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

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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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: An analytical investigation was conducted, using proximate analysis, mineral content determination, and Gas Chromatography-Mass Spectrometry (GC-MS) to characterize the palm oil samples' composition and contamination levels.
Place and Duration of Study: The research was carried out in Yenagoa Metropolis, Nigeria, from January to October 2023.

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Methods: Palm oil samples were collected from three distinct locations within Yenagoa Metropolis. Proximate analysis quantified moisture, ash, protein, fat, and carbohydrate contents. Mineral content was assessed for potassium, iron, magnesium, and phosphorus. GC-MS was employed to identify and quantify bioactive compounds and potential contaminants in the samples.
Results: Moisture content ranged from 0.00% in sample C to 3.00% in sample A. Ash content was highest in samples B and C, at 20.06%, while sample C had the highest fat content at 47.0%. Potassium (10.9%) and phosphorus (0.53%) were also highest in sample C. GC-MS analysis revealed key bioactive compounds, such as n-hexadecanoic acid and squalene, but also detected harmful contaminants especially in samples A and B. Presence of Isobutylene glycol and various oxiranes can cause skin, eye, and respiratory irritation, with prolonged exposure leading to severe health issues. Benzene, toluene, Trimethylamine compound with Borane, Pentane 3-ethyl-2-methyl and Heptane 2-methyl are associated with respiratory problems, neurological damage, and potential long-term organ effects. Contaminants in the oil samples were attributed to inadequate refining, contaminated raw materials, improper handling, and environmental pollution. This study emphasizes the nutritional value of palm oil while highlighting the need for improved quality control measures to ensure the safety and efficacy of palm oil products.

Keywords: Palm oil; nutritional profile; proximate analysis; chemical composition; residual solvents; GC-MS.

1. INTRODUCTION

Edible oils, including those derived from both plant and animal sources, are integral components of human diet, providing essential fatty acids, fat-soluble vitamins, and energy. These oils, rich in mono-, and polyunsaturated fatty acids, play crucial roles in maintaining human health [1]. Additionally, they serve as significant natural sources of carotenoids, which are precursors to Vitamin A, and are known to enhance immune function, cardiovascular health, and protect cells from oxidative damage [2,3].

Among edible oils, palm oil, derived from the fruit of the oil palm (*Elaeis guineensis*), stands out due to its extensive use and nutritional benefits. The oil palm produces two types of oils: the mesocarp-derived crude palm oil and the kernel-derived crude palm kernel oil. Palm oil has a long history of use, spanning over 5,000 years, and today, it is the most widely produced vegetable oil globally [4,5]. The nutritional profile of palm oil is particularly notable for its high beta-carotene content, which helps regulate hormonal levels and provides antioxidant properties that protect against cancer and cardiovascular diseases [5,6]. Furthermore, palm oil is rich in tocopherols, which contributes to its antioxidant capacity, and contains small amounts of omega-3 fatty acids, vitamin E, vitamin D, ubiquinone, and squalene, each contributing to various health benefits [7,8,9].

Despite these benefits, palm oil's production and processing have raised significant concerns regarding contamination. The solvent extraction method, often used to maximize oil recovery, introduces the risk of residual solvents, such as hexane, acetone, and other volatile organic compounds (VOCs), remaining in the final product [10,11]. These contaminants pose potential health risks, including peripheral neuropathy, respiratory issues, and even carcinogenic effects [12]. Furthermore, environmental factors, such as industrial activities near palm plantations, can introduce additional contaminants like benzene, toluene, and other VOCs into the oil through air, water, or soil pollution [13,14].

In local palm oil refineries, the Refining, Bleaching, and Deodorization (RBD) process is typically executed using more manual methods and less sophisticated equipment than in industrial settings. The process begins with degumming, wherein workers manually introduce water or acids to the crude oil in basic mixing tanks to facilitate the removal of phospholipids and impurities. This is followed by neutralization, where an alkali such as sodium hydroxide is mixed with the oil to neutralize free fatty acids (FFA), forming soap stock that is subsequently separated using simple gravity settling or rudimentary centrifugation techniques. The next step, bleaching, involves the manual addition of bleaching earth or activated carbon to heated oil tanks, after which the mixture is filtered through basic systems to eliminate color pigments and impurities. However, the effectiveness of this step may not be as tightly controlled as in larger operations. The deodorization process is conducted using small-scale steam distillation units where the oil is subjected to heat under vacuum to remove volatile compounds that

cause undesirable odors and flavors. However, local facilities may not achieve the same level of temperature control or vacuum pressure as industrial plants, potentially resulting in less effective deodorization. Consequently, the overall process yields refined palm oil, but often with greater variability in quality and a higher risk of residual contaminants due to the less precise control over each step [15,16]

There are many scholarly reports on the nutritional value of palm oil, highlighting its role in providing essential nutrients and bioactive compounds. Additionally, studies have explored the health implications of consuming palm oil, particularly its effects on cardiovascular health, cholesterol levels, and its potential anti-cancer properties [17,18,19].

However, the literature on palm oil contamination is less comprehensive, with many studies focusing primarily on microbial contamination rather than chemical residues. While some research have identified the presence of harmful contaminants, such as 3-monochloropropane-1,2-diol esters (3-MCPDE) and glycidyl esters (GE), the extent of residual solvent contamination, particularly in regions with less industrial activity, remains underexplored [20,21]. Moreover, the impact of environmental pollutants, such as benzene and toluene, introduced through industrial processes or packaging materials, has not been thoroughly investigated in palm oil studies.

Given these gaps, the current study aims to address the critical need for comprehensive analysis of both the nutritional and chemical profiles of palm oil, with a particular focus on identifying residual solvents and other contaminants in palm oil samples from Bayelsa State, Nigeria. By examining palm oil from various sources within the region, this research will contribute to a better understanding of the potential public health and food safety implications associated with palm oil consumption in areas less affected by industrial activities. The findings of this study will provide valuable insights for both consumers and policymakers, helping to ensure the safety and quality of palm oil products.

2. MATERIALS AND METHODS

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 Fig. 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.

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 [22].

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

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 [22].

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

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 (*Elaeis guineensis*) samples A, B and C were performed in triplicate, and the results are as shown in Table 1.

3.2 GC-MS Results

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

4. DISCUSSION

4.1 Proximate Composition

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. [23] 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 [24]. 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. [24] 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. [23], who found a protein content of 5.43%.

Table 1. Proximate and mineral composition of three (3) Palm oil (*Elaeis guineensis*) samples collected from Yenagoa Metropolis

Oil Samples	Proximate composition	Mean ± SD (%)	Elemental composition	Mean ± SD (mg)
Sample A	Moisture	3.00 ± 0.1	Potassium (K)	8.61 ± 0.2
Sample B		1.00 ± 0.3		5.63 ± 0.1
Sample C		0.00		10.9 ± 0.1
Sample A	Protein	5.80 ± 0.1	Iron (Fe)	0.19 ± 0.1
Sample B		7.40 ± 0.3		0.18 ± 0.2
Sample C		6.40 ± 0.2		0.19 ± 0.2
Sample A	Carbohydrate	2.00 ± 0.1	Sodium (Na)	106.3 ± 0.1
Sample B		2.00 ± 0.2		106.3 ± 0.1
Sample C		4.00 ± 0.2		107.1 ± 0.1
Sample A	Ash	13.2 ± 0.2	Copper (Cu)	10.00 ± 0.2
Sample B		20.6 ± 0.1		39.00 ± 0.1
Sample B		20.6 ± 0.2		20.00 ± 0.2
Sample A	Fat/Oil	34.0 ± 0.01	Magnesium (Mg)	0.10 ± 0.1
Sample B		20.0 ± 0.2		0.03 ± 0.2
Sample C		47.0 ± 0.2		0.10 ± 0.1
Sample A			Zinc	0.435 ± 0.1
Sample B				0.302 ± 0.1
Sample C				0.388 ± 0.1
Sample A			Phosphorus	0.30 ± 0.1
Sample B				0.50 ± 0.1
Sample C				0.30 ± 0.2

