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Research Article

Microbiological and Sensory Profile of Palm Kernel Oil Produced in Benin

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Abstract

In Benin, palm kernel oil is used for various purposes, including food, cosmetic, and medicinal applications. However, artisanal production processes raise concerns about the microbiological quality of these oils and may influence their sensory characteristics, thereby questioning consumer safety. The objective of this study was to evaluate the microbiological and sensory quality of palm kernel oils produced using different processing technologies in Benin. To achieve this, oil samples from three different technologies were considered: modern technology with kernel roasting (MT), modern technology with solar drying (MS), and semi-traditional technology (ST). A total of eighty-one palm kernel oil samples were aseptically collected from high-production areas and analyzed using standard methods. Data were processed using Excel 2016 and R 4.4.2 by calculating means and standard deviations, followed by comparisons using ANOVA and the Student–Newman–Keuls test ($P < 0.05$). The analyzed palm kernel oils were free from major pathogens (*Salmonella spp., Escherichia coli, Bacillus cereus*), confirming their microbiological safety. However, aerobic mesophilic bacteria (1.58×10^3–5×10^4 CFU/g), total coliforms (0.92×10^2–2.37×10^2 CFU/g), and yeasts/molds (up to 2.8×10^2 CFU/g) exceeded acceptable limits, and the presence of *Staphylococcus spp.* (1.5×10^1–2.0×10^1 CFU/g) suggests contamination related to handling, storage, or drying conditions. Sensory evaluation revealed that the semi-traditional technology (ST) best preserves aroma, taste, and overall acceptability, whereas roasting (MT) alters the organoleptic profile. These findings highlight the need to optimize hygiene practices and processing methods to ensure optimal microbiological and sensory quality, thereby guaranteeing the safety and acceptability of the oils produced.

Keywords

Palm Kernel Oil, Food Hygiene, Quality, Sensory Acceptability, Benin

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1. Introduction

West Africa is characterized by a rich diversity of food plants, with local species contributing significantly to food systems and the socioeconomic development of populations [1, 2]. Among these resources, oilseeds constitute an important component of the human diet and are widely recognized for their high nutritional value. They play a key role in providing lipids and proteins and represent potential raw materials for the food and cosmetic industries [1, 2]. Ensuring food quality and safety is a critical issue for the agri-food industry, with significant implications for public health and consumer confidence [3], particularly in West Africa where artisanal production chains dominate vegetable oil processing [4]. Palm kernel oil, derived from the kernels of the oil palm (*Elaeis guineensis*), is widely consumed in Benin for its food, cosmetic, and medicinal uses [5-7]. Although valued for its organoleptic and biochemical properties, this oil may be exposed to microbial and mycotoxin contamination, especially when hygiene conditions are poorly controlled during harvesting, storage, and processing stages [8-10]. Artisanal oils present a risk of contamination by yeasts, molds, and pathogenic bacteria, which can alter the organoleptic and chemical quality of the product and pose health risks to consumers [11, 12]. Aflatoxins, produced by aflatoxigenic fungi such as *Aspergillus spp*., are of particular concern because they are heat-resistant and may persist in finished products [5]. Indeed, several authors have reported frequent contamination of oilseeds by aflatoxin-producing fungi, leading to the presence of hazardous mycotoxins such as aflatoxins [9, 13]. Studies conducted in West Africa and Nigeria have documented contamination of various vegetable oils by these mycotoxins, highlighting the urgent need to characterize the microbiological quality of locally produced products [5, 8]. Beyond safety concerns, processing methods also influence the sensory properties of palm kernel oil, such as color, texture, odor, and taste, which determine its acceptability to consumers [14]. Flavor plays a key role in shaping consumer preferences, product differentiation, and the overall market success of food products [15]. However, few studies have focused on the microbiological characterization and sensory profile of palm kernel oil produced in Benin, as existing research has mainly addressed physicochemical and nutritional parameters. This creates a scientific gap that limits the valorization of the oil and the implementation of safer processing practices. In a context where quality and food safety requirements are becoming increasingly stringent at both national and international levels, it is essential to evaluate the microbiological and sensory characteristics of palm kernel oil produced using different processing methods in Benin. Such an evaluation will not only help determine compliance with international quality standards but also identify critical factors affecting its sensory value and safety. Therefore, the present study aims to characterize the microbiological and sensory profile of palm kernel oil produced in Benin.

