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Recycled cooking oils used for street foods in Kampala, Uganda: Quality and recycling frequency

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A B S T R A C T

Deep-fried foods are generally popular world over. To cut production costs, the oil used is often recycled. This is concerning because deep-frying is done aerobically at 160–190 °C leading to oil degradation and formation of hazardous compounds. This study evaluated the quality of cooking oil used to deep-fry potato chips (n = 35) and fish (n = 35) by street food-vendors in Kampala, Uganda. Additionally, a safe oil recycling frequency was determined by separately deep-frying several batches of fish and potato chips. After each frying cycle, the quality of oil was analyzed. Over 94 % of oils used to deep-fry chips and fish obtained from food vendors surpassed the recommended specification for peroxide value (10 mEq O_2/Kg). Their mean peroxide values were about four times higher than the recommendation. Moreover, none of these oils met the Thiobarbituric acid specification of <2 mg DA/Kg. Oil samples used by vendors to deep-fry fish (100 %) and chips (60 %) had acid values beyond the quality specification of 0.6 mg KOH/g. Their moisture contents and oil densities were almost twice the recommendations. In contrast, their iodine value and color intensities were below the quality specifications. The recycling experiments showed that peroxide values remained consistent while other parameters exceeded quality specifications after the second deep-frying cycle. Therefore, recycled oils used by street-food vendors in Kampala are unsuitable for human consumption. The practice of cooking oil recycling should be discouraged, though it has financial implications especially for commercial food establishments.

1. Introduction

Deep-frying involves immersing food in oil at 160–190 °C in the presence of air and moisture (Kamisah et al., 2012). This cooking method is rapid and makes foods highly palatable because of the appealing sensory properties (Multari et al., 2019). Street foods, known for their convenience and easy accessibility, often rely on deep-frying to impart their distinctive desirable flavors and textures. In an effort to cut costs, it is common practice for street-food vendors to overly re-use their cooking oil (Debnath et al., 2012). Cooking oil recycling should at least involve filtration/ decantation and although this does not make the oil completely safe, it somewhat may make it suitable for reuse in various culinary applications. It also mitigates waste and minimizes the environmental footprint associated with used oils. However, some street-food vendors in cities like Kampala, Uganda's capital ignore this and instead continue to deep-fry several batches of food without basic oil refinement practices (Okalany et al., 2023).

Despite the environmental and economic benefits of recycling cooking oil, a scientific examination reveals potential health risks associated with the consumption of foods prepared using overly recycled oils. The deep-frying process induces oil degradation through oxidation, hydrolysis, polymerization and Maillard reactions (Jurid et al., 2020; Negash et al., 2019). This increases oil viscosity, darkens its color, increases foaming and lowers its smoke point (Mekawi et al., 2019). Over time, these changes negatively affect the organoleptic, nutritional and chemical qualities of the fried foods (Yu et al., 2020). Exposure of the oil to frying temperatures also alters the chemical structure of triacylglycerols resulting in undesirable products such as trans fatty acids, free radicals and other toxins (Chaula et al., 2019; Ganesan et al., 2019). These get absorbed by the food and are associated with cardiovascular diseases, cancers, obesity, diarrhea, type 2 diabetes and gastrointestinal discomfort in humans (Hamsi et al., 2015; Karaman et al., 2014; Ma et al., 2021; Wu et al., 2019). Additionally, the volatile compounds such as polycyclic aromatic hydrocarbons and heterocyclic amines generated during frying, when inhaled over time expose food processors to respiratory tract cancer (Zhang et al., 2018). Overly recycled cooking oils are

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less nutritious to consumers since essential nutrients such as vitamin A and E are degraded over time. Short-term deep-frying, as practiced in households, is no exception to the detrimental changes cooking oil undergoes when exposed to high temperatures (Multari et al., 2019).

Various quality parameters, such as free fatty acid, peroxide, thiobarbituric acid, and iodine values, can be used to determine the extent of oil degradation (Oke et al., 2018). Unfortunately, in Uganda, regulatory agencies mainly focus on monitoring the quality of cooking oils produced by refining companies before their dispatch to the market. Beyond that, they do not follow up on the oil quality and handling practices of the oil users in the different commercial food establishments, particularly the street-food vendors.

Prior to this study, there was no documentation of the quality of recycled oil used to deep-fry street-vended-foods, which are now common in urban areas like Kampala. Additionally, the safe recycling frequency for oil used in deep-frying these foods was unknown. Consequently, this study aimed to fill this crucial knowledge gap by evaluating the quality of recycled oil used by street vendors for starchy foods (potato chips) and protein-rich foods (fish) in Kampala. It also determined the safe recycling frequency for oil used to deep-fry these popular street foods. This study highlights the need for protecting consumer health by regulating the quality of oil used for frying street vended foods.

