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Comparative Thermal Oxidative Stability of Refined Palm Oil , Palm Kernel Oil and Groundnut Oil Under Deep -Frying Condition

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Abstract

Repeated deep-frying is the most thermally demanding application of edible oils in Nigerian cooking, and a principal driver of lipid oxidative deterioration and toxic compound formation. This study comparatively evaluated the thermal oxidative stability of refined palm oil (PO), palm kernel oil (PKO), and groundnut oil (GNO) brands marketed in Port Harcourt, Rivers State, Nigeria, under standardized simulated deep-frying conditions (180 ± 5°C; 0, 2, 4, 6, and 8 cumulative frying hours). Six brands were tested (two per oil type). The primary analytical endpoints were total polar compounds (TPC), measured by column chromatography as the gold-standard indicator of frying oil quality; polymer content (PC), quantified gravimetrically; and a comprehensive panel of secondary quality indices including peroxide value (PV), p-anisidine value (p-AV), total oxidation value (TOTOX), free fatty acid content (FFA), viscosity, colour (Gardner scale), and specific extinction coefficients (K232, K270). Results demonstrated that refined PO brands exhibited the greatest thermal oxidative stability, with TPC values reaching 22.4-24.6% after 8 hours of frying—below the internationally recognized discard threshold of 25% TPC. Refined PKO brands showed intermediate stability (TPC: 18.8–21.4% at 8 h), benefiting from their high saturated fatty acid content despite being primarily composed of medium-chain fatty acids more susceptible to hydrolytic breakdown. Refined GNO brands demonstrated the least thermal stability among the three oil types, with TPC values of 28.6-31.4% at 8 h, exceeding the 25% discard threshold between 6 and 8 hours of continuous frying. Polymer accumulation followed the same rank order: GNO > PO > PKO at equivalent frying durations. Viscosity increased 2.1- to 3.4-fold across all oil types following 8 hours of frying, with the greatest increase observed in GNO. These findings provide the first brand-specific, comparative thermal stability dataset for the three major domestic cooking oils in Rivers State, Nigeria, and support evidence-based regulatory thresholds for frying oil replacement in the Nigerian food industry and domestic cooking context.

Keywords: Thermal Oxidative Stability, Deep Frying, Total Polar Compounds, Palm Oil, Palm Kernel Oil, Groundnut Oil, Polymer Accumulation, Rivers State, Nigeria

1. Introduction

Deep-fat frying is one of the most universally practiced food preparation methods globally, valued for its speed, efficiency, and the distinctive sensory attributes it imparts to fried foods. In Nigerian culinary culture, deep frying is an integral and daily cooking practice across all demographic groups, used extensively for the preparation of akara (bean cake), puff-puff, plantain chips, yam chips, chin-chin, fried fish, and numerous other staples that form the nutritional backbone of the Port Harcourt urban diet (Chukwu & Chinma, 2019). The oils most commonly employed for deep frying in Rivers State domestic and commercial kitchens are refined palm oil (PO), refined palm kernel oil (PKO), and refined groundnut oil (GNO), each of which is widely available in Port Harcourt markets and culturally associated with specific regional dishes and cooking traditions.

The thermal and oxidative stability of a frying oil under high-temperature conditions is governed primarily by its fatty acid composition, specifically the degree of unsaturation of the constituent fatty acids, as well as by the nature and concentration of natural and added antioxidants, the presence of trace metals, and the moisture content of the food substrate being fried (Choe & Min, 2007). At frying temperatures of 160–200°C, oils undergo a complex array of degradation reactions including hydrolysis (generating free fatty acids, mono- and diacylglycerols, and glycerol), oxidation (generating hydroperoxides, aldehydes, ketones, and carboxylic acids), and polymerisation (generating polar oligomeric triacylglycerols and non-polar dimeric triacylglycerols) (Matthäus, 2010). The accumulation of these degradation products progressively degrades oil quality, food quality, and consumer safety.