2. Methodology

2.1. Plant Material

The plant material consisted of palm kernel oil samples obtained from oil palm (*Elaeis guineensis*) kernels.

Figure 1. *Oil palm fruits (a) and palm kernel oils (b).*

2.2. Methods

2.2.1. Monitoring of Production and Sampling of Palm Kernel Oil

Samples were collected from local female producers using three processing methods: modern (solar drying), modern (roasting), and semi-traditional. For each method, sampling was conducted in three distinct areas, with three producers per area, and three 1-L samples per producer, resulting in twenty-seven (27) independent samples per method to ensure representativeness and account for inter-producer variability. Oils produced using the modern solar-drying method were collected from Toviklin (Couffo), Allada (Atlantique), and Takon (Ouémé); those from the modern roasting method were collected from Allada (Atlantique), Missérété (Ouémé), and Takon (Ouémé); and oils from the semi-traditional method, combining manual operations and rudimentary equipment, were collected from Aplahoué-center (Couffo), Allada (Atlantique), and Takon (Ouémé). In total, eighty-one (81) samples were collected, labeled, and stored in hermetically sealed containers, then transported to the laboratory aseptically with dry ice. Sampling was carried out from September to November 2025 at two-week intervals for each producer. Microbiological analyses were performed as soon as possible to minimize any changes in microbial load.

Figure 2. *Some palm kernel oil samples.*

2.2.2. Microbiological Analyses

Microbiological analyses were carried out not only for pathogenic microorganisms but also for indicator organisms reflecting good hygiene practices in food products [16]. The analyses included enumeration of aerobic mesophilic bacteria, total and thermotolerant coliforms, yeasts and molds, anaerobic sulfite-reducing bacteria, *Bacillus cereus*, enterobacteria, *Escherichia coli, staphylococci*, and detection of *Salmonella spp*. using cultures on synthetic nutrient media. Culture media were prepared according to the manufacturer's instructions and poured after inoculation, except for Sabouraud chloramphenicol agar and Baird-Parker agar enriched with egg yolk and potassium tellurite, which were pre-poured into Petri dishes. To prepare the stock solution, 10 mL of each sample was placed in a sterile stomacher bag, to which 2 mL of Tween 80 and 88 mL of buffered peptone water (EPT) were added under aseptic conditions and homogenized. Serial decimal dilutions were then performed from the stock solution. Aerobic mesophilic bacteria were enumerated on PCA agar after incubation at 30°C for 72 h ± 2 h [17]; total coliforms on VRBA agar at 37°C for 24 h ± 2 h [18]; thermotolerant coliforms on VRBA agar at 44°C for 24 h ± 2 h [19]. For *Escherichia coli,* TBX agar was used, and Petri dishes were incubated at 44°C for 24 h [20]. *Staphylococci* were enumerated on Baird-Parker agar with egg yolk and potassium tellurite after incubation at 37°C for 24–48 h [21]. *Salmonella spp.* detection was performed according to the ISO 6579-1 (2017) standard [22]; enterobacteria were enumerated on VRBG agar at 37°C for 24 h [23]. Enumeration of anaerobic sulfite-reducing bacteria (ASR) was performed on Tryptone Sulfite Neomycin (TSN) agar after incubation at 44°C for 48 h ± 1 h [24]. *Bacillus cereus* was enumerated on selective Mossel agar (PEMBA: Polymyxin Egg Yolk Mannitol Bromothymol Blue Agar) and incubated at 30°C for 24 h [25]. Yeasts and molds were enumerated on Sabouraud chloramphenicol agar and incubated at 25°C for 5 days [26]. All analyses were performed in triplicate, and the mean values were recorded.

Expression of results: according to the ISO 7218, V08-015 [27]

For colony counts between 15 and 300, two successive dilutions were retained. The microbial load was calculated using the formula recently applied by Nanoukon *et al.* [28]. The results obtained from the detection and enumeration of microbial flora were expressed in CFU/g or CFU/mL using the following formula (1):

$$N = \frac{\Sigma C}{V\,(n1+0{,}1\,n2)\times d} \quad (1)$$

N = Number of microorganisms expressed in CFU per g or per mL

ΣC = Sum of colonies counted on selected and countable plates

n1 = Number of countable plates at the first selected dilution

n2 = Number of countable plates at the second selected dilution

d = Dilution factor corresponding to the first selected dilution (the least diluted inoculum)

