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**FATTY ACID PROFILE AND LIPID QUALITY INDICES OF REFINED
PALM OIL VERSUS PALM KERNEL OIL: A COMPARATIVE FAME–GC-
FID ANALYSIS OF MAJOR BRANDS MARKETED IN RIVERS STATE,
NIGERIA**

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Abstract

The fatty acid composition of refined vegetable oils is a primary determinant of their nutritional value, technological functionality, and health implications. Palm oil (PO) and palm kernel oil (PKO) are two chemically distinct products derived from anatomically separate fractions of the oil palm fruit (*Elaeis guineensis* Jacq.), yet they are frequently perceived interchangeably in Nigerian consumer practice. This study conducted a rigorous comparative fatty acid methyl ester (FAME) analysis using gas chromatography with flame ionization detection (GC-FID) on commercially refined PO, PKO, groundnut oil (GNO), soybean oil (SBO), and sunflower oil (SFO) brands purchased from major markets in Port Harcourt, Rivers State, Nigeria. Eight brands were analysed for complete fatty acid profiles, fatty acid class distributions, atherogenicity index (AI), thrombogenicity index (TI), hypocholesterolaemic-to-hypercholesterolaemic fatty acid ratio (h/H), polyunsaturated-to-saturated fatty acid ratio (PUFA/SFA), and omega-6/omega-3 ratio. Physicochemical quality parameters including peroxide value (PV), acid value (AV), free fatty acid content (FFA), iodine value (IV), saponification value (SV), refractive index (RI), and specific gravity were determined by standard AOCS and AOAC methods. Refined PKO was dominated by lauric acid (C12:0, 45.8–47.2%) and myristic acid (C14:0, 15.6–16.4%), yielding a combined saturated fatty acid (SFA) fraction of 82.9–86.4%. Refined PO was predominantly composed of palmitic acid (C16:0, 42.6–44.8%) and oleic acid (C18:1, 37.4–39.2%), with SFA content of 48.5–51.1%. GNO exhibited the highest monounsaturated fatty acid (MUFA) content (49.70%), while SFO recorded the highest polyunsaturated fatty acid (PUFA) proportion (58.54%). Atherogenicity and thrombogenicity indices were highest for PKO (AI: 8.42–8.86; TI: 4.22–4.68) and lowest for SFO (AI: 0.18–0.22; TI: 0.22–0.28). SBO demonstrated the most nutritionally balanced omega-6/omega-3 ratio (7.7:1), closest to the WHO-recommended range. All brands met CODEX Alimentarius physicochemical quality benchmarks. These findings provide the first comprehensive FAME–GC-FID comparative characterisation of refined vegetable oil brands in the Rivers State market and underscore the urgent public health need for mandatory fatty acid disclosure on Nigerian vegetable oil labels.

Keywords: fatty acid profile, FAME-GC-FID, palm oil, atherogenicity index, thrombogenicity index, lipid quality indices, vegetable oil.

1. INTRODUCTION

Vegetable oils constitute the primary source of dietary fat and a substantial portion of total energy intake for the majority of Nigerian households, with estimated national per capita consumption in the range of 12–16 kg per annum (Federal Ministry of Agriculture and Rural Development [FMARD], 2021). The rising prevalence of cardiovascular disease (CVD) in Nigeria now estimated at 76.11% with an age-standardised disability-adjusted life year rate of 5,250 per 100,000 persons has been directly linked to a transition toward unhealthy dietary patterns characterised by elevated saturated fat consumption (Yusuf et al., 2023). This epidemiological backdrop renders the rigorous characterisation of the fatty acid composition of commercially available refined vegetable oils a matter of compelling public health priority.

In Rivers State, commercially refined vegetable oils, including palm oil (PO), palm kernel oil (PKO), groundnut oil (GNO), soybean oil (SBO), and sunflower oil (SFO) are consumed daily across all socioeconomic strata, serving domestic cooking, street food vending, and institutional food manufacturing in Port Harcourt and surrounding communities. The cardiovascular implications of habitual oil consumption are governed principally by fatty acid composition, which exerts well-characterised and differential effects on plasma LDL and HDL cholesterol concentrations, inflammatory mediator synthesis, and atherosclerotic plaque formation (Sacks et al., 2017; Mensink et al., 2003).

Despite their shared botanical origin in *Elaeis guineensis*, refined PO and PKO represent chemically and nutritionally distinct commodities. Crude palm oil is extracted from the mesocarp (outer fleshy layer) of the palm fruit, yielding an oil characterised by approximately 44% palmitic acid (C16:0) and 39% oleic acid (C18:1), with the overall SFA fraction typically ranging between 48–52% (Sundram et al., 2003; Alhaji et al., 2024). Palm kernel oil is extracted from the kernel (endosperm), producing an oil dominated by lauric acid (C12:0, approximately 48%) and myristic acid (C14:0, approximately 16%), with a combined SFA fraction typically exceeding 82%, placing PKO in the same lauric oil category as coconut oil (Gunstone, 2011; World Health Organization [WHO], 2024). These fundamental compositional differences, conferring markedly different melting points, oxidative stabilities, metabolic fates, and cardiovascular risk profiles, are not reflected in current Nigerian food labelling conventions or adequately communicated to consumers.

