


## Quality Changes in Fresh and Recycled Frying Oil in Nigeria

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### HIGHLIGHTS:

- Prolonged reuse of frying oil by street vendors in Morogbo, Lagos State, Nigeria resulted in significant deterioration of oil quality.
- High levels of Polycyclic Aromatic Hydrocarbons (PAHs) and acrylamide were detected in all oil samples.
- Vendors routinely reused and recycled frying oil without proper regulation or awareness of the associated toxicological risks.

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### Abbreviations

FFA=Free Fatty Acid  
HPLC=High Performance Liquid  
Chromatography  
KOH=Potassium Hydroxide  
PAHs=Polycyclic Aromatic  
Hydrocarbons  
ppb=parts per billion  
PV=Peroxide Value

### ABSTRACT

**Background:** Fried food business is common among street vendors in Nigeria, many of whom reuse frying oils repeatedly due to economic constraints and limited regulatory oversight. Repeated use of frying oil results in physical and chemical degradation, which introduces toxic compounds into the food. This work aimed to determine the physicochemical changes occurring in vegetable oils used by roadside food vendors in Morogbo, a rural area of Lagos state, Nigeria.

**Methods:** The safety and quality of these oils were assessed by analyzing samples collected from three street vendors on the first and fifth days of the week. Physical and chemical parameters- color intensity, viscosity, refractive index, acid value, Free Fatty Acid (FFA) content, iodine value, and peroxide value (PV)- were measured. Additionally, acrylamide and polycyclic aromatic hydrocarbons (PAHs) concentrations were quantified using High Performance Liquid Chromatography (HPLC). Fresh oils from the vendors served as controls. Results were expressed as the mean  $\pm$  Standard Error of Mean (SEM) and analyzed using one-way analysis of variance (ANOVA) followed by Tukey's Honestly Significant Difference (HSD) post-hoc test. Values of  $p < 0.05$  were considered statistically significant. Statistical analyses were performed using GraphPad Prism version 10.4.1

**Results:** There was significant difference ( $p < 0.05$ ) in the refractive index, viscosity, Peroxide Value (PV), and Free Fatty Acid (FFA) content between the control and the recycled oil. However, there was no significant difference in iodine value and color intensity between the fresh and recycled oil. All the oil samples, including the control, had high acrylamide while the recycled oil had elevated concentrations of some Polycyclic Aromatic Hydrocarbons (PAHs) like benzo[a]pyrene.

**Conclusion:** This study highlights the significant deterioration in the safety and quality of frying oils used by street vendors in the Morogbo rural area of Lagos State.

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## Introduction

Frying is a popular cooking method used both domestically and industrially to enhance texture, flavor, and appearance of foods (Rani *et al.*, 2023). Fried foods are popular and widely consumed all over the world due to their crispness, crunchiness, flavor, taste, and color (Rani *et al.*, 2023). During deep fat frying at temperatures between 170 °C – 200 °C, steam formed from moisture in the food and oxygen induces hydrolysis of triacylglycerols to produce di- and monoacylglycerols, glycerol, and Free Fatty Acids (FFA), while the present oxygen results in the thermal oxidation of oil (Oke *et al.*, 2018). Deep fat frying generates volatile compounds that contribute to the flavor of fried foods as well as decomposition products such as nonvolatile polar compounds, dimers, and polymers (Oke *et al.*, 2018). These non-volatile compounds accumulate in the oil and get absorbed into fried foods as the oil is repeatedly used (Nayak *et al.*, 2016) resulting in rancid taste and accumulation of toxic oxidation products (Bekdeşer *et al.*, 2024) which eventually ends up in our body system.

During frying, physicochemical reactions such as starch gelatinization, protein denaturing, and browning through Maillard reactions occur. The Maillard reactions responsible for the browning result in the formation of acrylamide, a carcinogenic and neurotoxic substance that poses a potential health risk when consumed in significant amounts (Rani *et al.*, 2023). Additionally, these reactions produce toxic substances such as Polycyclic Aromatic Hydrocarbons (PAHs), trans fatty acids, heterocyclic amines (Xin *et al.*, 2022). Thermal oxidation of oil further produces free radicals, peroxides, and other substances, thus decreasing oil quality (Liu *et al.*, 2019). Therefore, monitoring oil quality and the concentration of decomposition products is essential for the safety and quality of fried foods. Several analytical indices like color, odor, Peroxide Value (PV), acid value, FFA, iodine value, and pH value are used to determine the quality of oil (Bekdeşer *et al.*, 2024).

