*Original Research Article*

Effects of Unrefined Oils and Butter on the Physicochemical and Nutritional Properties of Fried Doughnuts

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ABSTRACT

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| **Aims:** This study aimed to investigate the health implications of using unrefined oils and butter in doughnut preparation by analyzing the physicochemical properties, fatty acid profiles, and elemental compositions of extracted frying oils.  **Study Design:** An experimental laboratory-based study was employed to evaluate the impact of preparing fried doughnuts with unrefined oils and butter combinations on oil quality and stability extracted from the doughnuts.  **Place and Duration of Study:** The study was conducted at the Chemistry Laboratory of Akwa Ibom State University (AKSU) and CTX-ION Analytics, Ikeja, Lagos, between March and June 2025.  **Methodology:** Doughnuts were prepared using locally sourced unrefined oil and butter from shops in Uyo, Akwa Ibom State, selected through purposive sampling. Soxhlet extraction using n-hexane was used to recover oils from fried doughnuts. The oils were analyzed for acid value, free fatty acid (FFA), peroxide value, iodine value, and saponification value. Fatty acid methyl esters (FAMEs) were profiled using GC-MSD, and elemental composition (Ca, Fe, K, Mg, Na, P) was determined by ICP-OES.  **Results:** The doughnut oil recorded a very high peroxide value (136.30 meq/kg), signaling severe oxidative degradation, likely from elevated iron content and high frying temperatures. Iodine and saponification values indicated moderate unsaturation and presence of medium-chain fatty acids. GC-MSD showed retention of both saturated (lauric, myristic) and unsaturated (oleic, linoleic) fatty acids. Elemental analysis revealed high iron and potassium levels, especially in doughnut oil, indicating susceptibility to oxidation and potential health risks. Butter contributed beneficial unsaturated fats but also excessive sodium.  **Conclusion:** Frying with unrefined oils and butter significantly compromises oil quality due to oxidative and hydrolytic degradation. The high peroxide value and mineral-induced oxidation highlight potential health hazards. Improved frying practices, use of antioxidants, and optimized fat blends are recommended to enhance nutritional quality and shelf life of fried snacks like doughnuts. |

*Keywords: characterization, extraction, fatty acids, health implication, snacks.*

1. INTRODUCTION

There has been a marked **global increase** in the consumption of snacks, particularly among children, adolescents, and working adults. This trend is driven by urbanization, increased work hours, convenience culture, and aggressive marketing of processed foods (Monteiro et al. 2013). Aggressive marketing, particularly toward children and teenagers, contributes significantly to their snack preferences. Television and social media advertisements heavily promote ultra-processed snacks (Hawkes, 2007). The rise in snack consumption is closely linked with increased prevalence of overweight, obesity, and non-communicable diseases such as type 2 diabetes, especially when snacks are energy-dense and nutrient-poor like doughnuts (WHO, 2016). Doughnuts are typically deep-fried, resulting in high levels of saturated fats and calories. Consuming foods high in calories, such as doughnuts, in excess can lead to cardiovascular disease, metabolic syndrome, and obesity (Astrup et al., 2011). Edible oils and fats used in frying doughnuts play an essential role in human nutrition and health, serving as significant sources of energy, essential fatty acids, and fat-soluble vitamins. Numerous studies have demonstrated that the consumption of different types of oils influences various physiological processes, including lipid metabolism, disease development, and overall well-being (Amri et al., 2017). In addition to their dietary functions, oils are widely utilized in pharmaceutical, cosmetic, and industrial applications due to their functional and bioactive components (Asuquo et al., 2012). Fats and oils are commonly incorporated into food both directly and indirectly: added to salads, cooked meals, or used as frying media (Arif et al., 2010). Beyond their nutritional contributions, they provide desirable sensory attributes such as flavor, texture, and mouthfeel. However, during extraction, processing, and culinary use; especially involving heat treatments like frying, oils undergo various physicochemical changes. These include oxidation, hydrolysis, and polymerization, which can degrade the oil's quality and produce potentially harmful compounds (Arif et al., 2010; Anyasa et al., 2009; Lendle et al., 2005). Vegetable oils are particularly valued for their high content of unsaturated fatty acids, which contribute to cell regeneration, tissue repair, and cardiovascular health (Arif et al., 2010). These oils primarily contain lipids in the form of triacylglycerols, composed of saturated and unsaturated fatty acids. Their quality and stability are routinely assessed through key physicochemical parameters such as iodine value (IV), saponification value (SV), peroxide value (PV), viscosity, and density (Ceriani et al., 2008; Mousavi et al., 2012). Several studies have explored the effects of thermal processing on the stability of edible oils. Parameters such as PV, IV, and viscosity are particularly sensitive to temperature-induced degradation (Farhoosh et al., 2008; Li et al., 2010; Jinfeng et al., 2011). Oxidation, in particular, significantly alters the structural and functional integrity of oils. During this process, unsaturated fatty acids react with oxygen and light, generating free radicals, which subsequently form hydroperoxides, aldehydes, and ketones. If unchecked, these reactions culminate in polymerization, further diminishing oil quality and digestibility, and leading to the destruction of fat-soluble vitamins (Arif et al., 2010; Anyasa et al., 2009). Deep frying is a widespread cooking method that subjects oils to high temperatures over prolonged periods. Repeated use of frying oil accelerates oxidative and thermal degradation, altering both its nutritional and sensory characteristics (Che Man & Jasvir, 2000). Factors such as initial oil quality, replenishment frequency, frying conditions, and oxygen exposure significantly influence the rate of degradation (Choe & Min, 2007). Oxidized oils not only reduce the sensory appeal of foods but also pose potential health risks due to the accumulation of toxic degradation products (Bhattacharya et al., 2008). Given these concerns, monitoring the quality of oils used in food preparation is imperative. It ensures consumer safety, preserves the sensory quality of fried products, and minimizes economic losses associated with premature oil disposal (Zahir et al., 2017). This study aims to evaluate the quality of doughnuts prepared using locally processed vegetable oils and butter. Specifically, the research investigates the physicochemical properties, fatty acid composition, and elemental metal profile of oils extracted from the doughnuts. The findings are expected to provide insights into how unrefined fat and oils blend influence the nutritional, sensory, and functional quality of fried snack products.

