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Wine Palm (*Elaeis guineensis*): In-Depth Characterization of a Traditional Senegalese Beverage

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Abstract

The expression palm wine is used both for palm tree sap and spontaneously fermented sap. Here, the expression refers to the sap of the palm tree. Palm wine has a significant social and cultural value, contributing to food security in many African, Asian countries, and in the Brazilian northeast. This study aims to characterize the sap of *Elaeis guineensis* from Senegal (Casamance). A comprehensive and in-depth chemical analysis was conducted, covering various parameters and utilizing advanced techniques to ensure the depth and accuracy of the results. The sap exhibits a slightly acidic pH (4.16), medium-low total titratable acidity (34 meq/L), and a total soluble solids content of 9.63˚ Brix. It is rich in phenolic compounds (0.8 mg of caffeic acid equivalent/mL) and demonstrates high antioxidant activity, as measured by DPPH and ABTS assays. Microbiological analysis confirms its safety (no fecal coliforms, *Salmonella* spp., *Listeria monocytogenes* and *Staphylococcus aureus* were detected). The initial yeast count was 2.1×10^2 CFU/mL. The metabolic profile of the sap reveals abundant bioactive compounds, including phenolic acids (notably caffeic acid) and flavonoids (such as tiliroside), alongside 18 volatile compounds and 48 polar compounds, such as sugars, organic acids, and alcohols. Additionally, the sap contains nine essential minerals, with a particularly high Ca concentration (1236.58 mg/L), highlighting its nutritional value. This palm wine at sap stage may possess nutritional properties comparable to, and potentially exceeding, those of human milk. These findings underscore the nutritional value of this extract and its potential to address nutritional deficiencies in children within the Casamance community. These findings substantiate the traditional

view of palm wine as a health-promoting product and provide a scientific basis for its nutritional and functional properties.

Keywords

Palm Sap, Casamance, Phenolic Compounds, Antioxidant Activity, Elemental Analysis, Volatile Organic Compounds

1. Introduction

Senegalese culture is deeply rooted in ancestral practices and customs, where offerings hold significant importance during life events such as baptisms, weddings, and funerals, as well as during seasonal transitions like the end of harvest and the onset of the rainy season. Among these offerings, palm wine occupies a central role in the Casamance region of southern Senegal, serving as more than just a beverage. It embodies material and immaterial value, influencing cultural, socio-economic, psychological, and environmental aspects [1]. Despite its cultural significance, the practice of palm wine collection has been declining, particularly among younger generations, largely due to the inherent risks involved in traditional harvesting methods, such as fatal falls during sap extraction [1].

Palm wine, derived from the sap of the African oil palm (*Elaeis guineensis*), is a product of a spontaneous fermentation, beginning immediately after sap collection. This white, sweet-tasting sap undergoes rapid transformation, with its alcohol content increasing to approximately 4% within hours of fermentation and transitioning to vinegar within days if left untreated [2]. The sap's limited shelf life and susceptibility to microbial growth present challenges for preservation, but also opportunities for the development of value-added products marketed globally [3].

The African palm (*E. guineensis*), a monocotyledonous species of significant ecological and economic value, thrives across diverse climates in South America, Africa, and Asia. Its sap collection involves ancestral techniques that preserve the tree's lifespan but are labor-intensive and underutilized, with collectors managing an average of only twenty trees per season, despite the planting densities of 135 - 160 trees per hectare [4]. This underutilization has contributed to a decline in sap production, raising concerns about the future sustainability of palm wine practices.

Research on palm wine has predominantly focused on three aspects: its cultural and social importance, its microbiological richness, and its chemical composition. Studies highlight its role in community livelihoods, its potential as a substrate for microorganisms, and its nutritional and therapeutic applications [5]. Despite these findings, gaps remain in understanding the detailed physicochemical properties of palm sap and wine, particularly for *E. guineensis* in Casamance. Additionally, cultural practices such as using palm wine as a dietary supplement for children, particularly orphans, underscore the need for scientific validation of its nutritional value and safety [1].

Given the growing demand for sustainable rural industrialization in Africa, the

valorization of palm sap offers a promising avenue for economic development aligned with the United Nations Sustainable Development Goals (SDGs), including Zero Hunger and Good Health and Well-being. This study aims to characterize the sap of *E. guineensis* from Senegal (Casamance), investigating its chemical composition. By exploring the metabolic profile of the sap, including its mineral, sugar, amino acid, and secondary metabolite content, this research seeks to bridge scientific knowledge gaps and support innovative strategies for sustainable development in rural communities.

2. Material and Methods

2.1. Palm Sap

Palm sap, also known as palm wine, was collected from eighty *E. guineensis* palm trees in the village of Essil (12˚47'08" north, 16˚31'18" west), Casamance, South of Senegal. Approximately 500 mL of fresh sap was obtained from each tree and immediately froze at −20˚C within an hour after the collection on the tree to preserve its original composition. This sap is at a pre-fermentation stage. To ensure its safety until the arrival in Brazil the sap was stored after the freezing process in a freezer and placed in an isopore box for 15 hours and placed directly back in a freezer when arrived in Brazil. The ethanol was not detected. The experimental design was carried out on the same species and all evaluations had been done in three bio replicates.

2.2. General Characterization

Physicochemical parameters were determined as follows: pH using a pH meter (model HI2221, Hanna Instruments, USA); total titratable acidity by titration to pH 8.1 and expressed as meq/L(Horwitz, 2006); soluble solids content by refractometry (˚Brix) using a digital refractometer (PR-32*a*, Atago, USA); color by CIELab color system using a colorimeter (CR 300, Konica Minolta, USA); and total phenolic content by the Folin-Ciocalteu method (Paixão *et al.*, 2007), expressed as mg caffeic acid equivalent/mL. Antioxidant capacity was assessed using the DPPH and ABTS radical scavenging assays, with results expressed as μmol Trolox/mL [6] [7]. Finally, L-ascorbic acid content was determined using a method adapted [8] by liquid chromatography (HPLC) and result were expressed in mg/100 mL.

For microbiological analysis, the microorganisms were counted [9]. Decimal dilutions were performed up to the 10^{-5} dilution and, subsequently, 0.1 mL aliquots of each dilution were transferred to Petri dishes containing De Man Rogosa & Sharpe (MRS) agar (Acumedia®, Lansing, USA), which were incubated at 37˚C for 72 h. Counts were expressed in colony-forming units (CFU)/mL. The total, fecal coliforms, *Salmonella* spp., *Listeria monocytogenes* or *Staphylococcus aureus* were searched by EC medium: the production of gas after 24 h of incubation at 44.5˚C in an EC broth medium was detected by ELISA kits [9].

