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Effects of Heat and Food Items on the Fatty Acids Profile of Palm Oil Produced in Nigeria

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Abstract

Nigeria is the highest producer of palm oil in Africa and generates huge volume of waste palm oil (WPO), annually. When palm oil is used to fry food items, the fatty acid (FA) profile of the WPO changes significantly. This study investigates the effect of heat and food items on the FA composition of Nigerian palm oil. The effluents of palm oil produced in Nigeria used to fry some food items were subjected to FA profile determination. The results showed that the concentration of C16:0 ranged from 37.46 % to 47.58 % while that of C18:1 in the samples was between 42.43 % and 47.17 % which constituted the major FA in the neat palm oil and WPO samples. The detection of C18:2 and C10:0 in the WPO and not in the neat palm oil is due to the effect of the heat that degraded the longer chain FA molecules. The coefficient of variation at a 95 % confidence level was high between 84.43 % and 121.48 % shows the type of food the palm oil was used to fry significantly affected the FA composition of the WPO. More collaborative studies on the optimization of frying parameters of palm oil.

1. Introduction

Increased population growth, urbanization, globalization, and socioeconomic development have led to a significant rise in food consumption in the past few decades. Timely and quality food consumption provides energy, helps fight diseases, and supplies the daily strength required for human activities. Vegetable oil is one of the most popular foods in the world and a major source of dietary fats and oils. Globally, palm oil is the most consumed vegetable oil and accounts for over 40 % of vegetable oil usage. Palm oil is liquid at room temperature and reddish and extracted from the mesocarp (reddish pulp) of the fruit of the oil palms [1, 2]. Palm oil is used as food, and for the production of cosmetic and personal care products, oleochemicals, livestock feeds, and feedstock for biofuel [3]. Palm oil, also known as red palm oil is rich in vitamin E, beta-carotene, antioxidants, and other fatty acids such as palmitic acid. Consumption of palm oil helps to improve eyesight, engenders soft skin, enhances hair growth, and reduces the risk of cancer and cardiovascular diseases.

The many avenues of utilization of palm oil have led to increased production and consumption over the past decades, globally. The global production of palm oil rose from 58.92 million metric tons (MMT) in 2015/16 to 73.08 MMT in 2019/20 and further to 77.22 MMT in 2022/23. During the same period, 59.38 MMT, 71.07 MMT, and 76.04 MMT of palm oil was consumed in 2015/16, 2019/20, and 2022/23, respectively [4, 5]. In the year 2022, Indonesia and Malaysia were the leading producers of palm oil globally and they jointly supplied about 85 % of the global palm oil in 2019. Indonesia, India, and China account for about 45 % of the total global palm oil consumption. India spent about USD 11.7 million to import palm oil in 2022 to top the palm oil importing countries in 2022. Table 1 shows the top five palm oil-producing, consuming, and importing countries in 2022.

Table 1. Top 5 palm oil producing, consuming, and importing countries in 2022

Top 5 countries	Production (MMT)
Indonesia	46
Malaysia	18.6
Thailand	3.42
Colombia	1.77
Nigeria	1.4
Top 5 countries	**Food use (MMT)**
Indonesia	18.76
India	8.62
China	4.3
European Union	2.0
Thailand	1.3
Top 5 countries	**Importation (million USD)**
India	11.7
China	5.8
United States	2.4
Netherlands	2.1
Italy	1.8

Source: [3, 6]

Nigeria is Africa's largest palm oil producer and the fifth largest in the world. Nigeria's total palm oil production rose from 0.6 MMT in 1990 to 0.971 MMT in 2010 and 1.4 MMT in 2023. The domestic consumption of palm oil (including as food, body lotion, and sociocultural uses) was 0.62 MMT in 1990 became 1.36 MMT in 2010, and currently stands at 1.87 MMT. The palm oil domestic consumption for food (for cooking, frying, etc.) rose to 0.435 MMT in 2020 and was projected to rise to 0.475 MMT by the end of 2023 [6]. Figure 1 shows the production, domestic consumption, and food use of palm oil in Nigeria from 1990 to 2023. In recent years, the Federal Government of Nigeria has initiated various programmes to make the country self-sufficient in palm oil and stop importation. The growing youthful population and increased urbanization will continue to drive domestic consumption of palm oil.

