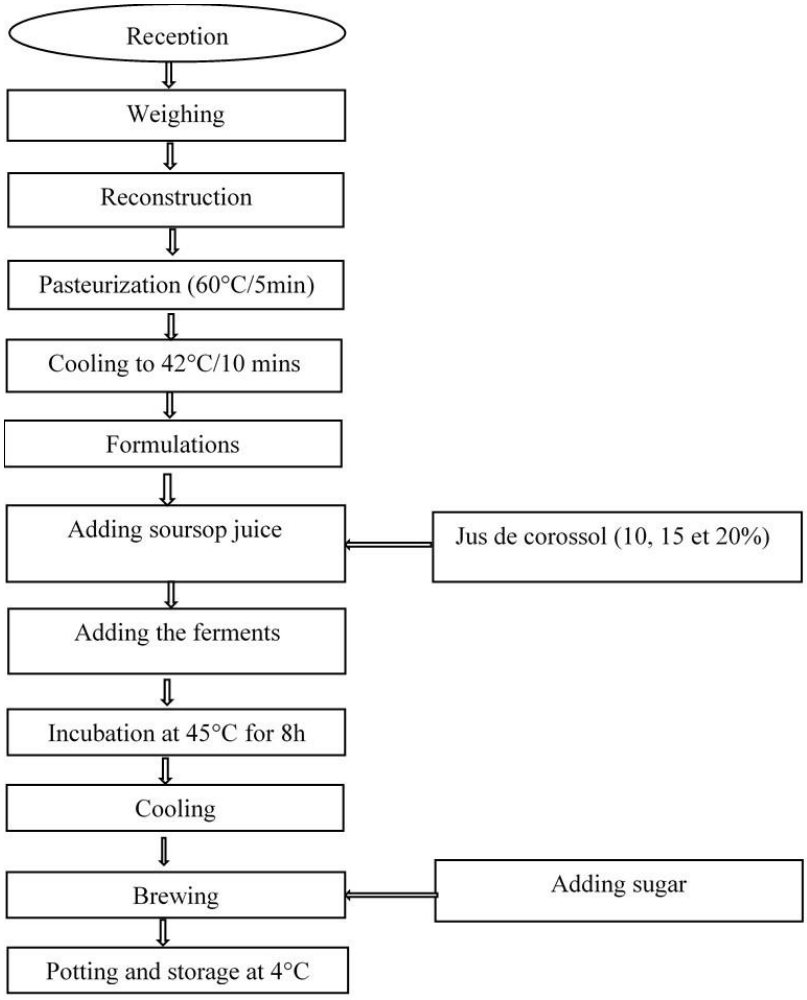

Figure 1. *Yogurt production stages.*

The mixture was heated to 85 °C for 10 minutes to inactivate undesirable microorganisms that could compromise yogurt quality, followed by controlled cooling. Once the temperature was suitable, soursop juice was gradually incorporated into the reconstituted milk. Several juice concentrations were tested to identify the formulation providing the most suitable balance of flavor and texture. A lactic starter culture composed of *Lactobacillus delbrueckii subsp. bulgaricus* and *Streptococcus thermophilus* was then added. These strains drive fermentation by converting lactose into lactic acid, thereby contributing to the characteristic acidity, texture, and sensory profile of the final yogurt. The yogurt production steps are summarized in Figure 1.

The resulting mixtures were distributed into three batches and transferred into sterile glass jars, which were immediately sealed to maintain aseptic conditions. The jars were incubated in a controlled chamber at 44 °C for 4 hours, allowing lactic acid bacteria to proliferate and convert lactose into lactic acid, thereby acidifying the medium and developing the characteristic flavor of yogurt. After fermentation, the yogurts were dispensed into containers, labeled, and cooled.

2.7. Microbiological Analyses

Microbiological analyses were carried out at the laboratory of the National Office for Quality Control (ONCQ, Matoto) to quantify Total Mesophilic Aerobic Flora (TMAF), total coliforms (TC), fecal coliforms (FC), Staphylococcus aureus, and sulfite-reducing anaerobes (SRA). The analytical procedures followed current international standards and included the preparation of culture media, preparation of the initial suspension, decimal dilutions, and enumeration of target microorganisms.

