Effects of Thermal Treatment on The Characteristics Quality of Some Ghanaian Vegetable Oils (Palm, Coconut and Groundnut)

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Abstract

Introduction: Vegetable oils contain natural antioxidants and other properties reported to impart anti-diabetic properties when consumed, in animal study. In humans however, these oils are subjected to high temperatures during cooking before consumption. High temperature tends to affect the characteristic quality and potential to impart on health benefits such as antidiabetic properties. The objective of this work was to determine the characteristics quality of vegetable oils after thermal treatment that equates to temperatures oils are subjected to during food processing/cooking.
Methodology: Three portions of 200g of each fresh unrefined red palm oil, coconut oil and groundnut oils in three conical flasks T1, T2 and T3 were heated to room temperature 28°C (T1) to 100°C in boiling water (T2) and to 200°C in electric cooker oven (T3) for 10 minutes. Acid, iodine, peroxide, saponification, unsaponification values of the oils were then determined after cooling to room temperature.

Results: Coconut oil heated to 200°C had the least Acid value of 2.89±0.135 whiles Palm oil heated to 100°C had the highest value of 19.57±0.165. There were no peroxides formed in Coconut and Palm oils at 28 °C as well as Palm oil at 100 °C. However, peroxides were highest in Coconut oil at 200°C with value of 15.28±2.315. Saponification value of groundnut oil at 28 °C was the least at 89.52 ± 2.18 and 296.57±1.045 the highest in coconut oil at 200 °C. Heating however increased the unsaponifiable matter in all the vegetable oils used.

Conclusion

The quality of the oils in terms of acid value, iodine vale, peroxide value and saponification value were retained after one heat treatment. This implies the quality of the oils are maintained during food processing.

Key Words

Vegetable oils, Thermal treatment, Diabetes Mellitus,

Introduction
Vegetable oils are triglycerides extracted from plants and termed as plant oils that are mostly liquid at room temperature or fat when solid [1]. Vegetable oils are used for many purposes, mostly for cooking, as fuels, paints, and in skin care product and other pharmaceutical products [2-3-4].

Medical benefits from the consumption of vegetable oils are conflicting. Some of these oils have been associated with the induction of cardiovascular diseases due to their atherogenic effect because they contain high amounts of omega-6 fats and excessive consumption of omega-6s can create chronic inflammatory reactions [5] which is associated with the development of atherosclerosis [6-7], particularly the long chain and saturated fatty acids [8]. Other researchers have found that linoleic acid-rich vegetable oil in place of saturated fat, produced no evidence for reductions in either coronary heart disease mortality or all-cause mortality [9]. A positive association after consumption of some oils has been observed in cardiovascular disease (CVD) and type 2 diabetes mellitus (DM). Consumption of olive oil was inversely associated with serum cholesterol and glucose levels and systolic blood pressure [10], Ngala et al showed that 10% by weight vegetable oil: coconut oil, groundnut oil and red palm oil added to rodent chaw significantly reduced blood glucose level in diabetic mice and showed no dyslipidaemic effect [11].

Red palm oil is an edible vegetable oil derived from the mesocarp (reddish pulp) of the fruit of the oil palms, primarily the African oil palm (*Elaeis guineensis*) [12]. Red palm oil is rich in carotenoids, such as alpha-carotene, beta-carotene and lycopene, which give it a characteristic dark red color [13-14]. Palm oil is mainly composed of fatty acids, esterified with glycerol. It has a high concentration of saturated fat; palmitic acid and oleic acid which is monounsaturated. Unrefined palm oil is a significant source of tocotrienol, part of the vitamin E family [12]. Coconut oil or copra oil is obtained from the dried kernel of coconut [15]. Coconut (*Cocos nucifera*) oil contains medium chain fatty acids, basically comprises of lauric acid (47.5%) which is reported to be a
better alternative to other saturated fatty acids. Groundnut or Peanut oil, is a mild-tasting vegetable oil derived from groundnut (arachis hypogeal) [16]. Its major component fatty acids include oleic acid (46.8% as olein), linoleic acid (33.4% as linolein), and palmitic acid (10.0% as palmitin). The oil also contains some stearic acid, arachidic acid, behenic acid, lignoceric acid and other fatty acids [17]. It is believed that the antioxidant carotenes, unsaturation and short chain fatty acids confer the oils their antidiabetic effect [11].