The type of fried food significantly influences oil degradation (Adu *et al.*, 2019), and practices for oil reuse vary among food vendors. For instance, in a survey conducted in Malawi on oil used for preparing potato chips, most vendors (59.4%) reported discarding the oil after 1 day of use, whereas 12.5% discarded the oil after three days and only 3.1% after four days (Phiri, Mumba and Mangwera, 2006). A survey on the repetitive use of oil in Ilishan-Remo Nigeria revealed that degraded oil is constantly mixed with fresh oil while frying (Ngozi *et al.*, 2019). In Japan, restaurant frying oils are typically used for approximately 3 h per day at 180 °C and are discarded after 9 days, corresponding to a total frying time of about 27 h (Wai, 2007).

Frying foods is a lucrative business among low-income earners especially in rural areas. The practice is widespread among street vendors in Nigeria, who rely on frying to prepare popular and affordable foods and snacks such as yam fries, plantain chips, akara (bean cakes), and puff-puff (fried dough) (Adu *et al.*, 2019). However, due to the high cost of vegetable oil, it is common for vendors to use unbranded vegetable oils and reuse frying oil repeatedly, often continuing until the color visibly changes (Adelagun *et al.*, 2023; Adu *et al.*, 2019; Fekadu, Abera and Weldemichael, 2024; Oladunjoye and Aluko, 2024). This repeated use of oil can lead to its degradation, resulting in the accumulation of non-volatile polar compounds, free radicals, and other toxic oxidation products (Liu *et al.*, 2019; Xin *et al.*, 2022). These substances not only compromise the taste and safety of the fried food but also pose potential health risks to consumers (Adelagun *et al.*, 2023). The lack of awareness and enforcement of food safety regulations in rural areas exacerbates the problem, making it critical to assess the quality of oils used in such settings (Adelagun *et al.*, 2023). Therefore, the aim of this study was to analyze the physicochemical properties and biochemical products formed in vegetable oil used in frying foods by road-side food vendors in a rural area, Morogbo, in Lagos State.

## Materials and methods

### *Collection of oil samples and experimental design*

Oil samples were obtained from three street vendors in Morogbo, Lagos State, Nigeria using amber glass bottles. Sampling was conducted twice a week (Monday and Friday) from three different roadside food outlets in Morogbo. During the second round of sampling, oil was collected only if the vendor continued using the same type. Approximately 200 ml of hot oil was drawn directly from the fryer, passed through a filter paper with the aid of an aspirator to remove food residues and stored in a bottle flushed with nitrogen gas prior to sealing to limit oxidative changes. The samples were labeled and stored at –20 °C until analyzed. All physical and chemical assessments were conducted in duplicate. A structured researcher-developed questionnaire adapted from Yilmaz and Aydeniz, (2011), was used to obtain information on frying practices, oil handling, fryer cleaning, and food types prepared by street vendors.

### *Determination of physicochemical properties*

PV, iodine value, acid value, and FFA content of the oil samples were determined according to the American Oil Chemists' Society ([AOCS], 1998) method.

### Determination of color

Oil color was measured using a Lovibond tintometer (Model F, England). Oil samples were melted and filtered using a filter paper. The filtered oil was transferred into a clean glass cell, which was then placed in the tintometer. The yellow and red slides were matched with the color shade of the oil in a tintometer. To minimize errors, a composite color factor was used, calculated as the yellow (Y) units plus 5 or 10 times the total red units, following the standard method (I.S.I., 1984).

### Determination of viscosity

The viscosity of the oil was measured using a Lamy Viscometer RM100 (Lamy, France). A 25 ml oil sample was placed in the Tube's outer cylinder, and the bob was inserted (tube radius: 16.25 mm; bob radius: 15.5 mm; bob length: 54 mm). Measurements were conducted in mode MS 19 with a measurement time of 60 s. A circulatory water bath maintained temperatures of 26, 30, 38, 40, 50, 70, and 90 °C. Torque values were recorded across shear rates ranging from 64.5 to 4835 s<sup>-1</sup>. Each sample was measured in triplicate, with each replicate run twice: first increasing and then decreasing the shear rate. The mean torque value at each shear rate was recorded (Diamante and Lan, 2014).