Culture media were prepared according to the manufacturer's instructions. Dehydrated media were dissolved in distilled water under heated agitation until complete dissolution, then sterilized by autoclaving in accordance with ISO 4833.

The preparation of the initial suspension was performed following NF V08-010 (1996). Twenty-six grams of sample were aseptically transferred into a sterile stomacher bag and homogenized with 234 mL of sterile buffered peptone water to obtain a 10^{-1} mother suspension. The mixture was homogenized for 1 min and then allowed to stand for 30 min to enable the physiological recovery of potentially stressed bacterial cells.

Enumeration of total aerobic mesophilic flora was performed on Plate Count Agar (PCA) according to ISO 4833. Total and fecal coliforms were quantified following the method described in NF V08-060 (1996). Enumeration of Staphylococcus aureus and sulfite-reducing anaerobes was conducted according to their respective standard protocols, using selective media appropriate for each microbial group.

2.8. Physico-chemical Analyses

Physico-chemical analyses were performed on the raw materials and the yogurt samples. The parameters assessed included moisture content, pH, titratable acidity, carbohydrate content, lipid content, total protein content, and total ash content.

2.8.1. Moisture Content Determination

Moisture content was determined according to NF V18-109. A 5 g test portion was weighed into a pre-dried, pre-weighed Petri dish and dried in an oven at 105 ± 2°C for 90 min. The dishes were then cooled in a desiccator and reweighed to calculate moisture loss.

2.8.2. pH Determination

A portable pH meter (Fisherbrand Accumet AE6) was used. A 5 g sample was weighed into a pre-tared beaker, mixed with 100 mL of distilled water, and homogenized using a magnetic stirrer. The mixture was filtered through Whatman No. 4 paper into a 100 mL volumetric flask and made up to volume with distilled water. The filtrate was transferred to a beaker, and the pH electrode was immersed for measurement.

2.8.3. Titratable Acidity Determination

Titratable acidity was measured following NF EN 12147 (1997). A 10 g sample was dissolved in 90 mL of distilled water. Two to five drops of phenolphthalein were added, and the mixture was titrated with 0.1 N NaOH until a persistent pink coloration appeared.

2.8.4. Carbohydrate Determination

Carbohydrate content was determined according to ISO 2173. A 16.26 g test portion was transferred to a 100 mL volumetric flask, diluted to volume with distilled water, and mixed until fully dissolved. The refractometer was rinsed with distilled water and with the sample, then a final drop of sample was placed on the prism. The°Brix value was recorded.

Calculation:

$$Ts = \frac{Brix}{Pe} x100$$

Ts: sugar content
Pe: test portion
Brix: sugar concentration measured by refractometry.

2.8.5. Fat Determination

Fat content was determined using NF V18-117, based on solvent extraction with n-hexane or petroleum ether followed by solvent evaporation. Suction cups were weighed (Pv), then 5 g of sample (Pe) was placed in an extraction cartridge. The cartridge was immersed in 150 mL of hexane, fitted to the extractor, and extraction was performed. After extraction, beakers were dried at 105°C for 1 h and reweighed (Pc).

Calculation:

$$\%MG = \frac{Pc-Pv}{Pe} x100$$

%MG: fat content
Pc: weight of cup with extracted fat
Pv: empty cup weight
Pe: test portion.

Proteins determination

Protein content was determined according to ISO 5983: 1997. A 0.5 g sample was weighed into a digestion tube, mixed with 15 mL concentrated sulfuric acid and catalysts, and digested for 1 h until complete clarification. The digested sample was distilled using an automated distillation unit connected to 32 % sodium bicarbonate and distilled water reservoirs. The released ammonia was collected in 30 mL boric acid and titrated with 0.1 N HCl until the color changed from green to pale pink:

Nitrogen calculation:

$$\%N = \frac{(V-V0)x14}{P_e} \times 100$$

%Proteins =%N x 6,25

%N: nitrogen content
V: sample titration volume
V_0: blank titration volume
14: molar mass of nitrogen
Pe: test portion
6.25: nitrogen-to-protein conversion factor

Total ash determination

Total ash content was determined following NF V18-117. Crucibles were washed, dried at 105°C for 30 min, cooled in a desiccator for 15 min, and weighed (Pv). A 5 g test portion (Pe) was placed in each crucible, which was then incinerated in a muffle furnace at 750–800 °C until white ash was obtained. Crucibles were cooled in a desiccator and reweighed (Pc).

