

Analysis of Nutritional Profiles, Mineral Content, and Contaminants in Palm Oil from Yenagoa Metropolis, Nigeria: Assessing Quality and Safety Standards

ABSTRACT

Aim: This study aims to evaluate the nutritional profiles, chemical compositions, and potential contamination of palm oil samples from different locations in Yenagoa Metropolis, Nigeria, to assess their quality and safety.

Study Design: The research was conducted as an analytical investigation, employing proximate analysis, mineral content determination, and Gas Chromatography-Mass Spectrometry (GC-MS) to characterize the composition and contamination levels of the palm oil samples.

Place and Duration of Study: The study was conducted in Yenagoa Metropolis, Nigeria, between January and October, 2023.

Methods: Palm oil samples were systematically collected from three distinct locations within Yenagoa Metropolis. Proximate analyses were performed to quantify moisture, ash, protein, fat, and carbohydrate content. Mineral content was analyzed for potassium, iron, magnesium, and phosphorus concentrations. GC-MS was utilized to identify and quantify bioactive compounds and potential contaminants in the samples.

Results: Moisture content varied from 0.00% in sample C to 3.00% in sample A. Ash content was highest in samples B and C, both at 20.06%, while sample C exhibited a notably higher fat content (47.0%) compared to the other samples. The highest concentrations of potassium (10.9%) and phosphorus (0.53%) were also observed in sample C. GC-MS analysis identified key bioactive compounds, including n-hexadecanoic acid and squalene, alongside harmful contaminants such as toluene and mesitylene, predominantly in samples A and B. The presence of these contaminants underscores the potential risks associated with processing and storage practices.

This study highlights the nutritional potential of palm oil while underscoring the critical need for enhanced quality control measures to safeguard consumer health.

Keywords: *Palm oil, Nutritional profile, proximate analysis, Chemical composition, Residual solvents, GC-MS*

1. INTRODUCTION

Edible oils, also referred to as cooking oils, are primarily derived from plant and animal sources. These oils, a form of dietary fat, are rich in fatty acids, including saturated fatty acids as well as mono- and polyunsaturated fatty acids [1]. They play a crucial role in

the daily diet by serving as carriers for fat-soluble vitamins and providing essential energy necessary for human health [2]. Edible oils are also considered significant natural sources of carotenoids, which the human body converts into Vitamin A. Carotenoids are known to enhance immune function, improve cardiovascular health, and act as biological antioxidants, thereby protecting cells and tissues from oxidative damage caused by free radicals [3].

The oil palm (*Elaeisguineensis*) is a monocotyledonous plant within the palm family *Arecaceae*. It produces male and female inflorescences in an alternating cycle [4]. The oil palm fruit yields two distinct types of oil: the orange-red crude palm oil, which is extracted from the mesocarp, and the brownish-yellow crude palm kernel oil, derived from the seeds (kernels). Palm oil, historically used in food preparation for over 5,000 years [5], is the most widely produced edible vegetable oil globally, with its nutritional and health benefits extensively documented.

Beta-carotene in palm oil contributes to the regulation of hormonal levels in the body [5]. Additionally, palm oil is rich in tocopherols, potent antioxidants that target and eliminate cancerous cells [6]. Experimental studies have demonstrated that palm oil is effective in treating thrombosis in rat models [7]. When consumed in moderation, palm oil aids in maintaining balanced cholesterol levels [8]. It also contains a small amount of omega-3 fatty acids, which support cardiovascular and endocrine health (Cleveland Clinic). Vitamin E in palm oil provides both anti-inflammatory and antioxidant benefits [9]. Furthermore, palm oil is a valuable source of vitamin D, which supports healthy joints and bone density. It also contains ubiquinone, an energy booster, and a minor amount

of squalene, which has cholesterol-lowering and anti-cancer properties. Red palm oil is notably rich in co-enzyme Q10 [10][11].

During palm oil extraction, solvent extraction is recognized as the most efficient method for maximizing oil recovery (Anderson International Corp). Common solvents used in this process include hexane, petroleum ether, ethanol, isopropanol, and acetone.

Despite its high nutritional value, palm oil can be susceptible to microbial contamination, including species such as *Bacillus cereus*, *Bacillus subtilis*, *Escherichia coli*, *Klebsiella* sp., *Serratia marcescens*, *Pseudomonas aeruginosa*, *Staphylococcus aureus*, and *Staphylococcus epidermidis* [12]. Contaminants such as aromatic hydrocarbons, 3-monochloropropane-1,2-diol esters (3-MCPDE), and glycidyl esters (GE) have also been reported [13][14]. Incomplete purification or recovery of extraction solvents can result in residual traces of aromatic hydrocarbons in the oil [15].

Industrial activities adjacent to palm plantations may release benzene, toluene, and other volatile organic compounds (VOCs) into the atmosphere, which can subsequently deposit on palm fruits. Contaminated water sources used for irrigation or polluted soil may introduce these chemicals into the palm trees, ultimately affecting the extracted oil. Additionally, the use of certain industrial lubricants and cleaning agents that contain benzene, toluene, or their derivatives in processing equipment can lead to oil contamination [16]. Packaging materials that have been in contact with or derived from substances containing these contaminants can also contribute to oil contamination. Moreover, pesticides and herbicides used in palm plantations, which may contain impurities such as benzene or toluene, can further contaminate palm oil. Accidental spills or leaks of industrial chemicals near processing facilities or during transportation

are additional sources of contamination. Such contaminants in palm oil pose significant health risks, including peripheral neuropathy from hexane exposure, characterized by numbness, tingling, and muscle weakness, and respiratory tract irritation, dizziness, and central nervous system depression from acetone exposure [17].

Although ethanol is generally considered less toxic than other solvents, elevated concentrations can lead to liver damage and adverse effects on the central nervous system. Benzene is recognized as a human carcinogen, while chronic exposure to toluene has been linked to developmental delays and congenital malformations [18].

This study is designed to analyze the nutritional, chemical constituents and residual solvent contamination in three palm oil samples collected from the Bolou-Orua local oil mill, Akenfa market, and Swali market in Bayelsa State, Nigeria. The research will further assess the potential public health and food safety implications of these samples within the region.

2. EXPERIMENTALS

Three palm oil (*Elaeis guineensis*) samples were collected from Yenagoa metropolis. Sample A was obtained from a local oil mill in Bolou-Orua, while Samples B and C were sourced from Akenfa and Swali markets, respectively, within Bayelsa State, Nigeria. The oils, as depicted in Figure 1, were accurately identified at the Biotechnology Department of the University of Africa, Toru-Orua. Subsequently, the samples were transferred into three distinct reagent bottles, appropriately labeled, and stored in a cupboard for further analysis.