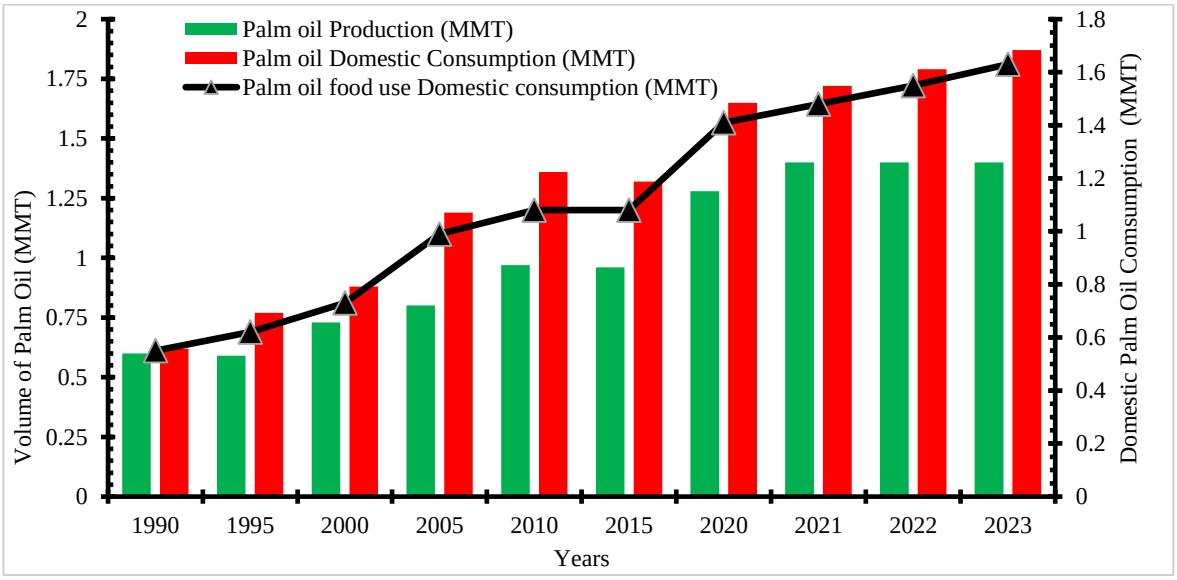

Figure 1. Production and consumption of palm oil in Nigeria 1990-2023

When palm oil is used to fry food items, they undergo repeated heating and contamination as a result of the high temperature associated with frying and the infiltration of the oil with the particles of the food item. During the frying process, palm oil undergoes some physicochemical alteration such as oxidation, hydrolysis, thermal degradation, and polymerization [7, 8]. When palm oil has been used for frying or cooking, they are termed waste palm oil (WPO) and unfit for human consumption. The WPO contains toxic chemicals and other polar compounds which makes oil to become carcinogenic and unsuitable for human consumption. Various health challenges such as heart diseases, obesity, diabetes, etc. have been traced to prolonged consumption of WPO [9, 10]. The repeated thermal degradation and contamination affect the physical, chemical, and compositional properties of the oil. Specifically, such usage is believed to significantly alter its fatty acid (FA) composition due to the effect of thermal degradation.

The breakdown of fats in food generates FAs, which can be absorbed into the blood. FAs molecules combine in groups of three to form triglycerides. A carboxyl group (—COOH) is present at one end of the straight chain of the FA, which comprises an even number of carbon atoms. Hydrogen atoms are situated along the length of the chain and at the other end of the chain. Experimentally, the composition of FA is determined by a gas chromatograph mass spectrometer (GCMS) and measured in percentage. The consumption of saturated and trans-fatty acids is dangerous and instigates various health challenges while linoleic acid is safe for consumption [11].