### Determination of refractive index

The refractive index of the oil samples was measured using an Abbe 60 Refractometer (Bellingham + Stanley, UK). A drop of oil was placed on the open prism and the cover was secured by tightening the screws. Water was circulated through the instrument and allowed to equilibrate for several minutes to ensure that the sample and instrument reached the same temperature. Between readings, the prism was cleaned with a cotton pad moistened with ethyl alcohol and allowed to dry. The lighting and instrument settings were adjusted to obtain optimal readings. The refractometer temperature was carefully maintained within ±0.1 °C in a water bath. When temperature correction was necessary, the refractive index was calculated using the following formula: (Bureau of Indian Standards, 2005; Nova analytics, 2008).

$$R = R^1 + K^1(T^1 - T)$$

Where R = Reading of the refractometer reduced to the specified temperature T °C

R<sup>1</sup> = Reading at T<sup>1</sup> °C

K = constant 0.000365 for fats and 0.000385

T<sup>1</sup> = temperature at which the reading R<sup>1</sup> is taken

T = specified temperature (generally 40 °C)

### Acrylamide analysis by High Performance Liquid Chromatography (HPLC)

One g of oil was poured in a 50 ml centrifuge tube, spiked with 1000 µl of 20 ng/ml internal standard and 1000

ng/ml spiking solution, then shaken vigorously for 1 min. Five ml of n-hexane was then added, and shaken for another minute. This was followed by the addition of 9 ml of water and 10 ml of acetonitrile, accompanied by vigorous vortexing for 1 min. A Bond QuEChERS salt packet was added for acrylamide extraction, and the mixture was shaken for another minute, followed by centrifuging for 5 min at 4000 rpm, and the upper hexane layer discarded (Kostopolou *et al.*, 2007).

### Dispersive SPE cleanup

A 6 ml aliquot of the acetonitrile layer was applied to a Bond ElutQuEChERS dispersive SPE 15 ml tube and centrifuged for 5 min at 4000 rpm. The supernatant was transferred into an autosampler vial for analysis by HPLC-DAD (Agilent Technologies, USA) (Pule and Torto, 2009).

### Chromatographic analysis

This was done on an Agilent ZORBAX HILIC Plus column (4.6mm x 50mm x 3.5µm, p/n 959943-901) using isocratic elution with 3% 5 mm acetic acid and 97% acetonitrile as the mobile phase. The column temperature was 30 °C and the flow rate was 0.2ml/min.

### PAHs analysis by HPLC

The method employed utilized an internal standard approach with Benzo(b)Chrysene at a concentration of 250 parts per billion (ppb) serving as the internal standard. This procedure was adapted from ISO 15753: 2006 and further refined. The technique involved gradual enrichment of PAHs in the oil phase, followed by a two-step solid-phase extraction cleanup to isolate the PAHs. A total of 15 PAHs were analyzed.

### Liquid-liquid extraction

A 2.5 g sample was spiked with 100 µl of internal standard, Benzo(b)Chrysene, at a concentration of 250 ppb. Extraction of PAHs was done using 10 ml of a 60/40 acetonitrile/acetone mixture by vortexing and ultrasonication. The mixture was centrifuged and the supernatant collected into a 100 ml conical flask. The procedure was repeated twice, and the extracts concentrated at 35 °C using a rotary evaporator.

### Clean up

The oil residue was extracted with 21 ml of a 60:40 (v/v) acetonitrile/acetone solution in a centrifuge tube. The mixture was vortexed and centrifuged, after which the supernatant was carefully decanted. The supernatant was poured onto a C18 solid-phase extraction cartridge that had been preconditioned sequentially with 24 ml each of methanol and acetonitrile. The extraction procedure was carried out twice to ensure optimal recovery. The PAH was

then eluted with 5 ml of 60:40 acetone/acetonitrile, and the eluate was collected in a 50 ml conical flask and concentrated at 35 °C using a rotary evaporator. The concentrate was then dissolved in 1 ml of hexane and applied to a Florisil bonded-phase cartridge. The conical flask was rinsed with 1 ml of 25:75 dichloromethane/hexane three times and each rinse was transferred onto the cartridge. The eluate was collected in a 50 ml conical flask, concentrated at 35 °C using a rotary evaporator and brought to dryness under a nitrogen stream. The residue was reconstituted in 1 ml of acetonitrile, followed by agitation, filtration and then prepared for HPLC injection.