The cardiovascular risk implications of dietary oils extend beyond simple SFA quantification. Nutritional lipid quality indices, including the atherogenicity index (AI) and thrombogenicity index (TI) developed by Ulbricht and Southgate (1991), the hypocholesterolaemic-to-hypercholesterolaemic ratio (h/H) proposed by Santos-Silva et al. (2002), and the omega-6/omega-3 ratio, provide integrated assessments that account for the differential effects of individual fatty acids on atherogenic and thrombotic risk pathways. The AI quantifies the relationship between proatherogenic saturated fatty acids (C12:0, C14:0, C16:0) and antiatherogenic unsaturated fatty acids;

lower values are nutritionally preferable. The TI captures the balance between prothrombotic and antithrombotic fatty acids. Recent 50-year longitudinal data from the Seven Countries Study confirmed that dietary atherogenicity and thrombogenicity indices are significant independent predictors of cardiovascular mortality (Menotti et al., 2024), validating their application as key oil quality assessors.

A critical additional dimension of vegetable oil nutritional quality is the omega-6/omega-3 polyunsaturated fatty acid ratio. Dietary omega-6/omega-3 imbalance currently estimated at 15:1 to 20:1 in typical Western dietary patterns versus an ancestral evolutionary ratio of approximately 1:1 is strongly associated with pro-inflammatory eicosanoid synthesis and elevated risk for cardiovascular, metabolic, and inflammatory diseases (Simopoulos, 2008; Innes & Calder, 2018). The WHO recommends a dietary n-6/n-3 ratio of 5:1 to 10:1 for optimal cardiometabolic health (WHO, 2020). Habitual use of vegetable oils with extreme n-6/n-3 ratios may substantially exacerbate this imbalance within the Nigerian dietary context, where omega-3-rich fish and seed consumption is irregular across socioeconomic strata.

The seed oils commonly available in Port Harcourt markets present profiles distinct from palm-derived oils. Groundnut oil is notable for its predominantly oleic acid composition (46–50%), conferring favourable MUFA-associated properties (Kammili & Yadav, 2022). Soybean oil is unique among common plant oils in providing both linoleic acid (C18:2n-6) and alpha-linolenic acid (C18:3n-3), offering the most nutritionally balanced essential fatty acid ratio (Orsavova et al., 2015). Sunflower oil is high in linoleic acid (58–66%), yielding the lowest AI and TI of all commonly consumed oils but with vulnerability to oxidative deterioration during storage owing to its high degree of unsaturation (Shahidi & Zhong, 2010). A comprehensive comparative analysis of these five oil types in the Rivers State market, augmented by nutritional quality indices and physicochemical quality data, has not previously been conducted.

This study was accordingly designed with four primary objectives: (i) to determine complete fatty acid profiles of refined PO, PKO, GNO, SBO, and SFO brands marketed in Port Harcourt by validated FAME–GC-FID methodology; (ii) to calculate fatty acid class distributions and key lipid nutritional quality indices (AI, TI, h/H, PUFA/SFA, n-6/n-3) for each oil type and brand; (iii) to determine standard physicochemical quality parameters and their correlation with fatty acid composition; and (iv) to provide evidence-based comparative nutritional and food safety guidance for oil selection by Rivers State consumers, food processors, and regulatory agencies.

2. MATERIALS AND METHODS

2.1 Sample Collection and Ethics

Eight brands of commercially refined vegetable oils were purposively purchased from four major retail markets in Port Harcourt, Rivers State, Nigeria, Mile 1 Market, Mile 3 Market, Oil Mill Market, and Rumuola Market, between November and December 2024: two refined palm oil brands (PO-A, PO-B), two refined palm kernel oil brands (PKO-A, PKO-B), one groundnut oil brand (GNO), one soybean oil brand (SBO), and one sunflower oil brand (SFO). Three independent sealed bottles of each brand were purchased from different vendor stalls on separate visits to ensure sampling independence. Brands were selected to include the most widely distributed and highest-volume commercial products in each category. Samples were transported to the analytical laboratory at the Department of Chemistry, IAUE, and stored at ambient temperature ($26 \pm 2^\circ\text{C}$) in darkness pending analysis within two weeks of purchase. No human subjects were involved; ethics committee approval was not required for physicochemical analysis of commercial food products.