2.3. Individual Phenolic Compounds

For phenolic compounds, 2 mL palm wine was mixed with 5 mL of methanol. Sam-

ples were sonicated in a water bath at 20˚C for 15 min, centrifuged (5752 g for 5 min), and the supernatants were collected. The supernatants were filtered through 0.2 µm nylon membrane (Merck Millipore Corporation, Germany). LC-MS/MS analyses were performed on a liquid chromatography system coupled to a quadrupole time-of-flight (QToF) mass spectrometer (Shimadzu, model LCMS-9030, Kyoto, Japan). Separation of metabolites was performed using a C18 type column (Durashell RP, 3 µm, 150 Å, 100 × 2.1 mm, Agela technologies). Mobile phases were aqueous with 0.1% formic acid (solvent A), and acetonitrile with 0.1% formic acid (solvent B). The gradient program started at 5% B, increasing linearly to 90% B at 15 min and maintained for 3 min at 90% B; returned to 5% B in 2 min, and maintained at 5% B for six more minutes at 0.2 mL/min flow rate. Injection volumes were 10 µL.

Variables and parameters for MS analysis were set using negative ionization mode with spectra acquired over a mass range from 150 to 950 m/z, with interface voltage of 3.5 kV. For MS/MS (DDA), the range was from 100 to 950 m/z, with collision energy of 30 eV; EC Spread (+/−) was 17, using N_2 as collision gas. Maximum loop time was 0.5 s, with maximum number of events of 6. Nebulizing gas flow was 3.0 L/min, heating gas flow was 12 L/min, and interface temperature was 350˚C. Ion guide/drying gas flow was 12 L/min, while DL and heat block temperatures were 250˚C and 400˚C, respectively. Calibration was performed with 2.6 mM sodium iodide.

LabSolutions Insight and LabSolutions Insight Explore were used for data acquisition in DDA mode and data processing of MS and MS/MS spectra for efficient detection and identification of targeted and untargeted compounds. The identity of catechin, epicatechin, caffeic acid, p-coumaric acid, ferulic acid, and quercetin was confirmed with external standards (Sigma-Aldrich). For quantitative analysis, a calibration curve for each available phenolic standard was constructed (10 to 1050 ng/mL; R^2: 0.99). For the identified phenolic compounds for which a commercial standard was not available, quantification was performed using the calibration curve of other compounds from the same phenolic group. Results were expressed as ng/mL wine palm, as mean ± standard deviation of three replicates.

2.4. Volatile Compounds Analysis

Samples containing Volatile Organic Compounds (VOCs) were prepared by solid-phase microextraction (HS-SPME). Approximately 1 mL of wine palm, 1 g of NaCl, 2960 µl of ultrapure water and 20 µL of the internal standard (benzophenone solution 0.25 µg/mL in methanol) were placed into a 10 mL glass vial together with a micro-stirring bar and sealed with an aluminum crimp cap with a needle pierceable polytetrafluoroethylene/silicone septum. Solid-Phase Microextraction (SPME) was performed with a 50/30 µm divinyl-benzene/carboxen/polydimethylsiloxane (DVB/CAR/PDMS) fiber (Supelco, Belafonte, USA). The sample was placed in a 40˚C water bath and stirred at 800 rpm. After allowing 10 min for the sample to equilibrate, the needle of the SPME device was inserted into the vial and the fiber

was exposed to the headspace of the sample. After 40 min of exposure, the fiber was retracted from the vial headspace and inserted into the gas chromatograph injector. The gas chromatograph Shimadzu QP 2010 Ultra equipped with a mass detector (GC-MS) was used for the analysis of volatile compounds adsorbed on the SPME fiber. The column used was RTX-5MS (30 m × 0.32 mm × 0.25 µm). Helium gas flow was 1.77 mL/min. The injector was operated in splitless mode set at 260˚C. The fiber remained in the injector for 10 min. The column temperature was maintained at 40˚C for 5 min and increased to 200˚C at 4˚C/min for 10 min, for a total run time of 55 min. The conditions of the MS were as follows: source temperature of 200˚C; transfer line temperature of 290˚C; energy by electron impact (EI 70 eV) in 3 s^{-1} scans and mass range m/z at 29 - 400.

VOCs were identified by comparing similar indices and mass spectra with the National Institute of Standards and Technology (NIST11) system database. Compounds were quantified based on the internal standard area (benzophenone), and the results are expressed in µg/mL of palm wine. The calibration curve for benzophenone was linear over the range of 0.5 to 2560 µg/mL. The recovery rate for benzophenone was 90.23%, with a Limit of Detection (LOD) of 0.69 µg. The method demonstrated a repeatability level of 2.6%.

2.5. Polar Metabolites by GC-MS

Metabolite extraction followed the method [10]. 500 µL of wine palm was homogenized by vertexing for 10 s with 1400 µL of ice-cold methanol (−20˚C). Then, 60 µL of ribitol (aqueous solution 0.2 mg mL^{-1}), as internal standards, was added and vortexed for 10 s. The extracts were incubated in a water bath at 70˚C for 10 min followed by centrifugation at 20˚C, 7000 g for 10 min. The supernatants were collected in 15 mL centrifuge tubes and 750 µL of chloroform (−20˚C) and 1500 uL of ultrapure water (4˚C) were added and vortexed for 10 s, followed by centrifugation at 15˚C, 2200× g for 15 min. Then, 150 µL of the upper layer (methanol/water-polar fraction) was collected in 1.5 mL centrifuge microtubes and dried under nitrogen gas. The dry residue of the polar fraction was derivatized by adding 40 µL of methoxamine hydrochloride in pyridine (20 mg mL^{-1}), vortexed and incubated for 2 h at 37˚C. Then, 70 µL of N-methyl-N-(trimethylsilyl) trifluoroacetamide (MSTFA) was added and the sample was incubated for 30 min at 37˚C as described above. 100 µL of derivatized samples were transferred to 1.5 mL vials with inserts and injected into the GC-MS equipment. The gas chromatograph Shimadzu QP 2010 Ultra equipped with a mass detector (GC-MS) was used for the analysis. The column used was RTX-5MS (30 m × 0.32 mm × 0.25 µm). Helium gas flow was 1.77 mL min^{-1}. The injector was operated in split less mode set at 260˚C. The column temperature was maintained at 40˚C for 5 min and increased to 200˚C at 4˚C/min for 10 min, for a total run time of 55 min. The conditions of the MS were as follows: source temperature at 200˚C; transfer line temperature at 290˚C; energy by electron impact (EI 70 eV) in 3 s^{-1} scans and mass range m/z between 29 - 400.

Compounds were identified by comparing similar indices and mass spectra with the National Institute of Standards and Technology (NIST11) system database. Compounds were quantified based on the internal standard area (Ribitol), and the results are expressed as mg/mL of wine palm. For quantification, a calibration curve for ribitol was constructed with a linear range from 1 to 5000 µg/mL. The recovery rate was 82.36%. The Limit of Detection (LOD) was 1.26 µg, and the method exhibited a repeatability level of 4.9%.