Calculation:

$$\%C = \frac{Pc\text{-}P_v}{P_e} \times 100$$

%C: Total ash content;
Pv: Weight knows the crucible;
Pe: Weight of the assay take;
Pc: Weight of the loaded crucible containing the white ashes.

Sensory analysis

Sensory evaluation was conducted following the method described by Lutchmedia et al., (2004), with minor modifications. The tests were carried out in a dedicated sensory analysis room at the Food Technology Unit of the Higher Institute of Sciences and Veterinary Medicine of Dalaba, between 11: 00 and 13: 00, under controlled conditions. The panel consisted of 30 adult assessors (30–50 years old) selected based on their interest in the study and their prior experience in the sensory evaluation of fermented dairy products. The samples included plain yogurt without soursop (Control) and formulations containing 10 % (F10), 15 % (F15), and 20 % (F20) soursop juice.

All treatments were coded with random three-digit numbers and presented to the panelists in a randomized order. The sensory attributes evaluated were color, texture, flavor, and aroma.

Before the session, the study objectives and evaluation guidelines were explained to the participants. Each assessor received a standardized sensory evaluation form, a writing instrument, and potable mineral water for palate cleansing between samples.

2.9. Statistical Analyzes of Data

Analysis of variance (ANOVA) was performed using XLSTAT 2019 software, and Fisher's exact test was used to compare the means of the four formulations (Control, F10, F15, and F20). Graphs were created using Excel (Microsoft Office, 2019). An observed difference was considered not statistically significant unless $p < 0.05$ at a 95% confidence level.

3. Results and Discussion

3.1. Microbiological Analysis of Raw Materials (Milk and Soursop)

The results of the counts of total aerobic mesophilic flora, fecal and total coliforms, sulfite-reducing anaerobes and staphylococci obtained on the raw materials and the yogurts produced are presented in Table 4.

The identification of microorganisms in the powdered milk and soursop juice revealed the complete absence of total and fecal coliforms, sulfite‑reducing anaerobes, and staphylococci. In the case of soursop juice, only total mesophilic aerobic flora (TMAF) was detected, and at levels far below established microbiological criteria. These findings contrast with those reported by [9], who observed an increase in bacterial load in juices stored under refrigerated conditions, with counts too high to quantify, while coliform concentrations remained low (1.62 CFU/mL). Variations in the microbial load of fruits across different regions may be attributed to environmental contamination, including soil, irrigation water, transport conditions, washing or rinsing water, and handling practices during processing. The discrepancies between their results and ours may therefore reflect differences in processing conditions. The presence of TMAC at approximately 10 CFU/mL in fruits may also correspond to the natural microbiota. For dairy products, reported values range from 6 to 560 CFU/mL. In the powdered milk analyzed, TMAF levels reached 20 CFU/mL. These results indicate that the raw materials complied with microbiological standards and were therefore suitable for yogurt production. This observation aligns with findings by [6], who also reported the absence of coliforms in their samples. Conversely, our results differ from those of [10], who detected certain microorganisms in yogurts enriched with different soursop varieties. For the yogurts produced (Control, F10, F15, and F20), no contamination by total or fecal coliforms, sulfite‑reducing anaerobes, or staphylococci was detected, consistent with the results of [11]. However, TMAF were present in all formulations at varying concentrations, though always below recommended microbiological limits. The data also show that microbial counts increased with higher incorporation levels of soursop juice. These findings differ from those of [12], who reported that the type of fruit added influenced microflora development in yogurt, potentially affecting product shelf life. The overall compliance with microbiological standards may be attributed to adherence to good hygiene and manufacturing practices throughout yogurt production, as well as appropriate storage conditions. Based on the results obtained, all formulations corresponding to the different incorporation levels meet current microbiological requirements.

Table 4. Results of microbiological analyses of the different samples.