#### Statistical analysis

The results were expressed as the means  $\pm$  Standard Error of Mean (SEM). The data were analyzed using one-way analysis of variance (ANOVA) followed by Tukey's Honestly Significant Difference (HSD) post-hoc test. Values of  $p < 0.05$  were considered statistically significant. All statistical analyses were performed using Graph Pad Prism version 10.4.1

## Results and discussion

Deep frying is one of the oldest and frequently used methods of food preparation globally (Nayak et al., 2016). In Nigeria, deep frying is common among street vendors. To reduce expenses, the oil is recycled and topped off repeatedly as confirmed by the interview of the rural vendors in Morogbo area of Lagos State (Table 1). This practice is common due to the low level of awareness among the public about its possible adverse effects. In a study on the perception of food vendors in Lagos Nigeria, 99% repeatedly used the same frying oil for cooking till depletion (Oladunjoye and Aluko, 2024). Repeated use of oil degrades oil and releases toxic compounds that can be transferred into food (Adelagun et al., 2023). Therefore, we analyzed the quality of oil used by street vendors in Morogbo area of Lagos by investigating the physicochemical parameters, acrylamide, and PAH concentration in the frying oil.

From the questionnaires administered to the food vendors all respondents used Kings Oil as their preferred brand due to its perceived quality. The first vendor, Morogbo 1, engaged in frying for the longest duration, operating for 9 h per day. This vendor frequently topped up the oil, never changed oil and fried a variety of foods like akara, chicken, potato, and yam. The second respondent, Morogbo 2, had the shortest frying duration, operating for 3 h per day. This vendor regularly topped up and filtered the oil but never replaced it. All products, primarily pastries, were fried in the same oil. The third vendor, Morogbo 3, performed frying for 6 h per day, topped up oil and never changed oil. The vendor fried a variety of foods

like akara, fish, potato, yam, and plantain. The vendor did not use the same oil for frying all the products.

#### Physicochemical properties

The physicochemical properties of the frying oil samples collected from street vendors in Morogbo, a rural area in Lagos, Nigeria were analyzed to assess oil quality. Parameters analyzed include PV, iodine value, acid value, FFA content, color intensity (red and yellow), viscosity, and refractive index.

The PV is an indicator of the peroxides or hydroperoxides formed during primary oxidation of hydroxyl groups of unsaturated oils (Al-Khusaibi and Rahman, 2021; Gilbraith et al., 2021; Zhang et al., 2012). The PV quantifies the amount of chemically bound oxygen in the oil (Al-Khusaibi and Rahman, 2021). The PV of the oil samples ranged from 5 meq/kg to 18 meq/kg (Figure 1a). The PV was lowest in oil samples from Morogbo 1 and highest in samples from Morogbo 2. Notably, the PV of oil samples from Morogbo 2 was significantly higher ( $p < 0.05$ ) than the fresh oil samples. Auto oxidation of oils transforms peroxides or hydroperoxides into alcohols, ketones, and aldehydes, which impart rancid flavors and odors in oils. (Gilbraith et al., 2021). A high PV in freshly processed oil indicates a shorter shelf life. The PV analysis showed that the fresh oil and samples from Morogbo 1 had a PV lower than the Codex standards for refined oils (10 mEq/kg), while the samples from Morogbo 2 and 3 had a PV higher than the Codex standard (Codex Alimentarius Commission, 1999). This indicates a faster primary oxidation due to prolonged frying practices and oil reuse by the food vendors. These vendors typically top off the oil during continuous frying sessions lasting between 3 to 6 h per day but do not change the oil.