Fig. 1: Palm oil samples collected from Bolou-Orua (A), Akenfa market (B), and Swali market (C)

2.1 Proximate Analysis

The levels of moisture (water content), fat, ash, carbohydrates, protein, and non-fat nutrients were determined using the standard methodologies described by the Association of Official Analytical Chemists [19].

2.2 Elemental Results

The elemental composition of magnesium, iron, copper, phosphorus, sodium, potassium, and zinc was analyzed employing the techniques specified by the Association of Official Analytical Chemists [19].

2.3 Gas Chromatography-Mass Spectroscopy (GC-MS) analysis of bioactive components

GC-MS assessment of the hexane extracts from palm oil samples A, B and C was performed using an Agilent 6890 gas chromatograph (GC) coupled with an Agilent 5973N Mass Spectrometer (MS), both obtained from Agilent Technologies, Palo Alto, CA, USA. The GC-MS configuration included an Agilent 7683 Series Automatic Liquid Sampler for automated sample introduction.

Chromatographic separation was carried out employing a META X5 coated fused silica capillary column (30 meters in length, 0.25 mm internal diameter, with a stationary phase film thickness of 0.25 μm), with a maximum column temperature of 325°C. The GC oven temperature program initiated at 70°C, held for 2 minutes, and then increased to 300°C at a rate of 20°C/min.

Ultra-high purity helium (99.99%) served as the carrier gas at a flow rate of 1.0 mL/min. A 1 μL sample volume was injected in split mode with a split ratio of 20:1. The mass spectrometer was operated with the source and quadrupole temperatures set at 230°C and 150°C, respectively, and the injection port, transfer line, and ion source temperatures maintained at 280°C. Mass spectra were acquired over a scan range of 50 to 550 atomic mass units (amu) with an electron ionization energy of 70 electronvolts (eV). The electron multiplier voltage was adjusted through an autotune procedure.

.2.4 Identification of Components

The identification and characterization of chemical compounds within the sample extracts were achieved through the analysis of retention times as determined by gas chromatography. The corresponding mass spectra were compared against a reference spectra library using advanced computer algorithms. For the interpretation of the gas chromatography-mass spectrometry (GC-MS) data, the comprehensive database

maintained by the National Institute of Standards and Technology (NIST) was utilized, encompassing over 590,000 spectral patterns.

To elucidate the properties of the compounds present in the sample extracts, mass spectra of unidentified compounds were cross-referenced with those of known components cataloged in the NIST library (version 2014). This comparative analysis enabled the accurate determination of compound names, molecular weights, molecular formulas, structures, and fragmentation patterns.

3. RESULTS AND DISCUSSION

The findings from the analyses conducted on the three palm oil samples A, B and C are outlined below:

3.1 Proximate and elemental analyses results

Proximate and elemental analyses of the three (3) palm oil (*Elaeisguineensis*) samples A, B and C were performed in triplicate, and the results are as shown in Table 1.

Table 1: Proximate and mineral composition of three (3) Palm oil (*Elaeisguineensis*) samples collected from Yenagoa Metropolis

Oil Samples	Proximate composition	Mean \pm SD (%)	Elemental composition	Mean \pm SD (mg)
Sample A Sample B Sample C	Moisture	3.00 \pm 0.1 1.00 \pm 0.3 0.00	Potassium (K)	8.61 \pm 0.2 5.63 \pm 0.1 10.9 \pm 0.1
Sample A Sample B Sample C	Protein	5.80 \pm 0.1 7.40 \pm 0.3 6.40 \pm 0.2	Iron (Fe)	0.19 \pm 0.1 0.18 \pm 0.2 0.19 \pm 0.2
Sample A Sample B Sample C	Carbohydrate	2.00 \pm 0.1 2.00 \pm 0.2 4.00 \pm 0.2	Sodium (Na)	106.3 \pm 0.1 106.3 \pm 0.1 107.1 \pm 0.1
Sample A Sample B Sample B	Ash	13.2 \pm 0.2 20.6 \pm 0.1 20.6 \pm 0.2	Copper (Cu)	10.00 \pm 0.2 39.00 \pm 0.1 20.00 \pm 0.2
Sample A Sample B Sample C	Fat/Oil	34.0 \pm 0.01 20.0 \pm 0.2 47.0 \pm 0.2	Magnesium (Mg)	0.10 \pm 0.1 0.03 \pm 0.2 0.10 \pm 0.1
Sample A Sample B Sample C			Zinc	0.435 \pm 0.1 0.302 \pm 0.1 0.388 \pm 0.1
Sample A			Phosphorus	0.30 \pm 0.1

Sample B				0.50 ± 0.1
Sample C				0.30 ± 0.2

3.2 GC-MS Results

GC-MS results of hexane extracts of three (3) Palm oilsamples A, B and C, are shown in Tables 2-4.

Table 2: Identified compounds from the hexane extract of palm oil sample A by gas chromatography-mass spectrometry (GC-MS)