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	$C_2H_{10}BN$	59
2.	1.370	Trimethylamine, compd. with borane	88.9	$C_3H_{12}BN$	73
3.	1.394	Diaziridine,3,3-dimethyl	95.2	$C_3H_8N_2$	72
4.	1.441	Butane, 2,2-dimethyl	76.3	C_6H_{14}	86
6.	1.542	Isobutylene glycol	89.1	$C_5H_{10}O$	86
7.	1.585	Ethyl tert-butyl ether	91.9	$C_5H_{10}O$	86
8.	1.707	Furan, 2,5-dihydro-3-methyl	94.1	C_5H_8O	84
9.	1.824	Pentane, 3,3-dimethyl	84.0	C_7H_{16}	100
10.	1.880	Benzene	81.9	C_6H_6	78
11.	1.939	Cyclopentane, 1,1-dimethyl	70.9	C_7H_{14}	98
12.	2.042	Cycloheptane	76.8	C_7H_{14}	98
13.	2.103	Heptane, 3-4-dimethyl	82.3	C_9H_2O	128
14.	2.340	Cyclopentane,1-ethyl-1-methyl	84.2	C_8H_{16}	112
15.	2.403	Cyclopentane, ethyl1-	88.5	C_7H_{14}	98
16.	2.444	Cyclopentane, 1,2,4-trimethyl	70.9	C_8H_{16}	112
17.	2.509	Cyclopentane, 1,2,3-trimethyl-	66.6	C_8H_{16}	112
18.	2.604	Pentane, 3-ethyl-2-methyl	79.1	C_8H_{18}	114
19.	2.677	Heptane, 2-methyl-	80.3	C_8H_{18}	114
20.	2.752	Toluene	80.5	C_7H_8	92
21.	2.844	Cyclohexane, 1,3-dimethy-	72.7	C_8H_{16}	112
22.	2.864	Cyclohexane, 1,4-dimethyl	60.5	C_8H_{16}	112
23.	2.910	Cyclohexane, 1,1-dimethyl-	81.4	C_8H_{16}	112
24.	2.932	Cyclopentane, 1-ethyl-2-methyl-	58.4	C_8H_{16}	112
25	3.012	Octane	74.5	C_8H_{18}	114
26.	3.038	Cyclohexane, 1,2-dimethyl-	69.5	C_8H_{16}	112
27.	3.085	Cyclohexane, 1,3-dimethyl-	59.4	C_8H_{16}	112
28.	3.261	Heptane, 2,6-dimethyl	81.4	C_9H_{20}	128
29.	3.326	1-Nonene	44.0	C_9H_{18}	126
30.	3.361	Cyclohexane, ethyl-	88.3	C_8H_{16}	112
31.	3.389	Cyclohexane, 1,1,3-trimethyl-	83.0	C_9H_{18}	126
32.	3.421	1,1,4-Trimethylcyclohexane	81.6	C_9H_{18}	126

S/N	Retention Time (min)	Name of compound	Probability (%)	Molecular formula	Molecular weight
33.	3.536	Cyclohexane, 1,2,4-trimethyl-	72.8	C_9H_{18}	126
34.	3.627	Benzene, 1,3-dimethyl	62.4	C_8H_{10}	106
35.	3.820	Cyclopentane, butyl-	73.7	C_9H_{18}	126
37.	3.853	1-Ethyl-3-methylcyclohexane	66.1	C_9H_{18}	126
37.	3.889	Cyclohexane, 1-ethyl-4-methyl-	73.6	C_9H_{18}	126
38.	3.931	Nonane	74.3	C_9H_{20}	128
39.	4.020	Cyclohexane, 1-ethyl-2-methyl	61.6	C_9H_{18}	126
40.	4.132	Bicyclo[3.2.1]octane	59.9	C_8H_{14}	110
41.	4.210	Cyclohexane, propyl	85.8	C_9H_{18}	126
42.	4.442	Dichloroacetic acid, heptadecyl ester	40.5	$C_{19}H_{36}Cl_2O_2$	366
43.	4.474	Benzene, 1-ethyl-3-methyl	68.6	C_9H_{12}	120
44.	4.530	Benzene, 1,2,3-trimethyl-	61.4	C_9H_{12}	120
45.	4.703	Decane	77.7	$C_{10}H_{22}$	142
46.	4.102	Mesitylene	74.1	C_9H_{12}	120
47.	4.144	Cyclohexane, propyl-	85.8	C_9H_{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	$C_{10}H_{10}O_2S$	194
2.	1.354	1-Propene, 3-methoxy	93.4	C_4H_8O	72
3.	1.401	5-Oxazolecarbonitrile, 4-methyl	97.9	$C_5H_4N_2O$	108
4.	1.432	2-Hexyn-1-ol	86.3	$C_6H_{10}O$	98
5.	1.475	Oxirane, 2-ethyl-2-methyl	91.9	$C_5H_{10}O$	86
6.	1.519	4-Cyclopentene-1,3-diol, trans	94.1	$C_5H_8O_2$	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_5H_8O	84
9.	1.663	1,3-Cyclobutanedicarbonitrile	71.3	$C_6H_6N_2$	106
10.	1.696	2-Undecyne	63.4	$C_{11}H_{20}$	152
11.	1.816	2-Pyridinecarbonitrile, 6-chloro	98.6	$C_6H_3ClN_2$	138
12.	1.873	Benzene	81.9	C_6H_6	78
13.	1.900	2,4-Hexadiyne	86.5	C_6H_6	78
14.	1.971	1,3-Cyclobutanedicarbonitrile	71.3	$C_6H_6N_2$	106
15.	2.238	4-Cyclopentene-1,3-diol, trans-	94.1	$C_5H_8O_2$	100
16.	2.327	2-Hexene, 5-methyl-	69.0	C_7H_{14}	98
17.	2.363	Heptane, 3-methylene	78.5	C_8H_{16}	112
18.	2.423	3-Octene	64.1	C_8H_{16}	112
19.	2.619	N-(4-Carboxymethyl)-N'-phenyl-urea	97.7	$C_{15}H_{14}N_2O_3$	270
20.	2.668	2-Penten-4-yne, 2-methyl-	84.8	C_6H_8	80
21.	2.757	Cyclopropanecarboxylic acid, 2-methylene-, methyl ester	97.6	$C_6H_8O_2$	112
22.	2.774	7,8-Dioxabicyclo[3.2.1]oct-2-ene	94.7	$C_6H_8O_2$	112
23.	2.816	Cyclooctane	63.7	C_8H_{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	$C_6H_8O_2$	112
26	2.992	2,4-Dimethyl-3-hexene(c,t)	52.8	C_8H_{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_9H_{20}	128
29.	3.160	Heptane, 2,6-dimethyl	81.4	C_9H_{20}	128
30.	3.230	Cyclooctane, methyl	59.7	C_9H_{18}	126
31.	3.270	trans-4,4-Dimethyl-2-hexene	51.0	C_8H_{16}	112
32.	3.298	3-Hexene, 2,3-dimethyl-	65.7	C_8H_{16}	112
33.	3.328	1,1,4-Trimethylcyclohexane	81.6	C_9H_{18}	126