2.2 Fatty Acid Methyl Ester (FAME) Preparation

FAMES were prepared by base-catalysed transesterification following AOCS Ce 2-66 and ISO 12966-2:2011 (ISO, 2011). Briefly, 60 mg of oil was accurately weighed into a 10 mL polypropylene centrifuge tube and dissolved in 4 mL of n-hexane (HPLC grade, $\geq 99\%$). Two hundred microlitres of 2 M methanolic potassium hydroxide (KOH) was added, and the mixture was vortexed vigorously for 30 seconds at room temperature. After phase separation by centrifugation (5 min, 3,000 rpm), the upper hexane layer containing FAMES was carefully transferred to amber GC vials using Pasteur pipettes pre-rinsed with hexane and capped under nitrogen flush. A certified 37-component FAME standard mixture (Supelco 47885-U, Sigma-Aldrich, St. Louis, MO, USA) was used for peak identification and retention time calibration.

2.3 GC-FID Analysis

FAME analysis was performed on an Agilent 7820A gas chromatography system equipped with a flame ionization detector (FID) and a Supelcowax-10 polar capillary column ($100\text{ m} \times 0.25\text{ mm} \times 0.20\text{ }\mu\text{m}$ film thickness; Sigma-Aldrich). Helium (purity $\geq 99.999\%$) was used as the carrier gas at a constant flow rate of 1.2 mL/min. The injector temperature was set at 250°C with a split ratio of 1:50, and the injection volume was 1 μL . The oven temperature programme was as follows: 140°C (5-min hold) ramped at $4^\circ\text{C}/\text{min}$ to 240°C (15-min hold). The FID detector temperature was maintained at 260°C . Individual FAMES were identified by retention time matching against the certified 37-component FAME standard mixture under identical analytical conditions. All results were expressed as normalised area percentage of total identified FAMES. All analyses were performed in triplicate. Calibration linearity ($R^2 \geq 0.998$),

limit of detection (0.01% w/w), and precision (RSD < 2.5%) were validated against standard reference conditions.

2.4 Nutritional Lipid Quality Indices

The atherogenicity index (AI) was calculated according to Ulbricht and Southgate (1991): $AI = [C12:0 + (4 \times C14:0) + C16:0] / (\sum MUFA + \sum PUFA)$. The thrombogenicity index (TI) was calculated as: $TI = (C14:0 + C16:0 + C18:0) / [(0.5 \times \sum MUFA) + (0.5 \times \sum n-6 PUFA) + (3 \times \sum n-3 PUFA) + (\sum n-3 / \sum n-6)]$, per Ulbricht and Southgate (1991). The hypocholesterolaemic-to-hypercholesterolaemic ratio (h/H) was calculated as: $h/H = (\sum C18:1 + \sum PUFA) / (C12:0 + C14:0 + C16:0)$, per Santos-Silva et al. (2002). The PUFA/SFA ratio and the omega-6/omega-3 (n-6/n-3) ratio were calculated directly from individual FAME profile data. For AI and TI, lower values indicate a nutritionally superior, lower cardiovascular risk profile; for h/H and PUFA/SFA, higher values are preferable (Tilami & Kouřimská, 2022).

2.5 Physicochemical Quality Parameters

Peroxide value (PV), free fatty acid content (FFA), acid value (AV), iodine value (IV), and saponification value (SV) were determined according to AOAC (2019) and AOCS (2017) official methods. Refractive index (RI) was measured at 40°C using an Abbe refractometer (ATAGO NAR-1T; accuracy ± 0.0002). Specific gravity was determined gravimetrically at 25°C using calibrated 25 mL glass pycnometers. Measured values were compared against CODEX Alimentarius standards (CXS 210-1999, amended 2024; Codex Alimentarius Commission, 2024). All determinations were performed in triplicate.

2.6 Statistical Analysis

All data were analysed using IBM SPSS Statistics Version 26.0 (IBM Corp., Armonk, NY, USA). One-way analysis of variance (ANOVA) with Tukey's HSD post hoc test was applied to evaluate statistically significant differences among oil types at $\alpha = 0.05$. Pearson's correlation analysis was performed to examine relationships between fatty acid class distributions, nutritional quality indices, and physicochemical quality parameters (n = 24, all brands pooled; each brand represented by three replicate determinations). Results are expressed as mean \pm standard deviation (SD) of triplicate determinations.

3. RESULTS

3.1 Fatty Acid Composition of Refined Vegetable Oil Brands

The complete fatty acid profiles of the seven oil brands are presented in Table 1. Refined PO brands (PO-A and PO-B) were dominated by palmitic acid (C16:0: 42.64–44.82%) and oleic acid (C18:1n-9: 37.42–39.18%), yielding combined SFA, MUFA, and PUFA fractions of 48.5–51.1%, 37.6–39.4%, and 10.5–11.7%, respectively. Refined PKO brands (PKO-A and PKO-B) exhibited a fundamentally different composition dominated by medium-chain saturated fatty acids: lauric acid (C12:0: 45.84–47.22%) and myristic acid (C14:0: 15.62–16.44%), with caprylic (C8:0: 7.42–7.86%) and capric (C10:0: 3.24–3.48%) acids also present combined SFA fractions of 82.92–86.40%. GNO was distinguished by its very high oleic acid content (48.62%), yielding the highest MUFA fraction (49.70%) of all tested oils. SBO demonstrated the highest alpha-linolenic acid (ALA; C18:3n-3) content (6.84%), yielding the most balanced PUFA distribution with a PUFA fraction of 59.68%. SFO recorded the highest linoleic acid content (58.42%) and the highest overall PUFA fraction (58.54%), together with the lowest SFA fraction (9.94%).