V = Volume of inoculum applied to each plate

For low counts ranging from 1 to 14 colonies, only one dilution was retained, and the microbial load was calculated using the following formula (2):

$$N = \boldsymbol{C/vn} \quad (2)$$

Where: N = number of CFU observed on all selected plates

C: colonies counted on the plates retained from the selected dilution

v: volume of inoculum plated

n: number of countable plates

d: dilution factor corresponding to the selected dilution

Interpretation of Microbiological Results

The microbiological results, expressed in CFU/g, were interpreted according to a three-class plan shown in Figure 3:

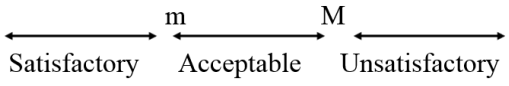

Figure 3. *Three-Class Microbiological Quality Criteria.*

m = Official microbiological criterion: all results less than or equal to this value are considered satisfactory;

M = Acceptability threshold representing the value above which results are no longer considered satisfactory, without the product necessarily being toxic. M values vary depending on the type of sample: liquid (M = 30m) or solid (M = 10m);

1) Result ≤ m: quality is satisfactory

2) Result between m and M: quality is acceptable

3) Result > M: quality is unsatisfactory

Confirmatory Tests for Bacterial Isolates

To identify bacterial strains enumerated on the different culture media, specific tests were performed, including Gram

staining, oxidase, catalase, and H_2S production tests.

1) Gram Staining

The bacterial smear was first heat-fixed onto a glass slide. The slide was then covered with crystal violet for 30 to 60 seconds and rinsed with tap water to remove excess stain. It was subsequently treated with Lugol's iodine solution for 30 to 60 seconds and rinsed again. The slide, held vertically, was decolorized with alcohol for 30 to 60 seconds, followed by another rinse. Finally, the smear was counterstained with diluted Ziehl fuchsin (1/10) for 10 to 20 seconds and rinsed. After drying, immersion oil was applied, and the slide was observed under a light microscope using the ×100 objective [29]. Gram-positive bacteria appeared purple, whereas Gram-negative bacteria appeared pink.

2) Catalase test

A drop of hydrogen peroxide was placed on a clean, dry glass slide using a Pasteur pipette. A small amount of bacterial colonies from the culture medium was then added using a platinum loop. A positive reaction was indicated by the release of oxygen bubbles, forming a foamy solution [29].

3) Oxidase test

A suspected colony from a selective isolation medium was spread onto a test strip containing N, N, N', N'-tetramethyl-p-phenylenediamine dihydrochloride using a Pasteur pipette. A purple coloration indicated a positive oxidase reaction, whereas the absence of color change indicated a negative result.

4) H_2S production test

A suspected colony from a selective isolation medium was inoculated into Kligler–Hajna medium by streaking the slant and stabbing the butt. The medium was incubated at 37°C for 24 h with the cap loosened. H_2S production was indicated by black coloration between the slant and the butt or along the stab line.

2.2.3. Sensory Analyses

The parameters evaluated included color, texture, taste, odor, aftertaste, and overall acceptability using the standardized hedonic method described in the ISO 11136, with a panel of 40 randomly selected and trained assessors [30]. Panelists compared palm kernel oil samples using the following scale: 1 = Very unpleasant, 2 = Unpleasant, 3 = Neither pleasant nor unpleasant, 4 = Pleasant, 5 = Very pleasant. Consumer preference was subsequently determined. The analysis was repeated a second time using white bean dishes.

2.2.4. Statistical Analyses

Data obtained from the analyses were processed using Microsoft Excel 2016. Means and standard deviations were calculated. Mean comparisons were performed using analysis of variance (ANOVA) followed by the Student–Newman–Keuls test, using R software (version 4.4.2). The level of statistical significance was set at 5% ($P < 0.05$).

3. Results

3.1. Microbiological Characteristics of Palm Kernel Oil from Different Production Methods in Benin

The microorganisms investigated included aerobic mesophilic bacteria, total and thermotolerant coliforms, yeasts and molds, anaerobic sulfite-reducing bacteria, *Bacillus cereus*, Enterobacteriaceae, *Escherichia coli, staphylococci*, and *Salmonella spp.* Table 1 presents the microbiological characteristics of palm kernel oil produced using different processing methods.