S/N	Retention Time (min)	Name of compound	Probability (%)	Molecular formula	Molecular weight
34.	3.380	5-Eicosene	36.5	$C_{20}H_{40}$	280
35.	3.445	Cyclohexane, 1,2,4-trimethyl	75.9	C_9H_{18}	126
36.	3.534	1,5-Hexadien-3-yne, 2-methyl	91.5	C_7H_8	92
37.	3.650	Furazan-3-carbohydrazide-4-methyl-N2-benzylideno	95.6	$C_9H_9N_3O_2$	191
38.	3.713	Bicyclo[3.2.1]octane	59.9	C_8H_{14}	110
39.	3.738	Cyclohexane, 1,2,4-trimethyl-	75.9	C_9H_{18}	126
40.	3.775	cis-1-Ethyl-3-methyl-cyclohexane	67.1	C_9H_{18}	126
41.	3.814	Cyclohexane, 1-ethyl-4-methyl-, trans-	61.1	C_9H_{18}	126
42.	3.844	1,5-Hexadien-3-yne, 2-methyl-	91.5	C_7H_8	92
43.	3.950	Cyclohexane, 1-ethyl-2-methyl-	61.6	C_9H_{18}	126
44.	3.984	trans-1,2-Diethyl cyclopentane	80.3	C_9H_{18}	126
45.	4.063	Hexenyl angelate, 4z-	76.9	$C_{11}H_{18}O_2$	182
46.	4.102	Mesitylene	74.1	C_9H_{12}	120
47.	4.144	Cyclohexane, propyl-	85.8	C_9H_{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_8H_{14}	110
50.	4.303	Cyclohexane, 1,3-dimethyl-2-methylene-, trans-	68.8	C_9H_{16}	124
51.	4.362	Benzene, propyl-	89.4	C_9H_{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_9H_{12}	120
54.	4.442	Benzene, 1-ethyl-2-methyl-	63.3	C_9H_{12}	120
55.	4.478	Mesitylene	68.6	C_9H_{12}	120
56.	4.570	Cyclohexane, 1-ethyl-1-methyl-	72.5	C_9H_{18}	126
57.	4.672	Mesitylene remove	68.6	C_9H_{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_9H_{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 ester	92.1	$C_{17}H_{34}O_2$	270
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	$C_5H_{11}Cl$	106
2.	1.388	Butane,2,2-dimethyl-	76.3	C_6H_{14}	86
3.	1.455	Pentane, 2-methyl-	91.8	C_6H_{14}	86
4.	1.490	Pentane, 3-methyl-	74.3	C_6H_{14}	86
5.	1.533	n-Hexane	90.2	C_6H_{14}	86
6.	1.641	1-Hexyl trifluoroacetate	92.5	$C_8H_{13}F_3O_2$	198
7.	1.805	1,3-Hexadien-5-yne	84.9	C_6H_6	78
8.	1.931	Cyclopentane, 1,2-dimethyl-, cis-	54.8	C_7H_{14}	98
9.	1.971	Heptane	83.7	C_7H_{16}	100
10.	2.194	Cycloheptane	76.8	C_7H_{14}	98
11.	2.305	Hexane, 2-methyl-4-methylene-	79.7	C_8H_{16}	112
12.	2.370	Cyclopentane, 1,2,3-trimethyl-	66.6	C_8H_{16}	112
13.	2.502	Heptane, 2-methyl-	80.3	C_8H_{18}	114

S/N	Retention Time (min)	Name of compound	Probability (%)	Molecular formula	Molecular weight
14.	2.592	Toluene	80.5	C_7H_8	92
15.	2.678	Cyclohexane, 1,3-dimethyl-	67.2	C_8H_{16}	112
16.	2.839	Octane	74.5	C_8H_{18}	114
17.	2.874	Cyclohexane, 1,2-dimethyl-, trans-	69.5	C_8H_{16}	112
18.	2.938	Cyclohexane, 1,3-dimethyl-	67.2	C_8H_{16}	112
19.	3.190	Cyclooctane, methyl-	59.7	C_9H_{18}	126
20.	3.223	Ethylcyclohexane	83.3	C_8H_{16}	112
21.	3.251	3-Hexene, 2,3-dimethyl-	65.7	C_8H_{16}	112
22.	3.533	Ethylbenzene	74.8	C_8H_{10}	106
23.	3.615	1,4-Dimethylbenzene	69.6	C_8H_{10}	106
24.	3.830	1,2-Dimethylbenzene	65.8	C_8H_{10}	106
25.	4.129	Cyclohexane, 2-propenyl-	88.7	C_9H_{16}	124
26	4.420	Benzene, 1-ethyl-2-methyl-	63.3	C_9H_{12}	120
27.	4.480	Hemimelitene	61.4	C_9H_{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

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. [23] 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. [24] reported a carbohydrate content of 0.01756% in palm oil samples from Bayelsa State.

4.2 Nutritional Composition

Table 1 also 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 [25].

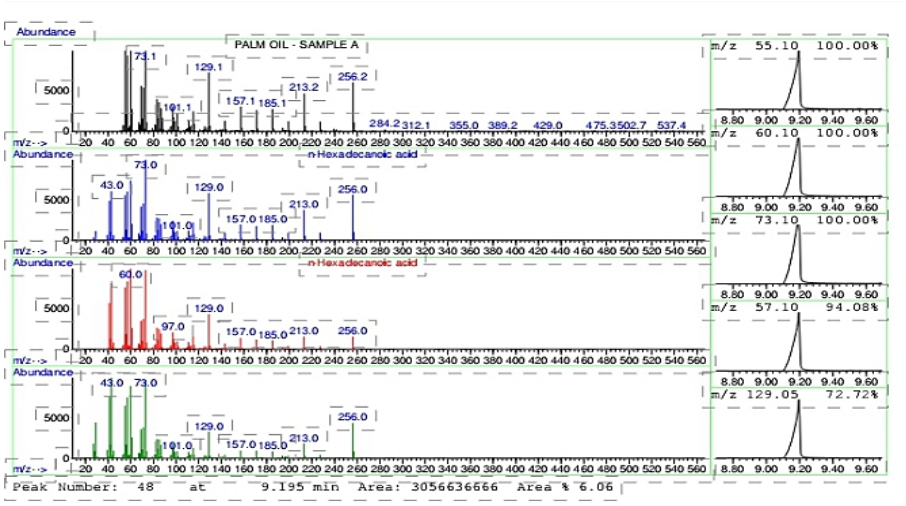
The iron (Fe) concentrations in samples A, B, and C were 0.19%, 0.18%, and 0.19%, respectively. These low levels of iron suggest that palm oil is not a significant source of this mineral. Magnesium (Mg) concentrations were 0.10% in sample A, 0.03% in sample B, and 0.01% in sample C. Phosphorus (P) levels 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 [26,27]. This comparative study indicates that palm oil samples A, B, and C contain essential proximate and mineral nutrients necessary for various bodily functions.