S/N	Retention Time (min)	Name of compound	Probability (%)	Molecular formula	Molecular weight
1.	1.303	Borane, compd. with dimethylamine (1:1)	93.5	C ₂ H ₁₀ BN	59
2.	1.370	Trimethylamine, compd. with borane	88.9	C ₃ H ₁₂ BN	73
3.	1.394	Diaziridine,3,3-dimethyl	95.2	C ₃ H ₈ N ₂	72
4.	1.441	Butane, 2,2-dimethyl	76.3	C ₆ H ₁₄	86
6.	1.542	Isobutylene glycol	89.1	C ₅ H ₁₀ O	86
7.	1.585	Ethyl tert-butyl ether	91.9	C ₅ H ₁₀ O	86
8.	1.707	Furan, 2,5-dihydro-3-methyl	94.1	C ₅ H ₈ O	84
9.	1.824	Pentane, 3,3-dimethyl	84.0	C ₇ H ₁₆	100
10.	1.880	Benzene	81.9	C ₆ H ₆	78
11.	1.939	Cyclopentane, 1,1-dimethyl	70.9	C ₇ H ₁₄	98
12.	2.042	Cycloheptane	76.8	C ₇ H ₁₄	98
13.	2.103	Heptane, 3-4-dimethyl	82.3	C ₉ H ₂₀	128
14.	2.340	Cyclopentane,1-ethyl-1-methyl	84.2	C ₈ H ₁₆	112
15.	2.403	Cyclopentane, ethyl1-	88.5	C ₇ H ₁₄	98
16.	2.444	Cyclopentane, 1,2,4-trimethyl	70.9	C ₈ H ₁₆	112
17.	2.509	Cyclopentane, 1,2,3-trimethyl-	66.6	C ₈ H ₁₆	112
18.	2.604	Pentane, 3-ethyl-2-methyl	79.1	C ₈ H ₁₈	114
19.	2.677	Heptane, 2-methyl-	80.3	C ₈ H ₁₈	114
20.	2.752	Toluene	80.5	C ₇ H ₈	92
21.	2.844	Cyclohexane, 1,3-dimethyl-	72.7	C ₈ H ₁₆	112
22.	2.864	Cyclohexane, 1,4-dimethyl	60.5	C ₈ H ₁₆	112
23.	2.910	Cyclohexane, 1,1-dimethyl-	81.4	C ₈ H ₁₆	112
24.	2.932	Cyclopentane, 1-ethyl-2-methyl-	58.4	C ₈ H ₁₆	112
25.	3.012	Octane	74.5	C ₈ H ₁₈	114
26.	3.038	Cyclohexane, 1,2-dimethyl-	69.5	C ₈ H ₁₆	112
27.	3.085	Cyclohexane, 1,3-dimethyl-	59.4	C ₈ H ₁₆	112
28.	3.261	Heptane, 2,6-dimethyl	81.4	C ₉ H ₂₀	128
29.	3.326	1-Nonene	44.0	C ₉ H ₁₈	126
30.	3.361	Cyclohexane, ethyl-	88.3	C ₈ H ₁₆	112
31.	3.389	Cyclohexane, 1,1,3-trimethyl-	83.0	C ₉ H ₁₈	126
32.	3.421	1,1,4-Trimethylcyclohexane	81.6	C ₉ H ₁₈	126
33.	3.536	Cyclohexane, 1,2,4-trimethyl-	72.8	C ₉ H ₁₈	126
34.	3.627	Benzene, 1,3-dimethyl	62.4	C ₈ H ₁₀	106
35.	3.820	Cyclopentane, butyl-	73.7	C ₉ H ₁₈	126
37.	3.853	1-Ethyl-3-methylcyclohexane	66.1	C ₉ H ₁₈	126
37.	3.889	Cyclohexane, 1-ethyl-4-methyl-	73.6	C ₉ H ₁₈	126

38.	3.931	Nonane	74.3	C ₉ H ₂₀	128
39.	4.020	Cyclohexane, 1-ethyl-2-methyl	61.6	C ₉ H ₁₈	126
40.	4.132	Bicyclo[3.2.1]octane	59.9	C ₈ H ₁₄	110
41.	4.210	Cyclohexane, propyl	85.8	C ₉ H ₁₈	126
42.	4.442	Dichloroacetic acid, heptadecyl ester	40.5	C ₁₉ H ₃₆ Cl ₂ O ₂	366
43.	4.474	Benzene, 1-ethyl-3-methyl	68.6	C ₉ H ₁₂	120
44.	4.530	Benzene, 1,2,3-trimethyl-	61.4	C ₉ H ₁₂	120
45.	4.703	Decane	77.7	C ₁₀ H ₂₂	142
46.	4.102	Mesitylene	74.1	C ₉ H ₁₂	120
47.	4.144	Cyclohexane, propyl-	85.8	C ₉ H ₁₈	126
48.	9.195	n-hexadecanoic acid	94.3	C ₁₆ H ₃₂ O ₂	256
49.	9.784	oleic acid	71.1	C ₁₈ H ₃₄ O ₂	282
50.	9.819	n-decanoic acid	93.3	C ₁₈ H ₃₆ O ₂	284
51.	10.948	Docosanic acid	98.3	C ₂₂ H ₄₄ O ₂	340
52.	11.773	Squalene	80.1	C ₃₀ H ₅₀	410

Table 3: Identified compounds from the hexane extract of palm oil sample B by gas chromatography-mass spectrometry (GC-MS)

S/N	Retention Time (min)	Name of compound	Probability (%)	Molecular formula	Molecular weight
1.	1.316	Benzene,(methylenecyclopropyl)sulfonyl]-	96.5	C ₁₀ H ₁₀ O ₂ S	194
2.	1.354	1-Propene, 3-methoxy	93.4	C ₄ H ₈ O	72
3.	1.401	5-Oxazolecarbonitrile, 4-methyl	97.9	C ₅ H ₄ N ₂ O	108
4.	1.432	2-Hexyn-1-ol	86.3	C ₆ H ₁₀ O	98
5.	1.475	Oxirane, 2-ethyl-2-methyl	91.9	C ₅ H ₁₀ O	86
6.	1.519	4-Cyclopentene-1,3-diol, trans	94.1	C ₅ H ₈ O ₂	100
7.	1.542	Carbonic acid, but-3-yn-1-yl octyl ester	93.5	C ₁₃ H ₂₂ O ₃	226
8.	1.586	Furan, 2,5-dihydro-3-methyl	94.1	C ₅ H ₈ O	84
9.	1.663	1,3-Cyclobutanedicarbonitrile	71.3	C ₆ H ₆ N ₂	106
10.	1.696	2-Undecyne	63.4	C ₁₁ H ₂₀	152
11.	1.816	2-Pyridinecarbonitrile, 6-chloro	98.6	C ₆ H ₃ ClN ₂	138
12.	1.873	Benzene	81.9	C ₆ H ₆	78
13.	1.900	2,4-Hexadiyne	86.5	C ₆ H ₆	78
14.	1.971	1,3-Cyclobutanedicarbonitrile	71.3	C ₆ H ₆ N ₂	106
15.	2.238	4-Cyclopentene-1,3-diol, trans-	94.1	C ₅ H ₈ O ₂	100
16.	2.327	2-Hexene, 5-methyl-	69.0	C ₇ H ₁₄	98
17.	2.363	Heptane, 3-methylene	78.5	C ₈ H ₁₆	112
18.	2.423	3-Octene	64.1	C ₈ H ₁₆	112
19.	2.619	N-(4-Carboxymethyl)-N'-phenyl-urea	97.7	C ₁₅ H ₁₄ N ₂ O ₃	270
20.	2.668	2-Penten-4-yne, 2-methyl-	84.8	C ₆ H ₈	80
21.	2.757	Cyclopropanecarboxylic acid, 2-methylene-, methyl ester	97.6	C ₆ H ₈ O ₂	112
22.	2.774	7,8-Dioxabicyclo[3.2.1]oct-2-ene	94.7	C ₆ H ₈ O ₂	112
23.	2.816	Cyclooctane	63.7	C ₈ H ₁₆	112
24.	2.922	Carbonic acid, but-2-yn-1-yl hexadecyl este	74.5	C ₂₁ H ₃₈ O ₃	338