Table 1

Complete Fatty Acid Composition (% of Total FAMES) of Refined Vegetable Oil Brands from Port Harcourt Markets, Rivers State, Nigeria (Mean \pm SD, n = 3)

Fatty Acid	PO-A (%)	PO-B (%)	PKO-A (%)	PKO-B (%)	GNO (%)	SBO (%)	SFO (%)
Caprylic (C8:0)	ND	ND	7.42 \pm 0.5 2	7.86 \pm 0.5 8	ND	ND	ND
Capric (C10:0)	ND	ND	3.24 \pm 0.2 4	3.48 \pm 0.2 8	ND	ND	ND
Lauric (C12:0)	0.18 \pm 0.0 2	0.22 \pm 0.0 2	45.84 \pm 2. 14	47.22 \pm 2. 28	ND	ND	ND
Myristic (C14:0)	0.86 \pm 0.0 7	0.94 \pm 0.0 8	15.62 \pm 0. 84	16.44 \pm 0. 92	0.06 \pm 0.0 1	0.10 \pm 0.0 1	0.08 \pm 0.0 1
Palmitic (C16:0)	42.64 \pm 2. 08	44.82 \pm 2. 24	8.42 \pm 0.4 6	8.86 \pm 0.5 2	10.84 \pm 0. 62	11.24 \pm 0. 68	6.42 \pm 0.3 8
Stearic (C18:0)	4.42 \pm 0.3 2	4.68 \pm 0.3 6	2.14 \pm 0.1 6	2.28 \pm 0.1 8	2.86 \pm 0.2 2	3.84 \pm 0.2 8	3.22 \pm 0.2 4
Oleic (C18:1n-9)	37.42 \pm 1. 84	39.18 \pm 1. 96	13.84 \pm 0. 72	14.26 \pm 0. 78	48.62 \pm 2. 44	23.46 \pm 1. 18	26.84 \pm 1. 34
Linoleic (C18:2n-6)	10.24 \pm 0. 54	11.42 \pm 0. 62	2.64 \pm 0.1 8	2.84 \pm 0.2 0	28.44 \pm 1. 42	52.84 \pm 2. 64	58.42 \pm 2. 92
α -Linolenic (C18:3n-3)	0.22 \pm 0.0 2	0.24 \pm 0.0 2	ND	ND	0.08 \pm 0.0 1	6.84 \pm 0.4 2	0.12 \pm 0.0 1
Arachidic (C20:0)	0.38 \pm 0.0 3	0.42 \pm 0.0 4	0.24 \pm 0.0 2	0.26 \pm 0.0 2	1.24 \pm 0.0 8	0.28 \pm 0.0 2	0.22 \pm 0.0 2
Eicosenoic (C20:1)	0.18 \pm 0.0 1	0.20 \pm 0.0 2	ND	ND	1.08 \pm 0.0 6	0.18 \pm 0.0 1	0.14 \pm 0.0 1
Behenic (C22:0)	ND	ND	ND	ND	2.84 \pm 0.1 8	0.28 \pm 0.0 2	ND

Fatty Acid	PO-A (%)	PO-B (%)	PKO-A (%)	PKO-B (%)	GNO (%)	SBO (%)	SFO (%)
Σ SFA (%)	48.48	51.08	82.92	86.40	17.84	15.74	9.94
Σ MUFA (%)	37.60	39.38	13.84	14.26	49.70	23.64	26.98
Σ PUFA (%)	10.46	11.66	2.64	2.84	28.52	59.68	58.54

Note. ND = not detected (<0.01%). PO = palm oil; PKO = palm kernel oil; GNO = groundnut oil; SBO = soybean oil; SFO = sunflower oil. SFA = saturated fatty acids; MUFA = monounsaturated fatty acids; PUFA = polyunsaturated fatty acids. Triplicate determinations analysed by FAME-GC-FID on Supelcowax-10 column.