However, the antidiabetic properties of vegetable oil may be deteriorated by thermal effect during food processing that leads to lipid oxidation. Prolonged consumption of repeatedly heated oil has been shown to increase blood pressure and total cholesterol, cause vascular inflammation and vascular changes which predisposes to atherosclerosis as a result of lipid peroxidation [18-19].

The 10% vegetable oil added to mouse chaw [11] that showed antiglycaemic effect was at room temperature. However, humans normally process these oils during cooking at high temperatures before consumption. This work is aimed at determining quality of the oils after a single heating at different food processing temperatures, this will help determine the mode of application of the oils in human trials.

Methods

Fresh unrefined palm, coconut and groundnut oils were bought from the Ghana Food Distribution Corporation. 200g of each of the oils were placed in three conical flasks T1 T2 and T3. All the oils in T1 flasks were maintained at room temperature (28°C) whilst those in T2 and T3 flasks were heated in water bath and electric oven to 100 and 200 respectively for 10 minutes and analysis were then made on the three different oils in their three different temperature treatments after cooling to room temperature using methods from AOAC (1990) [20].
Acid Value Determination

5g grams of each of the oil treated at T1, T2 and T3 were weighed into a 250ml conical flask. 100ml of freshly neutralized ethanol and 1ml of phenolphthalein indicator were added to each of the oil samples. The mixtures were then boiled for 5min and titrated against a 1M sodium hydroxide solution. The acid value was then calculated using the formula

$$\text{Acid Value} = \frac{56.1VN}{W}$$

where (V = vol. of NaOH used, N = Normality of NaOH and W = wt. of

Iodine Value Determination

To determine the iodine value, 0.5g of treated oil samples were weighed into 2 separate 500ml glass-stopped flasks. Afterwards, 10ml of chloroform was added to each sample to dissolve the oils whiles 2 blanks were prepared by adding only 10ml of the chloroform into the 500ml glass-stopped flasks. 25ml of Wij’s solution was then added to each flask and swirled gently to mix and incubated in the dark for 30 min. After the incubation, 20ml of (1M) potassium iodide solution was added to each flask, followed by washing down of any free iodine on the stopper with a 100ml freshly boiled and cooled water. The liberated iodine in the flasks was then titrated with 0.1N sodium thiosulphate solution, adding it gradually with vigorous shaking until the yellow color almost disappeared. 1ml of starch indicator was then added while continuing the titration until the blue color disappeared entirely. The volume of the titrant was then recorded and the iodine value was calculated from it using the formula:

$$\text{Iodine Value} = \frac{(B-S) \times N \times 126.9}{W} \times 100$$
(Where B = vol. of titrant for blank, N = normality of Na$_2$SO$_3$, S = vol. of titrant for sample,
126.9 = MW. Of Iodine, W = weight of sample)

**Peroxide value determination**

5g of each of the treated oils was weighed into two 250ml glass-stopped erlenmeyer flasks respectively. 30ml of acetic acid-chloroform solution (3:2) was added to each flask and swirled to dissolve. 0.5ml saturated KI solution and 30 ml distilled water were then added, the samples were then titrated slowly with 0.1N sodium thiosulphate solution with vigorous shaking until yellow color almost disappeared. 0.5ml of starch indicator was then added while continuing the titration to liberate all iodine from the chloroform layer until the blue color disappeared entirely. The procedure was then repeated using a blank without oil as the control, the volume of the titrant was recorded and used to calculate for the peroxide value from the formula:

\[
\text{peroxide value} = \frac{(S-B) \times N}{w} \times 1000
\]

(where B = vol. of titrant for blank, N = normality of NA$_2$SO$_3$, S = vol. of titrant for sample,
126.9 = mw. of iodine, w = weight of sample)

**Saponification Value Determination**

The saponification values of the vegetable oils were determined by weighing 1.5g each of treated oils into two 250ml Erlenmeyer flasks. 25ml of alcoholic KOH solution was pipetted into each flask including a blank. The sample and the blank flasks were connected to air condensers and kept in a water bath boiling gently. Saponification was completed when the oily solution was clear. After cooling, the condenser was washed down with 10ml ethanol. Excess KOH was then titrated
with 0.5N HCL using 1ml phenolphthalein as indicator. Using the titrant obtained, the saponification values calculated obtained using the formula:

\[
\text{Saponification Value} = \frac{56.1(B-S) \times N}{W}
\]