Researchers such as Awogbemi et al. [1], Azahar et al. [12], and Lai et al. [13] have studied the impact of thermal degradation of palm oil and reported the various thermophysical changes that occur in the oil. The thermophysical changes make the oil unfit for consumption and a source of pollution to surface and underground water when disposed of inappropriately. Application of thermal and biotechnological techniques for the recycling and conversion of WPO to biofuel and other products have been suggested as one of feasible and sustainable management strategies [14]. The

outcomes of various studies on the impact of usage on the appearance, properties, composition, and utilization potentials of used vegetable oil show that used vegetable oil is a resource and can contribute to a circular economy [15-17]. Undoubtedly, many grounds have been covered in the generation and conversion of used vegetable oil in recent years, particularly in producing biodiesel, biolubricants, surfactants, and other products from used vegetables across various jurisdictions [18-20].

Despite the myriads of research on the domain, the relevant questions to ask are whether enough studies have been conducted on the composition of the WPO generated from Nigeria. What is the FA composition changes that occurred to NPO during usage? How do different food items affect the FA composition of WPO? In the opinion of the authors, there has not been any studies deploying laboratory and statistical techniques to the FA composition of Nigerian palm oil used to fry some Nigerian food items. Going be the wide usage and consumption of palm oil in Nigeria, it is pertinent to investigate the FA composition of both the neat and used palm oil. While it is undebatable that diverse changes occurred during the use of neat palm oil (NPO) for frying, the impact of the different food items on the FA composition needs to be investigated. These form the motivations for the current study. The aim of the study, therefore, is to investigate the effects of repeated heat addition and contamination on the FA composition from food items on Nigerian palm oil. The objective of the study is to engage laboratory and statistical techniques to analyze the FA composition of palm oils used to fry Nigerian foods. The novelty of the current study is the use of descriptive and inference statistical analyses to interpret the FA composition of Nigerian palm oil used to fry different food items to gain better insights into the behavior and utilization potentials of the WPO. The outcome of this study will enrich the literature by providing updated information on the FA composition of Nigerian palm oil used to fry some food items. The current intervention is limited to the use of GCMS to determine the FA composition and statistical techniques to interpret the data. The use of mathematical, optimization, and modelling tools as well as the conversion of WPO into biofuel and other products are beyond the scope of this work.

2. Material and Method

2.1. Materials selection

Thirteen (13) litres of red NPO, tubers of yam, potato, ripe plantain, and beans were purchased from the King's market, Ado Ekiti. Nigeria. The four selected food items are readily available, affordable, and mostly consumed stable foods by households in Nigeria. All the reagents used for the analysis were purchased at analytical grade. All the materials were transferred to the Laboratory for analysis.

2.2. Frying process and samples preparation

The yam tuber, potato tuber, and ripe plantain were washed, peeled, sliced, and small quantity of table salt added. the bean was soaked in warm water for 10 minutes, dehulled, ground into a paste, and salt, onions, pepper added. The palm oil was divided as follows; three litres each for the frying of yam, potato, ripe plantain, and bean paste, and the remaining one litre was stored in a clean airtight glass vial and kept in a secured place for analysis.

The palm oil was heated to 180 °C to fry the prepared food items in different basins for 15 minutes per batch. The frying was carried out for five batches daily and for three days when the oil became dark brown. During the frying, there was no topping up of the palm oil [21]. The frying basins were allowed to cool and the palm oil was decanted, sieved, and stored in a clean airtight glass vial and labelled accordingly, ready for analysis. Table 2 shows the frying conditions.