2. Materials and methods

2.1. Recycled cooking oil

Recycled cooking oil samples used to separately deep-fry potato chips ($n = 35$) and fish ($n = 35$) were collected from street food-vendors in Kampala. About 100 ml of each oil sample were collected in dark-colored glass bottles kept on ice. The oil samples were held for 12 h overnight at −20 °C before analysis.

2.2. Refined cooking oil, fish and potatoes chips

Refined palm oil was purchased from a local shop within Kampala. Fresh potatoes (*Solanum tuberosum*) and fresh Nile perch (*Lates niloticus*) were purchased from a local market in Kampala.

2.3. Analyses

2.3.1. Color intensity

Color intensity was determined according toAOCS (2017). Briefly, 1 ml of oil was diluted to 25 mL using absolute methanol followed by stirring for 30 min using a magnetic stirrer to enable proper color extraction. The mixture was left to stand for 10 min then centrifuged at 4500 rpm for 5 min. The optical density of the supernatant was measured at 420 and 520 nm. Color intensity was calculated using Eq. (1).

$$\mathrm{Absorbance}_{420\ \mathrm{nm}} + \mathrm{Absorbance}_{\ 520\ \mathrm{nm}} \tag{1}$$

2.3.2. Density

The density of the cooking oil was measured by gravimetric analysis (Analytical scale: 9T202, Adam, Germany). In brief, 10 mL of oil were pippeted into a pre-weighed falcon tube. The weight of oil was calculated by subtracting the weight of the empty tube from the weight of the tube containing the oil. The density $_{(\mathrm{Kg/m3})}$ of the oil was then calculated using Eq. (2).

$$[\mathrm{Weightofcontainerwithoil} - - \mathrm{weightofemptycontainer}]/\mathrm{mLofoilused} \tag{2}$$

2.3.3. Moisture content

This was determined according to theISO, 662:1998 method. In summary, 2 g of the oil were added to a pre-conditioned weighed aluminum dish. The dish was oven-dried at 105 °C for 16 h. The % moisture content was computed using Eq. (3).

$$[\mathrm{Weightofwaterlost} \,/\, \mathrm{weightofoilused}] \times 100 \tag{3}$$

2.3.4. Peroxide value

Peroxide value was determined according toAOCS (2003). In brief, 1 g of oil was placed in an iodine flask and 50 mL of 3 parts acetic acid: 2 parts chloroform mixture added. The flask was swirled for 1 min to dissolve the oil. To this mixture, 1 mL of a saturated solution of potassium iodide was added. The solution was swirled and kept in the dark for 1 min. The liberated iodine was titrated to pale yellow followed by the addition of 1 mL of 1 % starch solution. This was further titrated to a colorimetric endpoint using 0.01 N sodium thiosulphate. Peroxide value ($\mathrm{mEqO_2/Kg}$) was computed using Eq. (4).

$$[(\mathrm{SampletitrationmL} - - \mathrm{blanktitrationmL}) \times 100 \times \mathrm{normalityofthiosulphate}]/\mathrm{sampleused(g)} \tag{4}$$

2.3.5. Acid value

Acid value was analyzed as described by AOAC (2003). Briefly, 1 g of the oil was dissolved in 50 mL of a neutral 1 part diethyl ether: 1 part ethanol mixture. Using phenolphthalein indicator, the mixture was titrated against a standardized solution of 0.1 N KOH until the first rose pink color appeared and persisted for at least 1 min. Acid value was calculated using Eq. (5).

$$\mathrm{Nettitre} \times 56.11 \times \mathrm{normalityofhydroxide}]/\mathrm{sampleused(g)} \tag{5}$$

2.3.6. Iodine value

This was determined according to the ISO (2009) iodometric method. Oil (0.2 g) was weighed into a 500 mL iodine flask. Thereafter, 15 mL of chloroform were added and the flask swirled to dissolve the oil. Then, 25 mL of Wijs' solution were added and the mixture shaken vigorously. The conical flask was kept in the dark for 1 h with shaking at 10 min intervals. This was followed by addition of 20 mL of 15 % potassium iodide and 100 mL of distilled water. The mixture was shaken vigorously and titrated against 0.1 N sodium thiosulphate until the pale-yellow just appeared. Thereafter, 1 mL of 1 % starch solution was added and titration continued again until the blue color of the starch indicator disappeared. Iodine value (g of I_2/ g of oil) was calculated using Eq. (6).

$$[(\mathrm{BlanktitrationmL} - - \mathrm{sampletitrationmL}) \times 12.69 \times \mathrm{normalityofthiosulphate}]/\mathrm{sample(g)} \tag{6}$$