4.3 GC-MS Analysis

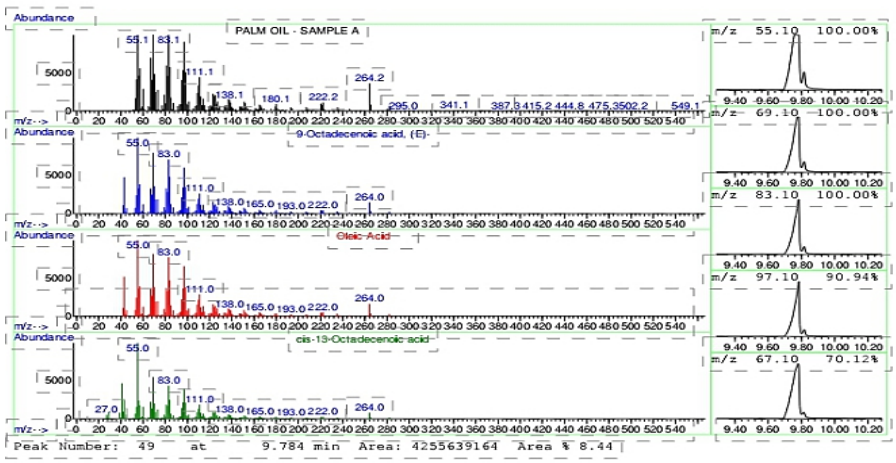
The Gas Chromatography-Mass Spectrometry (GC-MS) analyses of hexane extracts from palm oil samples A, B, and C are detailed in Tables 2 through 4. Table 2, which presents data for oil sample A, lists fifty-two compounds along with their retention time, molecular weight, molecular formula, and peak area 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%).

The compound n-hexadecanoic acid, also known as palmitic acid (Fig. 2a), imparts texture, stability, and flavor to food products [28], although, 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 [29]. Oleic acid (Fig. 2b) is recognized for its anti-

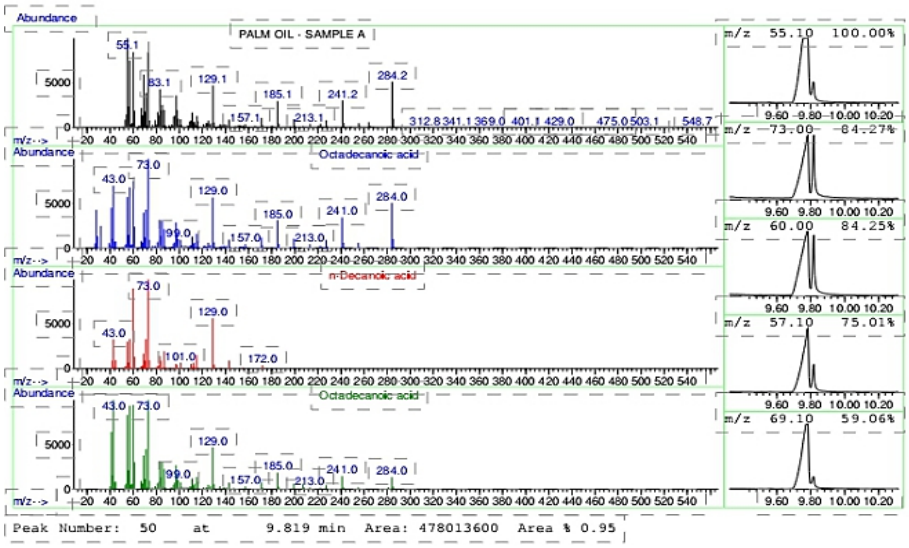
inflammatory properties [30]. In contrast, n-decanoic acid (Fig. 2c) exhibits antiseizure effects [31]. Docosanoic acid, or behenic acid (Fig. 2d), is known to raise cholesterol levels in humans [32]. Squalene (Fig. 2e) is valued for its antioxidant and moisturizing properties [33].



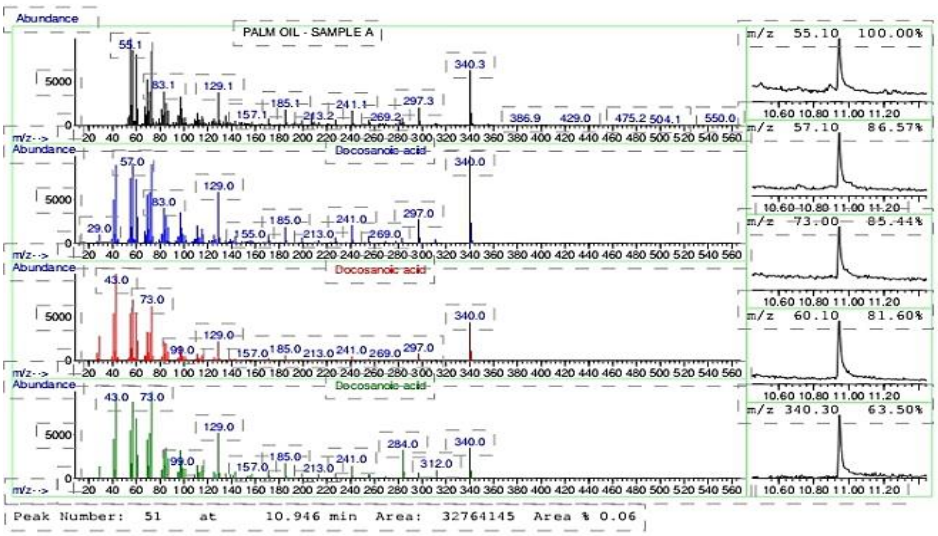
(a)



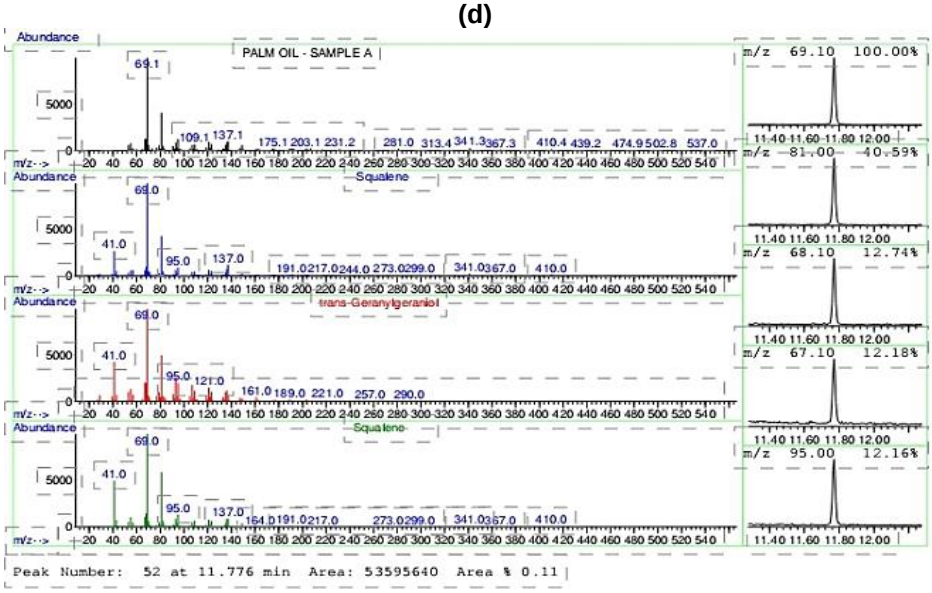
(b)



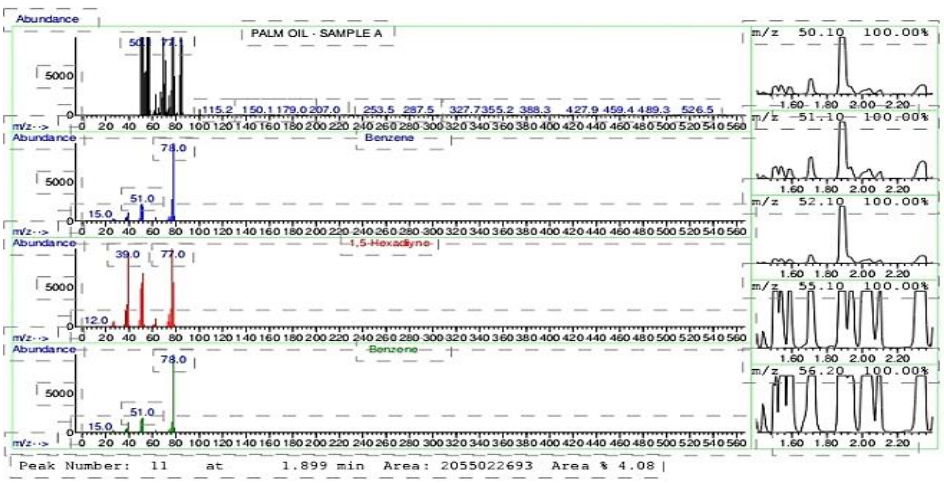
(c)