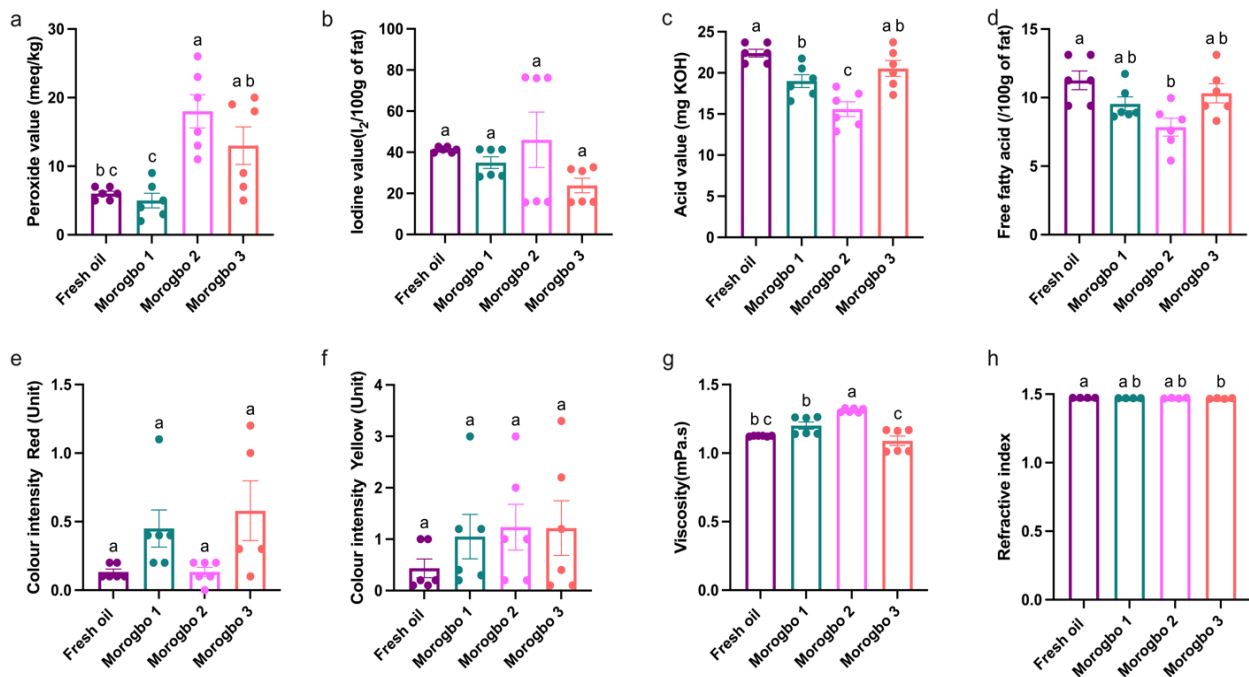
The PV for the Morogbo 2 samples was significantly higher ( $p < 0.05$ ) than the fresh oil but this was not the case for Morogbo 1 and 3. This variation could be an indication of differences in oil handling and storage practices among the vendors. Continuous exposure of oil to factors such as temperature, light, and storage time can negatively affect PV and oil quality (Idun-Acquah, Obeng and Mensah, 2016; Kaleem, Aziz and Iqtedar, 2015). It is worthy of note that although the Morogbo 1 and 3 samples were used to fry fish and chicken, which are foods typically associated with faster oil oxidation, while Morogbo 2 was used primarily for pastries, the Morogbo 2 samples still exhibited a higher PV. This indicates that factors other than the type of fried food contributed to the elevated PV observed in Morogbo 2.

The Iodine value is a measure of the degree of unsaturation in oils with higher values indicating a higher number of double bonds in the fatty acids. Prolonged heating during frying can promote oxidation and

polymerization, which can break double bonds and subsequently reduce the iodine value (Al-Khusaibi and Rahman, 2021). The iodine value of the oil samples ranged from 23.84 I<sub>2</sub>/100 g of fat for the Morogbo 3 samples to 46.04 I<sub>2</sub>/100 g of fat for the Morogbo 2 samples (Figure 1b). The iodine value of oils from Morogbo 1 and Morogbo 3 were statistically significant from the fresh oil. The oil used by the vendors is produced from refined palm olein. All the samples, including the fresh sample, had an iodine value less than the Codex standard of 56 or greater (Codex Alimentarius Commission, 1999). The observed iodine value suggests that the oil used may have been adulterated with high saturated fat (Kalia and Mishra, 2019). The observed reduction in iodine value for Morogbo 1 and 3 samples indicates a deterioration of the frying oil. In the study by Chebet, Kinyanjui and Cheplogoi (2016), the highest decrease in iodine value of vegetable oil was observed after a 5-day storage at room temperature compared to those stored at 4 °C.