2. material and methods

**2.1 Materials and reagents**

Soxhlet Extractor, Condenser, Round Bottom Flak, Heating Mantle (with stirring function): 98-11-B, Retort Stand, Analytical Balance: JA 11003 , Conical Flask, Beaker, Electrical Water Bath: HH-S , Desiccator, Burette Boiling Tube, Cotton Wool/Filtered Paper, Thermostat Oven: DHG-9023A, Measuring Cylinder, Burette, Pipette, N-Hexane, Potassium Iodide, Solvent Mixture Of Glacial Acetic Acid And Chloroform, Wij’s Solution, Distilled Water, Starch Indicator, Powdered Potassium Iodide, Sodium Thiosulfate Solution, Sodium Hydroxide, Hydrochloric Acid, Locally Processed Oil, Locally Processed Butter, Flour, Analytical Balance: ADAM AAA250LE Weighing Balance (UK), Vortex Mixer: Heidolph REAX 2000 (Germany), Dichloromethane: GC Ultratrace, Scharlau (Spain), n-Hexane: GC Ultratrace, Scharlau (Spain), Methanol: HPLC Grade ACS, Scharlau (Spain), Potassium Hydroxide: Mollychem, India etc.

**2.2 Sample collection**

Oils, butters, and flour used in preparing the doughnut were bought from different shops at Uyo, Akwa Ibom State, Nigeria. A purposive sampling technique was employed to select various shops in Uyo, where commonly patronized brands of oils, butters, and flour were purchased. This was adopted to ensure the inclusion of products that are widely used by local consumers for doughnut preparation. The doughnuts were prepared using locally processed (unrefined) oil and locally processed (unrefined) butter.

**2.3 Doughnut Preparation**

Active dry yeast (10 g) was combined with warm water in a bowl and set aside to activate. In a large bowl, the dry ingredients, all-purpose flour (250 g), sugar (50 g), salt (2.5 g), and flavors were thoroughly mixed together. Butter (50 g) was incorporated into the dry mixture and blended well. A well was made in the center of the dry mixture, and the activated yeast was poured in. The mixture was kneaded until a smooth dough formed. The dough was placed in a greased bowl, covered with cling film, and left to rise for 1 hour, or until it doubled in size. The risen dough was rolled out to about ½ inch thick and cut into doughnut shapes using a doughnut cutter. The shaped doughnuts were arranged on a tray, covered, and allowed to rise again for 30 minutes. The doughnuts were carefully placed in hot oil, a few at a time, and fried for about 2 minutes on each side until golden brown. They were then removed and drained on paper towels.



**Plate 1: Doughnut prepared from a locally processed oil and butter**

**2.4 Extraction of snack (doughnut**)

Extraction of oil from the doughnut was carried out by soxhlet extraction. About 50 g of finely chopped doughnuts was weighed in batches with a filtered paper on a weighing balance, wrapped and stapled, then put in already set up soxhlet apparatus and n-hexane was added and extracted for an hour at a temperature of about 60oC. The solvent (n-hexane) was removed from the extracted oil with rotary evaporator. The oil extracted from the doughnut alongside unrefined oil and butter were each analyzed for physicochemical properties, fatty acids and elemental compositions.