2.3.7. Thiobarbituric acid value

The thiobarbituric acid value was determined as described by the AOCS (2009). In summary, 0.2 g of oil was weighed into a 50 mL volumetric flask and extracted using 1-butanol. Five milliliters of the mixture were pipetted into a stoppered test tube and mixed with 5 mL of Thiobarbituric acid reagent (0.2 g Thiobarbituric acid in 100 mL 1-butanol). The flask was incubated at 95 °C for 120 min, cooled to 25 °C and absorbance measured at 530 nm. Thiobarbituric acid (mg MDA/Kg) value was calculates using Eq. (7).

$$50 \times \mathrm{absorbance of sample} \, / \, \mathrm{weight of sample used} \tag{7}$$

2.4. Cooking oil recycling

To make the chips, the potatoes were first washed in potable water, peeled and sliced into rectangular pieces (approx. 1 cm × 1 cm × 3 cm). The fish was also washed in potable water and chopped into cubes (approx. 3 cm × 4 cm × 1.5 cm). One liter of new refined palm oil was placed in a steel pan and heated on a charcoal stove to between 160 and 190 °C. Thereafter, 600 g of potato slices was added. These were deep-fried for approximately 10 min and placed on a metallic sieve to drain the oil. Thereafter, 50 mL of the used hot oil was collected in a colored glass bottle, cooled to room temperature (24 °C) and frozen at −18 °C before analysis. The remaining oil in the pan was re-used to deep-fry more chips as previously described up to the seventh cycle. After each cycle, an oil sample was drawn for analysis. The oil in the pan was exposed to air overnight and a sample analyzed. This was to mimic storage practices of the street-food vendors (Okalany et al., 2023). The same procedure was followed using a separate pan and fresh oil for the fish. About 300 g of fish were deep-fried in 1 L of fresh oil. There was no topping up of oil after each frying cycle. The recycling experiments were carried out in triplicates. Oil samples were analyzed for peroxide value, acid value, iodine value, Thiobarbituric acid value, moisture, density and color intensity as earlier explained.

2.5. Data analysis

Descriptive statistics were used to summarize the data from the characterization of the recycled oil of the street food-vendors. An independent samples *t*-test was carried if there were significant differences between the cooking oil used for frying potato chips and fish. One-way analysis of variance was used to test for significant differences in the quality parameters during the oil recycling experiments. Mean separation was conducted using the Tukey Honestly Significant Difference posthoc test. Statistical significance was set at $p < 0.05$. Data analysis was done using the Statistical Package for Social Scientists (SPSS), version 20, developed by IBM, USA.

3. Results and discussion

3.1. Characterization of recycled oil from street food vendors

Table 1 shows the physicochemical characteristics of the oil obtained from the street-food-vendors as well as the conformance to quality specifications. None of the oil samples met the specifications for Thiobarbituric acid value (2 mg MDA/Kg). The oil used for frying fish and chips had peroxide values that were about four times the quality specification of 10 mEqO_2/Kg. The acid value of the oil used to deep-fry potato chips (0.8 mg KOH/g) was just above the quality specification of 0.6 mg KOH/g whereas that used for fish was about four times above it. The moisture contents and oil densities were almost twice the quality specification. In contrast, the iodine value and color intensities were below the quality specifications.

Peroxide value is a measure of the extent to which an oil has undergone primary oxidation, giving the initial evidence of oxidative rancidity in unsaturated fats (Esfarjani et al., 2019). It is an indicator of active oxygen bound by oil and thus reflects the formation of peroxides resulting from oxidation (Debnath et al., 2012). Its value depends on storage conditions, temperature, time and composition of the fatty acids (Esfarjani et al., 2019). Freshly refined oils should have a peroxide value approximately 10 mEq/kg oil, while rancid oils have present peroxide values above 30 mEq/kg (Gordon, 2001). Furthermore, peroxide values as high as 100 mEq O_2/kg have been linked to cases of food poisoning (Gotoh & Wada, 2006). For the oils in this study (Table 1) to have mean peroxide values about four times above the quality specification implied their extensive primary oxidation. Peroxides are responsible for the off-flavors and off-odors of the oil and foods in which they are fried. It is important to note that given the unstable nature of peroxides, peroxide value alone cannot be used as an accurate indicator of the amount of oil oxidation. Therefore, another indicator, thiobarbituric acid must be conducted for conclusive findings.

The thiobarbituric acid value measures the amount of secondary oxidation products resulting from peroxide decomposition or oxidation (Semb, 2012). It specifically, reflects the presence of thiobarbituric acid reactive substances, particularly malondialdehydes (Koh & Surh, 2015). An elevation of these substances indicates lipid peroxidation, with the extent revealing the degree of peroxidation that has transpired (Karimi et al., 2017). Thiobarbituric acid reactive substances often correlate with sensory testing, thus serving as an indicator of food rancidity, with 1–2 mg MDA/Kg generally considered the limit for objectionable odors or tastes due to rancidity (Karimi et al., 2017). It was therefore, concerning that the thiobarbituric acid values of all oils in this study were significantly above the quality specification (Table 1). Moreover, mean value for oil used to deep-fry fish was nearly three times higher than that for potato chips. This is potentially attributed to the higher unsaturated lipids in Nile perch leading to more secondary oxidation products in the oil (Koh & Surh, 2015). It is noteworthy that during secondary oxidative rancidity certain products of peroxide breakdown such as free radicals,

Table 1
Physicochemical characteristics of recycled oil used by street food-vendors to deep-fry potato chips and fish.