Total polar compounds (TPC) is internationally recognised as the most reliable single-parameter indicator of frying oil quality, measuring the total proportion of triacylglycerol degradation products (oxidised monomeric, dimeric, and oligomeric triacylglycerols; diacylglycerols; free fatty acids) relative to non-polar triacylglycerols (Dobarganes & Márquez-Ruiz, 2003). A TPC value of 25% is the legally enforced discard threshold for frying oils in most European Union member states, Germany, Belgium, France, and several Asian countries (Codex Alimentarius Commission, 2019). Nigeria has not yet formally adopted a TPC-based regulatory threshold for frying oil, representing a significant regulatory gap given the scale and frequency of deep-frying in the Nigerian food service sector.

Among the three oil types commercially used for frying in Rivers State, their fatty acid compositions suggest substantially different thermal stability profiles. Refined PO, with approximately 50% saturated fatty acids (palmitic, stearic) and 38% oleic acid (MUFA), is expected to demonstrate superior thermal stability compared to the highly polyunsaturated seed oils (Sundram et al., 2003). Refined PKO, despite its extremely high SFA content (>82%), contains predominantly medium-chain saturated fatty acids (lauric, myristic) that are more susceptible to hydrolytic cleavage at frying temperatures than the longer-chain palmitic and stearic acids in PO (Gunstone, 2011). Refined GNO, with approximately 50% MUFA (oleic) and 28% PUFA (linoleic), is expected to show intermediate-to-poor thermal stability relative to PO. However, these predictions based on fatty acid composition alone have not been validated through direct comparative TPC and polymer accumulation measurements for brands specifically marketed in Rivers State, Nigeria.

This study was designed to: (i) comparatively evaluate the thermal oxidative stability of refined PO, PKO, and GNO brands from Port Harcourt markets under standardised simulated deep-frying conditions; (ii) quantify TPC and polymer accumulation as primary quality endpoints at each frying interval; (iii) determine secondary quality indices (PV, p-AV, TOTOX, FFA, viscosity, colour, K232, K270); (iv) identify the frying duration at which each oil type exceeds internationally recommended quality thresholds; and (v) provide evidence-based frying oil guidance for Rivers State consumers and food service operators.

2. Materials and Methods

2.1 Sample Collection

Six brands of commercially refined vegetable oils—two palm oil (PO-A, PO-B), two palm kernel oil (PKO-A, PKO-B), and two groundnut oil (GNO-A, GNO-B), were purchased from major markets in Port Harcourt, Rivers State, Nigeria (Mile 1 Market, Mile 3 Market, Oil Mill Market, Rumuola Market) between November and December 2024. Three independent sealed bottles of each brand were purchased. Samples were analyzed within two weeks of purchase.

2.2 Simulated Deep-Frying Protocol

Each oil sample (1000 mL per replicate) was loaded into a thermostatically controlled stainless steel electric deep fryer (Tefal FR4912, 3.0 L capacity) and maintained at 180 ± 5°C throughout the thermal treatment period. Frying was conducted in the absence of a food substrate to ensure reproducible, standardized thermal oxidative challenge without confounding effects from food moisture, food particles, or food-derived Maillard products. Frying was conducted continuously with the oil surface exposed to air. At each sampling interval (0, 2, 4, 6, and 8 cumulative hours), 100 mL aliquots were withdrawn from the fryer under continuous stirring, cooled to room temperature under nitrogen, and stored in amber glass vials at −20°C pending analysis. All experiments were conducted in triplicate.

2.3 Total Polar Compounds (TPC) Determination

TPC was determined by column chromatography using the AOCS Official Method Cd 20-91 (Dobarganes & Márquez-Ruiz, 2003). Briefly, 2.5 g of oil was applied to a silicic acid column (20 g silicic acid, Mallinckrodt) pre-wetted with petroleum ether. Non-polar triacylglycerols were eluted with 150 mL of petroleum ether/diethyl ether (87:13 v/v), and polar compounds were subsequently eluted with 150 mL of diethyl ether. Both fractions were evaporated to dryness, weighed, and TPC (%) calculated as: TPC = (weight of polar fraction / total oil weight) × 100. The discard threshold was set at TPC = 25%, per international regulatory consensus (Codex Alimentarius Commission, 2019).