**2.5 Physiochemical characterization of oils**

**2.5.1 Determination of Iodine Value**

Carbon tetrachloride (10 mL) was added to 1.0 g of oil and dissolved. Wijis solution (20 mL) was added and then the stopper (previously moistened with potassium iodine solution) inserted and allowed to stand in the dark for 30 minutes. About 15 mL of potassium iodide solution (10%) was added and made up to 100 mL with distilled water and swirled for the solution to mix. The mixture containing the oil was then titrated against 0.1 M thiosulphate (Na2S2O3) solution with constant swirling using 2 mL of 1% starch solution as an indicator just before the end point (i.e., when the blue colour disappears). A blank titration was conducted following the same procedure and the iodine value calculated using the expression

Where: b = titre value of blank

a = titre value of sample

N = normality of Na2S2O3

**(**Codex Alimentarius Commission, 2021; Dressman et al., 2024**)**

**2.5.2 Determination of Peroxide Value**

Approximately 1.0 g of oil was weighed into a clean dry flask and dissolved in 20 mL acetic acid/chloroform (3:2) solution and swirled in clockwise and anticlockwise direction for 60 s to dissolve the oil in the chemical mixture. 0.5 mL saturated potassium iodide solution was added followed by 25 mL of distilled water and swirled again for another 60 s to obtain homogenous mixture. The resultant mixture was then titrated with 0.01 M sodium thiosulphate (Na2S2O3) solution with constant and vigorous swirling until the yellow colour disappears. 0.5 mL of 1% starch solution was then added which turned the mixture blue. The titration continued until the blue colour disappeared at the end point and the peroxide value calculated as shown below.

, N = Normality of Na2S2O3. **(**AOAC 2000; Dressman et al., 2024**)**

**2.5.3 Determination of Free Fatty Acid and Acid Value**

Diethyl ether (25 mL) was mixed with 25 mL of alcohol and 1 mL of phenolphthalein solution (1%). It was then carefully neutralized with 0.1 M NaOH. About 1.0 g of the oil was dissolved in the mixed neutral solvent and titrated with aqueous 0.1 M NaOH with constant shaking until a pink color which persisted for 15 seconds was obtained. Acid value was calculated as follows.

Acid value =

N = Normality of the potassium hydroxide or sodium hydroxide. The Free Fatty Acid figure is usually calculated as oleic acid (1 ml 0.1 M). Sodium hydroxide = 0.0282 g oleic acid), in which case the acid value = 2 x free fatty acid. For most oils, acidity is noticeable to the palate when free fatty calculated as oleic acid is about 0.5 – 1.5 %. **(**AOAC 2000; AOCS 1998; Dressman et al., 2024**).**

**2.5.4 Determination of Saponification Value**

The saponification value is determined by taking 1.0 g of oil sample in a conical flask and exactly 25 mL of the alcoholic potassium hydroxide solution was added. A reflux condenser was attached and flask heated in boiling water with frequent shaking until a clear solution (indicating complete saponification of the oil) is obtained. 1 mL of phenolphthalein (1%) solution was added and the hot excess alkali solution was allowed to cool and later titrated against 0.5 M hydrochloric acid. The volume of the acid used was recorded. A blank titration was carried out using the same procedure and saponification value calculated using the expression:

*Saponification value* =

N = Normality of Hydrochloric acid

b = Volume of HCl used in the blank

a = Volume of HCl used in the sample **(**AOCS 1998; Dressman et al., 2024**)**

**2.6 Analysis of Fatty Acid Methyl Esters by Gas Chromatography–Mass Spectrometry Detector (GC-MSD)**

**2.6.1 Instrument Description**

An Agilent 7890B GC with an Agilent 5977B MSD System equipped with a split/splitless inlet and an Agilent 7693 Automatic Liquid Sampler was used for this analysis. The table below shows the instrumental conditions used in the data acquisition.

**Table 1: Chromatographic Conditions**

|  |  |
| --- | --- |
| GC | Agilent 7890A coupled with 5977B Mass selective Detector |
| Sampler | Agilent 7693 Injector tower with 10 µL syringe |
| Carrier | Helium [flow; 1.3 mL/min] |
| Injection | 1µL Splitless, 250 °C |
| Column | Rtx-1ms 15 m, 0.25 mm ID, 0.25 μm |
| Oven | 60 °C (hold 0 min) to 300 °C at 15 °C/min (hold 0 min) |
| MSD | Transfer line temp [280] Quadrupole temp [150 °C] Ion source temp [230 °C] |

**2.6.2 Calibration**

FAMES standard Mix (Catalog Number: FAMQ 005) containing 37 FAMES components was purchased from Accu Standard. Five (5) point serial dilution calibration standards (10,20,40,60,80PPM) was prepared from the stock and used to calibrate the GC-MS.

**2.6.3 Extraction Procedure**

The oil extract (1 g) was dissolved with 10 mL of n-Hexane and 1 mL of 2 N methanolic KOH was added and the mixture was shaken thoroughly for 30 seconds. The mixture was then centrifuged, and the supernatant obtained. The supernatant was transferred into 2 mL vials and injected into the GC-MS. The analysis was carried out in scan mode.