2.6. Mineral Composition Analysis

The samples of wine palm were prepared by filtering the decomposed samples on a 0.2 mm thick filter paper with 35 µm pores. Multielement analyte solutions were prepared from ICP Stock Solution (Sigma-Aldrich, Germany) containing 100 $mg{\cdot}L^{-1}$ of each analyte. The determination of the elemental analysis of palm wine followed the methodology [11]. For the execution, a Microwave Induced Plasma Optical Emission Spectrometer (MIP OES) model 4200 (Agilent Technologies, Australia) was used. This equipment is equipped with a simultaneous multi-element solid-state CCD detector (charge-coupled device), a Czerny-Turner monochromator, a OneNeb series 2 nebulizer and a cyclonic nebulization chamber. The nitrogen used to maintain the plasma is extracted from atmospheric air using a model 4107 nitrogen generator (Agilent Technologies, Australia), with flows of 20 L/min and 1.5 L/min for the plasma gas and of 1.5 L/min for the auxiliary gas (nebulization). For plasma ignition, an Argon (Ar) gas flow was used, provided by an internal storage cylinder installed in the device (Agilent Technologies, Australia). All reagents used in this study are of analytical grade and all prepared solutions used deionized water, obtained through a quartz distillation system, model MA078/5 (Marconi, Brazil), followed by deionization through a model CS1800 Evolution column (Permutation, Brazil). The HNO_3 (Dinâmica, Brazil) used in the sample preparation step was double-distilled below the boiling point in a quartz distiller, model MA-075 (Marconi, Brazil). H_2O_2 35% (w/v) was also used (Exod scientific, Brazil). The result was expressed in mg/L wine palm.

3. Results

3.1. General Composition of Palm Wine

To better understand the wine palm, a general characterization was initially performed (Table 1). From this evaluation, it was found that the wine palm has a relatively acidic pH (4.16) and medium-low total titratable acidity (34 meq/l), 9.63˚ Brix total soluble solids and 3.7 g/l total ash. The color is "whitish" (Chroma and Hue of both). There is a wealth of total phenolic compounds (0.8 mg of caffeic acid equivalent/mL), and high antioxidant activities measured by DPPH (4364.72 µmol Trolox/mL) and ABTS (222.94 µmol Trolox/mL). A presence of L-ascorbic acid (6.33 mg/100 mL) has also been detected. The yeast presence (2.1×10^2 CFU/mL) was confirmed. No fecal coliforms were detected, neither *Salmonella* spp., *Listeria monocytogenes* or *Staphylococcus aureus*.

Table 1. Wine palm (*Elaeis guineensis*), Senegal (Casamance): general physicochemical characteristics (pH, total titrable acidity, total solid solubles, color total phenolic compounds, antioxidant activities (ABTS and DPPH), L-ascorbic acid) and yeast initial number.

Wine palm	
pH	4.16 ± 0.01
Total titratable acidity (meq/L)	34 ± 0.01
Total solid solubles (˚Brix)	9.63 ± 0.12
Total ashes (g/l)	3.7 ± 0.32
Total phenolic compounds (mg CA/mL)	0.86 ± 0.31
DPPH (µmol Trolox/mL)	4364.72 ± 171.5
ABTS (µmol Trolox/mL)	222.94 ± 27.78
L-ascorbic acid (mg/100 mL)	**6.33 ± 0.25**
Yeast initial number (CFU/mL)	2.1×10^2
Total, fecal coliforms, *Salmonella* spp., *Listeria monocytogenes* or *Staphylococcus aureus*	<LOD

<LOD: Inferior to the Limit of Detection.

3.2. Phenolic Compounds Profile

The individual phenolic compounds identified by HPLC-MS are presented in Table 2. A total of 8 phenolic compounds were identified in the palm wine valuated in the present study, three phenolic acids (caffeic acid, ferulic acid, p-coumaric acid) and five flavonoids were identified (catechin, tiliroside, epicatechin, piceid, quercetin). Among the phenolic acids, caffeic acid showed the highest concentration (215.38 ng/mL), while tiliroside (997.47 ng/mL) was the most abundant compound in the class of flavonoids. The sum of all phenolic compounds resulted in the concentration of 1517 ng/mL, with 31.65 ng/mL being phenolic acids and 1186 ng/mL being flavonoids.

Table 2. Individual phenolic compounds identified and quantified by LC-MS/MS in wine palm (*Elaeis guineensis*) from Senegal (Casamance).

Compounds	RT (min)	[M-H]- experimental	[M-H]- measured	Molecular formula (M)	Diff. (ppm)	(ng/mL)
Phenolic acids						
Caffeic acid	6.99	179.03498	179.03396	$C_9H_8O_4$	−5.7	215.38. ± 14.21
Ferulic acid	8.14	193.0505	193.0506	$C_{10}H_{10}O_4$	0.4	84.57 ± 6.53
p-coumaric acid	7.82	163.04007	163.03899	$C_9H_8O_3$	−6.6	31.70 ± 3.85
Flavonoids						
(+)-Catechin	6.59	289.07176	289.07103	$C_{15}H_{14}O_6$	−2.5	56.09 ± 4.33
Tiliroside	6.83	593.13006	593.12958	$C_{30}H_{26}O_{13}$	−0.8	997.47 ± 20.44
(−)-Epicatechin	7.24	289.07176	289.07065	$C_{15}H_{14}O_6$	−3.8	44.10 ± 2.70
Piceid	8.26	389.12419	389.12386	$C_{20}H_{22}O_8$	−0.8	87.47 ± 29.42
Quercetin	9.54	301.03538	301.03419	$C_{15}H_{10}O_7$	−3.9	1.18 ± 0.04

RT: Retention Time.

3.3. Volatile Compounds Profile

To identify the compounds that participate in the aroma of wine palm, the description of Volatile Organic Compounds (VOCs) was made by GC-MS (Table 3, Figure 1), obtaining the respective ions, experimental and theoretical retention indices. This method allowed the identification of 18 compounds, with emphasis on six esters (Hexanoic acid ethyl ester, octanoic acid methyl ester, octanoic acid ethyl ester, decanoic acid ethyl ester, Propanoic acid, 2-methyl-, 1-(1,1-dimethylethyl)-2-methyl-1,3-propanediyl ester, ethyl 9-decenoate), 1 aldehydes (Nonanal), three alcohols (1-nonanol, 1-octanol, 1-butanol 3 methyl, acetate), two ketones (5,9-Undecadien-2-one, 6,10-dimethyl-, (E)-3(2H)-Thiophenone, dihydro-2-methyl; 2-Cyclopenten-1-one, 2,3,4,5-tetramethyl-), four organic acids (octanoic acid, nonanoic acid, hexanoic acid, 2-ethyl) and two heterocyclic sulfur compounds (1,2,4-Trithiolane, 3,5-dimethyl isomer 1, 1,2,4-Trithiolane, 3,5-dimethyl-Isomers 2: these analytes were identified separately because of their difference of retention time due to differences in polarity, volatility, or molecular shape). When quantifying the VOCs, the total concentration was 929.2 µg/mL. The major VOCs were octanoic acid ethyl ester, decanoic acid ethyl ester and Hexanoic acid ethyl ester in concentrations of 294.00 µg/mL 150.06 µg/mL, 52.03 µg/mL, respectively, representing more than 80% of the total.