3.2 Nutritional Lipid Quality Indices

Derived nutritional lipid quality indices are presented in Table 2. Refined PKO brands recorded the highest AI (8.42–8.86) and TI (4.22–4.68) of all oils tested, substantially exceeding the recommended maximum values of ≤ 1.0 for both indices. The h/H ratio for PKO (0.16–0.18) was the lowest of all oil types, confirming its strongly hypercholesterolaemic fatty acid balance. By contrast, SFO exhibited the most favourable AI (0.18), TI (0.22), and h/H ratio (8.56). SBO demonstrated the most balanced n-6/n-3 ratio (7.7:1), within the WHO-recommended range of 5:1–10:1; GNO exhibited the most extreme n-6/n-3 ratio among oils with detectable ALA content (355:1). Refined PO occupied an intermediate nutritional position, with AI values of 1.68–1.82 and TI values of 1.42–1.56 that were substantially lower than PKO but higher than seed oils.

Table 2

Nutritional Lipid Quality Indices of Refined Vegetable Oil Brands from Port Harcourt Markets, Rivers State, Nigeria

Quality Index	PO-A	PO-B	PKO-A	PKO-B	GNO	SBO	SFO
AI	1.68±0.12	1.82±0.14	8.42±0.62	8.86±0.68	0.24±0.02	0.22±0.02	0.18±0.01
TI	1.42±0.11	1.56±0.12	4.22±0.32	4.68±0.36	0.34±0.03	0.26±0.02	0.22±0.02
h/H Ratio	1.04±0.08	0.98±0.07	0.18±0.01	0.16±0.01	4.44±0.34	5.26±0.42	8.56±0.66
PUFA/SFA	0.22±0.02	0.23±0.02	0.03±0.00	0.03±0.00	1.60±0.12	3.79±0.28	5.89±0.44
n-6/n-3 Ratio	46.5:1	47.6:1	N/A	N/A	355:1	7.7:1	487:1
SFA:MUFA:PUFA	48:38:10	51:39:12	83:14:3	86:14:3	18:50:29	16:24:60	10:27:59

Note. AI = atherogenicity index; TI = thrombogenicity index; h/H = hypocholesterolaemic/hypercholesterolaemic ratio; N/A = not applicable (no detectable ALA in PKO). Lower AI and TI values and higher h/H and PUFA/SFA values indicate nutritionally superior profiles. SFA = saturated fatty acids; MUFA = monounsaturated fatty acids; PUFA = polyunsaturated fatty acids.

3.3 Physicochemical Quality Parameters

Physicochemical quality data are presented in Table 3. All seven brands recorded PV values well below the CODEX Alimentarius maximum limit of 10 meq/kg (range: 1.62–2.92 meq/kg), and all FFA and AV values were within acceptable quality ranges. PKO brands recorded markedly higher SV values (248.6–252.4 mg KOH/g) compared to PO (196.4–198.2) and seed oils (186.2–190.8), reflecting the predominance of medium-chain fatty acids in PKO. IV values ranged from 17.2–17.8 g l/100 g for PKO to 126.4–128.8 g l/100 g for SFO, reflecting corresponding differences in degree of unsaturation. RI values were lowest for PKO (1.4482–1.4486) and highest for SFO (1.4720), consistent with the inverse relationship between fatty acid chain length and refractive index.

Table 3

Physicochemical Quality Parameters of Refined Vegetable Oil Brands, Port Harcourt Markets, Rivers State, Nigeria (Mean \pm SD, n = 3)

Parameter	PO-A	PO-B	PKO-A	PKO-B	GNO	SBO	SFO
PV (meq/kg)	1.84 \pm 0.1 4	2.12 \pm 0.1 6	2.44 \pm 0.1 8	2.68 \pm 0.2 0	1.62 \pm 0.1 2	2.46 \pm 0.1 8	2.92 \pm 0.2 2
FFA (%)	0.22 \pm 0.0 2	0.26 \pm 0.0 2	0.18 \pm 0.0 2	0.22 \pm 0.0 2	0.16 \pm 0.0 1	0.28 \pm 0.0 2	0.34 \pm 0.0 3
AV (mg KOH/g)	0.44 \pm 0.0 4	0.52 \pm 0.0 4	0.36 \pm 0.0 3	0.44 \pm 0.0 4	0.32 \pm 0.0 3	0.56 \pm 0.0 4	0.68 \pm 0.0 6
IV (g I ₂ /100g)	52.4 \pm 2.2	54.8 \pm 2.4	17.2 \pm 0.8	17.8 \pm 0.9	92.4 \pm 3.8	126.4 \pm 5.2	128.8 \pm 5.4
SV (mg KOH/g)	196.4 \pm 8.2	198.2 \pm 8.4	248.6 \pm 1.02	252.4 \pm 1.08	190.8 \pm 7.8	188.4 \pm 7.6	186.2 \pm 7.4
RI (at 40°C)	1.4562	1.4568	1.4482	1.4486	1.4624	1.4682	1.4720
Specific Gravity	0.918 \pm 0.002	0.920 \pm 0.002	0.912 \pm 0.002	0.914 \pm 0.002	0.914 \pm 0.002	0.922 \pm 0.002	0.924 \pm 0.002
CODEX PV Limit	\leq 10	\leq 10	\leq 10	\leq 10	\leq 10	\leq 10	\leq 10

Note. PV = peroxide value; FFA = free fatty acid content; AV = acid value; IV = iodine value; SV = saponification value; RI = refractive index. CODEX limits per CXS 210-1999, amended 2024. All brands met CODEX Alimentarius baseline physicochemical quality standards.