**2.7 Elemental Analysis by Inductively Coupled Plasma–Optical Emission Spectroscopy** **(ICP-OES)**

**2.7.1 Analysis Procedure**

The Agilent 720-ES with megapixel CCD detector was used which provided simultaneous measurement while the Agilent SPS3 autosampler was used for sample introduction. Agilent Expert II Software was used to control the instrument and acquire data. Calibration and Quality Control (QC) solutions were prepared from the following reference material: Accustandard QCSTD-27 Quality Control Standard and Deionized water from Elga B114 Wall Mounted Deionizer System. Appropriate concentrations range of working standards from the multi-elements stock standard were prepared through serial dilution method. A new worksheet was created from the ICP-OES Expert software into which was programmed the individual sample codes as well as the method. After the instrument was programmed, the calibration curves were then obtained by running the standards and then the samples were also analyzed according to the sequence specified in the sequence parameters of the newly created worksheet.

3. results and discussion

**3.1** **Physiochemical Properties of Butter and Oils**

The data provided in table 2 compares the physicochemical properties of a locally processed oil (K1), a locally processed butter (O), and an oil extracted from doughnuts prepared using a combination of these two (C). The physicochemical properties of oils, such as acid value, free fatty acids, peroxide value, iodine value, and saponification value, are crucial indicators of oil quality, stability, and suitability for consumption and industrial applications (Codex Alimentarius Commission, 2021). The acid value and free fatty acid (FFA) content are measures of hydrolytic rancidity, indicating the

**Table 2: Physiochemical properties of oils extracted from doughnuts prepared using unrefined oil and butter**

|  |  |  |  |
| --- | --- | --- | --- |
| Parameters/sample | K1 | O | C |
| Acid values (mgKOH/g) | 7.01 | 1.07 | 3.93 |
| %Free fatty acids | 3.51 | 0.54 | 1.97 |
| Peroxide value (mequiv/kg) | 48.30 | 32.50 | 136.30 |
| Iodine value (gI2/100g) | 11.63 | 31.84 | 27.34 |
| Saponification values (mg KOH/g) | 428.44 | 348.75 | 412.29 |

*\*The data are means of the duplicate results obtained for each parameter. K1 = locally processed (unrefined) oil; O = locally processed (unrefined) butter; C = Oil from doughnut prepared using locally processed oil and locally processed butter*

extent to which triglycerides have broken down into glycerol and free fatty acids. Locally processed oil (K1) had the highest acid value (7.01 mgKOH/g) and % FFA (3.51%). This suggests that the oil has undergone some hydrolytic degradation or was not optimally processed or stored. High free fatty acid content can negatively impact the flavor and smoke point of an oil (O'Brien, 2009). Conversely, the lowest values in butter (O) indicate a more stable lipid profile. Interestingly, the oil from doughnuts (C) had intermediate values, implying that while the butter may have buffered some degradation, the frying process accelerated hydrolysis, especially due to heat and moisture interactions (Choe & Min, 2007). The peroxide value (PV), a primary indicator of oxidative rancidity, was notably highest in oil extracted from doughnuts (136.30 meq/kg), a value far exceeding acceptable limits (typically <10 meq/kg for fresh edible oils per FAO/WHO standards). This suggests severe oxidative stress during frying, which involves high temperatures and oxygen exposure that lead to rapid formation of hydroperoxides and secondary oxidation products (Guillén & Cabo, 2002; Munekata et al., 2017; Dressman et al., 2024). The iodine value, reflective of unsaturation level, was lowest in locally processed oil (11.63 gI₂/100g), pointing to high saturation, while butter (O) had the highest (31.84 gI₂/100g). The doughnut oil's iodine value (27.34 gI₂/100g) aligns more with the butter, indicating the butter's higher unsaturated fatty acid content influenced the final blend. However, thermal degradation of double bonds during frying may explain the slight reduction from butter to doughnut oil (Warner, 2007). The **s**aponification value, inversely related to fatty acid chain length, was highest in the locally processed oil (428.44 mgKOH/g), suggesting more short-chain fatty acids (figure 1). The doughnut oil had a value (412.29 mgKOH/g) closer to this, indicating that the locally processed oil predominantly shaped the average molecular weight profile of the doughnut oil, despite the butter component. This study underscores the need for improved processing and storage of local oils and the importance of controlling frying conditions to limit degradation. The application of natural antioxidants or oil stabilization techniques could mitigate rancidity and extend the shelf life of products like doughnuts.