25.	2.946	2-Cyclopenten-1-one, 4-methoxy	95.3	C ₆ H ₈ O ₂	112
26	2.992	2,4-Dimethyl-3-hexene(c,t)	52.8	C ₈ H ₁₆	112
27.	3.049	Dodecane, 2,2,11,11-tetramethyl-	86.8	C ₁₆ H ₃₄	226
28.	3.079	Heptane, 2,4-dimethyl-	69.3	C ₉ H ₂₀	128
29.	3.160	Heptane, 2,6-dimethyl	81.4	C ₉ H ₂₀	128
30.	3.230	Cyclooctane, methyl	59.7	C ₉ H ₁₈	126
31.	3.270	trans-4,4-Dimethyl-2-hexene	51.0	C ₈ H ₁₆	112
32.	3.298	3-Hexene, 2,3-dimethyl-	65.7	C ₈ H ₁₆	112
33.	3.328	1,1,4-Trimethylcyclohexane	81.6	C ₉ H ₁₈	126
34.	3.380	5-Eicosene	36.5	C ₂₀ H ₄₀	280
35.	3.445	Cyclohexane, 1,2,4-trimethyl	75.9	C ₉ H ₁₈	126
36.	3.534	1,5-Hexadien-3-yne, 2-methyl	91.5	C ₇ H ₈	92
37.	3.650	Furazan-3-carbohydrazide-4-methyl-N2-benzylideno	95.6	C ₉ H ₉ N ₃ O ₂	191
38.	3.713	Bicyclo[3.2.1]octane	59.9	C ₈ H ₁₄	110
39.	3.738	Cyclohexane, 1,2,4-trimethyl-	75.9	C ₉ H ₁₈	126
40.	3.775	cis-1-Ethyl-3-methyl-cyclohexane	67.1	C ₉ H ₁₈	126
41.	3.814	Cyclohexane, 1-ethyl-4-methyl-, trans-	61.1	C ₉ H ₁₈	126
42.	3.844	1,5-Hexadien-3-yne, 2-methyl-	91.5	C ₇ H ₈	92
43.	3.950	Cyclohexane, 1-ethyl-2-methyl-	61.6	C ₉ H ₁₈	126
44.	3.984	trans-1,2-Diethyl cyclopentane	80.3	C ₉ H ₁₈	126
45.	4.063	Hexenyl angelate, 4z-	76.9	C ₁₁ H ₁₈ O ₂	182
46.	4.102	Mesitylene	74.1	C ₉ H ₁₂	120
47.	4.144	Cyclohexane, propyl-	85.8	C ₉ H ₁₈	126
48.	4.182	Heptane, 3-ethyl-2-methyl-	79.6	C ₁₀ H ₂₂	142
49.	4.215	1-Methyl-2-methylenecyclohexane	52.9	C ₈ H ₁₄	110
50.	4.303	Cyclohexane, 1,3-dimethyl-2-methylene-, trans-	68.8	C ₉ H ₁₆	124
51.	4.362	Benzene, propyl-	89.4	C ₉ H ₁₂	120
52.	4.386	Nonane, 2-methyl-	72.5	C ₁₀ H ₂₂	142
53.	4.413	Benzene, 1-ethyl-3-methyl-	61.7	C ₉ H ₁₂	120
54.	4.442	Benzene, 1-ethyl-2-methyl-	63.3	C ₉ H ₁₂	120
55.	4.478	Mesitylene	68.6	C ₉ H ₁₂	120
56.	4.570	Cyclohexane, 1-ethyl-1-methyl-	72.5	C ₉ H ₁₈	126
57.	4.672	Mesitylene remove	68.6	C ₉ H ₁₂	120
58.	4.790	4,5-Dihydro-4,4-undecamethylene-2-phenyl-1,3-oxazin-6-one	97.6	C ₂₁ H ₂₉ NO ₂	327
59..	4.817	Decane, 4-methyl-	62.3	C ₁₁ H ₂₄	156
60.	4.887	Benzene, 1,2,3-trimethyl-	61.4	C ₉ H ₁₂	120
61.	4.931	Cyclohexane, (2-methylpropyl)-	93.6	C ₁₀ H ₂₀	140
62.	5.117	Benzene, 1,3-diethyl-	70.1	C ₁₀ H ₁₄	134
63..	5.144	Naphthalene, decahydro-	66.8	C ₁₀ H ₁₈	138
64.	5.338	Undecane	55.0	C ₁₁ H ₂₄	156
65.	8.462	Tetradecanoic acid	92.0	C ₁₄ H ₂₈ O ₂	228
66.	9.017	Hexadecanoic acid, methyl	92.1	C ₁₇ H ₃₄ O ₂	270

		ester			
67.	9.268	1-(3-Methylbutoxy)-1-methyl-1-silacyclohexane	95.3	C ₁₁ H ₂₄ OSi	200
68.	9.613	9-Octadecanoic acid (Z)-, methyl ester	44.1	C ₁₉ H ₃₆ O ₂	296
69.	9.842	6-Octadecanoic acid, (Z)-	61.0	C ₁₈ H ₃₄ O ₂	282
70.	9.876	Octadecanoic acid	93.3	C ₁₈ H ₃₆ O ₂	284
71.	11.867	Squalene	91.3	C ₃₀ H ₅₀	410

Table 4: Identified compounds from the hexane extract of palm oil sample C, by gas chromatography-mass spectrometry (GC-MS)