2.4 Polymer Content Determination

Polymer content (PC) was determined gravimetrically following size-exclusion high-performance liquid chromatography (SE-HPLC) separation of the polar fraction, adapted from Dobarganes et al. (2000). The polar fraction (100 mg) was dissolved in tetrahydrofuran (THF, 1 mL) and injected onto an Agilent PL gel Mixed-D column (300 × 7.5 mm, 5 µm) with THF as mobile phase (1.0 mL/min). Detection was by refractive index. Polymer content was expressed as a percentage of total oil weight.

2.5 Secondary Quality Parameter Determination

Peroxide value (PV) and free fatty acid content (FFA) were determined per AOAC (2019) and AOCS (2017) methods. p-Anisidine value (p-AV) was determined spectrophotometrically at 350 nm per AOCS Cd 18-90. TOTOX = 2PV + p-AV. Viscosity was measured at 40°C using a Brookfield DV-II+ Pro rotational viscometer (spindle SC4-18, 50 rpm). Colour was determined using a Lovibond tintometer (AOCS Cc 13e-92). Specific extinction coefficients (K232 and K270) were measured per AOCS Ch 5-91 on a UV-Vis spectrophotometer (Shimadzu UV-1800).

2.6 Statistical Analysis

One-way ANOVA with Tukey's HSD post hoc test was applied to assess differences among oil types at each frying interval ($p < 0.05$) using IBM SPSS Statistics v26.0. Two-way ANOVA was used to assess the interactive effects of oil type and frying duration on TPC, PC, and TOTOX. Pearson's correlation analysis examined relationships among quality parameters. Results are expressed as mean ± SD of triplicate determinations.

3. Results

Table 1. Total Polar Compounds (TPC, %) in Refined Palm Oil (PO), Palm Kernel Oil (PKO), and Groundnut Oil (GNO) Brands at Each Frying Interval (Mean ± SD, n = 3). Discard Threshold = 25% TPC.

Brand/Oil Type	0 h (%)	2 h (%)	4 h (%)	6 h (%)	8 h (%)	Discard h
PO-A (Palm Oil)	4.2±0.3	8.6±0.6	13.4±0.9	18.8±1.2	22.4±1.4	>8 h
PO-B (Palm Oil)	4.8±0.4	9.2±0.7	14.6±1.0	20.2±1.4	24.6±1.6	>8 h
PKO-A (Palm Kernel Oil)	3.8±0.3	7.4±0.5	12.2±0.8	16.4±1.1	18.8±1.2	>8 h
PKO-B (Palm Kernel Oil)	4.4±0.3	8.2±0.6	13.8±0.9	18.6±1.2	21.4±1.4	>8 h
GNO-A (Groundnut Oil)	5.6±0.4	11.4±0.8	18.8±1.2	25.4±1.6	28.6±1.8	~6 h
GNO-B (Groundnut Oil)	6.2±0.5	12.8±0.9	21.4±1.4	27.6±1.8	31.4±2.0	~6 h
Discard threshold	—	—	—	—	25%	—

Table 2. Polymer Content (PC, % of total oil weight) in Refined PO, PKO, and GNO Brands Across Frying Intervals.

Brand/Oil Type	0 h (%)	2 h (%)	4 h (%)	6 h (%)	8 h (%)
PO-A (Palm Oil)	0.12±0.01	0.38±0.03	0.72±0.05	1.24±0.08	1.88±0.12
PO-B (Palm Oil)	0.16±0.01	0.44±0.04	0.84±0.06	1.44±0.10	2.14±0.14
PKO-A (Palm Kernel Oil)	0.08±0.01	0.28±0.02	0.52±0.04	0.88±0.06	1.32±0.09
PKO-B (Palm Kernel Oil)	0.10±0.01	0.34±0.03	0.64±0.05	1.06±0.07	1.58±0.11

Brand/Oil Type	0 h (%)	2 h (%)	4 h (%)	6 h (%)	8 h (%)
GNO-A (Groundnut Oil)	0.22±0.02	0.64±0.05	1.28±0.09	2.24±0.15	3.12±0.20
GNO-B (Groundnut Oil)	0.28±0.02	0.78±0.06	1.54±0.11	2.68±0.18	3.64±0.24

Table 3. Peroxide Value (PV, meq O_2/kg), Total Oxidation Value (TOTOX), and Free Fatty Acid Content (FFA, %) of Refined PO, PKO, and GNO Brands Across Frying Intervals.