Parameters	Oil used to fry chips	Conforming samples, *n* (%)	Oil used to fry fish	Conforming samples, *n* (%)	Specification (Max.)	Reference
Peroxide value (mEqO_2/Kg)	$40.5^a \pm 13.3$	1 (2.9)	$40.5^a \pm 23.6$	2 (5.7)	10	Codex Alimentarius (1999)
Thiobarbituric acid (mg MDA/Kg)	$8.7^b \pm 4.3$	0 (0)	$21.8^a \pm 13.4$	0 (0)	2	Karimi et al. (2017)
Acid value (mg KOH/g)	$0.8^b \pm 0.3$	14 (40)	$2.6^a \pm 2.0$	0 (0)	0.6	Codex Alimentarius (1999)
Iodine value (g of I_2/g oil)	$13.7^a \pm 2.3$	2 (5.7)	$9.8^b \pm 3.4$	18 (51.4)	4.1–11	APCC (2009)
Color intensity (nm)	$0.03^b \pm 0.02$	34 (97.1)	$0.15^a \pm 0.11$	25 (71.4)	0.01	Based on fresh oil
Density (Kg/m^3)	$1720^a \pm 86.0$	10 (28.6)	$1699^a \pm 98.0$	6 (17.1)	921–924	Codex Alimentarius & FAO/WHO (1993)
Moisture (g/100 mL)	$0.3^a \pm 0.5$	19 (54.3)	$0.4^a \pm 0.5$	16 (45.7)	0.2	Codex Alimentarius (1999)

$N = 35$ (oil used for chips) and $n = 35$ (oil used for fish). Values are means ± standard deviations of two independent determinations. Means with different superscripts in the same row are significantly different ($p < 0.05$).

which are highly reactive compounds that can contribute to oxidative stress in the body. Prolonged oxidative stress is associated with inflammation, cardiovascular illnesses, cancer and digestive discomfort among others (Wu et al., 2019; Hamsi et al., 2015; Karaman et al., 2014; Ma et al., 2021).

Acid value refers to the milligrams of potassium hydroxide required to neutralize one gram of lipid (Mehmood et al., 2012). It is an indicator of the level of free fatty acids in lipids (Tarmizi et al., 2016, 2013). Accumulation of free fatty acids is associated with increased lipid autoxidation, undesirable odors and flavors (Nayak et al., 2016). Free fatty acids form during deep-frying through the hydrolysis of lipid ester bonds, accelerated by high temperatures and water/steam from the food (Tabee, 2008). The immediate immersion of washed food in hot oil, along with its residual moisture during sample collection in this study, likely accelerated hydrolytic rancidity (Bordin et al., 2013). The significantly higher acid value in oil used to deep-fry fish (2.6 mg KOH/g) compared to that for potato chips (0.8 mg KOH/g) is attributed to the higher lipid content in Nile perch fish. On dry weight basis Nile perch fish contains 15–18 % oil while potatoes contain only 0.1–0.7 % (Shuai et al., 2021; Turon et al., 2005).The release of lipids from the fish into the oil likely promoted hydrolysis hence elevating the acid value of the oil. This discrepancy may explain why only 60 % of oils used for chips met quality specifications, while none for fish did (Table 1).

The iodine value, which represents the grams of iodine consumed per 100 g of lipid, is a measure frequently utilized to assess lipid unsaturation (Yu et al., 2020). Low iodine values are an indicator of lipid oxidation and are consistent with the decrease in double bonds as oil becomes oxidized during heating (Jahanban-Esfahlan et al., 2019). The lower iodine value in Nile perch oil compared to chip oil suggests a complex interplay of factors, potentially involving the presence of both unsaturated and saturated fatty acids in the fish (Ogwok et al., 2008). The leaching of these fatty acids into the frying medium, combined with the pro-oxidant effects of copper and iron present in Nile perch, exacerbates lipid autoxidation (Chen et al., 2013; Koh & Surh, 2015). Nile perch has higher copper (8.4 mg/Kg) and iron (87.4 mg/Kg) content (Bekele et al., 2015), compared to lower levels in potatoes with 1.7 mg/Kg copper and 8.0 mg/Kg iron (Luis et al., 2011). This likely contributed to the heightened oxidation of the oil used to fry Nile perch, demonstrating the multifaceted nature of lipid degradation in different food types.