Table 2. Frying conditions

Parameters	Details
Oil used for frying	Red palm oil
Source of oil	Ado Ekiti, Nigeria
Frying temperature	180 °C
Total frying time	15 minutes
Total number of bathes	5
Type of frying	Deep frying with stirring
Quantity of food items fried per patch	250 g

2.3. Pretreatment of WPO samples

The recovered WPO were sieved, poured into a beaker, and heated at 110°C in an electric heater for 15 min to remove moisture. After the WPO samples had cooled down to room temperature, a vacuum filtration process was utilized to eliminate any traces of food debris and other suspended solid particles that might have been present in the samples. An airtight glass container was used to store the uncontaminated WPO samples which are labeled accordingly as shown in Figure 2. Table 3 shows the details of the samples.

Figure 2. The samples

Table 3. Details of the samples

Sample notation	Description
A	Neat palm oil
B	Palm oil used to fry yam
C	Palm oil used to fry potato
D	Palm oil used to fry ripe plantain
E	Palm oil used to fry bean cake

2.3.1. Determination fatty acid composition

The FA composition of samples A-E was analyzed via GCMS, utilizing Shimadzu GCMS equipment (Kyoto, Japan) and an Ultra-alloy-5 capillary column. GCMS-QP2010 Plus software (Version 2.5, Shimadzu Corporation, Kyoto, Japan) was used during the process. A sample size of 2 µL, helium as a carrier gas and an inlet temperature of 250 °C were used during the determination. The analysis used an Ultra-alloy-5(MS/HT) column with 30 m, 0.25 mm internal diameter, and 0.25 µm film thickness at a flow rate of 3 mL/min.

2.3.2. Statistical analysis

The data were subjected to both descriptive and inferential statistical analysis.

The descriptive statistical analysis involves the calculation of the mean, standard deviation (SD), and coefficient of variation (CV %) of the data obtained from the results of the fatty acids analysis. For the inferential statistical analysis, the correlation model was used to determine whether there were statistical differences existed within the samples [17, 22]. In this case, the confidence level was set at 95 % ($p<0.05$) which translates to a critical level (r_{xy}) of 0.05. The degree of freedom (df) was n-2 where n = number of items involved in the correlational analyses. The coefficient of correlation (σ_{xy}) in the statistical analysis was further expanded to include the coefficient of determination (σ_{xy^2}), regression coefficient (R_{xy}), coefficient of alienation (C_A), and index of forecasting efficiency (IFE). According to Adeyeye and Adubiaro [23], the CV %, C_A, and IFE are calculated according to equations 1-3. The mapping of the data was carried out by pairing the data A/B, A/C, A/D, A/E, B/C, B/D, B/E, C/D, C/E, and D/E. This is done to compare the NPO sample A with WPO samples B, C, D, and E. Where

$$CV\% = \frac{SD}{Mean} \times 100 \quad (1)$$

$$C_A = \sqrt{1 - (r_{xy})^2} \quad (2)$$

$$IFE = 1 - C_A \quad (3)$$

The Chi-square calculations were also carried out as appropriate; here, the df was n-1.

3. Results and discussion

3.1. Fatty acids composition of samples

Table 4 shows the FA composition of the samples. Three FAs, namely palmitic acid, oleic acid, and stearic acid were common to all the samples while linoleic acid and capric acid were peculiar to the WPO samples and not found in the NPO samples [1, 24]. Two FAs, mainly palmitic acid and oleic acid, were the most prominent FAs in the samples comprising between 80 % and 94 % of the FAs. NPO and WPO samples contained mainly palmitic acid and oleic acid in equal proportion. The NPO contained 52.82% saturated fatty acid (SFA), 47.17 % monounsaturated fatty acid (MUFA), and no polyunsaturated fatty acid (PUFA). The usage of NPO to fry some Nigerian food items significantly impacted the NPO and altered its FA composition [1, 25, 26]. For example, the utilization of NPO to fry some Nigerian food items led to the formation of linoleic acid and capric acid in the WPO during usage. Similarly, unlike the NPO sample, there was a generation of about 5.3 %, 15.8 %, 12.5 %, and 11.14 % PUFA in samples B, C, D, and E, respectively. In the same vein, the percentage of SFA and MUFA were higher in the NPO sample than in the WPO samples (Figure 3). The NPO contained about 52 % SFA and its consumption would contribute to hormone production, promotion of cardiovascular health, and help to fight bacterial infections [27]. The formation of linoleic acid, a major PUFA makes the WPO unfit for human consumption as its continuous consumption can initiate and exacerbate cancer, diabetes, asthma, endothelial dysfunction, and other life-threatening diseases [28, 29].