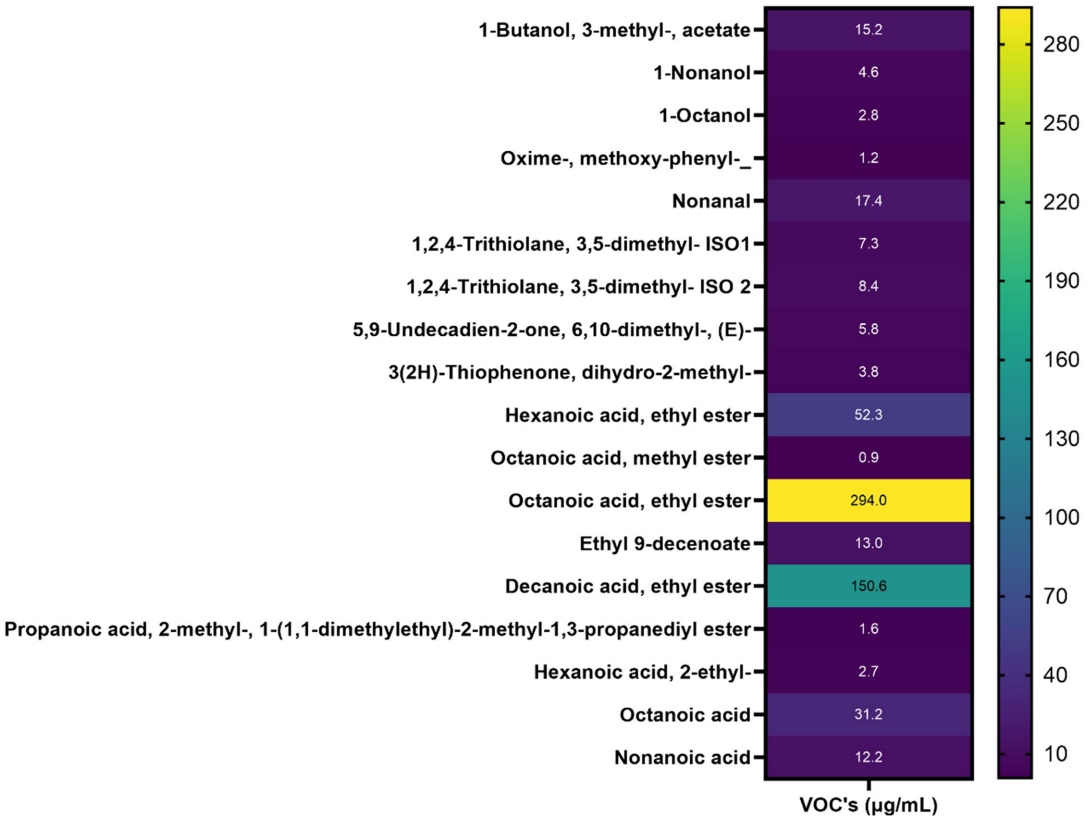

Figure 1. Volatile compounds identified and quantified, by GC-MS, in wine palm (*Elaeis guineensis*), Senegal (Casamance). The heat map scale corresponds to the concentration of each compound expressed in µg/mL. Yellow represents higher concentrations and bleu lower concentrations.

Table 3. Volatile compounds identified and quantified, by GC-MS, in wine palm (*Elaeis guineensis*) from Senegal (Casamance).

Compounds	IS	IRL	Reference ion	Wine palm (µg/mL)
Alcohol				
1-Nonanol	97	1290.301	56(100); 55(78); 70(72); 69(59); M+(0.00)	4.60 ± 0.98
1-Octanol	96	1202.183	56(100); 55(83); 41(67); 69(63); M+(0.03)	2.83 ± 0.31
1-Butanol, 3-methyl-, acetate	98		43(100); 70(61); 55(54); 41(18); M+(0.10)	15.19 ± 4.43
Total alcohol				**22.63** ± 6.68
Ketone				
5,9-Undecadien-2-one, 6,10-dimethyl-, (E)-	97	1503.132	43(100); 69(45); 41(32); 107(17); M+(0.93)	5.77 ± 1.25
2-Cyclopenten-1-one, 2,3,4,5-tetramethyl-	88	1250,425	73(100); 60(85.47); 43(84.42); M+(36.92)	8.64 ± 0.12
3(2H)-Thiophenone, dihydro-2-methyl-	93	1082.697	60(100); 116(68); 32(26); 58(21); M+(68.61)	52.29 ± 1.76
Aldehyde				**66.70 ± 26.06**
Nonanal	95	1223.994	57(100); 41(63); 56(61); 43(51); M+(0.10)	17.40 ± 9.12
Total aldehyde				**17.40 ± 9.12**
Ester				
Hexanoic acid, ethyl ester	98	1256.952	88(100); 99(53); 43(50); 70(33); M+(0.92)	52.29 ± 15.3
Octanoic acid, methyl ester	95	1248.196	74(100); 87(41); 43(23); 57(16); M+(0.79)	0.88 ± 0.14
Octanoic acid, ethyl ester	96	1312.540	88(100); 101(39); 70(31); 127(29); M+(1.73)	294.02 ± 34.62
Ethyl 9-decenoate	85	1460.208	88(100); 55(79); 41(53); 110(52); M+(0.27)	13.04 ± 1.97
Decanoic acid, ethyl ester	96	1469.233	88(100); 101(41); 70(23); 73(20); M+(2.82)	150.62 ± 40.48
Propanoic acid, 2-methyl-, 1-(1,1-dimethylethyl)-2-methyl-1,3-propanediyl ester	92	1612.416	71(100); 43(34); 111(6); 56(6); M+(0.00)	1.59 ± 0.37
Total ester				**512.44 ± 116.85**
Organic acid				
Hexanoic acid, 2-ethyl-	97	-	88(100); 73(96); 57(33); 41(25); M+(0.22)	2.75 ± 0.56
Octanoic acid	95	-	60(100); 73(65); 43(45); 41(29); M+(0.96)	31.21 ± 11.5
Nonanoic acid	95	-	60(100); 73(77); 57(65); 41(36); M+(2.37)	12.20 ± 0.52
Oxime-, methoxy-phenyl-_	68	1072.767	151(100); 133(92); 179(77); 135(70); M+(100)	1.19 ± 0.25
Total organic acid				**47.35 ± 13.80**
Heterocyclic sulfuric compound				
1,2,4-Trithiolane, 3,5-dimethyl-ISO 1	86	1228.798	152(100); 59(67); 92(65); 88(55); M+(100)	7.28 ± 2.68
1,2,4-Trithiolane, 3,5-dimethyl-ISO 2	91	1234.728	152(100); 59(67); 92(65); 88(55); M+(100)	8.44 ± 0.70
Total				**15.72 ± 0.82**