The acid value measures the amount of FFA in the oil, serving as an indicator of hydrolysis caused by oxidation

and lipolytic enzymes. A lower acid value indicates a higher oil stability over a long period (Ekpe *et al.*, 2018). Acid value (Figure 1c) of the oil samples ranged from 15.6 mg Potassium Hydroxide (KOH) in Morogbo 2 samples to 22.40 mg in fresh oil. Acid value was lower in all the recycled oil samples compared to the control. However, only the samples from Morogbo 1 and Morogbo 2 were significantly lower ( $p < 0.05$ ) than the fresh control. The acid value of both fresh and frying oils were extremely higher (15.6-22.4 mg KOH) than the Codex standard of 0.6 mg KOH/g oil, indicating the poor stability of the frying oil (Codex Alimentarius Commission, 1999). The acid value of the fresh vegetable oil was significantly higher than those of the Morogbo 1 and Morogbo 2 samples. This indicates that, contrary to the expected increase during repeated use, the acid value was actually decreased in the recycled oils compared to the fresh sample. This unexpected pattern may be attributed either to poor storage conditions of the fresh oil, which could have promoted hydrolysis, or to the periodic replenishing and topping-up of oil during frying, which can dilute accumulated FFA.



**Figure 1:** Physicochemical properties of oils sampled

Bars represent mean values  $\pm$  Standard Error of Mean (SEM). Bars with different letters (a, b, c) indicate significant difference.

a=Peroxide value; b=Iodine value; c=Acid value; d=Free fatty acid content, e=Color intensity (red); f=Color intensity (yellow); g=Viscosity, h=refractive index

FFAs, which result from oil hydrolysis, increased with repeated frying cycles. FFAs are commonly used for monitoring oil quality as their accumulation along with their oxidized compounds can create off flavors in frying oil (Karimi, Wawire and Mathooko., 2017). The recommended Codex FFA value should not exceed 0.3%.

The FFA value (Figure 1d) ranged from 7.840 /100 g of fat in Morogbo 2 samples to 11.26/100 g of fat in the fresh oil samples. The FFA values of the recycled oil were lower than the fresh oil; however, only the Morogbo 2 samples were significantly lower ( $p < 0.05$ ). All the oil samples had higher FFA content than the recommended value (Codex

Alimentarius Commission, 1999). The FFA content also followed similar trend as the acid value. In the study by Emelike, Ujong and Achinewu (2020), on oils used by local food vendors in Port Harcourt, Nigeria, the frying oils, except for the branded oils, had FFA contents higher than the reference. Notably, the lowest FFA values were observed in oil samples used for 3 h per day, indicating that both frying time and cycles play a role in the accumulation of FFA.

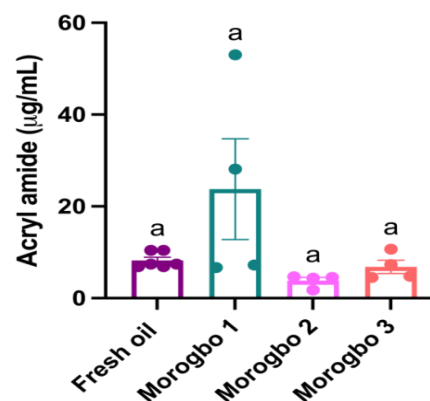
The change and deepening in the color intensity of frying oil is a reflection of oil deterioration and accumulation of degradation products (Manzoor *et al.*, 2022; Zhang *et al.*, 2012). The color intensity (red) ranged from 0.13 lovibond unit in both fresh oil and Morogbo 2 samples to 0.58 lovibond unit in Morogbo 3 samples (Figure 1e). The color intensity (red) was higher in Morogbo 1 and Morogbo 3 compared to the fresh oil, though not significantly. Fresh oil showed the lowest colour intensity (red) but did not differ significantly from any other sample. The sample from Morogbo 2 matched the fresh oil in colour intensity, likely due to its shorter frying time (3 h/day) compared to Morogbo 3 (6 h/day) and Morogbo 1 (9 h/day), which exhibited higher color intensities.