Samples	Number of germs per (CFU/mL)					Appreciation
	TMAF	CT	CF	*Staph A*	ASR	
Powdered milk	20	00	00	00	00	Satisfying
Soursop juice	10	00	00	00	00	Satisfying
Control	6	00	00	00	00	Satisfying
F10	10	00	00	00	00	Satisfying
F15	70	00	00	00	00	Satisfying
F20	560	00	00	00	00	Satisfying
Microbiological criteria	$\leq 10^6$ CFU/mL	≤102 CFU/mL	≤ 10 CFU/mL	Abs/mL	Abs/mL	-

TMAF: Total Mesophilic Aerobic Flora; CT: Total Coliforms; CF: Fecal Coliforms; Staph: AStaphylococci; ASR: Sulfite-Reducing Anaerobes; CFU/mL: Colony-Forming Units per millilitre; Control: 1000 g of powdered milk and 6000 mL of water; F10: 1000 g of powdered milk, 600 mL of soursop juice, and 5400 mL of water; F15: 1000 g of powdered milk, 900 mL of soursop juice, and 5100 mL of water; F20: 1000 g of powdered milk, 1200 mL of soursop juice, and 4800 mL of water

3.2. Physicochemical Analysis

The physicochemical analyses performed on the yogurts focused on the determination of titratable acidity, pH, dry matter, sugars, fat, proteins, and total ash contents.

3.2.1. Titratable Acidity Determination

The acidity values were 1.81%, 2.22%, 3.37%, and 3.49% in the control, F10, F15, and F20 formulations, respectively. Analysis of variance (ANOVA) indicated that the addition of soursop juice induced a significant variation ($p < 0.05$) in acidity among the different formulations. Furthermore, formulations F10, F15, and F20 exhibited relatively similar acidity levels (2.22% to 3.49%), whereas the control formulation showed a lower acid content (1.81%) (Figure 2).

The values obtained in this study are higher than those reported by [6], who observed acidity levels ranging from 0.62% to 0.77% in soursop-flavored yogurts. This discrepancy may be attributed, on one hand, to the higher proportion of soursop juice incorporated into the formulations, which could contribute to increased acidity, and on the other hand, to the maturity stage of the soursop used. Moreover, our results also exceed those reported by [13], who found lower acidity levels in their yogurt samples.

3.2.2. Determination of Dry Matter, Protein, and Carbohydrate Contents in Yogurts Produced

The dry matter, protein, and carbohydrate content were determined in the different types of yogurt. As shown in Figure 3, the physicochemical parameters varied significantly in the different formulations (Control, F10, F15, and F20).

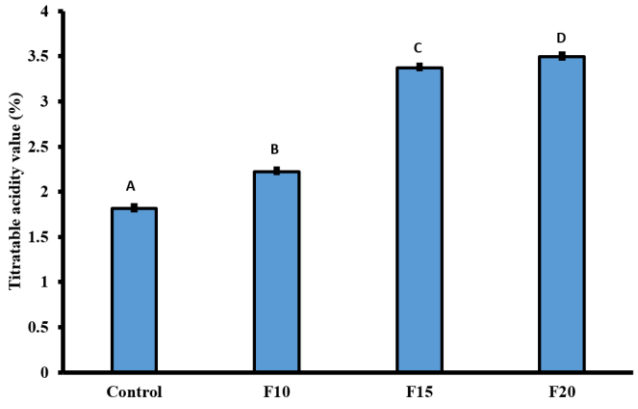

Figure 2. Titratable acid content of yogurts.

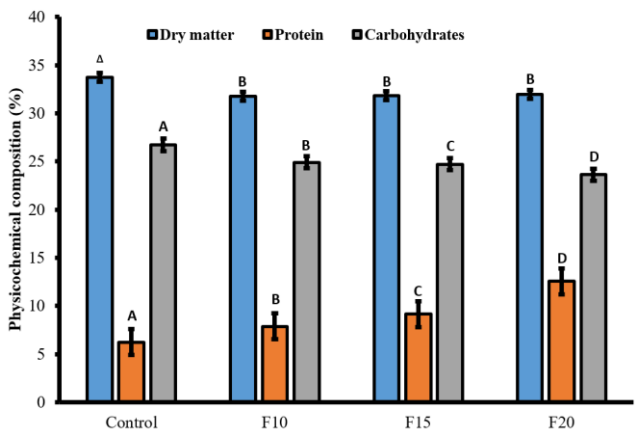

Figure 3. Results of physicochemical parameter determination.