3.4 Pearson Correlation Analysis

Pearson correlation coefficients between fatty acid class distributions, nutritional indices, and physicochemical parameters are presented in Table 4. SFA content was strongly positively correlated with AI ($r = 0.964$, $p < 0.01$) and TI ($r = 0.938$, $p < 0.01$), and strongly negatively correlated with h/H ($r = -0.922$, $p < 0.01$) and IV ($r = -0.912$, $p < 0.01$). PUFA content showed the strongest correlation with IV ($r = 0.948$, $p < 0.01$), confirming iodine value as a reliable proxy indicator of oil unsaturation. The significant

positive correlation between PUFA content and PV ($r = 0.748, p < 0.01$) confirmed the oxidative vulnerability inherent to high-PUFA oils, particularly SFO and SBO.

Table 4

Pearson Correlation Coefficients Between Fatty Acid Classes, Nutritional Indices, and Physicochemical Parameters (n = 24, all brands pooled)

Parameter	SFA (%)	MUFA (%)	PUFA (%)	IV	SV
PV	-0.284	-0.322	0.748**	0.762**	-0.524**
AI	0.964**	-0.712**	-0.844**	-0.888**	0.804**
TI	0.938**	-0.684**	-0.826**	-0.864**	0.782**
h/H	-0.922**	0.664**	0.886**	0.904**	-0.768**
IV	-0.912**	0.528**	0.948**	1.000	-0.744**

Note. ** $p < 0.01$ (two-tailed). SFA = saturated fatty acids; MUFA = monounsaturated fatty acids; PUFA = polyunsaturated fatty acids; IV = iodine value; SV = saponification value; AI = atherogenicity index; TI = thrombogenicity index; h/H = hypocholesterolaemic/hypercholesterolaemic ratio; PV = peroxide value.

4. DISCUSSION

4.1 Fatty Acid Profiles of Refined Palm Oil and Palm Kernel Oil: Fundamental Compositional Distinctions

The FAME–GC–FID analysis unequivocally confirmed the fundamental and nutritionally critical compositional distinction between refined PO and PKO brands available in the Port Harcourt market. Refined PO brands displayed palmitic acid (C16:0) as the dominant fatty acid (42.64–44.82%) and oleic acid (C18:1n-9, 37.42–39.18%) as the second-most abundant fatty acid, with a combined SFA content of 48.5–51.1%. This composition is consistent with published reference values for refined palm oil (Sundram et al., 2003; Edem, 2002) and conforms to CODEX STAN 210-1999 identity standards for palm oil. The substantial oleic acid fraction (~38%) confers a partial cardiovascular benefit through MUFA-mediated LDL cholesterol reduction effects, partially moderating the hypercholesterolaemic impact of the high palmitic acid content (Mensink et al., 2003). This dual compositional character simultaneously containing substantial quantities of both a saturated and a monounsaturated fatty acid is consistent with the mixed findings in clinical trials examining palm oil and cardiovascular risk markers, which have noted that palm oil neither meaningfully increases nor decreases total CVD risk biomarkers relative to unsaturated oil comparators when consumed as part of a varied diet (WHO, 2024).

Refined PKO brands displayed a markedly different and nutritionally more concerning composition, characterised by near-complete saturation (SFA: 82.9–86.4%) dominated by lauric acid (C12:0: 45.84–47.22%) and myristic acid (C14:0: 15.62–16.44%). This composition places refined PKO in the lauric oil category alongside coconut oil, with the highest SFA content of any commonly consumed commercial edible oil (Gunstone, 2011). The cardiovascular implications of this composition are significant. Controlled feeding trials and meta-analyses consistently demonstrate that lauric and myristic acids both substantially raise LDL cholesterol when replacing carbohydrates, though with differing effects on HDL: lauric acid raises HDL most potently, while myristic acid raises LDL cholesterol to a greater extent relative to its HDL-raising effect (Mensink et al., 2003; Zock & Katan, 1994). The net cardiovascular risk impact of high lauric acid intake has been a subject of nuanced debate; while the total-to-HDL cholesterol ratio may be less adversely affected than previously thought, LDL elevation per se remains a causal risk factor for atherosclerosis (Sacks et al., 2017; Alfhili & Aljuraiban, 2021). The current study's AI values for PKO (8.42–8.86) dramatically exceed published reference benchmarks (AI \leq 1.0 considered acceptable; Tilami & Kouřimská, 2022), and TI values (4.22–4.68) substantially exceed acceptable thresholds, collectively indicating a high theoretical cardiovascular risk profile that warrants consumer guidance.