Table 1. *Microbiological characteristics of palm kernel oil from different production methods.*

MICROORGANISMS (CFU/g)	Palm kernel oils			Codex Alimentarius [31]
	MS	MT	ST	
Aerobic mesophilic bacteria	$2{,}26.10^4 \pm 1{,}06$	$5.10^4 \pm 2{,}37$	$1{,}58.10^3 \pm 1{,}51$	$m \leq 10^4$
Total coliforms	$0{,}92.10^2 \pm 0{,}84$	$2{,}37.10^2 \pm 1{,}58$	$1{,}17.10^2 \pm 0{,}36$	$m \leq 10^2$
Thermotolerant coliforms	$2.10^1 \pm 0{,}10$	$5{,}50.10^1 \pm 0{,}16$	$1.10^1 \pm 1{,}06$	$m \leq 10^2$
Escherichia coli	0	0	0	$m \leq 10$
Enterobacteriaceae	$8 \pm 0{,}04$	$10 \pm 0{,}08$	$5 \pm 0{,}05$	$m < 10^2$
Salmonella spp	Absence	Absence	Absence	Absence /25 g
Staphylococcus spp	$2{,}0.10^1 \pm 1{,}41$	$1{,}5.10^1 \pm 0{,}71$	$1{,}63.10^1 \pm 1{,}06$	$m \leq 10^2$
Anaerobic sulfite-reducing bacteria	Presence	Absence	Absence	Absence/1g
Bacillus cereus	<10	<10	<10	$m < 10^2$
Yeasts	$10^2 \pm 0{,}04$	$1{,}1.10^2 \pm 0{,}03$	$< 10^2$	$m < 10^2$

MICROORGANISMS (CFU/g)	Palm kernel oils			Codex Alimentarius [31]
	MS	MT	ST	
Molds	$2{,}3.10^2 \pm 0{,}04$	$2{,}8.10^2 \pm 0{,}05$	$2.10^2 \pm 0{,}035$	$m < 10^2$

MT = Modern technology with roasted kernels; MS = Modern technology with sun-dried kernels; ST = Semi-traditional technology

Analysis of Table 2 shows that aerobic mesophilic bacteria counts were 2.26×10^4 CFU/g for MS, 5×10^4 CFU/g for MT, and 1.58×10^3 CFU/g for ST, indicating that MS and MT slightly exceeded the maximum limit of 10^4 CFU/g, whereas ST complied with the standard. Total coliform counts were 0.92×10^2 CFU/g for MS, 2.37×10^2 CFU/g for MT, and 1.17×10^2 CFU/g for ST. Thermotolerant coliforms were within acceptable limits in all samples (2×10^1, 5.5×10^1, and 1×10^1 CFU/g, respectively). *Escherichia coli* and *Salmonella spp.* were absent in all samples, and Enterobacteriaceae counts were low (8, 10, and 5 CFU/g), complying with the limit of less than 10^2 CFU/g. Similarly, *Staphylococcus spp*. levels (2.0×10^1, 1.5×10^1, and 1.63×10^1 CFU/g) were within acceptable limits. Anaerobic sulfite-reducing bacteria were detected only in MS samples, while *Bacillus cereus* counts were below 10 CFU/g in all samples, indicating compliance. Yeast counts slightly exceeded the acceptable limit in MS and MT (10^2 and 1.1×10^2 CFU/g), whereas ST samples were compliant. Finally, mold counts exceeded the limit of 10^2 CFU/g in all samples (2.3×10^2, 2.8×10^2, and 2.0×10^2 CFU/g). Figure 4 shows images of yeast, mold, and ASR colonies. Figure 5 presents Gram-negative bacilli (a) and Gram-positive bacilli (b) observed under a microscope after Gram staining.

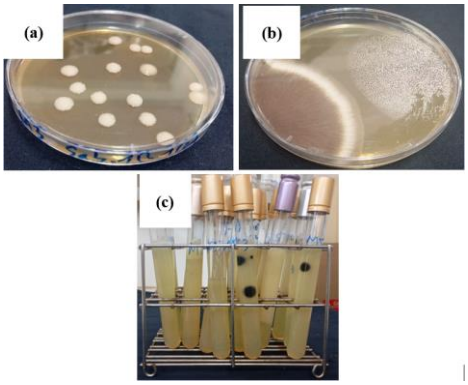

Figure 4. *Images of yeast colonies (a), mold colonies (b), and ASR colonies (c).*

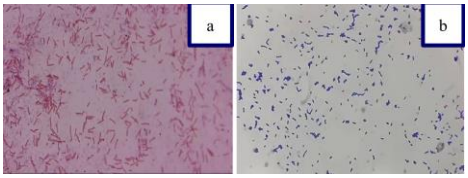

Figure 5. *Gram-negative bacilli (a) and Gram-positive bacilli (b).*

The Figure 6 shows a positive result of a strain in the catalase test.