The dry-matter contents were 33.72%, 31.80%, 31.83%, and 31.98% in the Control, F10, F15, and F20 formulations, respectively. These results indicate that the addition of soursop juice produced a significant difference among formulations, as confirmed by analysis of variance (ANOVA), which showed a significant effect ($p < 0.05$). The control sample exhibited the highest dry-matter content (33.72%), whereas the lowest value (31.80%) was recorded in F10. This difference may be related to refrigeration time and the amount of water used during preparation. Our values are higher than those reported by [14], who found dry-matter contents of 16.31% and 9.89%, likely due to the incorporation of soursop juice and the amount of water used for reconstitution. Conversely, our results are lower than those of [15], who reported dry-matter values of 92.78%, 94.46%, and 93.5% in soursop yogurts.

The protein contents obtained for the different formulations were 6.26%, 7.88%, 9.15%, and 12.58%. Comparison of means showed that the 20% incorporation rate produced the highest protein content (12.58%). These values exceed those reported by [16], who found protein levels of 3.75% and 9.6%. This variation may be attributed to differences in incorporation rates and the type of milk used. Our results are also consistent with those of [15], who reported similar protein levels in soursop-enriched yogurts.

The carbohydrate contents were $26.72 \pm 0.01\%$, $26.72 \pm 0.01\%$, $24.72 \pm 0.01\%$, and $23.62 \pm 0.01\%$ for the Control, F10, F15, and F20 formulations, respectively. The control and F10 samples showed the highest and identical carbohydrate levels ($26.72 \pm 0.01\%$), which can be explained by the added sugar. The lowest value was observed in F20 ($23.62 \pm 0.01\%$), likely due to the higher proportion of soursop juice. These values are lower than those reported by [17], who found carbohydrate contents of $10.03 \pm 0.01\%$, $13.49 \pm 0.01\%$, and $14.51 \pm 0.01\%$, a difference that may be linked to the amount of soursop used and its maturity at the time of processing. Our results are also lower than those of [3], who reported 15% carbohydrates in their soursop yogurts.

3.2.3. Measurement of pH in the Produced Yogurts

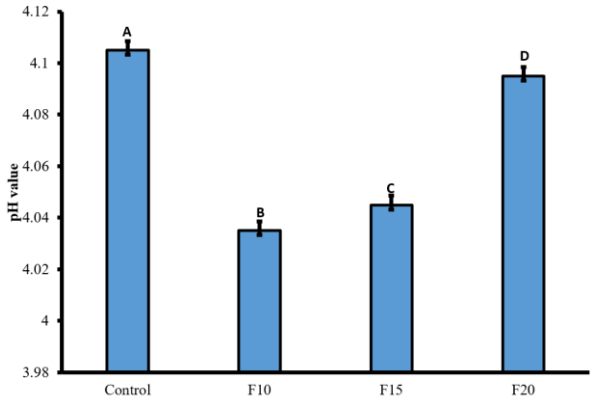

Figure 4. *pH values of the different yogurt samples.*

The pH values obtained for the soursop-enriched yogurts were 4.08 ± 0.03, 4.03 ± 0.05, 4.04 ± 0.04, and 4.09 ± 0.04 for the Control, F10, F15, and F20 formulations, respectively.

The results indicate that the addition of soursop juice induced a significant variation among the different formulations, as confirmed by the analysis of variance (ANOVA), which also revealed a significant difference ($p < 0.05$). The F20 formulation exhibited the highest pH value (4.09 ± 0.04), which may be attributed to the intrinsic pH of the soursop juice, as reported by par [9]. The pH values obtained for formulations F10 and F15 were higher than those reported by [13], who observed pH levels ranging from 3.15 to 3.62 in soursop-enriched yogurts. This discrepancy may be related to the incorporation of soursop juice, which contains substantial amounts of organic acids, particularly ascorbic acid. These values are slightly lower than those reported by [6] for soursop-fortified yogurts (pH 4.47), a difference that may be explained by variations in processing methods, equipment, and the intrinsic characteristics of the fruit used. Furthermore, our values are also lower than the pH of 4.43 reported by the same authors for yogurt containing soursop. Overall, these findings demonstrate that the pH of soursop-enriched yogurt is highly variable and strongly influenced by the specific properties of the fruit used [6].