S/N	Retention Time (min)	Name of compound	Probability (%)	Molecular formula	Molecular weight
1.	1.327	Cyclopropyl(2-nonyloxy-benzyl)amine	92.3	C ₅ H ₁₁ Cl	106
2.	1.388	Butane,2,2-dimethyl-	76.3	C ₆ H ₁₄	86
3.	1.455	Pentane, 2-methyl-	91.8	C ₆ H ₁₄	86
4.	1.490	Pentane, 3-methyl-	74.3	C ₆ H ₁₄	86
5.	1.533	n-Hexane	90.2	C ₆ H ₁₄	86
6.	1.641	1-Hexyl trifluoroacetate	92.5	C ₈ H ₁₃ F ₃ O ₂	198
7.	1.805	1,3-Hexadien-5-yne	84.9	C ₆ H ₆	78
8.	1.931	Cyclopentane, 1,2-dimethyl-, cis-	54.8	C ₇ H ₁₄	98
9.	1.971	Heptane	83.7	C ₇ H ₁₆	100
10.	2.194	Cycloheptane	76.8	C ₇ H ₁₄	98
11.	2.305	Hexane, 2-methyl-4-methylene-	79.7	C ₈ H ₁₆	112
12.	2.370	Cyclopentane, 1,2,3-trimethyl-	66.6	C ₈ H ₁₆	112
13.	2.502	Heptane, 2-methyl-	80.3	C ₈ H ₁₈	114
14.	2.592	Toluene	80.5	C ₇ H ₈	92
15.	2.678	Cyclohexane, 1,3-dimethyl-	67.2	C ₈ H ₁₆	112
16.	2.839	Octane	74.5	C ₈ H ₁₈	114
17.	2.874	Cyclohexane, 1,2-dimethyl-, trans-	69.5	C ₈ H ₁₆	112
18.	2.938	Cyclohexane, 1,3-dimethyl-	67.2	C ₈ H ₁₆	112
19.	3.190	Cyclooctane, methyl-	59.7	C ₉ H ₁₈	126
20.	3.223	Ethylcyclohexane	83.3	C ₈ H ₁₆	112
21.	3.251	3-Hexene, 2,3-dimethyl-	65.7	C ₈ H ₁₆	112
22.	3.533	Ethylbenzene	74.8	C ₈ H ₁₀	106
23.	3.615	1,4-Dimethylbenzene	69.6	C ₈ H ₁₀	106
24.	3.830	1,2-Dimethylbenzene	65.8	C ₈ H ₁₀	106
25.	4.129	Cyclohexane, 2-propenyl-	88.7	C ₉ H ₁₆	124
26.	4.420	Benzene, 1-ethyl-2-methyl-	63.3	C ₉ H ₁₂	120
27.	4.480	Hemimelitene	61.4	C ₉ H ₁₂	120
28.	4.658	Decane	77.7	C ₁₀ H ₂₂	142
29.	9.030	methyl palmitate	92.1	C ₁₇ H ₃₄ O ₂	270
30.	9.029	Pentadecanoic acid-3-methyl, methyl ester	92.1%	C ₁₇ H ₃₄ O ₂	270
31.	9.224	n-Hexadecanoic acid	94.3%	C ₁₆ H ₃₂ O ₂	256
32.	9.624	9-Octadecanoic acid, methyl ester	44.6%	C ₁₉ H ₃₆ O ₂	296
33.	9.687	Methyl stearate	90.5%	C ₁₉ H ₃₈ O ₂	298

34.	9.807	9-Octadecenoic acid	62.8%	C ₁₈ H ₃₄ O ₂	282
35.	9.847	n-Decanoic acid	93.3%	C ₁₈ H ₃₆ O ₂	284

Table 1 presents the proximate analysis results for oil samples A, B, and C collected from Yenagoa Metropolis. The moisture content for these samples was 3.00%, 1.00%, and 0.00%, respectively. Ajiboye *et al.* [20] reported a moisture content of 2.11%, indicating that observed differences may be due to variations in palm fruit species. Extremely low moisture levels can adversely affect the quality of oil and fat products, as residual water significantly impacts their appearance and shelf life [21]. The ash content for samples A, B, and C were 13.02%, 20.06%, and 20.06%, respectively. This indicates that sample A has a lower inorganic residue compared to samples B and C. Raji *et al.* [21] reported lower ash content, suggesting that differences in ash content could be due to variations in soil conditions across different geographic locations. Protein content in samples A, B, and C were 5.80%, 7.40%, and 6.40%, respectively. This is in line with the value reported by Ajiboye *et al.* [20], who found a protein content of 5.43%.

The fat content of samples A, B, and C were 34.0%, 20.0%, and 47.0%, respectively. Sample C exhibited a significantly higher fat content compared to samples A and B. Ajiboye *et al.* [20] reported a higher fat content of 78.19%, suggesting that variations in fat composition could be attributed to factors such as genetic variations, geographical location, agricultural practices, harvesting time, and storage conditions. The carbohydrate content of samples A, B, and C were 2.00%, 2.00%, and 4.00%, respectively. In comparison, Raji *et al.* [21] reported a carbohydrate content of 0.01756% in palm oil samples from Bayelsa State.

Table 2 presents the mineral content of palm oil samples A, B, and C. The potassium concentrations were 8.61% in sample A, 5.63% in sample B, and 10.9% in sample C, with sample C exhibiting the highest potassium content. Potassium is a critical nutrient in oil palm production, playing a vital role in converting light into biochemical energy during photosynthesis and facilitating the efficient transport of assimilates from the leaves to other plant organs [22].

The iron (Fe) concentrations in samples A, B, and C were 0.19%, 0.18%, and 0.19%, respectively. These low levels of iron suggest that palm oil is not a significant source of this mineral. Magnesium (Mg) concentrations were 0.10% in sample A, 0.03% in sample B, and 0.01% in sample C. Phosphorus (P) levels were 0.30% in sample A, 0.50% in sample B, and 0.53% in sample C, with sample C having the highest phosphorus concentration. Phosphorus is essential for ATP synthesis and bone mineralization [23][24]. This comparative study indicates that palm oil samples A, B, and C contain essential proximate and mineral nutrients necessary for various bodily functions.

The Gas Chromatography-Mass Spectrometry (GC-MS) analyses of hexane extracts from palm oil samples A, B, and C are detailed in Tables 3 through 5. Table 3, which presents data for oil sample A, lists fifty-two compounds along with their retention time, molecular weight, molecular formula, and peak area percentages. Bioactive components with peak area percentages below 5% were considered insignificant. Notable bioactives include n-hexadecanoic acid (94.3%), oleic acid (71.1%), n-decanoic acid (93.3%), docosanic acid (98.3%), and squalene (80.1%).