PALM OIL - SAMPLE A
Docosanoic-acid
Docosanoic-acid
Docosanoic-acid
Peak Number: 51 at 10.946 min Area: 32764145 Area % 0.06

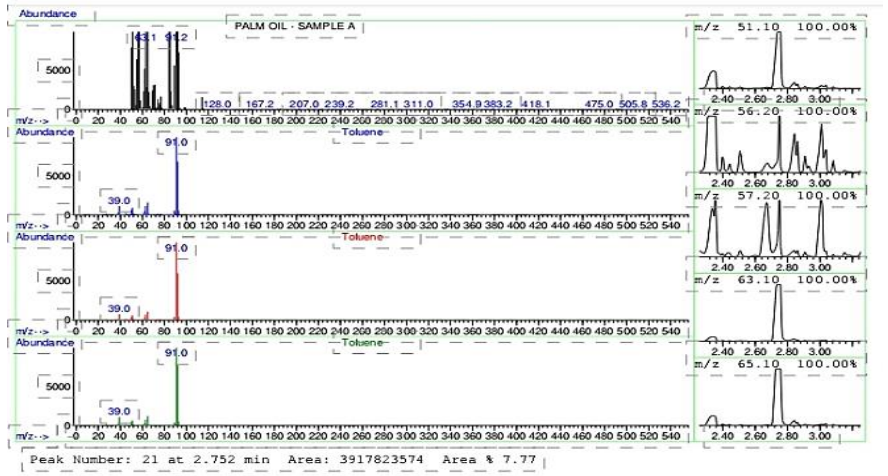
(d)


PALM OIL - SAMPLE A
Squalene
trans-Geranylgeraniol
Squalene
Peak Number: 52 at 11.776 min Area: 53595640 Area % 0.11

(e)


PALM OIL - SAMPLE A
Benzene
1,5-Hexadiyne
Benzene
Peak Number: 11 at 1.899 min Area: 2055022693 Area % 4.08

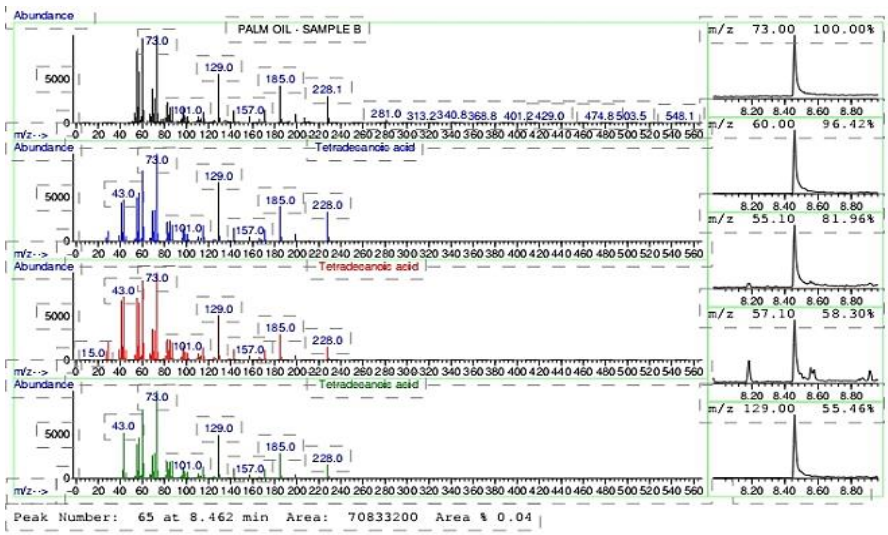
(f)



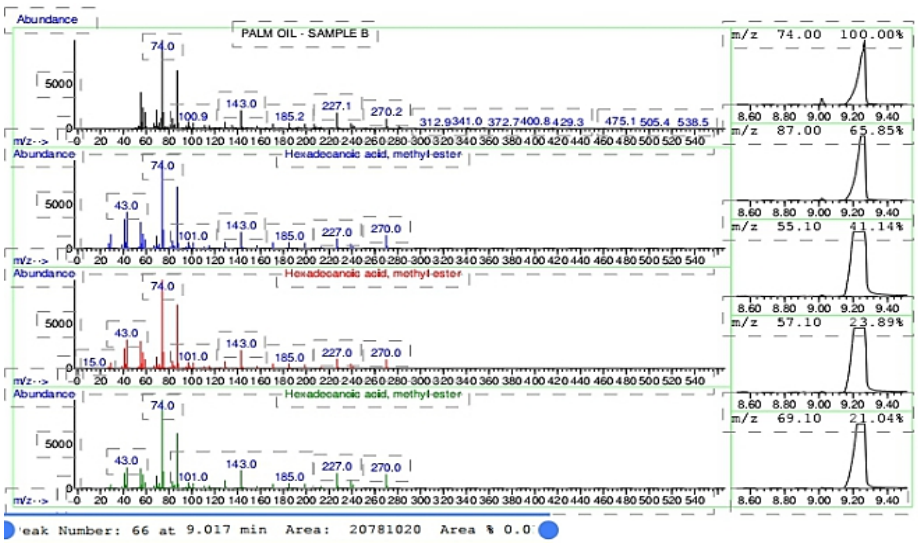
(g)

(h)

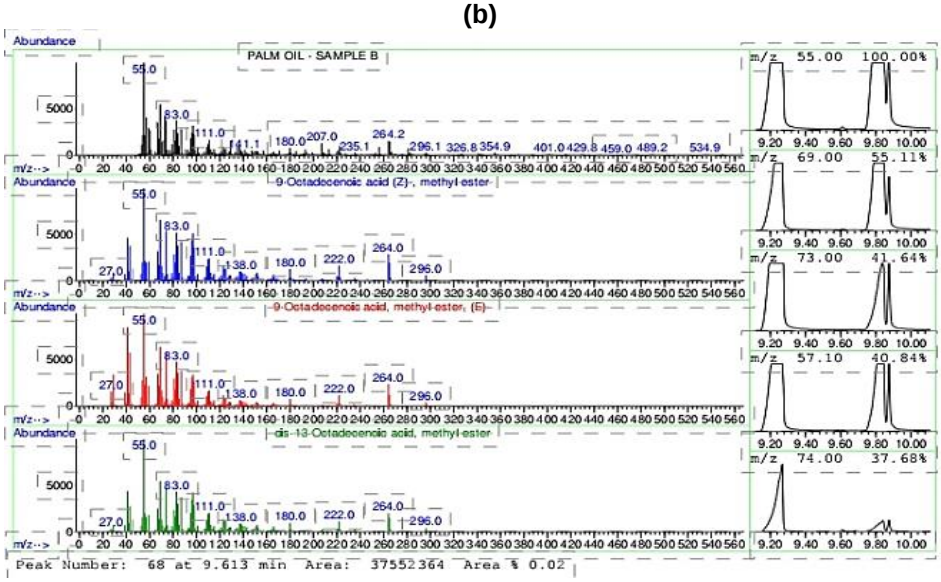
Fig. 2. Chromatograms of major naturally occurring bioactive compounds present in palm oil sample A: hexadecanoic acid (a); Oleic acid (b); n-decanoic acid (c); Docosanic acid (d); Squalene (e), Benzene (f), Toluene (g), Mesitylene (h)