Fig. 1 shows the color of some of overly recycled oil used by study participants. Sebastian et al. (2014)) reported that in some fast food restaurants in Toronto, Canada, one of the oil quality parameters that is usually monitored is its color. Dissolved compounds such as carotenoids and other pigments influence oil color (Jurid et al., 2020). Oil color is also influenced by the type and amount of food fried and frying duration (Nayak et al., 2016). This was illustrated in Table 1 where the color intensity of only one oil sample used to deep frying potato chips did not conform to the quality specification. In contrast, ten samples of oil used to deep-fry fish failed the same test. This is possibly due to migration of more color pigments from the fish into the oil. Ogwok et al. (2008) reported that Nile perch contains a high content of β-carotenes (3–5 mg/100 g of oil) and α-tocopherols (2–11 mg/100 g of oil). These compounds likely contributed to the changes in oil color. Additionally, reactions such as thermal oxidation, polymerization, hydrolysis, Maillard's reaction, polymerization, caramelization, strecker degradation among others, which occur during deep-frying also affect the physical properties of oil (El-Naggar, 2019; Song et al., 2017). These reactions produce insoluble, non-volatiles in oil, which not only darken the color but also increase viscosity and foaming (Peng et al., 2017; Zhang et al., 2021). Among other factors, the extent of formation of these compounds is dependent on the composition of the food composition matrix. Nile perch fish contains more protein (18–20 %), lipids (0.6 %) and moisture (80 %) (Okeyo et al., 2009). On the other hand, potatoes have less protein (1–1.5 %), lipids (0.1 %) and moisture (75 %) (Khalid et al., 2020). Therefore, the more protein, lipids and moisture in the fish likely produced more degradation compounds making the oil significantly darker.

The densities of the oils used for the chips and fish were above the quality specification (Table 1), indicating prolonged exposure to deep-frying and increased viscosity. Similar to oil color, density is influenced by oil composition, food matrix, and degradation during deep-frying (Chebet et al., 2016; Smigic et al., 2016). Oil density is important in food processing because it affects the heat transfer by natural convection and buoyant movement of gas bubbles in a liquid (Nayak et al., 2016). It also influences the oil drainage rate from the food after frying as well as the mass transfer rate during cooling of the food (Sahasrabudhe et al., 2017). The more viscous oil is, the more easily it is absorbed by the food making it soggy especially if low frying temperatures are used. This is concerning since more harmful degradation products are imbibed by food prior to its consumption. Monitoring oil darkening and viscosity aids quick and efficient quality control in food processing (Mekawi et al., 2019).

The moisture contents of the oils used to deep-fry potato chips and the fish were just above the quality specification (Table 1). This was not surprising because deep-frying occurs above the boiling point of water for close to 10 min or so. The slight elevation of values above the specification could be due to traces of water left from the food fried. As earlier mentioned, it was noted that after the potato chips and fish were washed, they, together with their residual wash water were immediately immersed in the hot oil, significantly hydrating it.

Fig. 1. Overly recycled cooking oil used to deep-fry potato chips (L) and fish (R).

Table 2
Effect of frying cycle on the rancidity indicators of oils used in deep-frying potato chips or fresh fish.