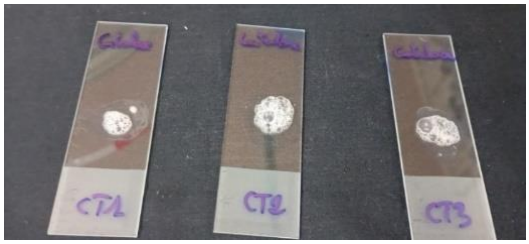

Figure 6. *Positive result of a strain in the catalase test.*

Figure 7 shows the positive and negative results of strains in the oxidase test.

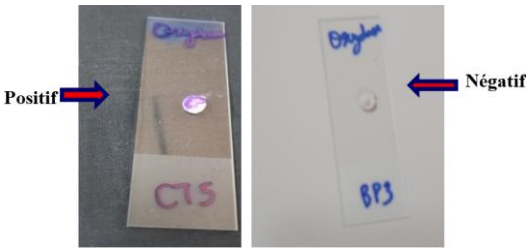

Figure 7. *Positive and negative results of strains in the oxidase test.*

Figure 8 shows the results of H_2S production tests of the strains.

Figure 8. *Results of H_2S production tests of the strains.*

3.2. Organoleptic Characteristics of Palm Kernel Oil from Different Production Methods in Benin

Table 2 presents the organoleptic characteristics of palm kernel oil obtained from different production methods in Benin.

Table 2. *Organoleptic characteristics of palm kernel oil from different production methods in Benin.*

Samples	Color	Texture	Odor	Taste	Aftertaste	Overall acceptability
MT	3,97 ± 0,16a	3,89 ± 0,54a	2,73 ± 0,74c	2,43 ± 0,82c	2,24 ± 0,71c	2,76 ± 0,83c
MS	3,94 ± 0,52a	3,81 ± 0,52a	3,27 ± 0,71b	2,97 ± 0,84b	3,00 ± 0,70b	3,24 ± 0,65b
ST	4,02 ± 0,52a	3,81 ± 0,68a	3,70 ± 0,86a	3,86 ± 0,78a	3,62 ± 0,83a	4,03 ± 0,58a

Values bearing the same letters in the same column are not significantly different at the 5% level. MT = Modern technology with roasted kernels; MS = Modern technology with sun-dried kernels; ST = Semi-traditional technology

Table 3 presents the organoleptic characteristics of palm kernel oil from different production methods in Benin when used in white bean dishes.

Table 3. *Organoleptic characteristics of palm kernel oil from different production methods in Benin in white bean dishes.*

Samples	Color	Texture	Odor	Taste	Aftertaste	Overall acceptability
MT	4,00 ± 0,43a	3,81 ± 0,48a	2,84 ± 0,69b	2,38 ± 0,74c	2,11 ± 0,54c	2,57 ± 0,80c
MS	3,89 ± 0,54a	3,92 ± 0,35a	2,86 ± 0,62b	2,84 ± 0,65b	2,78 ± 0,70b	3,08 ± 0,60b
ST	4,11 ± 0,58a	3,82 ± 0,56a	3,73 ± 0,81a	3,68 ± 0,87a	3,73 ± 0,76a	3,86 ± 0,68a

Values bearing the same letters in the same column are not significantly different at the 5% level. MT = Modern technology with roasted kernels; MS = Modern technology with sun-dried kernels; ST = Semi-traditional technology

Sensory analysis results show a clear preference for oil produced using the semi-traditional technology (ST). In contrast, the modern roasting technology (MT) recorded the lowest scores for all organoleptic attributes (odor, taste, and acceptability). The modern solar-drying technology (MS) ranked at an intermediate level, producing an oil with stable, acceptable odor and taste, but slightly less appreciated than ST oil. These results were consistent when the analysis was repeated using white bean dishes.