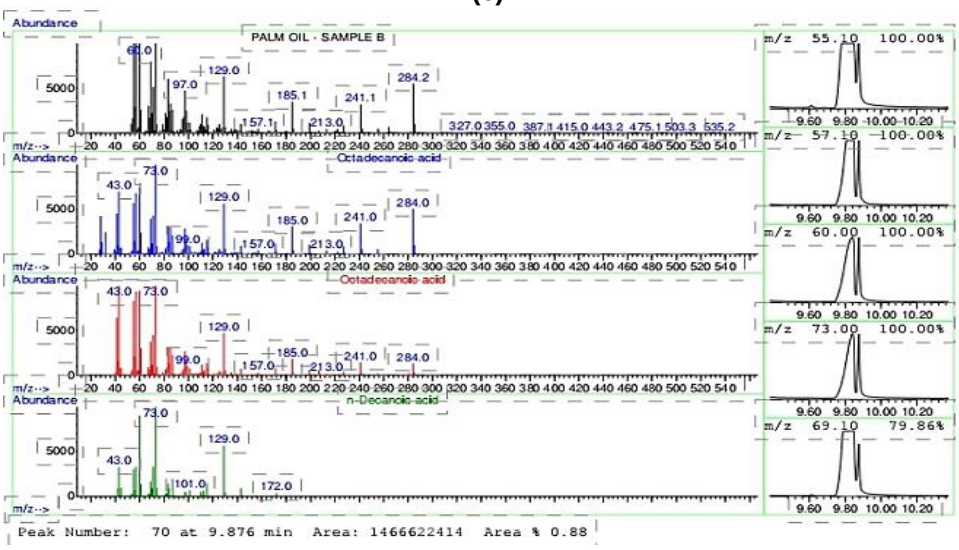
(a)


PALM OIL - SAMPLE B
Hexadecanoic acid, methyl ester
Peak Number: 66 at 9.017 min Area: 20781020 Area % 0.0

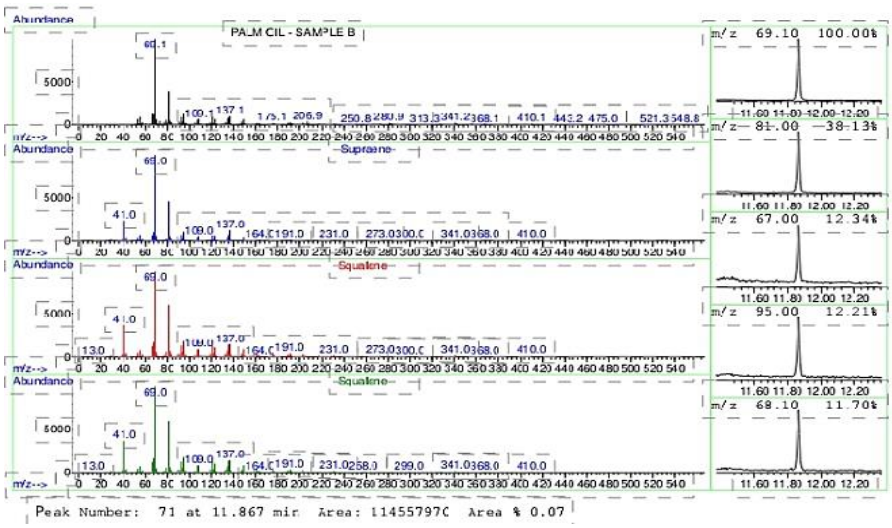
(b)


PALM OIL - SAMPLE B
9-Octadecenoic acid (Z)-, methyl ester
9-Octadecenoic acid, methyl ester, (E)-
cis-13-Octadecenoic acid, methyl ester
Peak Number: 68 at 9.613 min Area: 37552364 Area % 0.02

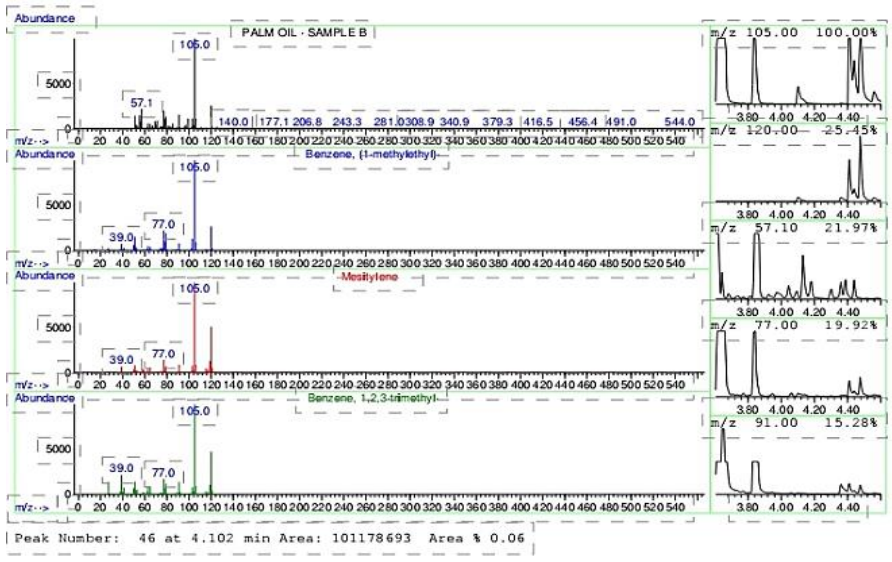
(c)


PALM OIL - SAMPLE B
Octadecanoic acid
Octadecanoic acid
n-Decanoic acid
Peak Number: 70 at 9.876 min Area: 1466622414 Area % 0.88

(d)



(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)

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 %).

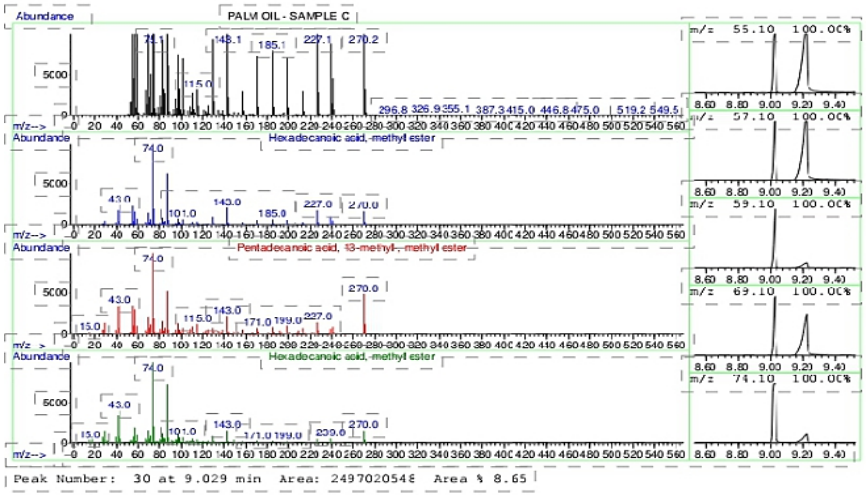
In the analysis of sample B, a total of 71 bioactive compounds were examined, as detailed in Table 3. Some of the identified compounds and their respective concentrations are as follows: Tetradecanoic acid (Myristic acid) (92.0%), Hexadecanoic acid methyl ester (92.1%), 9-Octadecanoic acid (Z)-methyl ester (Methyl oleate) (44.1%), 6-Octadecanoic acid (Z)- (61.0%), Octadecanoic acid (93.3 %), and Squalene (91.3 %).