3.2.4. Determination of Fat and Total Ash Content

Table 5 presents the fat and total ash contents obtained for the different yogurt formulations.

Table 5. *Ash and Lipid contents of the different yogurt produced.*

Samples	Ash (%)	Fat (%)
Control	2.05 ± 0.03^{A}	0.175 ± 0.32^{A}
F10	0.88 ± 0.31^{B}	2.855 ± 0.40^{B}
F15	0.41 ± 0.33^{C}	1.375 ± 0.12^{C}
F20	0.68 ± 0.25^{D}	0.635 ± 0.31^{D}

Values are expressed as means ± standard deviations of three determinations. Values in the same column followed by the same letter are significantly different ($p < 0.05$); the superscript letters "A-C" separate the means obtained by ANOVA using Fisher's multiple comparison test. Control: 1000 g of powdered milk and 6000 mL of water; F10: 1000 g of powdered milk, 600 mL of soursop juice, and 5400 mL of water; F15: 1000 g of powdered milk, 900 mL of soursop juice, and 5100 mL of water; F20: 1000 g of powdered milk, 1200 mL of soursop juice, and 4800 mL of water.

The analysis of this table shows that ash contents of 2.05 ± 0.03, 0.88 ± 0.31, 0.41 ± 0.33, and 0.68 ± 0.25 were obtained for the Control, F10, F15, and F20 formulations, respectively. These results indicate that incorporating soursop juice into the yogurt led to a significant difference among formulations, as confirmed by the analysis of variance (ANOVA),

which revealed a significant effect ($p < 0.05$). The Control sample exhibited the highest ash content (2.05 ± 0.03), which may be attributed to the raw materials used and the composition of the ingredients. Our ash values are higher than those reported by [16], who found 0.59 ± 0.01 and 0.60 ± 0.01. This variation may be explained by the mineral richness of the raw materials and the effect of atomization during thermal processing. Conversely, our results are lower than those reported by Sunmonu *et al*., (2023), who obtained ash contents of 2.40 and 3.05 in their soursop yogurt formulations. The table also shows that the lipid contents of the soursop-enriched yogurts were $0.17 \pm 0.32\%$, $2.85 \pm 0.40\%$, $1.375 \pm 0.12\%$, and $0.635 \pm 0.31\%$ for the Control, F10, F15, and F20 formulations, respectively. The F10 formulation exhibited the highest lipid content ($2.85 \pm 0.40\%$), which may be attributed to the addition of soursop juice.

These lipid values are lower than those reported by [11], who found lipid contents of 4.39%, 2.50%, and 3.73%. Such differences may be due to the nature of the raw materials and adherence to good manufacturing practices. Furthermore, our results are lower than those reported by [16] for soursop yogurt production.

3.3. Sensory Analysis Results

The sensory evaluation conducted on the produced yogurts focused on assessing color, texture, aroma, odor, taste, and overall acceptability. The results are presented in Figures 5 and 6 and in Tables 6 and 7. Color is one of the most critical parameters in the perception of food quality. In this study, the color of the yogurts was evaluated on a scale ranging from white to light beige. Fifteen (15) panelists participated in the evaluation, and the results (Figure 5) show that the incorporation of soursop juice affected the color of the yogurts. The formulations containing soursop juice F10, F15, and F20 displayed a darker beige color compared with the Control yogurt, which was described as white.