(Where \(B\) = vol. of HCL for blank, \(N\) = normality of standard HCL, \(S\) = vol. of HCL for sample, \(W\) = weight of oil sample)

**Unsaponification Value Determination**

The unsaponification values of the treated oils were determined by weighing 5g each of the respective treated oils into 250ml Erlenmeyer flasks. 50ml of alcoholic KOH solution was pipetted into each flask. The flasks were then connected to an air condenser and boiled for an hour to complete the saponification process. The condenser was then washed with 10ml ethanol. The saponified mixture was then transferred into a separating funnel, rinsed with water and cooled. 50 ml of petroleum ether was then added to each flask and mixed. The lower soap layer was then transferred into another separating funnel and the process repeated three times to get maximum extraction. The ether extract was then washed 3 times with 25ml portions of aqueous alcohol followed by 25 ml portions of distilled water to ensure that the ether extracts are free from alkali. The ether solution was transferred into a 250ml beaker and all ether evaporated into a flask. While heating on a water bath, 2ml of acetone was added to remove solvents completely. The last traces of ether were removed by drying at 100°C for 30 min till constant weight was obtained. The residues were then dissolved in 50ml warm ethanol neutralized to a phenolphthalein endpoint. The solutions obtained were then titrated with 0.02N sodium hydroxide solution. The titrant obtained was used to calculate for the unsaponification value of each sample using the formula:

\[
\frac{100(A-B)}{W}
\]
(Where, $A = \text{wt. of residue}$, $B = \text{wt. of FFA in the extract}$, $W = \text{weight of the sample}$)

**Statistical Analysis**

Normality of data was checked using the Kolmogorov-Smirnov test. The data analysis was done using Graph Pad Prism version 8.00 for windows (GraphPad Software, San Diego California, USA). Baseline characteristics were expressed as mean ± standard error of means (SEM). One-way analysis of variance (ANOVA) with Dunnett’s test was used for multiple comparisons between the oil groups. $P \leq \text{value} < 0.05$ was considered significant.

**Results**

**Table 1.0**

Table 1 depicts palm oil had the highest acid value, whilst coconut had the least acid value between the oils. There were no statistically significant changes in the acid values in the individual oils at different temperature treatment (room temperature 100°C and 200°C).

The acid value represents the degree of degradation of the oil quality resulting from hydrolysis of triacylglycerols of the oils as a result of temperature and moisture on lypolytic enzyme lipase [21-22]. It has been well-established that heating of dietary oils and fats results in oxidation, hydrolysis,
polymerisation and isomerisation. Heating oil elevate the percentage of peroxide value by 8-fold, free fatty acid value by 15-fold, acid value by 14-fold, trans fatty acid isomer value (2.5-fold), p-anisidine value (39-fold), total oxidation value (19-fold), and thiobarbituric acid reactive substance (TBARS) value (8.5-fold) compared to the control [23].

The reactions are deleterious to the stability of fatty acids and other biochemical parameters of the oil [24-25]. Furthermore, vitamin E, which is a natural antioxidant, in the oil also deteriorates after repeated heating [26]. In most food processing particularly deep frying may heat oils to above 180°C.

From this study, first time thermal treatment of oil up to 200°C may not significantly destroy the acid value of the oils.

Table 2.0

There were no significant changes in the iodine (IV) values of the individual oils after thermal treatment (Table 2.0). However, in between the oils the iodine values were significantly higher in the groundnut oil, followed by palm oil after each thermal treatment. This implies there are more unsaturated bonds in groundnut oil compared to palm oil and coconut oil, and coconut oil had the least unsaturation.

The Iodine value (IV) is a measure of the degree of unsaturation in the oils and determines the vulnerability of the oil to oxidation. The higher the iodine value, the more susceptible the oil is to oxidation [22].
Heating of the various oils (Palm, Coconut and Groundnut oils) up to 200°C had no significant effect (p > 0.05) on the iodine values compared to the values of the unheated oils. This was similar to a work reported by Gharby et al. [27], in which heat applied to Virgin Olive oil had no significant effect (p > 0.05) in the iodine values of the oil. This implies no change in the degree of unsaturation of the oil after the thermal treatment, and the oils may not be further susceptible to peroxidation as was observed in the acid values.