Table 4. Fatty acid composition of samples

Fatty acids				Samples				
Systematic name	Common name	Structural formula	Lipid numbers	A	B	C	D	E
Hexadecanoic acid	Palmitic acid	$CH_3(CH_2)_{14}COOH$	C16:0	47.58	46.48	37.46	40.00	38.24
Octadecenoic acid	Oleic acid	$CH_3(CH_2)_7CH=CH(CH_2)_7COOH$	C18:1	47.17	46.45	42.43	44.23	44.79
Octadecadienoic acid	Linoleic acid	$CH_3(CH_2)_4CH=CHCH_2CH=CH(CH_2)_7COOH$	C18:2	-	5.30	15.80	12.54	11.14
Octadecanoic acid	Stearic acid	$CH_3(CH_2)_{16}COOH$	C18:0	0.74	0.37	0.83	0.82	0.86
Decanoic acid	Capric acid	$CH_3(CH_2)_8COOH$	C10:0	-	1.40	3.48	1.08	3.52
Octanoic acid	Caprylic acid	$CH_3(CH_2)_6COOH$	C8:0	4.51	-	-	1.33	1.45
Saturated Fatty Acid (%)				52.83	48.25	41.77	43.23	44.07
Monounsaturated Fatty Acid (%)				47.17	46.45	42.43	44.23	44.79
Polyunsaturated Fatty Acid (%)				-	5.30	15.80	12.54	11.14

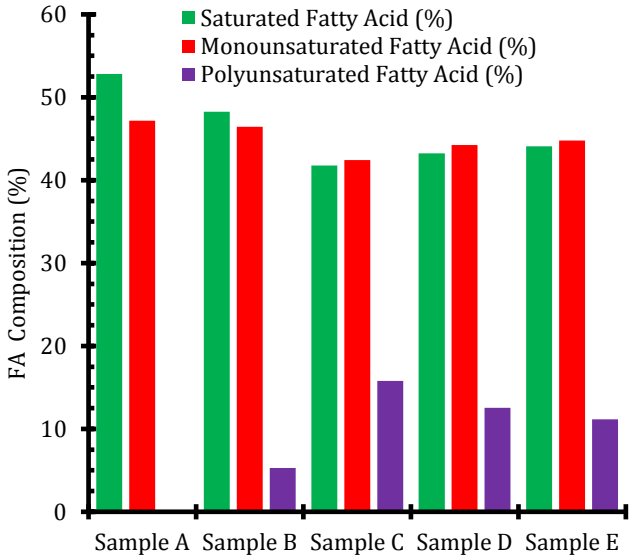

Figure 3. SFA, MUFA and PUFA compositions of samples

3.2. Statistical and Chi-square analyses

There are ten statistical mappings for the five samples A – E, in four groups, as shown in Table 5. Group A mappings contain sample A paired with samples B, C, D, and E, while group B mappings contain sample B paired with samples C, D, and E. It must be noted that there must be no repetition in the pairings. The FA profile of the. There are six concerned fatty acids in the samples including C16:0, C18:1, C18:2, C18:0, C10:0, and C8:0. As shown in Table 6, Chi-square analysis showed no significant difference at $\alpha_{0.05}$ for each FA and many of the CV% were low but generally from 4.163 % to 74.16 %. On the other hand, the pairwise comparisons when subjected to correlation analysis at α_0.05 showed that significant differences existed between these paired samples: A/B, B/C, B/D, B/E, C/D, C/E, and D/E but not in A/C, A/D, and A/E. Table 7 contains the values of the σ_{xy}, σ_{xy^2}, R_{xy}, C_A, and IFE for each mapping. Both the σ_{xy} and σ_{xy^2} are close to 1.0 which indicates a good reliability of model. The IFE ranges between 0.7595 and 0.9929. The result of the inferential analysis of the mappings shows that all the pairings are significant except for A/C, A/D, and A/E which are not significant at a 95 % confidence level [30, 31]. Table 8 shows the summary of the mean, SD, and CV% of the correlated groups.