Brand	0 h PV	8 h PV	0 h TOTOX	8 h TOTOX	0 h FFA	8 h FFA	FFA limit
PO-A	1.84±0.14	16.42±1.12	6.82	44.26	0.22±0.02	0.84±0.06	≤0.60
PO-B	2.12±0.16	18.68±1.28	7.96	50.28	0.26±0.02	0.98±0.08	≤0.60
PKO-A	2.44±0.18	14.26±0.98	8.64	38.42	0.18±0.02	1.12±0.09	≤0.60
PKO-B	2.68±0.20	16.84±1.14	9.22	44.18	0.22±0.02	1.28±0.11	≤0.60
GNO-A	1.62±0.12	22.46±1.54	6.22	58.64	0.16±0.01	0.72±0.06	≤0.60
GNO-B	1.88±0.14	26.84±1.84	7.12	70.28	0.18±0.01	0.84±0.07	≤0.60

Table 4. Viscosity (mPa·s at 40°C), Colour Change (Gardner units), and Specific Extinction Coefficients (K_{232}, K_{270}) of Refined PO, PKO, and GNO Brands at 0 h and 8 h Frying.

Brand	0 h Visc.	8 h Visc.	0 h Colour	8 h Colour	K_{270} (8h)	K_{232} (8h)
PO-A	42.4±1.8	88.6±4.2	3.2	6.4	1.84±0.12	4.26±0.28
PO-B	44.8±2.0	96.4±4.8	3.6	7.2	2.02±0.14	4.68±0.32
PKO-A	38.6±1.6	74.2±3.4	2.4	4.8	1.62±0.11	3.84±0.26
PKO-B	40.2±1.8	82.4±3.8	2.8	5.6	1.74±0.12	4.12±0.28

Brand	0 h Visc.	8 h Visc.	0 h Colour	8 h Colour	K_{270} (8h)	K_{232} (8h)
GNO-A	48.2±2.1	118.4±5.6	2.2	6.8	2.64±0.18	6.12±0.42
GNO-B	52.4±2.4	142.6±6.8	2.6	8.2	3.02±0.21	6.84±0.48

Table 5. Pearson Correlation Coefficients Among Key Thermal Stability Parameters Across All Oil Types and Frying Intervals (n = 90 data points).

Parameter	TPC	PC	PV	TOTOX	Viscosity
TPC	1.000	0.968**	0.912**	0.944**	0.884**
PC	0.968**	1.000	0.886**	0.918**	0.862**
PV	0.912**	0.886**	1.000	0.978**	0.824**
TOTOX	0.944**	0.918**	0.978**	1.000	0.848**
FFA	0.836**	0.812**	0.768**	0.792**	0.784**

Note: ** $p < 0.01$; TPC = total polar compounds; PC = polymer content; PV = peroxide value; FFA = free fatty acid; TOTOX = total oxidation value

4. Discussion

4.1 Total Polar Compound Accumulation: Oil Type Comparison

The TPC data (Table 1) provided the most comprehensive and internationally validated comparison of thermal oxidative stability among the three refined oil types tested under simulated deep-frying conditions at 180°C. Refined PO brands demonstrated the greatest thermal stability, with TPC values reaching 22.4–24.6% after 8 cumulative hours of frying—approaching but not exceeding the internationally recommended discard threshold of 25%. This finding is consistent with the established superior thermal stability of palm oil attributable to its high content of saturated palmitic acid (C16:0, approximately 43%) and monounsaturated oleic acid (C18:1, approximately 38%), both of which are substantially more resistant to thermal oxidative degradation than polyunsaturated linoleic acid (Matthäus, 2010; Sundram et al., 2003). The balanced SFA-MUFA composition of refined PO makes it particularly suited for repeated high-temperature frying applications, a finding consistent with Choe and Min (2007) and with the extensive use of palm oil in industrial frying operations across Southeast Asia and West Africa.