Oil type/ frying cycle	Peroxide value (mEqO_2/Kg)		Thiobarbituric acid value (mg MDA/Kg)		Acid value (mg KOH/g)		Iodine value g of I_2/g oil	
	Chips	Fish	Chips	Fish	Chips	Fish	Chips	Fish
New oil	$8.5^{a*} \pm 0.4$	$8.5^{a*} \pm 0.4$	$1.3^{a*} \pm 0.1$	$1.3^{a*} \pm 0.0$	$0.2^{a*} \pm 0.0$	$0.2^{a*} \pm 0.0$	$20.3^{a\#} \pm 0.1$	$20.3^{a\#} \pm 0.1$
Cycle 1	$9.2^{a*} \pm 0.4$	$8.8^{a*} \pm 0.0$	$3.4^{a\#} \pm 0.2$	$7.6^{b\#} \pm 0.2$	$0.5^{a*} \pm 0.0$	$0.4^{a*} \pm 0.0$	$9.6^{a*} \pm 0.0$	$8.8^{a*} \pm 0.0$
Cycle 2	$9.5^{a*} \pm 0.1$	$9.2^{a*} \pm 0.1$	$5.5^{a\#} \pm 0.3$	$8.5^{b\#} \pm 0.2$	$0.7^{a\#} \pm 0.0$	$0.6^{b*} \pm 0.0$	$9.2^{a*} \pm 0.1$	$8.7^{a*} \pm 0.0$
Cycle 3	$16.5^{a\#} \pm 0.1$	$17.9^{a\#} \pm 0.2$	$5.1^{a\#} \pm 0.1$	$10.2^{b\#} \pm 0.0$	$0.9^{a\#} \pm 0.0$	$1.0^{a\#} \pm 0.0$	$8.4^{a*} \pm 0.3$	$8.0^{a*} \pm 0.4$
Cycle 4	$26.6^{a\#} \pm 0.4$	$25.9^{a\#} \pm 0.5$	$6.1^{a\#} \pm 0.1$	$10.8^{b\#} \pm 0.0$	$1.0^{a\#} \pm 0.1$	$1.1^{a\#} \pm 0.1$	$8.1^{a*} \pm 0.5$	$7.9^{a*} \pm 0.0$
Cycle 5	$37.3^{a\#} \pm 0.2$	$34.4^{a\#} \pm 0.4$	$5.7^{a\#} \pm 0.1$	$12.3^{b\#} \pm 0.2$	$1.1^{a\#} \pm 0.1$	$1.3^{b\#} \pm 0.0$	$8.6^{a*} \pm 0.4$	$7.5^{a*} \pm 0.1$
Cycle 6	$54.0^{a\#} \pm 0.9$	$43.8^{a\#} \pm 0.2$	$6.8^{a\#} \pm 0.5$	$12.4^{b\#} \pm 0.1$	$1.4^{a\#} \pm 0.1$	$1.5^{b\#} \pm 0.1$	$8.7^{a*} \pm 0.1$	$7.9^{a*} \pm 0.3$
Cycle 7	$58.4^{a\#} \pm 1.1$	$52.4^{a\#} \pm 0.9$	$7.0^{a\#} \pm 0.0$	$17.0^{b\#} \pm 0.0$	$1.8^{a\#} \pm 0.1$	$2.0^{b\#} \pm 0.2$	$7.9^{a*} \pm 0.0$	$7.8^{a*} \pm 0.3$
Oil in open pan overnight	$63.3^{a\#} \pm 1.3$	$74.8^{b\#} \pm 3.4$	$6.3^{a\#} \pm 0.2$	$17.4^{b\#} \pm 0.3$	$1.5^{a\#} \pm 0.2$	$1.7^{b\#} \pm 0.1$	$8.5^{a*} \pm 0.0$	$7.8^{a*} \pm 0.3$
Specification	10		2		0.6		4.1–11	
Reference	Codex Alimentarius (1999)		Karimi et al. (2017)		Codex Alimentarius (1999)		APCC (2009)	

Values are means ± standard deviations of two independent determinations. Means with * are significantly lower than or equal to the specification whereas means with # are significantly higher than the specification ($p < 0.05$). Means with different superscripts in the same row are significantly different ($p < 0.05$).

3.2. Effect of deep-frying on quality of recycled cooking oil

3.2.1. Effect on oil rancidity indicators

Table 2 shows the variations in the rancidity indicators of cooking oil during successive deep-frying cycles for potato chips and fish. The peroxide, thiobarbituric and acid values increased while the iodine values reduced with the increase in the deep-frying cycles. The thiobarbituric acid values exceeded the quality specification after the first cycle while the acid and peroxide values exceeded their quality specifications after the second cycle. Although the initial iodine value exceeded the quality range (4.1–11 I_2/g of oil), it normalized within this range after the first cycle. Prolonged exposure of used oil to the atmosphere overnight exacerbated the rancidity

The trends observed in Table 2 align with earlier discussions on the parameters outlined in Table 1. What was very peculiar about results shown in Table 2 was that based on the thiobarbituric acid values, a single exposure of the new/ unused oil to deep-frying rendered it unacceptable for human consumption irrespective of the food matrix fried. This was despite of the other rancidity indicators still being within the quality specifications after that cycle. Comparing Tables 1 and 2, the average thiobarbituric acid value for oil used to fry chips was 8.7 ± 4.3 mg MDA/Kg, while that for fish was 21.8 ± 13.4 mg MDA/Kg (Table 1), suggesting potential recycling of at least two and seven times, respectively (Table 2). With regards to the peroxide value, the average (about 41 mEqO_2/Kg) for both chip and fish oils (Table 1) suggests possible recycling of at least five times (Table 2). The average acid value was 0.8 ± 0.3 mg KOH/g for oil used for chips and 2.6 ± 2.0 mg KOH/g for oil used for fish (Table 1), probably implying that the vendors had been reused at least two and seven times, respectively (Table 2). Interestingly, the iodine value of the new oil was more than twice the quality specification (Table 2). However, this does not indicate poor quality, as it is a plant-based oil with unsaturation levels influenced by palm fruit variety, not subjected to partial hydrogenation during refining. Additionally, such oils meant for deep-frying do not undergo partial hydrogenation during refining. Nutritionally, unsaturated fatty acids are preferred to saturated ones due to their numerous health benefits (Lunn & Theobald, 2006). However, with regard to oil chemistry/quality the reverse is true because unsaturated oils are more prone to oxidation (Łukaszewicz et al., 2004). So, oil producers must add antioxidants like vitamins A and E among others to the oil during refining (Viana da Silva et al., 2022). When compared to results in Table 2, the mean iodine values of oil used for chips (13.7 ± 2.3 g I_2/g of oil) and fish (9.8 ± 3.4 g I_2/g of oil) (Table 1), it showed that the vendors may have recycled them at least once or twice.