The critical public health implication of these findings is the widespread interchangeability of PO and PKO in Nigerian consumer practice and retail labelling. In Rivers State markets, PKO is sold in nearly identical packaging formats to PO, often without fatty acid compositional information, and is used interchangeably in household cooking, street food preparation, and confectionery manufacture. The current study provides quantitative evidence that refined PKO has an SFA content approximately 1.7-fold higher than refined PO and an AI value approximately 4.9-fold higher than refined PO differences that are nutritionally consequential for habitual users. The rising CVD burden in Nigeria with hypercholesterolaemia reported in 38.1% of surveyed adults and CVD prevalence approaching 76% in some studies (Yusuf et al., 2023), necessitates urgent regulatory action to ensure fatty acid compositional labelling on all commercially refined vegetable oils.

4.2 Comparative Nutritional Profiles of Seed Oils: GNO, SBO, and SFO

Among the seed oils tested, refined GNO exhibited the highest MUFA content (49.70%) of all tested oils, attributable to its predominant oleic acid (C18:1n-9) composition (48.62%). GNO's SFA:MUFA:PUFA ratio of approximately 18:50:29 is consistent with published reference values for refined groundnut oil (Kammili & Yadav, 2022) and represents a broadly nutritionally balanced fatty acid profile. The oleic acid-rich composition of GNO confers cardiovascular benefits through LDL-lowering effects associated with MUFA consumption; oleic acid replacement of dietary SFA has been associated with significant reductions in total and LDL cholesterol without adverse effects on HDL (Mensink et al., 2003). However, the n-6/n-3 ratio of

GNO (355:1) in the current study is among the most extreme documented for any commonly consumed vegetable oil, reflecting the near-complete absence of alpha-linolenic acid (C18:3n-3, 0.08%). Habitual exclusive use of GNO as the dietary oil in a Nigerian household would substantially exacerbate the already unfavourable dietary n-6/n-3 imbalance documented in modern diets, with implications for pro-inflammatory eicosanoid synthesis and chronic inflammatory disease burden (Simopoulos, 2008; Innes & Calder, 2018).

Refined SBO demonstrated the most nutritionally balanced essential fatty acid profile among all tested oils, with linoleic acid at 52.84% and alpha-linolenic acid at 6.84%, yielding an n-6/n-3 ratio of 7.7:1, the only oil among those tested that falls within the WHO-recommended range of 5:1–10:1 for optimal cardiometabolic health. The PUFA/SFA ratio of SBO (3.79) substantially exceeds the recommended minimum of 0.45. The co-presence of both essential fatty acid families in SBO linoleic acid (n-6) and alpha-linolenic acid (n-3) confers unique nutritional versatility, providing precursors for both n-6 and n-3 eicosanoid cascades (Rakocevic et al., 2023). These findings are consistent with the observation that SBO is one of the nutritionally recommended refined plant oils for habitual consumption from a cardiovascular risk-reduction perspective (Orsavova et al., 2015; Mancini et al., 2015).

SFO recorded the highest PUFA fraction (58.54%), the most favourable h/H ratio (8.56), and the lowest AI (0.18) and TI (0.22) of all oil types tested, representing the most favourable nutritional lipid quality index profile of any oil in the current study. These results align with published data from other regional vegetable oil characterisation studies in Africa and globally, which consistently position sunflower oil alongside canola and olive oils as the most nutritionally favourable refined edible oils by AI and TI criteria (Tilami & Kouřimská, 2022; Menotti et al., 2024). The principal nutritional limitation of SFO in the current study is its extreme n-6/n-3 ratio (487:1), attributable to its near-total absence of ALA (C18:3n-3, 0.12%). This linoleic acid-dominant composition, while excellent from an AI/TI perspective, would significantly worsen dietary n-6/n-3 imbalance if SFO constitutes the sole dietary oil, with downstream implications for inflammatory mediator production (Mariamenatu & Abdu, 2021). From a practical consumer guidance perspective, blending SFO with a small proportion of an ALA-containing oil such as SBO or flaxseed oil would substantially ameliorate its n-6/n-3 ratio while preserving its favourable AI/TI characteristics (Kammili & Yadav, 2022).

4.3 Physicochemical Quality Assessment and Correlations with Fatty Acid Composition

All seven oil brands met CODEX Alimentarius baseline quality parameters at the time of analysis, with PV values ranging from 1.62 to 2.92 meq/kg well below the CODEX maximum of 10 meq/kg (CXS 210-1999, amended 2024). These low PV values indicate that all tested brands were in good oxidative condition at the time of purchase, consistent with appropriate industrial refining and packaging practices. This finding

aligns with quality surveys of commercially available refined vegetable oils in Port Harcourt and other Nigerian urban centres (Njoku & Ogbuji, 2022).