3.4. Mineral Composition

A total of 19 mineral compounds were evaluated using the microwave-induced plasma optical emission spectrometer method. Among these, calcium (Ca, 1236.58 mg/L), potassium (K, 1458.87 mg/L), and magnesium (Mg, 698.56 mg/L) collectively account for approximately 97% (m/v) of the total mineral content (Table 4). The remaining 3% (m/v) is comprised of sodium (Na, 69.87 mg/L), silicon (Si, 23.15 mg/L), zinc (Zn, 9.87 mg/L), iron (Fe, 1.56 mg/L), aluminum (Al, 1.3 mg/L), and boron (B, 1.23 mg/L).

Notably, heavy metals such as cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), nickel (Ni), lead (Pb), and vanadium (V) were not detected. Additionally, barium (Ba) and lithium (Li) were also absent. The total concentration of all detected and quantified minerals amounts to 3500 mg/L.

3.5. Polar Metabolites Profile

Polar compounds in palm wine were extracted using a water/methanol mixture, chemically derivatized, and analyzed by GC-MS. The analysis identified over 52 compounds (Table 5), including 33 sugars, 11 alcohols, and 4 organic acids. Among the sugars, glucose (11.88 mg/mL), gentiobiose (0.37 mg/mL), and sucrose (0.22 mg/mL) were predominant. Sorbitol was the most abundant alcohol, with concentrations of 2.31 mg/mL, while minor but notable levels of myo-inositol (0.08 mg/L) were detected.

Carboxylic acids were also identified, including octanoic acid in esterified (294.02 mg/mL) and free forms (31.21 mg/mL). The majority organic acid is the isobutyric acid (0.30 mg/mL).

Table 4. Mineral composition (mg/L) in wine palm (*Elaeis guineensis*) from Senegal (Casamance).

Metal	Symbol	Wine palm (mg/L)	Variation Coef. (%)	TWI (mg/kg)**	RDA (Recommended Dietary Allowance)	Tolerable Intake Level	Specification (age, gender, unity mg or mg per day)
Aluminum	Al	1.3 ± 0.12	7.59	1	-	-	-
Bore	B	1.23 ± 0.32	11.25	1	-	10 mg/day	Adults
						3 mg/day	1 - 3 years old
						4 mg/day	4 - 6 years old
						5 mg/day	7 - 10 years old
						7 mg/day	11 - 14 years old
						9 mg/day	15 - 17 years old
Barium	Ba	<LOD	-	-	-	-	-
Calcium	Ca	1236.58 ± 52.96	8.78	115	1600 mg/day	-	Men, 16- to 49-year-old (UK)
					1200 to 1500 mg/day	-	Children between 1.5 and 14 years (UK)
					1300 mg/day	-	Boys and girls between one and 4 years of age
					1400 and 1700 mg/day	-	Boys and girls 4 to 13 years of age (Dutsh)

Continued

Cadmium	Cd	<LOD	-	-	-	-	-
Cobalt	Co	<LOD	-	-	-	-	-
Croma	Cr	<LOD	-	-	-	-	-
Copper	Cu	<LOD	-	-	-	-	-
Iron	Fe	1.56 ± 0.32	9.87	-	-	-	-
Potassium	K	1458.87 ± 53.24	13.25	60	-	3367 mg/day	Men in Germany
					-	2653 mg/day	Women in Germany
Lithium	Li	<LOD	-	-	-	-	-
Magnesium	Mg	698.56 ± 13.25	6.75	7	-	400 mg	Men, 19 - 30 years
					-	310 mg	Women, 19 - 30 years
					-	420 mg	Men, 30 - 71 years
					-	320 mg	Women, 30 - 71 years
Manganese	Mn	<LOD	-	-	-	-	-
Nickel	Ni	<LOD	-	-	-	-	-
Lead	Pb	<LOD	-	-	-	-	-
Silicious	Si	23.15 ± 3.21	9.68	0.25			
Vanadium	V	<LOD	-	-	-	-	-
Zinc	Zn	9.87 ± 1.23	6.98	0.2	7 mg per day	-	Male/Female: 1 - 3 years UK
					10 mg per day	-	Male/Female: 4 - 6 years
					13 mg per day	-	Male/Female: 7 - 10 years
					18 mg per day	-	Male/Female: 11 - 14 years
					22 mg per day	-	Male/Female: 15 - 17 years
Sodium	Na	69.87 ± 8.96	8.74	35	-	65 mmol/day (4g salt/day)	Adults up to 50 years of age
					-	55 mmol/day (3,2 g salt/day)	Adults 51 and 70 years of age
						50 mmol/day (3 g salt/day)	For those aged over 70 years of age (FNB, 2004)

<LOD: Inferior to the Limit of Detection. **TWI: Tolerable weekly intake.

Table 5. Derivatized metabolites identified and quantified in wine palm (*Elaeis guineensis*) from Senegal (Casamance) by GC-MS analysis.

Metabolites	IS	IRL	Reference ion	Quant. mg/mL
Alcohol				
2.3-Butanediol	97	874.8	117(100); 73(68.66); 147(38); 75(12.79); M+(0.00)	0.04 ± 0.01
Glycerol Ether	94	990.0	73(100); 1475(57.11); 205(62.51); 117(27.90); M+(0.01)	0.18 ± 0.08
Adonitol	95	1108.0	73(100); 217(45.84); 147(53.56); 103(45.14); M+(0.00)	0.01 ± 0.00
Sorbitol ISO 1	92	1144.3	319(93.81); 73(100); 205(71.91); 147(34.40); M+(0.00)	2.31 ± 4.44
Sorbitol ISO 2	93	1145.3	319(93.81); 73(100); 205(71.91); 147(34.40); M+(0.00)	1.76 ± 4.44