In a previous study by Okalany et al. (2023) the food safety practices of these vendors were examined, revealing a concerning practice of supplementing recycled oil with fresh, unused refined oil. Therefore relying solely on Table 2 to explain those in Table 1 has some limitations. Nonetheless, it emphasized the excessive recycling of oils (observed in Table 1) indicating their unsuitability for human consumption. Although topping up used oil is not ideal, dilution with new/used oil slightly enhances quality. The best practice would be to use only new oil for deep-frying, but financial constraints may pose challenges.

The oil left an in open pan overnight underwent further rancidity (Table 2) due to its prolonged exposure to atmospheric oxygen and moisture, known to facilitate oxidative and hydrolytic rancidity, respectively (Mansoori et al., 2017). In the same previous study, Okalany et al. (2023)) reported that after each day's work vendors left the used oil in open pans until the next re-use (Okalany et al., 2023). They did not know that the practice compromised oil quality and consumer health.

Table 3
Effect of frying cycle on the physicochemical properties of oils used in deep-frying potato chips or fresh fish.

Oil type/ frying cycle	Color intensity (Absorbance units)		Density (Kg/m^3)		Moisture content (%)	
	Chips	Fish	Chips	Fish	Chips	Fish
New oil	$0.01^{a*} \pm 0.0$	$0.01^{a*} \pm 0.0$	$925.4^{a\#} \pm 9.1$	$925.4^{a\#} \pm 9.1$	$0.2^{a*} \pm 0.0$	$0.2^{a*} \pm 0.0$
Cycle 1	$0.01^{a*} \pm 0.0$	$0.03^{b\#} \pm 0.0$	$913.9^{a\#} \pm 1.8$	$913.7^{a\#} \pm 12.3$	$0.2^{a*} \pm 0.0$	$0.2^{a*} \pm 0.0$
Cycle 2	$0.02^{a\#} \pm 0.0$	$0.04^{b\#} \pm 0.0$	$938.6^{a\#} \pm 4.2$	$921.4^{a\#} \pm 20.0$	$0.1^{a*} \pm 0.0$	$0.1^{a*} \pm 0.0$
Cycle 3	$0.02^{a\#} \pm 0.0$	$0.05^{b\#} \pm 0.0$	$926.9^{a\#} \pm 5.0$	$935.7^{a\#} \pm 1.0$	$0.2^{a*} \pm 0.1$	$0.1^{a*} \pm 0.0$
Cycle 4	$0.02^{a\ a\#} \pm 0.0$	$0.06^{b\#} \pm 0.0$	$925.9^{a\#} \pm 7.6$	$931.7^{a\#} \pm 12.8$	$0.2^{a*} \pm 0.1$	$0.1^{a*} \pm 0.0$
Cycle 5	$0.03^{a\#} \pm 0.0$	$0.06^{b\#} \pm 0.0$	$931.5^{a\#} \pm 1.6$	$925.0^{\ a\#} \pm 6.3$	$0.1^{a*} \pm 0.0$	$0.1^{a*} \pm 0.0$
Cycle 6	$0.03^{a\#} \pm 0.0$	$0.06^{b\#} \pm 0.0$	$922.0^{a\#} \pm 7.0$	$948.3^{b\#} \pm 2.6$	$0.1^{a*} \pm 0.0$	$0.1^{a*} \pm 0.1$
Cycle 7	$0.04^{a\#} \pm 0.0$	$0.08^{b\#} \pm 0.0$	$935.1^{a\#} \pm 1.9$	$911.3^{b\#} \pm 0.0$	$0.1^{a*} \pm 0.1$	$0.1^{a*} \pm 0.0$
Oil in open pan overnight	$0.05^{a\#} \pm 0.0$	$0.11^{b\#} \pm 0.0$	$917.5^{a\#} \pm 0.0$	$905.0^{a\#} \pm 0.0$	$0.1^{a*} \pm 0.0$	$0.3^{b\#} \pm 0.0$
Specification	0.01		900		0.2	
Reference	Based on new oil		Codex Alimentarius & FAO/WHO (1993)		Codex Alimentarius (1999)	

Values are means ± standard deviations of two independent determinations. Means with * are significantly lower than or equal to the specification whereas those with # are significantly higher than the specification ($p < 0.05$). Means with different superscripts in the same row are significantly different ($p < 0.05$).