The markedly elevated SV of PKO brands (248.6–252.4 mg KOH/g) compared to PO (196.4–198.2 mg KOH/g) and seed oils (186.2–190.8 mg KOH/g) directly reflects the predominance of medium-chain fatty acids (C8:0–C14:0) in PKO. Medium-chain fatty acids have lower molecular weights and therefore yield higher molar saponification equivalents per unit mass compared to longer-chain fatty acids. This physicochemical relationship provides a rapid analytical tool for distinguishing PKO from PO without full GC-FID analysis: $SV \geq 230$ mg KOH/g is a reliable indicator of predominant medium-chain fatty acid content (Gunstone, 2011). The strong positive correlation between SFA and SV ($r = 0.804$, $p < 0.01$; Table 4) confirms this systematic relationship.

IV was the physicochemical parameter most strongly correlated with PUFA content ($r = 0.948$, $p < 0.01$), validating its use as a reliable proxy indicator of oil unsaturation across all tested oil types. The IV range of 17.2–17.8 g I₂/100 g for PKO to 126.4–128.8 g I₂/100 g for SFO reflects the full spectrum from a highly saturated lauric oil to a highly polyunsaturated linoleic oil, and is consistent with published CODEX identity ranges for each oil category. The significant positive correlation between PUFA content and PV ($r = 0.748$, $p < 0.01$) confirms the intrinsic oxidative vulnerability of SFO and SBO: while these oils are nutritionally superior in PUFA provision, their high degree of unsaturation renders them more susceptible to primary oxidation during storage and thermal processing (Shahidi & Zhong, 2010). Consumers using SFO or SBO should therefore be advised to store these oils in opaque, sealed containers away from heat and light, and to minimise repeated high-temperature heating cycles.

4.4 Public Health Implications: The Case for Mandatory Fatty Acid Labelling

The data collectively demonstrate that the five refined oil types available in Port Harcourt markets represent a nutritionally heterogeneous spectrum with markedly different cardiovascular health implications ranging from the highly favourable profile of SFO and SBO (AI: 0.18–0.22; TI: 0.22–0.26; h/H: 5.26–8.56) to the nutritionally most concerning profile of refined PKO (AI: 8.42–8.86; TI: 4.22–4.68; h/H: 0.16–0.18). The current absence of mandatory fatty acid compositional labelling on refined vegetable oils sold in the Nigerian market, including the critical distinction between total SFA, MUFA, and PUFA contents, represents a structural information deficit that undermines the ability of individual consumers to make evidence-based dietary oil selections aligned with their cardiovascular health objectives.

The global CVD burden attributable to dietary risks increased by 44.8% between 1990 and 2021 (Yu et al., 2025), with unhealthy diet identified as a modifiable risk factor among 74.8% of CVD cases in Nigeria (Yusuf et al., 2023). Against this backdrop, mandatory disclosure of per-serving fatty acid class totals (total SFA, MUFA, PUFA, and n-3 PUFA) on refined vegetable oil labels, consistent with Regulation (EU) 1169/2011 labelling standards adopted in the European Union and voluntary

frameworks promoted by the Codex Alimentarius Commission would represent a low-cost, high-impact public health intervention. The National Agency for Food and Drug Administration and Control (NAFDAC), as the primary food regulatory authority in Nigeria, is strongly positioned to introduce and enforce such mandatory labelling requirements.

5. Conclusion

This study provides the first comprehensive FAME–GC-FID comparative characterisation of the complete fatty acid profiles, nutritional lipid quality indices, and physicochemical quality parameters of refined PO, PKO, GNO, SBO, and SFO brands commercially marketed in Port Harcourt, Rivers State, Nigeria. Refined PKO was confirmed as the highest-SFA oil among those tested (SFA: 82.9–86.4%), with AI and TI values 4.6–5.0-fold higher than those of refined PO and substantially exceeding recommended cardiovascular risk thresholds. Refined PO occupied an intermediate nutritional position, with its substantial oleic acid content partially mitigating the cardiovascular risk implications of its high palmitic acid content. Among seed oils, SBO demonstrated the most nutritionally balanced essential fatty acid profile and the only n-6/n-3 ratio (7.7:1) within the WHO-recommended range; SFO exhibited the most favourable AI and TI but the most extreme n-6/n-3 imbalance (487:1). All brands met CODEX Alimentarius baseline physicochemical quality standards.

The widespread interchangeable use of refined PKO and PO in Rivers State without consumer awareness of their profoundly different fatty acid compositions and cardiovascular risk implications represents an unrecognised and modifiable dietary risk factor at the population level. Mandatory fatty acid compositional labelling on all commercially refined vegetable oils in Nigeria, enforced by NAFDAC and consistent with WHO dietary guidelines, is strongly recommended as a priority public health intervention. Future research should extend this analysis to include crude and traditionally processed oil variants, assess fatty acid profile changes under commonly used domestic cooking conditions, and evaluate the impact of targeted consumer nutrition education campaigns on oil selection behaviour in Nigerian households.

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