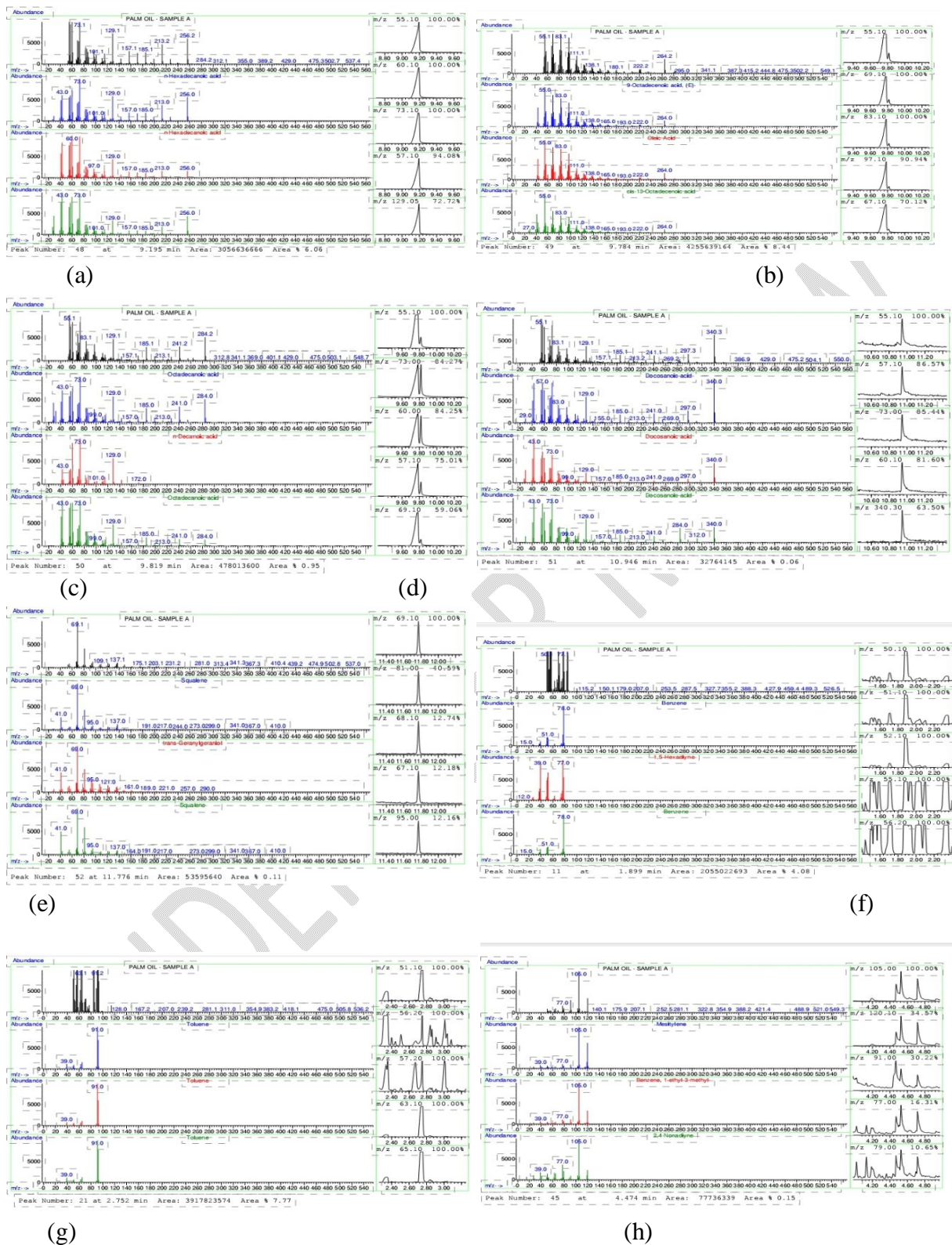


Fig. 2: Chromatograms of major naturally occurring bioactive compounds present in palm oil sample A: hexadecanoic acid (a); Oleic acid (b); n-decanoic acid (c); Docosanoic acid (d); Squalene (e), Benzene (f), Toluene (g), Mesitylene (h)

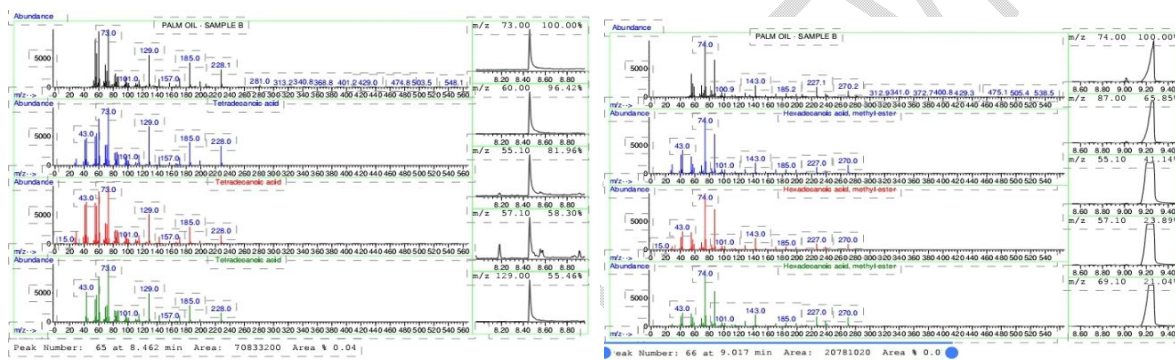
The compound n-hexadecanoic acid, also known as palmitic acid (Figure 2a), imparts texture, stability, and flavor to food products [25]. Despite its functional benefits, excessive intake of palmitic acid has been linked to adverse health effects, particularly in elevating low-density lipoprotein (LDL) cholesterol levels, which may contribute to the development of cardiovascular diseases [26]. Oleic acid (Figure 2b) is recognized for its anti-inflammatory properties [27]. In contrast, n-decanoic acid (Figure 2c) exhibits antiseizure effects [28]. Docosanoic acid, or behenic acid (Figure 2d), is known to raise cholesterol levels in humans [29]. Squalene (Figure 2e) is valued for its antioxidant and moisturizing properties [30].

In the analysis of sample A, 47 compounds not typically found in crude palm oil were identified at varying concentrations. These include Isobutylene glycol (89.1%), Oxirane 2-ethyl-2-methyl (91.9%), Furan 2,5-dihydro-3-methyl (94.1%), Benzene (81.9%), Trimethylamine compound with borane (88.9%), Diaziridine 3,3-dimethyl (95.2%), Cyclopentane 1-ethyl-1-methyl (82.2%), Cyclopentane 1,2,4-trimethyl (70.9%), Pentane 3-ethyl-2-methyl (79.1%), Heptane 2-methyl (80.3%), Toluene (80.5%), Cyclohexane 1,1-dimethyl (81.4%), 1,1,4-Trimethylcyclohexane (81.6%), Cyclohexane propyl (85.8%), and Benzene 1-ethyl-3-methyl (68.6%).

Isobutylene glycol, also known as 3-Methyl-2-buten-1-ol, is a synthetic compound used as a solvent, fuel additive, and chemical intermediate, but it is toxic to aquatic life [31]. Trimethylamine combined with borane and Diaziridine 3,3-dimethyl are foreign compounds in palm oil; Trimethylamine borane may cause lung irritation and shortness of breath [32]. Benzene (Figure 2f) has been associated with respiratory irritation and hematologic malignancies upon long-term exposure [33]. Toluene (Figure 2g) poses

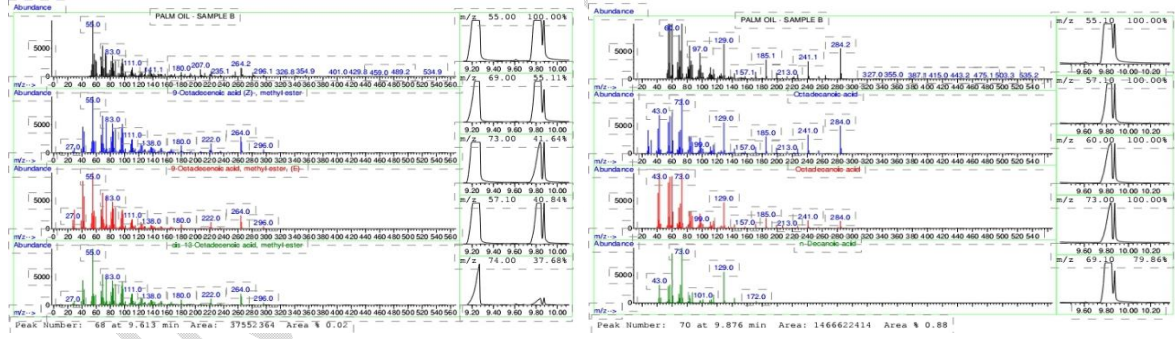
health risks including respiratory issues when present in palm oil [34]. Mesitylene (Figure 2h), a colorless liquid not naturally occurring in palm oil, can cause chemical pneumonitis if aspirated into the lungs [35].