The color intensity (yellow) ranged from 0.43 lovibond unit in fresh oil to 1.23 lovibond unit for Morogbo 2 (Figure 1f). The color intensity (yellow) was higher in all samples compared to fresh oil, but the difference was not statistically significant. This suggests an increase in color intensity (both yellow and red) due to the continuous heating of the oil. The increase in the color intensity of frying oil is similar to the study of Manzoor *et al.* (2022) where deep frying caused a pronounced change in color of oil. Most of the time, vendors repeatedly use the same frying oil and discard it when it smokes or becomes too dark (Fekadu *et al.*, 2024).

Viscosity is an indicator of oil degradation. Polymerization generates high-molecular-weight compounds that enhance oil resistance to flow (Pambou-Tobi *et al.*, 2010). An increase in viscosity indicates a decline in oil quality (Mariana *et al.*, 2020). Viscosities (Figure 7) of the oils ranged from 1.090 mPa.s in Morogbo 3 to 1.312 mPa.s in Morogbo 2. The viscosity of Morogbo 2 was significantly higher ( $p < 0.05$ ) than in the fresh oil. Similar finding was reported by Fekadu, Abera and Weldemichael (2024), where the viscosity of discarded oil was highest, followed by the used oil, compared to the fresh oil. The viscosity results in our study showed that there was deterioration in the quality of oil, which may be attributed to continuous heating and accumulation of the degradation products in oil (Fekadu

*et al.*, 2024).

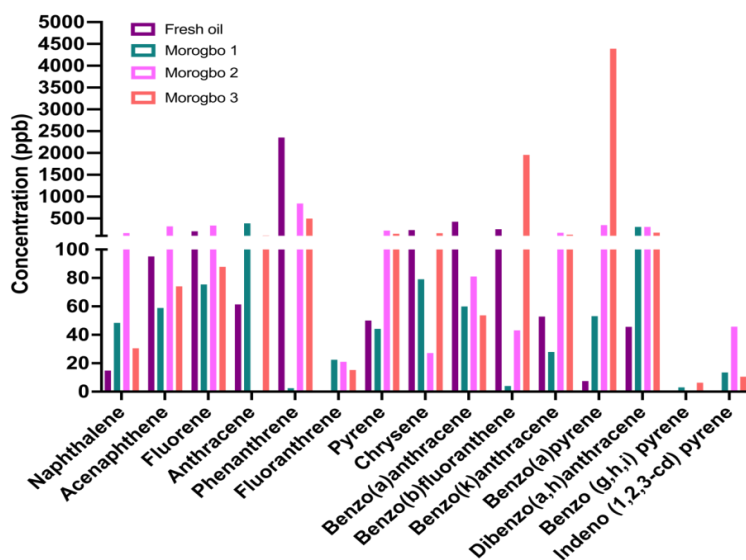
Refractive index is used to assess hydrogenation, isomerization, and purity of materials and it is influenced by factors like wavelength, degree of unsaturation, and the type of fatty acids. (Ichu and Nwakanma, 2019). According to the Codex standard, the recommended refractive index for palm olein ranges from 1.458–1.460 but all our samples had a refractive index above this range. Samples from Morogbo 3 had a significantly lower refractive index compared to the fresh oil, while samples from Morogbo 1 and 2 had similar refractive index compared to the fresh oil. In the study of Fekadu, Abera and Weldemichael (2024) the highest refractive index occurred in discarded oil, followed by used oil, relative to fresh oil. This is not the case in our study as the refractive index was similar in both the recycled and fresh oils with the exception of samples from Morogbo 3. The lack of difference between recycled and fresh oil may result from oil replenishment (“topping up”) and storage conditions.



**Figure 2:** Acrylamide concentration of fresh oil and recycled oil samples.

Bars represent mean values  $\pm$  Standard Error of Mean (SEM). Bars with different letters (a, b, c) indicate significant difference.