Table 5. Ten statistical mappings of the samples

Group A	Group B	Group C	Group D
A/B A/C A/D A/E	B/C B/D B/E	C/D C/E	D/E
A = x while y = B=C=D=E, as appropriate	B = x, while y = C=D=E, as appropriate	C= x, while y =D=E, as appropriate	D=x, and y=E

Table 6. Descriptive statistics and Chi-Square values of the data from Table 4

Lipid numbers	Mean	SD	CV%	x^2	df(n-1)	CL @ 0.05	Remark
C16:0	41.952	4.742	11.30	2.144	4	9.49	NS
C18:1	45.014	1.874	4.163	0.312	4	9.49	NS
C18:2	11.195	4.388	39.20	5.161	3	7.82	NS
C18:0	0.724	0.203	28.04	0.226	4	9.49	NS
C10:0	2.370	1.311	48.56	2.173	3	7.82	NS
C8:0	2.430	1.802	74.16	2.675	2	5.99	NS
SFA (%)	46.03	4.500	9.776	1.676	4	9.49	NS
MUFA (%)	45.014	1.874	4.163	0.312	4	9.49	NS
PUFA (%)	11.195	4.388	39.20	5.161	3	7.82	NS

x^2 in C18:1≡ MUFA (%)≡0.312; x^2 in C18:2≡ PUFA (%) ≡5.161; CL = confidence level; df = degree of freedom; x^2 = Chi-square; NS = not significant at $x^2_{0.05}$

Table 7. Inferential statistics of the data from Table 4

Statistical parameters	A/B	A/C	A/D	A/E	B/C	B/D	B/E	C/D	C/E	D/E
σ_{xy}	0.99998	0.99314	0.99539	0.98033	0.97066	0.98571	0.98731	0.99641	0.99319	0.99753
σ_{xy^2}	0.99995	0.98632	0.99079	0.97876	0.94217	0.97163	0.97478	0.99282	0.98644	0.99507
Rxy	0.9884	0.8379	0.8848	0.8708	0.7669	0.8554	0.8309	1.0943	1.0579	0.9706
C_A	0.0071	0.1170	0.0960	0.1457	0.2405	0.1684	0.1588	0.0047	0.1164	0.0702
IFE	0.9929	0.8830	0.9040	0.8543	0.7595	0.8316	0.8412	0.9953	0.8836	0.9298
n-2	1.0	1.0	1.0	1.0	3.0	3.0	3.0	3.0	3.0	4.0
Remark	SG	NS	NS	NS	SG	SG	SG	SG	SG	SG

SG = Value significant at α = 0.05 for the pairs and critical levels; A/B = 0.997; B/C = B/D = B/E = C/D = 0.878; D/E = 0.811. NS = Not significant at x = 0.05 at any of the critical level of n = 1.0

Table 8. Descriptive statistics of the correlate groups compared from Table 4

Paired group	Mean	SD	CV %
A/B	31.83/31.10	26.93/26.16	84.61/85.56
A/C	31.83/26.91	26.93/22.72	84.61/84.43
A/D	31.83/28.35	26.93/23.94	84.61/84.44
A/E	31.83/27.96	26.93/23.70	84.61/84.76
B/C	20.00/20.00	24/23/19.14	121.15/95.70
B/D	20.00/19.73	24.23/21.03	121.15/106.59
B/E	20.00/19.71	24.23/20.39	121.15/103.45
C/D	20.00/19.73	24.23/21.03	121.15/106.59
C/E	20.00/19.71	24.23/20.39	121.15/103.45
D/E	16.67/16.67	20.25/19.70	121.48/118.18