3.2.2. Effect on oil physicochemical properties

Table 3 shows physicochemical changes in recycled oil during successive deep-frying cycles for potato chips and fish. The color intensity was initially 0.9 but this doubled and tripled for fish oil and chip, respectively, after seven cycles. The density of the unused oil (925 Kg/m^3) exceeded the specification of 900 Kg/m^3. After the seventh frying cycles, it ranged between 911 and 935 Kg/m^3. The moisture content of the oils was within the quality specifications throughout all the frying cycles. The color intensities and densities of the oils kept in an open pan overnight were lower than observed after the seventh cycles. Under the same storage conditions, the moisture content of the oil used for chips, remained unchanged (0.1 %) while that for fish increased to 0.3 % when compared to results of the seventh cycle.

As earlier explained, color intensity and density of frying oil increase due to various factors (Mehmood et al., 2012). Comparing the results in Table 3, to those from the street food-vendors (Table 1), where the maximum color intensities for oil used for chips and fish were 0.03 ± 0.2 and 0.15 ± 0.11, respectively, it implies that the processors indeed overly recycled their oil and likely kept diluting it with new fresh oil to reduce its color intensity. Although the density of the oil at the start of frying was higher than the quality specification, it did not necessarily indicate poor oil quality. This may be because density/ viscosity of oil after refining is dependent on the variety of raw material used and the producer who determines how much stearin remains in the olein fraction. Therefore, having begun with a density above the quality specification makes it difficult to use this parameter alone as an oil quality indicator. Nonetheless, when results of density in Tables 1 and 3 were compared, they suggested that the vendors recycled their oil a lot more than seven times. This was because after seven frying cycles, the densities of the oil used for chips were only 935.1 Kg/m^3 and 911.3 Kg/m^3 for fish (Table 3) whereas those from vendors on average were 1720 ± 98 Kg/m^3 and 1669 ± 86 Kg/m^3, respectively (Table 1). For the oils kept in an open pan overnight, the color intensities and densities were lower than observed after the seventh cycles (Table 3) possibly due to the prolonged decantation effect. Hence, though not entirely effective in ensuring quality, this study recommends decanting, filtering or sieving of used oil to improve its quality. These processes reduce suspended matter such as food particles, polymeric substances and foam among others from the oil. In a similar study, the rancidity parameters in the majority of the fast food restaurants, which performed oil filtration, were lower than those that did not filter their oils (Esfarjani et al., 2019).

The moisture contents of the oils remained within the quality specification throughout all cycles (Table 3) due to the high temperatures used in deep-frying. The results were in line with the characteristic features of the frying process, which exhibits a drastic moisture loss at any particular temperature above 160 °C (Rani et al., 2015). The increase in moisture content of the oil used to fry fish and kept in an open pan overnight may be attributed to formation of hygroscopic polymeric substances in the oil that absorbed atmospheric moisture. Although moisture content is a key oil quality parameter given its role in hydrolytic rancidity it also cannot be used in isolation. This is explained by the fact that despite of the oil used to fry the chips having a moisture content (0.1 %) below the quality specification (Table 3); it was unfit for human consumption after the first and second cycles (Table 2).

4. Conclusion

The majority of recycled oil from street food vendors failed to meet quality standards, posing potential health hazards for consumers and compromising the safety of deep-fried foods. Urgent measures such as public education, awareness campaigns, and stringent laws to regulate usage of commercial cooking oil are needed to protect consumer health. With the exception of increasing the formation of secondary oxidation products, fish generally had similar effects like chips on the physicochemical properties of recycled oil. The study revealed that oil quality deteriorates after a single exposure to deep-frying conditions. The recycling of cooking oil used for deep-frying is thus discouraged despite the economic challenges. Future research should explore the influence of diverse food matrices, oils, and frying equipment on recycled cooking oil quality, establishing safe recycling frequencies for various food types. Additionally, investigations into other crucial properties of reused oil and different food matrices, including free radicals, acrylamides, vitamin E, total polar material, and anisidine value, should be considered.

Ethical statement—studies in humans and animals

Participants gave informed consent via the statement ``I am willing to offer a sample of my recycled cooking oil for research purposes strictly, and I agree to participate in this survey'' where an affirmative reply was required to enter the survey. They were able to withdraw from the survey at any time without giving a reason.

CRediT authorship contribution statement

Emmanuel Okalany: Writing – original draft, Software, Resources, Investigation, Funding acquisition, Data curation. **Stellah Byakika:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Ivan Muzira Mukisa:** Writing – review & editing, Supervision, Methodology, Conceptualization.

Declaration of competing interest

The authors declare that they have no conflict of interest.

Data availability

Data will be made available on request.

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