Acrylamide forms at high temperatures in foods, typically above 120 °C, due to Maillard reaction (Başaran and Turk, 2021). Exposure to acrylamide is associated with some cancer risk (Adani *et al.*, 2020; Başaran and Turk, 2021; Liu *et al.*, 2017). Acrylamide formation depends on factors such as oil, food type, pretreatment of food, frying temperature, and time (Başaran and Turk, 2021). The acrylamide concentration ranged from 3.83 in Morogbo 2 to 23.75 µg/ml in Morogbo 1 (Figure 2). The acrylamide was higher in oil samples from Morogbo 1 compared to all other oil samples but lower in Morogbo 2 and 3 compared to the control. However, these differences were not statistically significant.



**Figure 3:** The effect of continuous usage on various Polycyclic Aromatic Hydrocarbon (PAH) content in fresh oil and recycled oil samples from rural street vendors in Morogbo

PAHs have been shown to have carcinogenic and mutagenic properties (Li *et al.*, 2016). Humans are exposed to PAH from environmental contamination and food processing involving high temperatures such as frying, smoking, and grilling (Li *et al.*, 2016). The PAH content varied between the various oil samples (Figure 3). Phenanthrene was highest in fresh oil whereas benzo(b)fluoranthene and benzo(a)pyrene was highest in oil samples from Morogbo 3. Benzo(g,h,i)pyrene, indeno(1,2,3-cd)pyrene, and fluoranthrene were the lowest in the oil samples including the fresh control. The concentrations of most of the PAHs detected exceeded the standard safety limit of 10 ppb, raising concerns about potential health risks. According to the European Food Safety Authority (EFSA), in addition to benzo[a]pyrene the sum of 4 or 8 PAH serves as a more reliable indicator of the presence and associated toxicity of the genotoxic and carcinogenic PAHs. The PAH4 includes benzo[a]pyrene, chrysene, benz[a]anthracene and benzo[b]fluoranthene while the PAH8 includes benzo[a]pyrene, benz[a]anthracene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[ghi]perylene, chrysene, dibenz[a,h]anthracene and indeno[1,2,3-cd]pyrene (EFSA, 2008).

The European Union (EU) has set the maximum permissible level of PAH4 in palm oil at 10 µg/kg, equivalent to 10 ppb (Ingenbleek *et al.*, 2019). In this study, all the oil samples including the fresh oil had both PAH4 and PAH8 levels above the limit. Some of the PAHs, like Benzo (g,h,i) pyrene, Indeno (1,2,3-cd) pyrene, and Fluoranthrene, were not present in the fresh oil. Anthracene and Benzo (g,h,i) pyrene was also not detectable in Morogbo 2 samples. Oil samples from Morogbo 3 had the highest levels of benzo[a]pyrene

(4391.73 ppb), followed by Morogbo 2 (345.9) and Morogbo 1 (53.12) as compared to the fresh oil of (7.48). Overall, oil samples from Morogbo 3 had the highest PAH content. The frying time and the type of fried product may have played a role in the high PAH levels observed in Morogbo 3.

## Conclusion

The findings of this study highlight the significant deterioration in the quality of oil used by street vendors in the Morogbo, a rural community in Lagos State. The oil's physicochemical properties, including increased PVs, viscosity, and color intensity, indicate the harmful effects of repeated oil usage. The presence of high levels of PAH in frying oil is alarming as these compounds are well known for their carcinogenic and mutagenic potentials. This highlights the urgent need for the implementation of stronger regulations and enforcement measures to ensure that oils used in food preparation meet established safety standards. The current lack of awareness among food vendors about the potential risks of oil reuse and improper storage practices exacerbates the problem, as evidenced by the vendors' practices of continuously topping up and never changing the oil. There is also a need for adequate training and education of food vendors on hygienic practices, oil reusability, and storage.

## Author contributions

O.B.A., B.O.E., O.F., S.O and O.O. conceptualized the study; O.B.A. and B.O.E supervised the research. Q.M., A.Y., O.A and S.O.O. performed the experiments and collected data; S.O.O. and O.B.A. analyzed and interpreted

the data; O.B.A., O.O, O.F., Q.M., B.O.E., S.O., A.Y., O.A., and S.O.O wrote the manuscript. All authors reviewed the results and approved the final version of the manuscript.

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### Conflicts of interest

The authors declare that there is no conflict of interest.

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### Ethical consideration

Not applicable.

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