**3.2: Fatty Acids Profiling of Butter and Oils**

The GC-MSD analysis of the oils and butter samples (carried out under the experimental conditions provided in table 1) revealed significant variations in the types and quantities of fatty acids present, which closely reflect and explain their respective physicochemical properties as reported in Table 2. By correlating the data, a clearer understanding emerges of how the chemical composition of these lipids influences their functional quality and potential health outcomes. Sample K1 (locally processed oil) exhibited the highest concentrations of medium-chain fatty acids (MCFAs), particularly lauric acid (255.138 mg/L), myristoleic acid (254.826 mg/L), and myristic acid (130.727 mg/L). These shorter-chain saturated fatty acids are known for having high saponification values due to their lower molecular weights (Choe & Min, 2006). This aligns with the saponification value of 428.44 mgKOH/g recorded for sample K1 (the highest among the three samples) indicating a predominance of lower-molecular-weight fatty acids ideal for soap production and faster digestion (Dayrit, 2015). However, sample K1 also recorded the highest acid value (7.01 mgKOH/g) and free fatty acid (FFA) content (3.51%), suggesting a significant degree of hydrolysis. This could be due to the unrefined nature of the oil, which may retain moisture and endogenous enzymes that accelerate triglyceride breakdown. The abundant presence of saturated MCFAs, particularly myristic and lauric acids, which are more prone to hydrolysis, further supports this interpretation (Mensink et al., 2003). Interestingly, despite its richness in saturated fats, sample K1 had a low iodine value (11.63 gI₂/100g), consistent with its fatty acid profile that is dominated by saturated components and contains fewer unsaturated double bonds. Saturated fatty acids, being chemically stable, contribute less to iodine absorption, resulting in low iodine values: a known indicator of poor unsaturation levels in oils (Codex Alimentarius, 2019). In contrast, sample O (locally processed butter) presented a very different fatty acid and physicochemical profile. Although the total quantity of fatty acids was generally lower than in K1, sample O was relatively richer in palmitic acid (84.568 mg/L), oleic/linoleic acids (118.472 mg/L), and a modest amount of polyunsaturated fatty acids (PUFAs). These unsaturated components contributed to its higher iodine value (31.84 gI₂/100g), indicating a greater degree of unsaturation compared to K1. Oleic and linoleic acids, in particular, are monounsaturated and polyunsaturated fatty acids, respectively, that increase the iodine value due to their multiple carbon-carbon double bonds (Schwingshackl & Hoffmann, 2014). Sample O also exhibited the lowest acid value (1.07 mgKOH/g) and FFA (0.54%), reflecting a more stable and refined fat matrix with lower hydrolysis. This aligns with the relatively low concentration of hydrolysis-prone

**Table 3: Gc-Ms Results of fatty acids butter and oils**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| S/N | Compound Name | Sample K1  (mg/L) | Sample O  (mg/L) | Sample C  (mg/L) |
| 1 | Capric acid, methyl ester | 63.102700 | 0.367236 | 40.166600 |
| 2 | Undecanoic acid, methyl ester | 1.459000 | 0.020912 | 0.829790 |
| 3 | Lauric acid, methyl ester | 255.138000 | 8.133530 | 179.368000 |
| 4 | Tridecanoic acid, methyl ester | 1.843180 | 0.031816 | 0.898930 |
| 5 | Myristoleic acid, methyl ester | 254.826000 | 2.443570 | 167.206000 |
| 6 | Myristic acid, methyl ester | 130.727000 | 9.115390 | 94.112400 |
| 7 | cis-10-pentadecanoic acid, methyl ester | 0.037167 | 0.083101 | 0.134697 |
| 8 | Pentadecanoic acid, methyl ester | 0.356094 | 0.687789 | 0.777868 |
| 9 | Palmitic acid, methyl ester | 54.988700 | 84.568000 | 95.642000 |
| 10 | Linoleic/Oleic acid, methyl ester | 121.726000 | 118.472000 | 168.045000 |
| 11 | Stearic acid, methyl ester | 39.037400 | 31.320200 | 49.868200 |
| 12 | cis-5,8,11,14-Eicosapentaenoic acid, methyl estes | 0.290441 | 0.057248 | 0.601366 |
| 13 | 8,11,14-Eicosatrienoic acid, methyl ester | 3.017150 | 0.376508 | 5.345330 |
| 14 | cis-11,14-Eicosadienoic acid, methyl ester | 0.896968 | 0.108230 | 2.560090 |
| 15 | cis-11-14-17-Eicosatrienoic acid, methyl ester | 2.215780 | 1.041730 | 3.103260 |
| 16 | Eicosanoic acid, methyl ester | 1.626190 | 1.613590 | 3.358130 |
| 17 | Heneicosanoic acid, methyl ester | 0.076963 | 0.038976 | 0.066248 |
| 18 | cis-13,16-Docasadienoic acid, methyl ester | 0.049436 | 0.123327 | 0.103079 |
| 19 | Erucic acid, methyl ester | 0.040072 | 0.163866 | 0.091892 |
| 20 | Behenic acid, methyl ester | 0.290146 | 0.260346 | 0.501898 |
| 21 | Tricosanoic acid, methyl ester | 0.269004 | 0.068751 | 0.250441 |
| 22 | Nervonic acid, methyl ester | 0.150580 | 0.136681 | 0.051819 |
| 23 | Lignoceric acid, methyl ester | 0.526263 | 0.214970 | 0.556829 |



