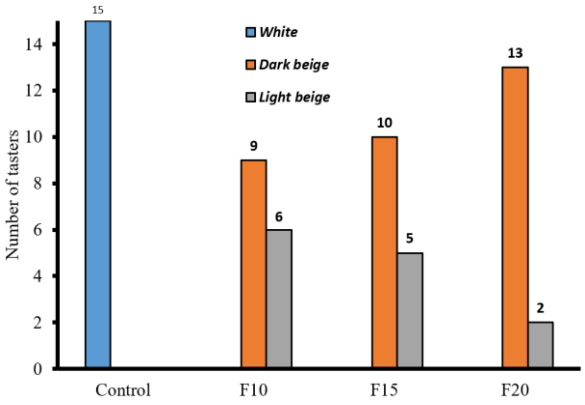

Figure 5. *Color evaluation test.*

The results indicate that the dark-beige coloration of the yogurts is proportional to the incorporation rate of soursop juice, as 9, 10, and 13 panelists respectively described formulations F10, F15, and F20 as having a dark-beige color. These findings are consistent with those reported by [6], who observed in their study that the addition of soursop at levels of 6.7% and 13% significantly influenced the color of yogurts. In contrast, the control formulation exhibited a white color, as unanimously noted by all panelists (100%). This observation is entirely expected, since a standard yogurt is normally characterized by a white appearance.

The results of the texture evaluation are presented in Figure 6. The texture of the manufactured yogurts was assessed based on the criteria thick, slightly thick, and very thick.

Texture evaluation

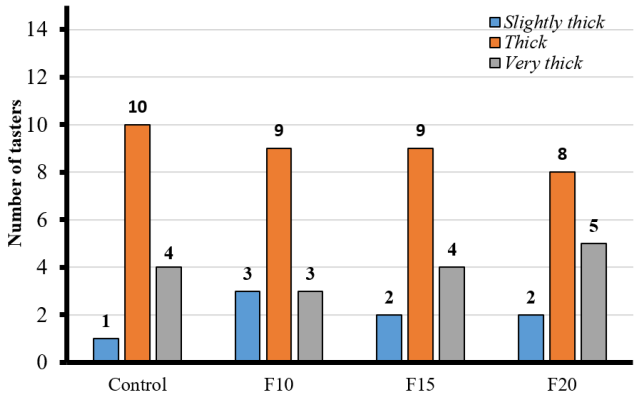

Figure 6. *Texture evaluation results.*

The findings indicate that the incorporation of soursop juice markedly influenced the textural properties of the yogurts. Formulations containing soursop juice (F10, F15, and F20) were predominantly described by panelists as having a thick texture. However, the addition of soursop juice at levels of 10–15% significantly enhanced the texture compared with formulation F20, which exhibited less favorable textural characteristics. This pattern diverges from the observations of [3], who reported a proportional improvement in yogurt texture with increasing soursop juice concentration. In contrast, the textural scores of F10 and F15 were comparable to those of the control formulation, suggesting that when soursop juice is incorporated at levels exceeding 15%, a deterioration of textural quality becomes apparent.

Aroma constitutes a critical determinant of yogurt acceptability, as it strongly shapes sensory perception and consumer preference. In this study, the aroma of the produced yogurts was evaluated according to three descriptors: non-aromatized, slightly aromatized, and highly aromatized. The corresponding results are presented in Table 6.

Table 6. Aroma evaluation test.

Formulations	Sensory attributes		
	Unflavored	Slightly flavored	Highly flavored
Control	14	1	0
F10	1	6	9
F15	0	5	10
F20	0	2	13

Control: 1000 g of powdered milk and 6000 mL of water; F10: 1000 g of powdered milk, 600 mL of soursop juice, and 5400 mL of water; F15: 1000 g of powdered milk, 900 mL of soursop juice, and 5100 mL of water; F20: 1000 g of powdered milk, 1200 mL of soursop juice, and 4800 mL of water.