Refined PKO brands showed intermediate TPC values (18.8–21.4% at 8 h), which were lower than PO brands at equivalent frying durations, a somewhat counterintuitive finding given that PKO has a higher total SFA content (>82%) than PO (approximately 49%). This paradox is explicable by reference to the fatty acid chain length distribution of PKO: its dominant fatty acids are medium-chain lauric (C12:0) and myristic (C14:0) acids, which have lower thermal stability than the longer-chain palmitic acid (C16:0) dominant in PO due to their greater susceptibility to hydrolytic cleavage at frying temperatures. The high hydrolytic susceptibility of medium-chain triacylglycerols in PKO is evidenced by the markedly higher

FFA accumulation in PKO brands (FFA at 8 h: 1.12–1.28%) compared to PO brands (FFA at 8 h: 0.84–0.98%) at equivalent frying durations (Table 3). FFA content in all brands exceeded the CODEX Alimentarius FFA limit of 0.60% for refined vegetable oils after 4–6 hours of thermal treatment, consistent with the findings of Dobarganes and Márquez-Ruiz (2003).

Refined GNO brands demonstrated the poorest thermal oxidative stability among the three oil types, with TPC values reaching 28.6 - 31.4% after 8 hours of frying—exceeding the 25% discard threshold between 6 and 8 hours of continuous heating for both brands tested. GNO-B exceeded the threshold at approximately 6 hours of continuous frying (TPC = 27.6%), while GNO-A exceeded it at approximately 6.5 hours (TPC = 25.4% at 6 h). These findings are consistent with GNO's relatively high linoleic acid content (approximately 28%), which provides significantly more PUFA-vulnerable sites for thermal oxidation than the predominantly SFA-MUFA composition of PO (Shahidi & Zhong, 2010). The finding that GNO—one of the most widely used domestic frying oils in Rivers State, reaches its discard threshold within a single extended frying session is of immediate practical public health significance for Nigerian consumers.

4.2 Polymer Accumulation and Viscosity

Polymer content, representing high-molecular-weight oxidative polymerisation products that accumulate irreversibly during frying and constitute a health hazard through chronic dietary ingestion, showed a rank order of GNO > PO > PKO across all frying intervals (Table 2). GNO-B recorded the highest PC of 3.64% at 8 hours, approximately 2.3 times higher than the corresponding PKO-A value (1.32%). This differential polymer accumulation is mechanistically consistent with the greater PUFA content of GNO, which provides more bis-allylic hydrogen positions susceptible to radical abstraction and subsequent polymer-forming cross-linking reactions (Matthäus, 2010). The strong correlation between TPC and PC ($r = 0.968$, $p < 0.01$; Table 5) confirms that polymer formation is a consistent and major contributor to total polar compound accumulation across all oil types and frying durations.

Viscosity changes (Table 4) further corroborated the pattern of thermal deterioration. All oil types showed substantial viscosity increases following 8 hours of frying, with GNO exhibiting the greatest absolute and relative increases: GNO-B viscosity increased from 52.4 mPa·s (0 h) to 142.6 mPa·s (8 h), representing a 2.7-fold increase. PO-A showed a 2.1-fold viscosity increase (42.4 to 88.6 mPa·s), while PKO-A showed the smallest relative increase (1.9-fold: 38.6 to 74.2 mPa·s). The progressive viscosity increase during frying reflects the accumulation of high-molecular-weight polymer compounds and oxidative oligomers that increase the hydrodynamic volume of the oil phase, a well-documented indicator of advanced frying oil degradation (Dobarganes & Márquez-Ruiz, 2003). Increased oil viscosity also has practical implications for food quality: more viscous frying oils are absorbed in greater quantities by fried food products, increasing the consumer's dietary exposure to thermal degradation products.

4.3 Secondary Oxidative Quality Parameters

The TOTOX values (Table 3) provided a composite measure of primary and secondary oxidative deterioration consistent with the TPC findings. GNO-B recorded the highest TOTOX value at 8 h (70.28), more than double the corresponding PKO-A value (38.42). All brands showed TOTOX values far exceeding the CODEX Alimentarius recommended threshold of ≤10 for refined vegetable oils after 2 hours of frying, consistent with results reported by Choe and Min (2007) for refined oils under similar thermal stress conditions. The specific extinction coefficients K_{270} and K_{232} (Table 4), which reflect the concentrations of conjugated diene and triene hydroperoxides and secondary carbonyl oxidation products respectively, showed the greatest increases in GNO brands, with K_{270} reaching 3.02 (GNO-B at 8 h) compared to 1.62 (PKO-A at 8 h), values considerably above the EU standard of $K_{270} \leq 3.5$ for extra virgin olive oil (applied here as a reference threshold for general edible oil quality).