**Figure 1:** **Structures of the major fatty acids identified**

MCFAs and suggests a more stable lipid profile suitable for storage and consumption. Additionally, its saponification value (348.75 mgKOH/g) was the lowest, consistent with the presence of longer-chain fatty acids and a lower content of short-chain saturates. Sample **C**, representing the oil extracted from doughnuts fried in a mixture of the two fat sources, displayed a composite fatty acid profile and intermediate physicochemical properties. It retained a significant portion of the MCFAs from sample K1 (e.g., lauric acid: 179.368 mg/L, myristic acid: 94.112 mg/L) while also containing higher levels of oleic/linoleic acid (168.045 mg/L) and PUFAs such as EPA (0.601mg/L) and eicosadienoic acid (2.560 mg/L). These unsaturated compounds likely contributed to its moderate iodine value (27.34 gI₂/100g) (lower than O but higher than K1) indicating a better balance between saturation and unsaturation. Notably, sample C recorded a very high peroxide value (136.30 meq/kg), substantially exceeding the acceptable limit for edible oils (typically ≤10–20 meq/kg per FAO/WHO standards). This suggests extensive lipid peroxidation, likely exacerbated by the high frying temperatures and the presence of PUFAs, which are susceptible to oxidative degradation (Choe & Min, 2006). The exposure to heat and oxygen during frying facilitates free radical formation, particularly in oils rich in unsaturated fats like EPA and linoleic acid. The acid value of C (3.93 mgKOH/g) and FFA content (1.97%) were moderate (higher than O but lower than K1) reflecting some degree of hydrolysis during frying but also a dilution effect from the butter’s more stable profile. Similarly, its saponification value (412.29 mgKOH/g) was intermediate, consistent with its blend of medium- and long-chain fatty acids. Overall, this integrative analysis illustrates that the chemical nature of fatty acids (specifically chain length and degree of unsaturation) has a direct impact on the functional characteristics of fats, such as oxidative stability (peroxide value), chemical reactivity (iodine value), and digestibility (saponification value). The unrefined oil (K1) offers a high-energy, MCFA-rich profile but is prone to degradation and rancidity. The butter (O) is chemically more stable and richer in unsaturated fatty acids, but has lower saponification potential. The fried doughnut oil (C) combines both profiles but shows significant oxidative damage, emphasizing the need for careful thermal processing to preserve nutritional quality.

**3.3 Elemental Analysis of Butter and Oils**

Table 4 reveals the elemental analysis results of oil samples K1, O and C. Locally processed oil (K1) had an exceptionally high potassium content (156106 ppm). Butter (O) had no detectable potassium (0 ppm). The doughnut oil (C) showed a significant amount of potassium (49006.8 ppm), indicating a substantial contribution from the locally processed oil to the final product's mineral content. Butter (O) had the highest sodium content (684.933 ppm), while K1 and C had much lower levels (18.192 ppm and 10.908 ppm, respectively). This suggests that the butter is a major source of sodium in the blend. Both locally processed oil (K1) and doughnut oil (C) had comparable and relatively high iron levels (85.4563 ppm and 84.7579 ppm, respectively), while butter (O) had a lower amount (62.1791 ppm). Iron can act as a pro-oxidant, potentially accelerating oxidative rancidity, especially at frying temperatures. The high iron content in the locally processed oil and subsequently in the doughnut oil could contribute to the observed high peroxide values. Calcium, magnesium, and phosphorus were present in all samples, with varying concentrations. The levels in the doughnut oil (C) generally fell between those of the locally processed oil (K1) and butter (O), reflecting the combined nature of the blend. For instance, C had 219.823 ppm Ca, 26.026 ppm Mg, and 11.4335 ppm P. The comprehensive analysis of physicochemical properties, fatty acid composition, and elemental content provides a thorough understanding of the locally processed oil, locally processed butter, and the oil extracted from doughnuts. The locally processed oil (K1) is characterized by high hydrolytic

**Table 4: Results of elemental analysis of butter and oils**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Sample ID | Ca (ppm) | | Fe (ppm) | K (ppm) | Mg (ppm) | Na (ppm) | P (ppm) |
| K1 | 244.9580 | 85.4563 | | 156106.0000 | 30.3084 | 18.1920 | 9.73751 |
| O | 178.2930 | 62.1791 | | 0.0000 | 21.8344 | 684.9330 | 29.31480 |
| C | 219.8230 | 84.7579 | | 49006.8000 | 26.0260 | 10.9080 | 11.43350 |

rancidity, a high degree of saturation, and very high potassium and iron content. The locally processed butter (O) shows better initial oxidative and hydrolytic stability, a more unsaturated fatty acid profile, and is a significant source of sodium. Crucially, the doughnut preparation process significantly impacts the oil's quality. The oil extracted from the doughnuts (C) exhibits a dramatic increase in oxidative rancidity, evidenced by its very high peroxide value. This is likely accelerated by the combination of high frying temperatures and the presence of pro-oxidant minerals like iron from the locally processed oil (Che Man & Jasvir, 2000; Choe & Min, 2007; Munekata et al., 2017). While the butter contributes beneficial unsaturated fatty acids to the blend, these become susceptible to oxidation during frying. The elemental profile of the doughnut oil reflects the combined contributions of the raw oil and butter. In conclusion, while the locally sourced ingredients offer unique profiles, the method of preparation (deep-fat frying) introduces significant challenges, particularly regarding oxidative stability. The substantial increase in oxidation products in the doughnut oil highlights the need for strategies to mitigate rancidity, such as optimizing frying conditions, incorporating antioxidants, or re-evaluating the blend proportions to enhance the quality and shelf-life of products made with these locally processed oils and butter. Furthermore, the presence of various minerals, particularly iron, warrants attention for its potential role in accelerating degradation.