The incorporation of soursop juice induced a significant modification of the yogurts' aromatic profile [14], as evidenced by the clear preference expressed for the enriched formulations (F10, F15, and F20). The perceived aromatic intensity increased proportionally with the level of juice addition: higher soursop concentrations resulted in a more pronounced aroma. This trend aligns with the findings of [3], who reported the highest sensory scores for yogurts containing 10% and 15% soursop nectar compared with plain yogurt. Conversely, the control yogurt was predominantly described as non-aromatized, with 14 out of 15 panelists confirming the absence of fruity notes. The addition of fruit is widely recognized for enhancing the sensory attributes of fermented dairy products, and the present results are consistent with this established pattern. Formulation F20 achieved the highest overall scores, suggesting that soursop contributes positively to both the visual appeal and aromatic expression of yogurt, in agreement with the observations of [18] and [3]. Furthermore, the improved product stability observed with the addition of soursop pulp may be related to its high dietary fiber content although this parameter was not measured in the present study corroborating the conclusions of [19]. Overall, incorporating soursop juice at levels of 10%, 15%, and 20% effectively enhances yogurt aroma while strengthening its sensory, nutritional, and technological qualities.

The results related to flavor perception are presented in Table 7. The sensory attributes assessed included acidic, moderately acidic, and slightly acidic characteristics.

Flavor Evaluation Results

The F20 formulation exhibited markedly higher acidity than the control, F10, and F15 formulations, all of which fell within a moderate acidity range. This difference, as shown in Table 7, contrasts with the findings of [20], who reported an acidic perception from the very first yogurt product evaluated. The discrepancy between the two studies may stem from the incorporation of soursop juice, whose intrinsically acidic flavor, combined with varying addition levels, directly influences sensory perception. The evolution of sensory attributes observed in the present formulations is consistent with the measured titratable acidity and pH values, which are recognized as key physicochemical indicators of yogurt quality [14]. The addition of soursop thus induced significant modifications in organoleptic characteristics particularly in terms of flavor profile and texture while preserving the integrity of the yogurt's physicochemical and functional properties.

Table 7. Flavor Evaluation Results of the Yogurts Produced.

Formulations	Sensory attributes		
	Slightly acidic	Slightly acidic	Slightly acidic
Control	8	6	1
F10	4	9	2
F15	5	7	3
F20	4	6	5

Control: 1000 g of powdered milk and 6000 mL of water; F10: 1000 g of powdered milk, 600 mL of soursop juice, and 5400 mL of water; F15: 1000 g of powdered milk, 900 mL of soursop juice, and 5100 mL of water; F20: 1000 g of powdered milk, 1200 mL of soursop juice, and 4800 mL of water.

4. Conclusion

The soursop-fortified yogurt exhibits notable advantages compared to plain yogurt, resulting in a significant improvement in its microbiological, physicochemical, and sensory characteristics. The present study aims to evaluate the effects of soursop juice on the physicochemical, microbiological, and sensory quality of yogurts. The production of a soursop-enriched yogurt demonstrated that this tropical fruit constitutes an excellent substrate for developing an innovative, nutritious dairy product that aligns with consumer preferences. The assessment of the physicochemical parameters of the prepared yogurts indicates that the addition of soursop juice influenced these parameters. Regarding hygienic quality, the yogurts showed microbiological characteristics that fully complied with established standards. Sensory evaluation revealed that yogurts containing 10% or 15% soursop juice were preferred over those containing 20%. In light of these findings, it appears necessary to conduct further research on the production of soursop-enriched yogurt in order to foster an ecosystem conducive to agri-food innovation and to maximize the economic and social impact of promoting local products. The results of the present study and the conclusions drawn from them open additional research perspectives. Future investigations are planned to more precisely characterize the structural

profile of these yogurts at the molecular scale, determine their mineral composition, and examine the effect of different storage conditions on the evolution of their physicochemical, microbiological, and sensory qualities over time.

Abbreviations

TAMF	Total Aerobic Mesophilic Flora
TC	Total Coliforms
FC	Fecal Coliforms
SRA	Sulfite-Reducing Anaerobes
PCA	Plate Count Agar (PCA)
ANOVA	Analysis of Variance

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Author Contributions

Moriken Sangare: Conceptualization, Data curation, Funding acquisition, Investigation, Methodology, Project administration, Software

Mamady Diawara: Visualization, Resources, Validation, Writing – review & editing

Aissatou Yaye Diallo: Methodology, Formal Analysis, resources, draft, Writing – review & editing

Yawa Rosaline Millimono: Funding acquisition, Methodology, Writing– original draft

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Conflicts of Interest

The authors declare that they have no known financial or personal conflicts of interest that could have influenced the work presented in this article.

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