Continued

Sorbitol ISO 3	74	1147.8	73(100); 319(42.74); 147(50.66); 103(33.93); M+(0.00)	0.01 ± 4.44
myo-Inositol ISO 1	91	1158.4	73(100); 318(89.39); 305(65.27); 217(66.17); M+(0.00)	0.04 ± 4.44
myo-Inositol ISO 2	92	1168.0	73(100); 305(54.16); 217(56.56); 147(68.37); M+(0.20)	0.04 ± 4.44
Maltitol ISO 1	90	1072.767	361(100); 73(62.17); 204(51.96); 362(31.83); M+(0.00)	0.03 ± 0.25
Maltitol ISO 2	80	1503.132	217(50.86); 73(56.06); 361(36.63); 103(19.32); M+(0.00)	0.04 ± 1.25
Maltitol ISO 3	87	1312.540	204(51.96); 361(100); 73(62.17); 319(11.01); M+(0.00)	0.06 ± 34.63
Total alcohol				**4.53 ± 0.81**
Organic acid				
Isobutyric acid	97	881.1	73(100); 147(87.11); 117(82.47); 191(24.58); M+(0.00)	0.32 ± 0.14
Succinic acid ISO 1	96	996.0	147(100); 73(45.94); 148(16.21); 75(21.82); M+(0.50)	0.004 ± 0.00
Succinic acid ISO 2	94	1047.3	73(100); 147(43.22); 233(20.17); 245(9.64); M+(0.15)	0.01 ± 0.00
Citric acid	94	1119.1	273(100); 73(87.89); 147(60.66); 347(30.63); M+(0.00)	0.11 ± 4.44
Total organic acid				**0.44 ± 0.14**
Sugars				
Xylose	92	1097.1	73(100); 103(84.09); 217(29.63); 307(21.42); M+(0.10)	0.02 ± 0.01
D-(-)-Tagatofuranose (isomer 2)	84	1114.4	217(100); 73(99.30); 257(4.10); 147(20.02); M+(0.01)	0.02 ± 0.00
Fructose (isomer 2)	91	1121.2	73(100); 217(74.48); 437(16.82); 147(36.53); M+(0.00)	0.06 ± 4.44
Fructose (isomer 3)	91	1122.3	73(100); 217(74.48); 437(16.82); 147(36.53); M+(0.00)	0.08 ± 4.44
d-Glucose ISO 1	93	1124.1	73(100); 204(63.02); 437(37.76); 147(24.75); M+(0.00)	0.09 ± 4.44
Tagatose	82	1126.9	73(100); 103(69.57); 189(7.51); 217(31.93); M+(0.03)	0.03 ± 4.44
Gluconic acid	94	1130.5	73(100); 129(29.93); 147(41.84); 319(18.52); M+(0.50)	0.05 ± 4.44
Glucose ISO 2	85	1133.1	217(48.18); 103(82.61); 307(45.26); 73(100); M+(0.34)	3.91 ± 4.44
Glucose ISO 3	87	1134.6	103(82.61); 73(100); 217(48.18); 307(45.26); M+(0.23)	3.25 ± 4.44
D-(+)-Glucose ISO 1	84	1137.4	73(77.81); 319(100); 205(83.75); 147(34.37); M+(0.00)	3.45 ± 4.44
D-(+)-Glucose ISO 2	92	1140.1	73(100); 319(42.64); 205(40.54); 147(42.74); M+(0.00)	1.18 ± 4.44
Mannobiose ISO 1	86	1143.0	73(100); 217(56.66); 3610(40.24); 147(38.83); M+(0.00)	0.06 ± 4.44
3α-Mannobiose ISO 2	86	1146.5	73(100); 217(56.66); 204(61.27); 361(40.24); M+(0.00)	0.01 ± 4.44
β-D-Glucopyranose	97	1149.3	204(100); 73(77.08); 191(38.03); 147(21.02); M+(0.00)	0.29 ± 4.44
D-Gluconic acid	97	1154.2	73(100); 333(41.00); 147(38.80); 292(26.20); M+(0.00)	0.30 ± 4.44
α-D-mannopyranoside	86	1156.6	**204(100); 73(86.98); 205(22.79); 319(0.93); M+(0.00)**	0.17 ± 4.44
D(+)-Sucrose ISO 1	96	1240.5	361(100); 73(60.27); 362(31.21); 217(30.04); M+(0.00)	0.02 ± 4.44
α-D-Arabinofuranose	76	982.723	217(100); 73(66.07); 103(7.01); 361(0.00); M+(0.00)	0.07 ± 4.44
D(+)-Sucrose ISO 1	81	982.723	361(98.80); 73(45.54); 204(0.00); 362(31.13); M+(0.00)	0.02 ± 4.44
Gentiobiose ISO 1	80	1290.301	217(30.04); 73(60.27); 361(100); 218(7.61); M+(0.00)	0.03 ± 0.98
D(+)-Sucrose ISO 2	80	1202.183	217(30.04); 73(60.27); 361(100); 218(7.61); M+(0.00)	0.01 ± 0.31
Maltose	89	1223.994	361(100); 73(75.48); 204(52.76); 362(31.43); M+(0.00)	0.51 ± 9.12
3α-Mannobiose ISO 3	85	1228.798	319(59.66); 73(100); 205(35.83); 362(4.60); M+(0.00)	0.01 ± 2.68

Continued

D-(+)-Turanose	87	1234.728	217(100); 73(100); 103(47.02); 204(53.86); M+(0.00)	0.01 ± 0.70
Maltose	94	1082.697	361(100); 73(75.48); 204(52.76); 217(46.74); M+(0.00)	0.24 ± 1.76
Gentiobiose ISO 2	92	1256.952	361(98.80); 73(45.54); 204(100); 217(27.02); M+(0.00)	0.20 ± 15.36
Gentiobiose ISO 3	90	1248.196	361(98.80); 73(45.54); 204(100); 217(27.02); M+(0.00)	0.02 ± 0.14
4-O-β-Galactopyranosyl-D-mannopyranose	90	1460.208	204(100); 73(37.93); 217(19.82); 205(20.22); M+(0.00)	0.01 ± 1.97
D(+)-Sucrose ISO 3	93	1469.233	361(100); 217(30.04); 73(60.67); 362(31.21); M+(0.00)	0.17 ± 40.84
α,β-Trehalose	91	1612.416	361(100); 362(31.93); 73(37.53); 204(11.41); M+(0.00)	0.03 ± 0.37
D-Glucopyranose	87	1612.416	204(100); 361(12.60); 73(48.40); 217(24.00); M+(0.00)	0.04 ± 0.37
Gentiobiose ISO 4	91	1612.416	361(98.80); 204(100); 73(45.54); 362(31.13); M+(0.00)	0.09 ± 0.37
Gentiobiose ISO 5	91	1612.416	361(98.80); 204(100); 73(45.54); 362(31.13); M+(0.00)	0.02 ± 0.37
Total sugars				**14.39 ±** 1.01

4. Discussion

Palm wine, which here in this work is palm sap, is a traditional drink, consumed by traditional people in more than 10 African countries, and in some Asian countries and even in northeastern Brazil. Its importance lies in three key aspects: its social contribution as a source of employment and income, its cultural legacy as an integral part of local traditions and daily life, and its nutritional value, as evidenced by popular knowledge regarding its health benefits. However, it is still an unstructured filiere, for three main reasons: 1) the risks of dangers included in the collection; 2) difficulty in organizing the links in the production chain, which go from collection to consumption, with other governance components (public authorities, academia and population); and 3) the lack of scientific basis demonstrating the properties of this product. It is in this third aspect that this work focuses on. Initially, it was observed that it is a relatively acidic sap, with a medium content of soluble solids and total minerals, rich in phenolic compounds (probably generating the high antioxidant activity observed), with a medium-low content of L-ascorbic acid (Table 1). As it is a product that is collected by drilling the plant, it is expected that this mechanical damage affects the phloem and xylem, as well as stimulating the synthesis of compounds from specialized metabolism as a defense response of the plant to stresses of this nature order [12]. This initial general analysis corroborates this hypothesis.