In the analysis of sample B, a total of 71 bioactive compounds were examined, as detailed in Table 4. The identified compounds and their respective concentrations are as follows: Tetradecanoic acid (Myristic acid) at 92.0%, Hexadecanoic acid methyl ester at 92.1%, 9-Octadecanoic acid (Z)-methyl ester (Methyl oleate) at 44.1%, 6-Octadecanoic acid (Z)- at 61.0%, Octadecanoic acid at 93.3%, and Squalene at 91.3%.



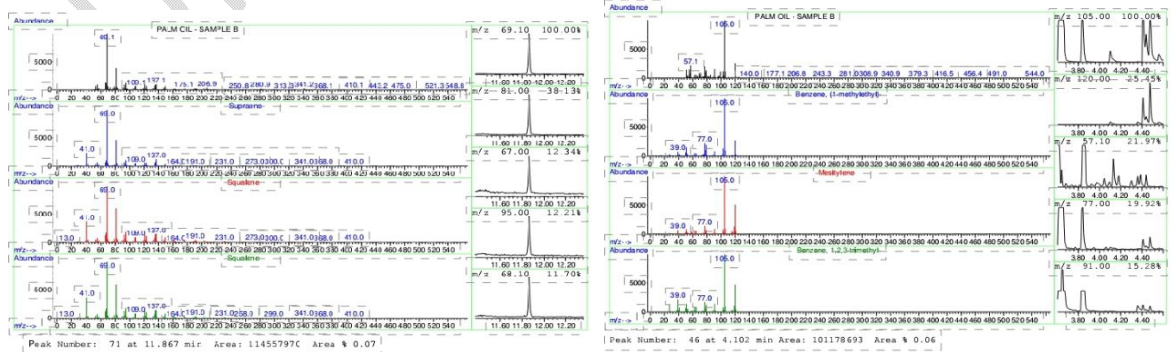
(a)

(b)



(c)

(d)



Peak Number: 71 at 11.867 min Area: 11455797C Area % 0.07

Peak Number: 46 at 4.102 min Area: 101178693 Area % 0.06

(e)

(f)

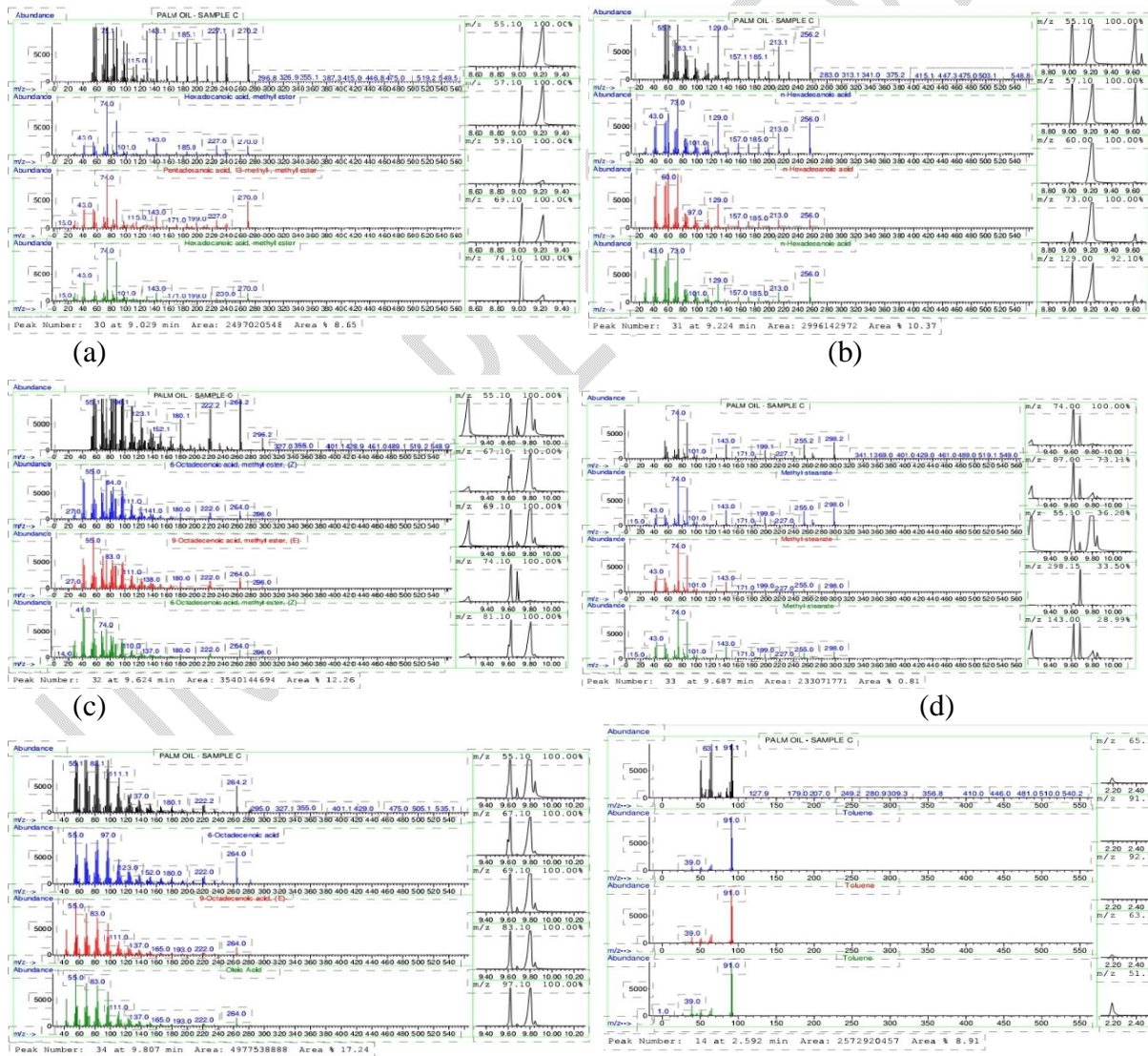
Fig. 3: Chromatograms of major chemical compounds analysed from Palm oil sample B: Tetradecanoic acid (a); Hexadecanoic acid, methyl ester (b); 9-octadecanoic acid methyl ester (c); Octadecanoic acid (d); Squalene (e); Mesitylene (f)