Principal correlate: Correlate group members,
A: A/B, A/C, A/D, A/E;
B: B/C, B/D, B/E;
C: C/D, C/E;
D: D/E

4. Conclusion

The study carried out the FA determination of neat palm oil produced in Nigeria and the WPO derived from frying yam, potato, ripe plantain, and bean cake. The FA profile of the neat palm oil and WPO samples showed that heat and food items affect the FA composition of Nigerian palm oil significantly but unevenly [32]. Whereas both C16:0, C18:1, and C18:0 were present in all the samples, both C18:2 and C10:0 were not detected in sample A; also C8:0 was not detected in samples B and C. High values were observed in C16:0 (37.46 % to 47.58 %) and C18:1 (42.43 % to 47.17 %) with sample A recording the highest value in each FA. Much lower values were observed for C18:2, C18:0, C10:0, and C8:0. The concentration categorization of the FAs were: SFA (41.77 % to 52.83 %)> MUFA (42.43 % to 47.17 %) > PUFA (5.30 % to 15.80 %). Whereas the likelihood of het fragmentation could be observed in the FA of longer chain, such was not pronounced in the food items. The only PUFA observed was n-6 PUFA(C18:2) and no n-3 PUFA (particularly ALA), hence no balancing between LA/ALA or n-6/n-3. Hence the WPO would not be good for human consumption.

Chi-square analysis showed no significant difference at $\alpha_{0.05}$ for each FA while the result of the inferential analysis of the mappings shows that all the pairings are significant except for A/C, A/D, and A/E. Hence, unlike in the Chi-square analysis where only the individual FAs were involved, the r_{xy} was calculated as a function of both the FA in conjunction with the food item; this might be due to the food effect of the results observed from the FA analysis.

The use of NPO to fry the identified food items alters the FA acid composition of the WPO with the SFA in the NPO converted to PUFA in the WPO samples. Note that PUFA was completely absent in the NPO but ranges between 5.3 % and 15.8 % in the WPO samples. The thermal degradation and food items contamination affect the dietary fat of the palm oil thereby making the used pal oil unfit for human consumption based on the evidence of the FA composition. The outcomes of the investigation reveal the potential health hazards in the human and animal consumption of WPO [2, 11]. Inappropriate disposal of WPO into drainages and water bodies contaminate aquatic ecosystem, reduces the oxygen content of water bodies, and impedes the normal growth of aquatic animals [33, 34]. However, WPO samples derived from the frying of food items are used as cost-effective and readily available feedstock for biofuels and other bioenergy [35-37].

More studies are required particularly in the optimization and modeling of the frying parameters and food varieties to predict the FA profile of WPO samples [38, 39]. The use of innovative frying technologies such as vacuum frying, microwave frying, etc. that allows for shorter frying duration and lower oil absorption [40, 41]. The effect of different frying temperatures on the FA composition of the WPO and the quality and dietary composition of the food items need to the investigated. The use of air frying technology is expected to prevent the degradation of palm oil during frying and contribute to the nutritional application of Nigerian palm oil. Governments should intensify sensitization campaigns to discourage the consumption of palm oil recovered from restaurants and households. More incentives should be given to the conversion of WPO into biofuels.

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Author contributions

Omojola Awogbemi: Conceptualization, Methodology, Writing-Original draft preparation, Writing-Reviewing and Editing, Software, Corresponding Author. **Ilesanmi Emmanuel Adeyeye:** Data curation, Writing-Original draft preparation, Writing-Reviewing and Editing, Statistical Analysis, Validation. **Ayodele Salami Lawal:** Conceptualization, Visualization, Investigation, Writing-Reviewing and Editing.

Conflicts of interest

The authors declare no conflicts of interest.

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