With a pH below 4.5, palm wine appears suitable for stabilization through pasteurization alone. In this study, the pH of the collected palm wine was slightly lower than the range reported [13], who observed a pH evolution from 4.73 to 8.73 during fermentation, with 4.73 corresponding to the early sap stage. This difference in pH could be attributed to species variation, as their study focused on *Borassus flabellifer* Linn, whereas our research examined *Elaeis guineensis*.

Considering statements that palm wine could be a carrier of microorganisms [14] that cause food poisoning, pathogenic microorganisms (thermotolerant coliforms and total coliforms) were analyzed. This statement is not true. No total coli-

forms were detected. Even so, thermotolerant coliforms were analyzed, which were also not detected. Likewise, food-relevant microorganisms such as Salmonella, Listeria and Staphylococcus were not detected. This indicates that, although the collection system is rustic, in an open environment, without the use of good formal collection practice procedures, no problems were evident. However, it's important to note that the number of samples analyzed was limited, and further investigation is needed to definitively ensure product safety.

Yeast presence was confirmed, as expected, given that alcoholic fermentation occurs shortly after palm wine collection. This is supported by scientific evidence and empirical observations [15]. When there is spontaneous fermentation, in addition to the formation of alcohol, there is also the formation of lactic aromas, resulting from fermentation by lactic acid bacteria. Studies in Ivory Coast have demonstrated the presence of diverse microbial communities in palm wine, including Lactobacillus, Acetobacter, Leuconostoc, Fructobacillus, Saccharomyces, and Hanseniapora [16].

While we initially hypothesized that lactic acid bacteria would be the primary drivers of spontaneous fermentation [17], we observed a yeast population of 2.1×10^2 CFU/mL. This finding aligns with a study by [5] in Nigeria, Ghana, and Cameroon, which reported high yeast concentrations (10^4 to 10^7 CFU/mL) in fermented palm wine from *Elaeis guineensis*. The lower yeast concentration in our samples can be attributed to the fact that we analyzed fresh sap, whereas [5] studied fermented wine.

The total phenolic content of the palm wine was determined to be 0.8 mg of caffeic acid equivalent (CA) per milliliter. The phytochemical composition of the sap is significantly influenced by various factors, including tree variety, climatic conditions, and soil fertility [18]. Analysis of individual phenolic compounds revealed significant concentrations of caffeic acid and the flavonoid tiliroside. Other phenolic acids and flavonoids were also detected, albeit in lower amounts. The high concentration of caffeic acid suggests considerable antioxidant potential. Caffeic acid is widely recognized for its diverse biological properties, particularly its potent antioxidant activity [19]. Additionally, this compound contributes to the relative astringency of foods and beverages in which it is present. Phenolic acids, including caffeic acid, are products of the phenylpropanoid pathway, whose synthesis is stimulated by biotic and abiotic stressors [19]. In the context of this study, the accumulation of caffeic acid is likely due to cellular leakage caused by sap extraction through drilling and/or localized synthesis in the affected region, as there are no reports that products are translocated via the phloem or xylem.

Regarding VOCs (volatile organic compounds), a total of 26 compounds were detected, including esters, acids, alcohols, aldehydes, and ketones. These compounds are not translocated through plant vessels, suggesting they were likely synthesized because of injuries sustained during sample collection. These VOCs are predominantly synthesized from fatty acids, which are metabolized into ketones, alcohols, and aldehydes. Additionally, esters are formed through the association

of alcohol and acids, catalyzed by alcohol acyltransferases. The primary esters identified were octanoic acid ethyl ester (294 μg/mL in wine), decanoic acid ethyl ester (150.6 μg/mL in wine) and hexanoic acid ethyl ester (52.3 μg/mL in wine). These compounds are associated with characteristic aromas, often described as buttery, fruity, floral, and occasionally reminiscent of banana or pineapple. Both esters are commonly found in a variety of foods and beverages, including apples, apricots, bananas, beer, cheese, kiwis, cherimoyas, cherries, and coconut water [20]. Although a descriptive sensory analysis was not performed due to the lack of trained personnel, empirical observations suggest the presence of fruity and sweet flavors and aromas.

Octanoic acid, also known as caprylic acid, is a medium-chain saturated fatty acid, it has a strong, unpleasant, rancid-cheesy odor and flavor when concentrated, but in trace amounts it can contribute to the complexity of flavors in fermented or aged foods. It serves multiple roles, including acting as an antibacterial agent and a metabolite in humans and *Escherichia coli* [21]. Hexanoic acid is characterized by a fatty, cheesy, waxy odor reminiscent of goats or barnyard animals. Naturally occurring in various animal fats and oils, it has a distinctive unpleasant smell [22]. This attribute likely contributes to the characteristic odor of palm wine, which is readily recognized by most consumers. Indeed, the study of [23] give sensory evaluation of palm wine (*Elaeis guineensis*) revealed that the profile was dominated by the acidic and yeast-like character of the palm wine, with additional citrusy and fruity notes, while also some slight nutty impressions were perceivable. During the retronasal evaluation, the overall character changed significantly to citrusy and fruity, while the acidic and yeast-like qualities were comparatively lower. There was a strong increase recognized by the sensory panel in the nutty impression. Apart from that, also a popcorn-like aspect was perceived. The major difference that could be pointed out between the sample studied here and this wine palm study is the fermentation stage. The wine palm sensory study of [23] was made with a more advanced fermented sample already in the Nigerian market while the sample in this study was freezed an hour after collection from the three (Fresh sap). The hypothesis would be that the evolution of the volatiles compound is connected to the fermentation stage, a deeper study could give an overview about the volatiles cinetic.