Tetradecanoic Acid (Myristic Acid), as depicted in Figure 3a, is a 14-carbon, straight-chain saturated fatty acid prevalent in both plant and animal sources. It serves as a food additive and flavor enhancer [36]. Hexadecanoic Acid Methyl Ester, shown in Figure 3b, is noted for its antibacterial properties [37]. 9-Octadecanoic Acid Methyl Ester (Methyl Oleate), illustrated in Figure 3c, is a naturally occurring component of palm oil, recognized as a monounsaturated fatty acid and a significant constituent of membrane phospholipids [38]. Octadecanoic Acid, represented in Figure 3d, has been associated with antioxidant properties [39]. Squalene, a natural constituent of palm oil shown in Figure 3e, is documented for its antitumor and anticancer effects against lung, ovarian, and breast cancers. Additionally, squalene is known to mitigate UV-induced skin damage, lower LDL cholesterol levels, and reduce overall blood cholesterol, thus aiding in the prevention of cardiovascular diseases [40].

In oil Sample B, sixty-five compounds not naturally present in crude palm oil were identified. These contaminants include octyl but-3-yn-1-yl carbonate (93.5%), (Methylenecyclopropyl)sulfonylbenzene (96.5%), 3-Methoxypropene (93.4%), 4-Methyl-5-oxazolecarbonitrile (97.9%), 2-Hexynyl alcohol (86.3%), 2-Ethyl-2-methyloxirane (91.9%), 3-Methyltetrahydrofuran (94.1%), Benzene (81.9%), Propylcyclohexane (85.8%), 1,3,5-Trimethylbenzene (68.6%), Furazan-3-carbohydrazide-4-methyl-N2-benzylideno (95.6%), Mesitylene (74.1%), and Decane, 4-methyl- (62.3%). Mesitylene,

illustrated in Figure 3f, poses a risk of aspiration into the lungs [35]. The substantial presence of these contaminants in palm oil signifies a potential health hazard [41][42].

From Sample C, thirty-five bioactive compounds were analyzed, as detailed in Table 4. Notable among these are Hexadecanoic Acid Methyl Ester (92.1%), n-Hexadecanoic Acid (94.3%), 9-Octadecenoic acid methyl ester (44.6%), Methyl Stearate (90.5%), 9-Octadecenoic Acid (Oleic Acid) (62.8%), and Octadecanoic Acid (93.3%). Both 9-Octadecenoic acid methyl Ester (Methyl oleate) and Methyl stearate are utilized in biodiesel production, lubrication, and cosmetic formulations [43][44][45][46].



(e)

(f)

Fig. 4: Chromatograms of major chemical compounds analysed from oil sample C: Pentadecanoic acid-3-methyl, methyl ester (a); n-hexadecanoic acid (b); 9-octadecenoic acid methyl ester (c); Methyl stearate (d); 9-Octadecanoic acid -(E) (e); Toluene (f)

In the analysis of palm oil samples, several compounds with notable biological activities and potential health impacts were identified. Pentadecanoic acid-3-methyl, methyl ester (Figure 4a) is a saturated fatty acid associated with cardiometabolic protection [47]. n-Hexadecanoic acid (Figure 4b) is recognized for its anti-inflammatory properties [48]. Hexadecanoic acid methyl ester (Figure 4c) exhibits antibacterial properties [37], while methyl stearate (Figure 4d) serves as a metabolite [49]. Additionally, 9-octadecenoic acid (Figure 4e) possesses antibiotic properties [50]. However, toluene (Figure 4f) in palm oil is known to be harmful to human health [34][51].

Furthermore, oil sample C contained twenty-nine compounds not naturally found in crude palm oil. These include isoamyl chloride (92.3%), n-hexane (90.2%), toluene (80.5%), 1-hexyl trifluoroacetate (92%), ethylcyclohexane (83.3%), 2-hexyn-1-ol (86.3%), ethylbenzene (74.8%), 1,4-dimethylbenzene (69.9%), 1,2-dimethylbenzene (65.8%), benzene, 1-ethyl-2-methyl (63.3%), and hemimellitene (61.4%). Many of these pollutants, such as toluene, are hazardous to human health [51][52]. Their presence in sample C is attributed to specific processing methods and storage conditions.

4. CONCLUSION

The proximate and mineral analyses of palm oil samples A, B, and C collected from Yenagoa Metropolis demonstrate notable differences in their compositional profiles. Sample A exhibited a moisture content of 3.00%, which was higher than samples B (1.00%) and C (0.00%). Low moisture levels in palm oil can negatively affect the quality

and shelf life of the product. The ash content was highest in samples B and C (20.06%), compared to sample A (13.02%), indicating a higher level of inorganic residue in the former. This variation in ash content may be attributed to differences in soil conditions and geographic factors. The protein content across the samples was relatively consistent, with sample A at 5.80%, sample B at 7.40%, and sample C at 6.40%. Fat content, however, varied significantly, with sample C having the highest fat content at 47.0%, compared to sample A (34.0%) and sample B (20.0%). This variation in fat content could be influenced by genetic factors, geographical location, agricultural practices, and storage conditions. In terms of mineral content, sample C had the highest potassium concentration (10.9%), which is crucial for plant health and nutrient conversion. The phosphorus content was also highest in sample C (0.53%), highlighting its importance in ATP synthesis and bone mineralization. Iron and magnesium levels were low across all samples, indicating that palm oil is not a significant source of these minerals.

GC-MS analyses revealed a range of bioactive compounds in the palm oil samples. Sample A contained notable bioactives such as n-hexadecanoic acid and oleic acid, with potential health benefits and some adverse effects. Sample B featured tetradecanoic acid and squalene, which have applications in skin care and cardiovascular health. Sample C had high concentrations of 9-octadecenoic acid and methyl stearate, which are useful in biodiesel production and cosmetics. Significantly, contaminants were identified in all samples, with the highest levels found in samples A and B. Contaminants such as toluene, benzene and mesitylene pose health risks, emphasizing the need for stringent quality control in palm oil processing and storage.

The presence of these contaminants indicates potential issues with processing methods and storage conditions.

Therefore, while the palm oil samples exhibit essential nutrients and beneficial bioactive compounds, the presence of contaminants and compositional variations highlight the necessity for improved quality control measures to ensure the safety and efficacy of palm oil products.

RECOMMENDATION

To reduce the health risks associated with consuming contaminated palm oil, it is essential to process palm oil in a manner that minimizes or eliminates residual solvents. Manufacturers should follow regulatory guidelines, and consumers should be informed about the potential risks of solvent residues in palm oil and other food products.

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