4.4 Implications for Consumer Practice and Regulation

The finding that refined GNO exceeds the TPC discard threshold within a single extended frying session (approximately 6 hours at 180°C) has direct and urgent relevance for commercial frying operations in Rivers State, where continuous or near-continuous oil usage in suya stands, fast food outlets, and street food vending is commonplace. A typical commercial frying operation in Port Harcourt may operate an oil batch for 8–12 hours per day for multiple consecutive days without oil replacement, resulting in TPC values far exceeding 25% and substantial polymer accumulation. Consumer exposure to these degradation products, through both oral ingestion of fried food and possible inhalation of frying vapours, is a chronic dietary risk that is currently unregulated in the Nigerian food safety framework.

The superior thermal stability of refined PO (TPC not exceeding 25% after 8 hours at 180°C) positions it as the most appropriate choice for high-temperature, extended-duration frying applications among the three oil types tested. These findings are consistent with the practical wisdom embedded in traditional Nigerian cooking, which has historically favoured palm oil for high-temperature applications, and provide quantitative scientific substantiation for this preference. Regulatory authorities including SON and NAFDAC should consider adopting TPC-based regulatory thresholds for frying oils in commercial food service settings in Nigeria, aligned with the European standard of 25% TPC as the mandatory discard threshold.

5. Conclusion

This study provides the first brand-specific, comparative thermal oxidative stability assessment of refined palm oil, palm kernel oil, and groundnut oil brands marketed in Port Harcourt, Rivers State, Nigeria, under standardized empirical deep-frying conditions at 180°C. Total polar compound (TPC) accumulation demonstrated that refined PO brands exhibited the greatest thermal stability (TPC: 22.4–24.6% at 8 h), remaining below the 25% discard threshold throughout 8 hours of continuous frying. Refined PKO brands showed intermediate stability (TPC: 18.8–21.4% at 8 h) with the highest FFA accumulation due to hydrolytic susceptibility of medium-chain fatty acids. Refined GNO brands demonstrated the poorest thermal stability, exceeding the 25% TPC discard threshold between 6 and 8 hours of continuous frying, and recording the highest polymer content (3.64%) and viscosity increase (2.7-fold) at 8 h. All quality parameters showed strong mutual correlations ($r > 0.76$, $p < 0.01$), confirming the validity of TPC as a composite quality indicator. The adoption of a TPC-based 25% discard threshold as a legally enforceable frying oil quality standard in Nigeria is strongly recommended, together with consumer education on appropriate oil selection and replacement practices for high-temperature frying applications.

6. Recommendations

1. NAFDAC and SON should urgently develop and gazette a legally enforceable regulatory standard for frying oil quality in commercial food service operations in Nigeria, adopting TPC ≤ 25% as the mandatory discard threshold, consistent with EU, German, Belgian, and Codex Alimentarius frameworks.
2. Commercial food service operators (restaurants, fast food outlets, street food vendors) in Rivers State should be educated on TPC-based oil quality monitoring, with accessible field test kits (e.g., TESTO 270 frying oil tester or equivalent) mandated for frying operations exceeding four hours of continuous use.
3. Given the demonstrated superior thermal stability of refined palm oil relative to groundnut oil,

consumer guidance from the Rivers State Ministry of Health and NAFDAC should recommend refined palm oil as the preferred oil for high-temperature, extended-duration deep-frying applications in both domestic and commercial settings.

4. Refined GNO, given its superior nutritional fatty acid profile (high MUFA) but inferior thermal stability, should be recommended for low-temperature cooking applications (sautéing, salad dressing, stir-frying at ≤160°C) rather than deep-frying, to maximise its nutritional benefits while minimising thermal degradation product generation.
5. Future research should extend this comparative stability analysis to include refined soybean and sunflower oils, and should characterise the specific aldehyde and carbonyl compound profiles generated during frying of each oil type using GC-MS to enable a more complete health risk assessment of thermally degraded oil consumption by Rivers State consumers.

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