4. Discussion

The microbiological results indicate that the analyzed palm kernel oils exhibit satisfactory safety with respect to major foodborne pathogens such as *Salmonella spp., Escherichia coli,* and *Bacillus cereus*. This suggests the absence of fecal contamination and generally acceptable hygiene conditions during processing. Similar findings were reported by Flora *et al*. and Gobena *et al.,* who observed an absence or very low levels of major pathogens in edible oils produced and marketed in West Africa [8, 12]. However, the exceedances observed for certain parameters highlight important critical control points. Elevated aerobic mesophilic bacteria counts in MS and MT suggest contamination related to handling or storage. Oil produced using MT showed the highest microbial load, followed by MS, while ST exhibited the lowest levels. Although roasting is a heat treatment, these results suggest that recontamination may occur during cooling, grinding, or post-processing handling when hygiene conditions are not strictly controlled [12, 32]. Slightly higher total coliform counts in MT indicate moderate hygiene conditions, although the absence of thermotolerant coliforms and *E. coli* suggests no recent fecal contamination. The presence of *Staphylococcus spp*. indicates human handling contamination, which may lead to toxin production if the oil is stored at room temperature for extended periods. Enterobacteriaceae levels remained below the acceptable limit ($m < 10^2$ CFU/g) across all technologies, with higher values in MT, intermediate in MS, and lower in ST. This trend may be associated with prolonged exposure of raw materials to the environment or additional handling steps prior to oil extraction, as also reported by Flora *et al*. in studies

on unrefined vegetable oils [8]. The detection of anaerobic sulfite-reducing bacteria in MS may indicate occasional contamination from the environment or production equipment. Furthermore, the relatively high levels of yeasts and molds compared to standards may be linked to palm kernel drying conditions, particularly residual moisture and prolonged exposure to air. Similar observations have been reported by other authors [8, 33], while other studies have emphasized the importance of controlling such contamination in order to reduce the health risks associated with edible oils [5, 9]. This highlights the importance of proper packaging and storage to prevent microbiological deterioration. Therefore, improving hygiene practices particularly during kernel drying and storage, as well as handling, filtration, and packaging is essential to maintain optimal microbiological quality and minimize the proliferation of microorganisms and environmental contaminants, which serve as indicators of the level of control of good hygiene and manufacturing practices, thereby ensuring better safety of the oils produced. Sensory evaluation of oils produced using different technologies revealed a significant influence of processing methods on perceived organoleptic qualities. Oil produced using the semi-traditional technology (ST) achieved the highest scores across all attributes, particularly odor, taste, and overall acceptability, reflecting a strong panel preference. These results suggest that ST better preserves volatile compounds responsible for the characteristic aroma and flavor of the oil [34, 35]. Conversely, oil obtained through roasting (MT) was the least appreciated by panelists. The low scores may be attributed to the formation of secondary compounds resulting from oxidation and Maillard reactions, imparting burnt or bitter notes. Similar effects of excessive thermal treatments on sensory degradation of oils have been reported in the literature [36-38]. The modern solar-drying technology (MS) showed intermediate scores, indicating a balance between preservation of sensory qualities and improved clarity. Overall, these findings confirm that excessive thermal processing negatively affects the sensory quality of oils, whereas milder processes help preserve a more desirable organoleptic profile for consumers.

5. Conclusions

The analyzed palm kernel oils are generally microbiologically safe, as evidenced by the absence of Salmonella spp., Escherichia coli, and Bacillus cereus, confirming the absence of fecal contamination and acceptable hygiene practices during processing. However, certain hygiene indicators, including aerobic mesophilic bacteria, Staphylococcus spp., as well as yeasts and molds, exceeded recommended limits, revealing contamination risks associated with handling, storage, or inadequate drying conditions. Sensory evaluation indicates that semi-traditional technology (ST) better preserves organoleptic qualities, whereas intensive thermal processes, particularly roasting (MT), reduce acceptability due to the development of bitter or burnt notes. These findings highlight the need to optimize hygiene practices, storage conditions, and thermal processing methods to ensure optimal microbiological and sensory quality, thereby guaranteeing the safety and acceptability of the oils produced.

Abbreviations

ANOVA	Analysis of Variance
CFU	Colony Forming Units
EPT	Buffered Peptone Water
H_2S	Hydrogen Sulfide
PCA	Plate Count Agar
PEMBA	Polymyxin Egg Yolk Mannitol Bromothymol Blue Agar
TBX	Tryptone Bile X-glucuronide Agar
TSN	Tryptone Sulfite Neomycin
VRBA	Violet Red Bile Agar
VRBG	Violet Red Bile Glucose Agar

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Data Availability Statement

The data supporting the outcome of this research work has been reported in this manuscript.

Conflicts of Interest

The authors declare no conflicts of interest.

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