Tetradecanoic Acid (Myristic Acid), as depicted in Fig. 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

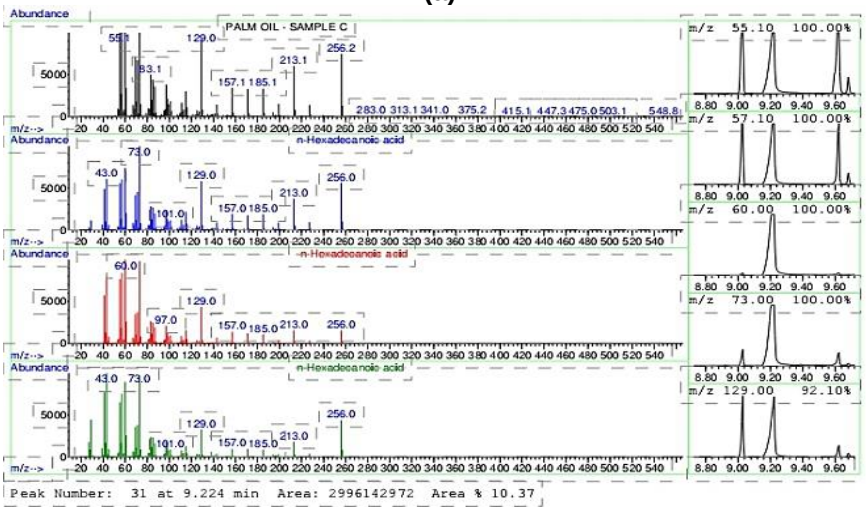
enhancer [34]. Hexadecanoic Acid Methyl Ester, shown in Fig. 3b, is noted for its antibacterial properties [35]. 9-Octadecanoic Acid Methyl Ester (Methyl Oleate), illustrated in Fig. 3c, is a naturally occurring component of palm oil, recognized as a monounsaturated fatty acid and a significant constituent of membrane phospholipids [36]. Octadecanoic Acid, represented in Fig. 3d, has been associated with antioxidant properties [37]. Squalene, a natural constituent of palm oil shown in Fig. 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 [38].

Sixty-five compounds not naturally present in crude palm oil were identified in oil sample B. 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%).

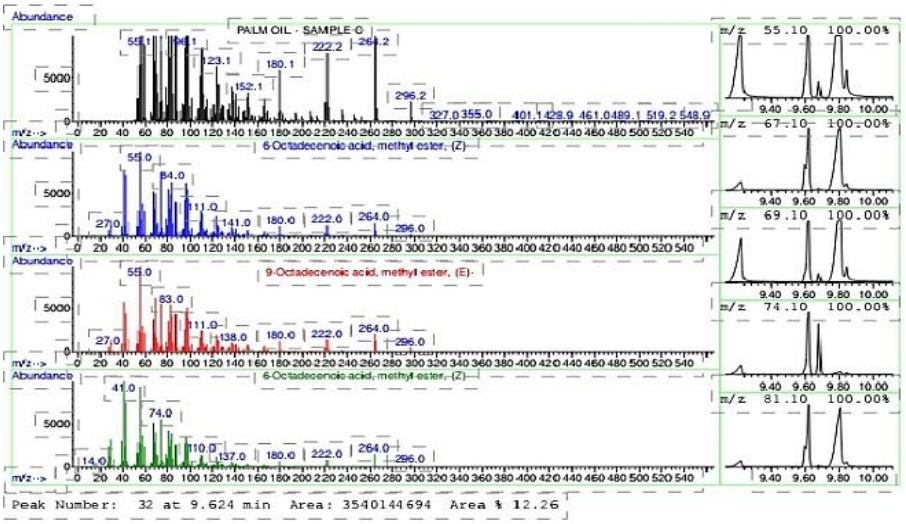
Thirty-five bioactive compounds were analyzed from smple C, as detailed in Table 4. Notable among these are Hexadecanoic Acid Methyl Ester (92.1%), n-Hexadecanoic Acid (94.3 %), 9-Octadecenoic acid methyl ester (44.6 %), Methyl Stearate (90.5%), 9-Octadecenoic Acid (Oleic Acid) (62.8 %), and Octadecanoic Acid (93.3 %). Both 9-Octadecenoic acid methyl Ester (Methyl oleate) and Methyl stearate are utilized in biodiesel production, lubrication, and cosmetic formulations [39,40,41,42].



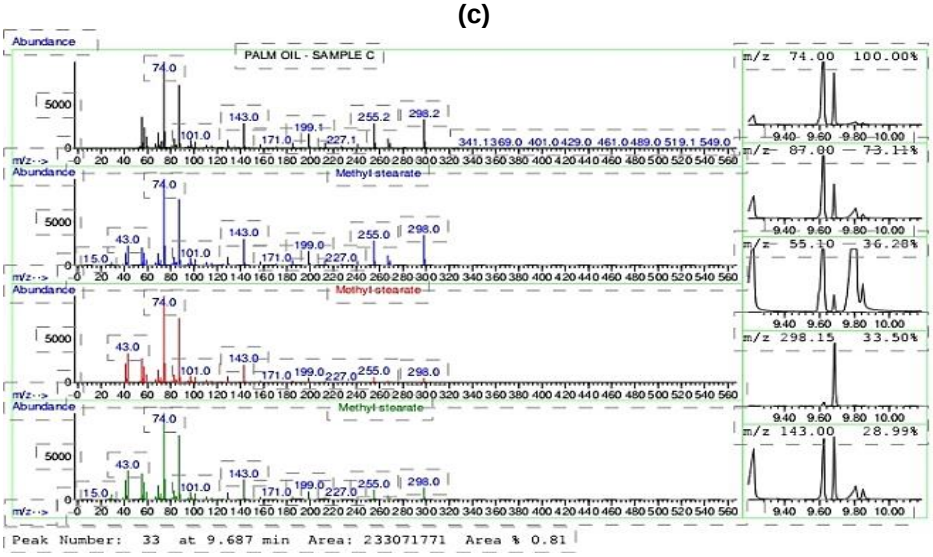
(a)



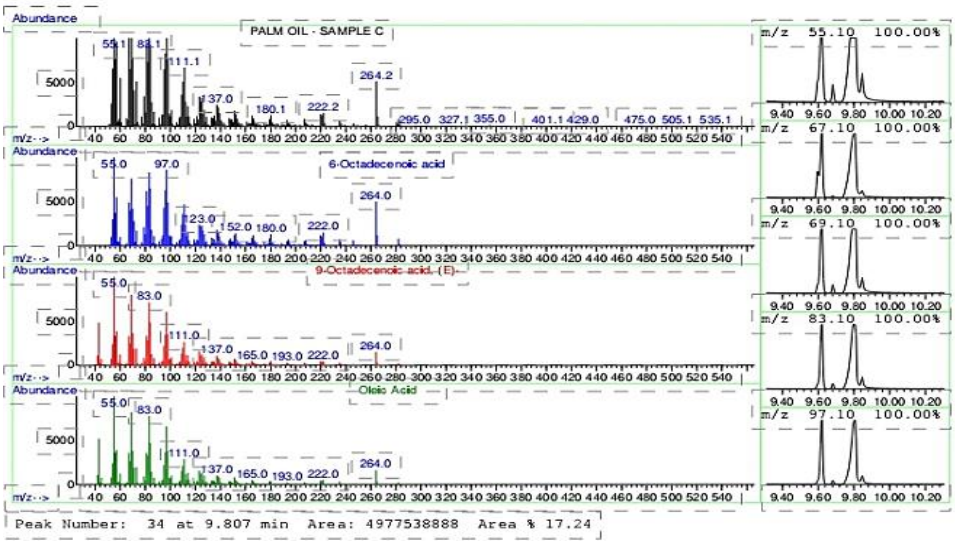
(b)