**3.4.** **Health Implications**

High acid value and FFA levels, as observed in the locally processed oil (K1) and the doughnut oil (C), are indicators of lipid hydrolysis and early-stage rancidity. Consumption of oils with elevated FFAs has been linked to gastrointestinal irritation and may impair nutrient absorption (Naz et al., 2005). Chronic intake of degraded fats can contribute to metabolic disorders and increase the risk of cardiovascular disease due to inflammatory responses (Farhoosh et al., 2009). While butter (O) had the lowest FFA, the doughnut oil (C) presented moderate levels, suggesting that frying exacerbates lipid breakdown, raising health concerns over repeated or long-term consumption of such products. The peroxide value of the doughnut oil (C) was extremely high (136.30 meq/kg), far exceeding acceptable safety limits (<10 meq/kg for edible oils) set by food safety guidelines (Codex Alimentarius Commission, 2021). This suggests extensive lipid oxidation during frying—a process that produces **lipid hydroperoxides, aldehydes**, and **ketones**, which have been linked to DNA damage, inflammation, and increased risk of chronic diseases such as **cancer, atherosclerosis**, and **neurodegenerative disorders** (Esterbauer et al., 1991; Gutteridge & Halliwell, 2010). The locally processed oil (K1) contains high levels of **medium-chain saturated fatty acids** (Lauric and Myristoleic acids), which, while easily metabolized, have also been shown to elevate **low-density lipoprotein (LDL)** cholesterol when consumed in excess, contributing to **cardiovascular disease risk** (Mensink et al., 2003). Conversely, the butter (O) and doughnut oil (C) have higher levels of **unsaturated fatty acids** (Linoleic/Oleic acids), which are typically cardioprotective when intact (Mozaffarian et al., 2010). However, these unsaturated fats are **highly prone to oxidation**, especially under high frying temperatures, forming **toxic lipid peroxidation products** that can promote **oxidative stress, cell membrane damage**, and **pro-inflammatory responses** (Choe & Min, 2007). The frying process not only induces oxidation but also degrades **vitamins A, D, E, and K**, and essential fatty acids. As a result, even oils originally rich in beneficial nutrients (like butter) may lose their health-promoting properties when used repeatedly or at high temperatures, such as during doughnut preparation (Naz et al., 2005). The elemental composition of edible oils directly influences not only their **nutritional value** but also their **oxidative stability** and potential health effects. In this study, locally processed oil (K1), locally processed butter (O), and doughnut oil (C) were also analyzed for their content of essential minerals including calcium (Ca), iron (Fe), potassium (K), magnesium (Mg), sodium (Na), and phosphorus (P). Iron is vital for oxygen transport and metabolic processes. However, **excess iron in oils** can promote the formation of **free radicals** through Fenton reactions, accelerating lipid oxidation (Choe & Min, 2007). Both locally processed oil (K1: 85.46 ppm) and doughnut oil (C: 84.76 ppm) showed **high iron content**, which likely contributed to the high peroxide value (136.30 meq/kg) observed in sample C. Oxidized fats are associated with **inflammation, atherosclerosis, and potential carcinogenic effects** (Esterbauer et al., 1991). Excess sodium intake is linked to **hypertension, stroke, and cardiovascular disease** (Mozaffarian et al., 2014). Butter (O) had a notably high sodium content (684.93 ppm), while locally processed oil and doughnut oil had much lower levels. Although the sodium content in the final doughnut oil (C) was diluted (10.91 ppm), cumulative dietary exposure from butter-based fried foods could pose risks, particularly in populations with pre-existing cardiovascular concerns. Potassium helps regulate blood pressure and counteracts the effects of sodium. The locally processed oil contained an exceptionally high potassium level (156,106 ppm), significantly higher than in the doughnut oil (C: 49,006.8 ppm). While this could be beneficial, **the bioavailability and daily intake levels from oils are uncertain**. Also, extremely high mineral concentrations in cooking oils may raise **concerns about contamination or improper refining**, which should be investigated further (Naz et al., 2005). These minerals are essential for bone health, enzymatic reactions, and neuromuscular function. Though present in moderate concentrations, their nutritional contribution from oil intake is limited due to **low oil consumption volumes** and **questionable bioavailability** from lipid matrices (Trumbo et al., 2001). Nonetheless, the mineral profile adds some nutritional value. The **elemental composition** of the oils analyzed reveals several critical health implications: i**ron** levels are high in the locally processed and doughnut oils, acting as pro-oxidants and potentially **worsening oil degradation during frying**, thus increasing exposure to harmful compounds; **sodium** is excessive in the butter, indicating **hypertension risk** if such oils are frequently used in fried or processed foods; **potassium**, while generally beneficial, is present in unexpectedly high amounts in the locally processed oil, requiring further validation for safety and source integrity and **other minerals** like calcium, magnesium, and phosphorus contribute to nutritional content but do not offset the risks posed by oxidized lipids or mineral imbalance. **Monitoring of mineral content** (especially iron and sodium) in locally processed oils should be a public health priority, use of **antioxidants or iron chelators** may improve the stability of such oils during frying and **public awareness** on the risks of excessive sodium and degraded frying oils should be promoted, especially in areas where these local oils are widely used in street foods are recommended.