The aroma profile of wine is significantly influenced by the presence of trace amounts of volatile compounds, including aldehydes (e.g., oxime methoxy-phenyl at 1.2 μg/mL) and ketones (e.g., 3(2H)-thiophenone, dihydro-2-methyl- at 3.8 μg/mL). A study [18] identified 41 odor-active compounds in palm wine, many previously unreported. Quantitative analysis and Odor Activity Values (OAVs) revealed that 3-isobutyl-2-methoxypyrazine (earthy), acetoin (buttery), ethyl hexanoate, 3-methylbutyl acetate (fruity), and 2-acetyl-1-pyrroline (popcorn-like) were the most potent odorants. Another one [24] also investigated the volatiles in bottled palm wine purchased from a Nigerian wine shop. They identified 13 key odorants, including 3-isobutyl-2-methoxypyrazine, acetoin, and 2-acetyl-1-pyrroline,

which were reported for the first time in palm wine aroma.

Elemental analysis (**Table 4**) revealed significant concentrations of potassium (1458.87 mg/L), calcium (1236.58 mg/L), and magnesium (696.56 mg/L) in the wine palm sap. Conversely, lower levels were observed for sodium (69.87 mg/L), silicon (23.15 mg/L), zinc (9.87 mg/L), aluminum (1.3 mg/L), and boron (1.23 mg/L). Heavy elements such as cadmium, cobalt, and chromium were absent. These elements, commonly found in our diet, play crucial roles in human nutrition. The presence of these elements in the sap is attributed to the collection method, which involves drilling into the plant and extracting fluids from the xylem and phloem. Physiologically, the upward movement of water and dissolved minerals within plants is a complex process involving cell-to-cell movement, transmembrane transport, and flow through xylem vessels [24].

Calcium is crucial for skeletal development and bone health. Potassium facilitates nerve impulse transmission to muscles, essential for skeletal muscle contraction and cardiomyocyte function (heart muscle cell contraction). Magnesium contributes to electrolyte balance and supports healthy teeth and bones. Notably, the calcium, magnesium, and potassium concentrations in 1 L of wine palm sap meet or exceed the Recommended Dietary Allowance (RDA) established by the European Food Safety Authority. Comparing these levels to human milk (280 mg/L calcium, 140 mg/L magnesium, 35 mg/L potassium) reveals a significant gap [25]. This observation supports the notion that wine palm sap may possess nutritional properties comparable to, and potentially exceeding, those of human milk. These findings underscore the nutritional value of this extract and its potential to address nutritional deficiencies in children within the Casamance community.

Furthermore, wine palm sap exhibits higher vitamin C content (6332 mg/100 mL) compared to human milk (4000 mg/100 mL) [25]. Vitamin C is a major constituent of the sap [26]. While vitamin C levels in *Elaeis guineensis* (oil palm) are not readily available, comparative data from *Cocos nucifera* (coconut) indicate a vitamin C content ranging from 16 to 65 mg/100 mL [27], which is lower than that observed in wine palm sap.

Polar metabolites analysis (**Table 5**) of the palm wine revealed a diverse profile dominated by sugars (95%). Glucose (11.88 mg/mL), gentiobiose (0.37 mg/mL), and sucrose (0.22 mg/mL) were the primary sugars identified. Sucrose is a major constituent of palm sap, with *Phoenix canariensis* exhibiting the highest sucrose content at 37.8% [28]. But in this study, it isn't the case that can be explained but the different types of metabolites that can be transported by the phloem. Indeed, metabolic analyses carried out in the past decades with different techniques have shown that phloem sap is not just a concentrated sucrose/amino acid solution [12]. During this study there is most sugars, then a few alcohols and carboxylic acids. The study [12] confirmed that in general, sugars are the major component of phloem sap, representing more than 70% of phloem sap metabolites. This wine palm analyzed has more phloem properties.

These sugars have significant technological applications. Indonesia and the

Philippines are leading producers of palm sugar, obtained through the caramelization of sap [29]. Furthermore, the sugar-rich environment of the sap can support microbial growth, leading to protein degradation or yeast autolysis, potentially reducing amino acid content [26].

GC-MS analysis of palm wine revealed a high concentration of sorbitol (2.31 and 1.76 mg/mL), a sugar alcohol with potential for enhancing food shelf life and improving texture, as well as applications in pharmaceuticals [30]. Minor amounts of myo-inositol, a compound with insulin-sensitizing properties, were also detected, suggesting potential health benefits. Furthermore, the presence of octanoic acid in both esterified (294.02 mg/mL) and simple (31.21 mg/mL) forms was observed. Previous research has demonstrated that octanoic acid-rich diets can enhance endurance capacity and alter skeletal muscle metabolism, indicating potential nutritional significance [31].

Overall, the wine palm characteristics give a rich biochemical and metabolic profile of the sap with an abundance of bioactive compounds, including phenolic acids (notably caffeic acid) and flavonoids (such as tiliroside), alongside 18 volatile compounds and 48 polar compounds, such as sugars, organic acids, and alcohols. Culturally, palm wine is used as a dietary supplement for children, particularly orphans [1]. That cultural belief was confirmed by the characterization made during this study. The biochemical diversity of this sap can explain these nutritional habits adopted by the population of Casamance. We have here an illustration of how cultural habits can be established by a population using the observation of the effect of a product. If we look into the food culture aspect [32], human beings' daily food intake is an intricate phenomenon that arises from the need to satisfy hunger (for survival and well-being) but also to meet social needs. Moreover, humans not only gather or hunt food, but they also cultivate plants and raise livestock. They cook food, use utensils for eating, create rules for behavior ("table manners"), and use food in social and religious rituals. We can think then that the specific use of wine palm as a nutritional supplement came from those social needs that could emerge. This study contributes to the scientific validation of Senegalese cultural habits, confirming the relevance of using wine palm as a nutritive element.

5. Conclusion

The characterization of wine palm sap from Senegal (Casamance) reveals that palm sap does not pose a biological hazard related to microorganism's indicative of fecal contamination, nor does it contain pathogenic microorganisms of the genera Salmonella, Listeria, and Staphylococcus. On the other hand, the presence of autochthonous yeasts is confirmed, while lactic acid bacteria are absent. Regarding its organic composition, this sap is rich in phenolic compounds, particularly caffeic acid and tiliroside, as well as volatile compounds, notably ethyl octanoate, ethyl decanoate, and ethyl hexanoate. It also contains sugars (glucose, gentiobiose, and sucrose), alcohol (sorbitol), and carboxylic acids (such as octanoic acid). To our knowledge,

this is the first time that the composition of compounds involved in the primary and specialized metabolism of this sap has been described in such detail. The richness in mineral compounds, especially calcium, potassium, and magnesium, explains the popular belief that it is a nutritionally rich food, even used as a supplement to maternal nutrition in cases of insufficient breast milk, and for nutritional fortification for people with nutritional deficiencies. In general, the concentration of these minerals exceeds that detected in breast milk. In conclusion, the findings presented here help explain the empirical knowledge and traditional wisdom of the native peoples inhabiting these ecosystems, where palm wine (whether fresh sap or fermented) has been consumed for centuries. It also gives a perspective on the relevance of a production of a wine palm as a commercialized product.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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