PALM OIL - SAMPLE C
6-Octadecenoic acid, methyl ester, (Z)-
9-Octadecenoic acid, methyl ester, (E)-
6-Octadecenoic acid, methyl ester, (Z)-
Peak Number: 32 at 9.624 min Area: 3540144694 Area % 12.26

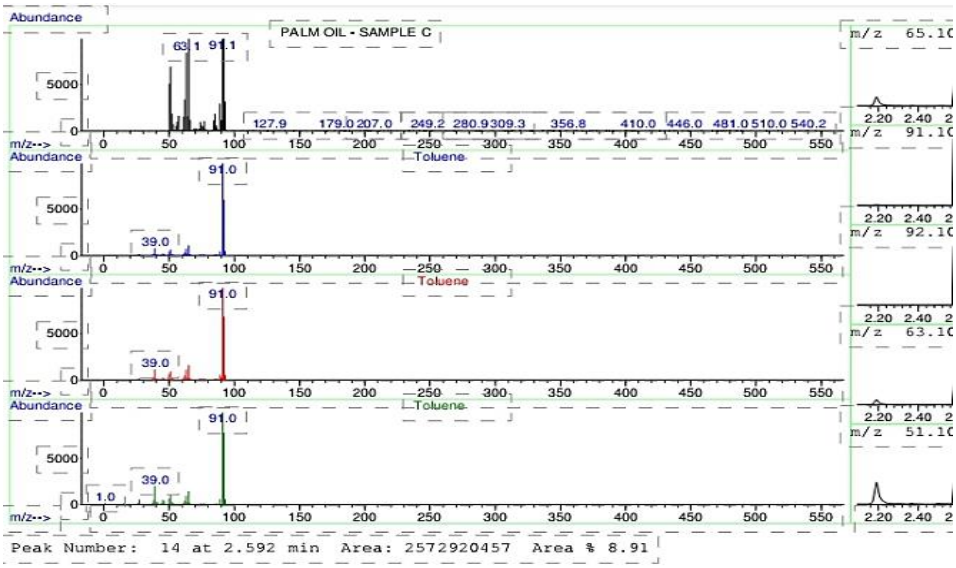
(c)


PALM OIL - SAMPLE C
Methyl stearate
Methyl stearate
Methyl stearate
Peak Number: 33 at 9.687 min Area: 233071771 Area % 0.81

(d)


PALM OIL - SAMPLE C
6-Octadecenoic acid
9-Octadecenoic acid, (E)-
Oleic Acid
Peak Number: 34 at 9.807 min Area: 4977538888 Area % 17.24

(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 stereate (d); 9-Octadecanoic acid -(E) (e); Toluene (f)

Pentadecanoic acid-3-methyl, methyl ester (Fig. 4a) is a saturated fatty acid associated with cardiometabolic protection [43]. n-Hexadecanoic acid (Fig. 4b) is recognized for its anti-inflammatory properties [44]. Hexadecanoic acid methyl ester (Fig. 4c) exhibits antibacterial properties [35], while methyl sterate (Fig. 4d) serves as a metabolite [45]. Additionally, 9-octadecenoic acid (Fig. 4e) possesses antibiotic properties [46].

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%).

4.4 Public Health Implications of Residual Solvents

Isobutylene glycol (3-Methyl-2-buten-1-ol) is toxic to aquatic life; may cause irritation to the skin, eyes, and respiratory tract. Prolonged exposure could have adverse effects on human health [47]. Oxirane 2-ethyl-2-methyl can cause skin and eye irritation. It may also have harmful effects on respiratory health with long-term exposure [48]. Benzene, (Fig. 2f) is associated with respiratory issues and hematologic malignancies such as leukemia. Chronic exposure can lead to severe health problems including blood disorders [49]. Trimethylamine Compound with Borane can cause lung irritation, coughing, and shortness of breath. Prolonged exposure may lead to more serious respiratory problems [50]. Pentane 3-ethyl-2-methyl can cause respiratory irritation and central nervous system effects, including dizziness and headache [51]. Heptane 2-methyl may cause skin and respiratory irritation. Prolonged exposure can lead to more serious health effects, including potential impacts on the liver and kidneys [52]. Toluene, (Figs. 2g, 4f) is associated with respiratory issues, headaches, dizziness, and neurological damage with long-term exposure. It can also affect liver and kidney function [53]. Mesitylene (Figs. 2h, 3f), also known as 1,3,5-Trimethylbenzene is a colorless liquid not naturally occurring in palm oil. 1,3,5-Trimethylbenzene can cause respiratory and skin irritation; long-term exposure may affect the liver, kidneys and lungs [54].

2-Ethyl-2-methyloxirane can cause skin and respiratory irritation. Prolonged exposure may have additional health impacts [55]. 3-Methyltetrahydrofuran is potentially irritating to the skin, eyes, and respiratory tract [56]. n-Hexane is known to cause neurological damage, including peripheral neuropathy, and can be irritating to the skin and respiratory system [57].

Ethylcyclohexane can cause skin and respiratory irritation; prolonged exposure may have additional health impacts [58]. Ethylbenzene is associated with respiratory and skin irritation; long-term exposure may affect liver and kidney function [59]. 1,4-Dimethylbenzene can cause skin and respiratory irritation; long-term exposure may affect the liver and kidneys [60]. 1,2-Dimethylbenzene is potentially irritating to the skin, eyes, and respiratory tract [61]. Hemimellitene can cause skin and respiratory irritation; long-term exposure may lead to more severe health effects [62].

5. CONCLUSION

The proximate and mineral analyses of palm oil samples A, B, and C collected from Yenagoa Metropolis reveal notable differences in their compositional profiles. Sample A exhibited a moisture content of 3.00%, which was higher than in samples B (1.00%) and C (0.00%), a factor that can negatively affect the quality and shelf life of the product. Ash content was highest in samples B and C (20.06%) compared to sample A (13.02%), indicating a higher level of inorganic residue, likely due to differences in soil conditions and geographic factors. 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%. However, fat content 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 exhibited the highest potassium concentration (10.9%), essential for plant health and nutrient conversion, and the highest phosphorus content (0.53%), important for 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 identified a range of bioactive compounds in the palm oil samples. Sample A contained notable bioactives such as n-hexadecanoic acid and oleic acid, which have potential health benefits and some adverse effects. Sample B featured tetradecanoic acid and squalene, compounds with applications in skin care and cardiovascular health. Sample C showed high concentrations of 9-octadecenoic acid and methyl stearate, which are useful in biodiesel production and cosmetics. Importantly, contaminants were identified in all samples, with the highest levels found in samples A and B. Contaminants such as toluene, benzene, n-Hexane, Ethylcyclohexane, Ethylbenzene, 1,4-Dimethylbenzene, 1,2-Dimethylbenzene and mesitylene pose significant health risks.

The presence of these contaminants points to potential issues with processing methods and storage conditions. Contaminants in the three palm oil samples was attributed to inadequate refining processes, contaminated raw materials, improper handling and storage, the use of low-quality additives, environmental pollution, and the recycling or reuse of materials without proper cleaning.

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

6. 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.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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