**Table 5: Summary of Health Implications**

|  |  |  |  |
| --- | --- | --- | --- |
| Health Concern | Sample K | Sample O | Sample C (Doughnut oil) |
| High Free Fatty Acids & Acidity | High risk (++) | Low risk (+++) | Moderate (++ |
| Oxidative Rancidity (Peroxide Value) | Elevated (++) | Moderate (++ | Very high risk (+) |
| Saturated vs Unsaturated Fat Balance | Saturated (++) | Unsaturated (+++) | Moderate balance (+++) |
| Mineral Nutrition (Fe, Ca, K, Mg) | Rich (+++) | Lacking K, Fe (++ | Balanced retention (+++) |
| Sodium Load | Low (+++) | Excessive (+) | Reduced (+++) |
| Phosphorus Burden | Low (+++) | High (++ | Safer level (+++) |

*\*Keys: +++ = health promoting, ++ = moderate concern, + = high health risk. \*High Free Fatty Acids & Acidity: High risk (Guillén & Cabo, 2002; Codex Alimentarius, 2019), Low risk (Warner & Gupta, 2003), Moderate (Pillon et al., 2012). \*Oxidative Rancidity (Peroxide Value): Elevated (Choe & Min, 2006), Moderate (Mohdaly et al., 2010), Very high risk (Ayala et al., 2014). \*Saturated vs Unsaturated Fat Balance: Saturated (Siri-Tarino et al., 2010), Unsaturated (Mensink et al., 2003), Moderate balance (Warner & Gupta, 2003). \*Mineral Nutrition (Fe, Ca, K, Mg): Rich (Adepoju et al., 2012), Lacking K, Fe (Ofori & Henshaw, 2017), Balanced retention (Naz et al., 2005). \*Sodium Load: Low (WHO, 2021), Excessive (WHO, 2021), Reduced (Calvo & Uribarri, 2013). \*Phosphorus Burden: Low (NIH, 2020), High (Calvo & Uribarri, 2013), Safer level (Matsumoto et al., 2012).*

From the summary of health implications (table 5), unrefined oil (K) offers superior mineral content but presents a risk due to high acidity and peroxide levels. Unrefined butter (O) is more chemically stable but has excessive sodium and lacks key minerals like potassium and iron while the doughnut oil (C) shows partial retention of beneficial elements but exhibits significant oxidation, which may pose long-term health risks if consumed frequently.

**4. CONCLUSION**

This study provided a detailed evaluation of the quality and health implications of doughnuts prepared using locally processed (unrefined) vegetable oils and butter. Through comprehensive physicochemical, fatty acid, and elemental analyses, it was evident that the deep-fat frying process significantly alters the chemical composition and stability of the fats used, particularly when unrefined sources are involved. The oil extracted from the fried doughnuts exhibited markedly elevated peroxide values (136.30 meq/kg), indicating severe oxidative rancidity far beyond acceptable safety thresholds. This oxidative degradation was attributed to the high frying temperatures, presence of polyunsaturated fatty acids (PUFAs), and pro-oxidant minerals such as iron, especially prominent in the locally processed oil. The acid value and free fatty acid (FFA) levels further suggested hydrolytic breakdown, compounding concerns about oil quality post-frying. Fatty acid profiling via GC-MSD revealed that the doughnut oil retained medium-chain saturated fatty acids (e.g., lauric, myristic) from the unrefined oil, and unsaturated fatty acids (e.g., oleic, linoleic) from the butter. This blend contributed to a moderate iodine value, indicating a balance between saturation and unsaturation. However, the presence of easily oxidizable unsaturated fats raised additional concerns under high-heat conditions. Elemental analysis showed significant retention of potassium and iron from the unrefined oil and high sodium content in the butter. While some minerals offer nutritional value, their high concentrations (particularly iron) may accelerate lipid peroxidation, posing further health risks. Overall, the findings underscore the dual role of fat sources in determining both the nutritional profile and stability of fried products. The use of unrefined fats without appropriate controls can lead to significant oxidative and hydrolytic degradation. Therefore, integrating natural antioxidants, optimizing frying parameters, and carefully selecting and proportioning fat blends are essential strategies to enhance the safety, stability, and nutritional quality of fried snacks like doughnuts.

Disclaimer (Artificial Intelligence)

Authors hereby declare that ChatGPT (an OpenAI Language model) was used to edit the abstract, introduction, discussion and conclusion sections of this paper.

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