3.0 Peroxide Value

The peroxides formed within the various oils (Palm, Coconut and Groundnut) at different temperatures are represented in Table 3.

Table 3.

The peroxide value can be defined as the amount of peroxide oxygen per 1 kilogram of fat or oil according to Kaleem et al. [28]. Oil with peroxide value between 1 and 5 meqO₂/kg is classified as low oxidation state and that between 5 and 10 meq O₂/kg as moderate oxidation and above 10 meq O₂/kg classified as high oxidation state [29].

Oxidative reactions of the oils can be affected by heat [30-31], oils with a higher degree of unsaturation are highly susceptible to autoxidation and hence the best test for autoxidation (oxidative rancidity) is the determination of the peroxide value (PV), because peroxides are intermediates in the autoxidation reaction [32].

There were no peroxides in palm oil at room temperature and at a100°C heating but very low oxidation (6.63 meq O₂/kg) at 200°C. At room temperature coconut oil similarly had no peroxide value but trace amount at 100°C and a very significant quantity at 200°C. Groundnut oil on the
other hand showed comparatively significant number of peroxides at room temperature 8.77 ±
0.100 meq O₂/kg and significantly high values at 100°C and 200°C. Autoxidation of palm oil is
protected by its high antioxidant properties consisting of vit E, carotenes etc and comparatively
higher degree of saturation [33].

Contrarily, because of the high degree of unsaturation in groundnut oil it was more oxidized even
at room temperature hence a high peroxide value.

4.0 Saponification Value

The Table 4.0 below represents the mean saponification values of the oils (Palm, Coconut and
Groundnut) after being subjected to different temperatures of heating.

Table 4.0

The saponification value of oil is the number of mg of potassium hydroxide (KOH) required to
saponify 1g of a fat or oil [34]. High saponification value is an indication that oils are normal
triglycerides. The saponification value is also an estimation of the molecular weight of the fat or
oil, the higher the molecular weight the smaller is its saponification value because larger molecules
have relatively fewer number of carboxylic functional groups per unit mass of the fat. Saponification value also indicates the carbon chain length of the acid present in the oil or fat, the
higher the saponification value, the greater is the percentage of the short chain acids present in the
glycerides of the oil or fats [1-35]. High saponification number is also an indication of high degree
of unsaturation in an oil sample.
The saponification value of coconut oil was significantly higher than that of groundnut and palm oils, (Table 4) this is possibly because of the higher amount of saturation and shorter chain length (lauric acid (C12:0) and or smaller molecular which confers the property of having a higher saponification value [36]. Even though groundnut oil has the higher unsaturation than the other oils but because of its high chain length and or molecular weight (mainly composed of lenoleic (C18:2) and arachidic acid (C20:0)) therefore rather has the lowest saponification value. However, the saponification values of the oils were significantly increased after thermal treatment.

Table 5

Unsaponifiable are components of an oily (oil, fat, wax) mixture that fail to form soaps when treated with sodium hydroxide (lye) or potassium hydroxide. Unsaponifiable constituents are an important consideration when selecting oil mixtures for the manufacture of soaps. Unsaponification values were significantly increased across the three thermal treatments and were higher for palm oils as compared to the other oils (Table 5).

Conclusion

There were no significant changes of acid value in groundnut oil, palm oil and coconut oil at higher temperature compared to the room temperature value, hence there was no significant degree of degradation of the oil quality resulting from hydrolysis of triacylglycerols of the oils as a result of heating. The Iodine value which is a measure of the degree of unsaturation in the oils was not significantly changed, therefore these oils are less susceptible to oxidation at high temperatures. Palm oil and coconut oil had low peroxide value at room temperature, no significant change at
100°C but a significant increase at 200°C. Groundnut oil on the other had comparatively had significant peroxide at room temperature and much higher values at the higher temperatures. The saponification value of coconut oil was significantly higher than that of groundnut and palm oils possibly due to its comparative higher unsaturation and smaller molecular weight. The overall quality of the oils was not significantly changed in just one heating.

References

1. Alajtal AI, Sherami FE, Elbagermi MA. Acid, Peroxide, Ester and Saponification Values for Some Vegetable Oils Before and After Frying. AASCIT Journal of Materials. 2018; 4 (2): 43-47.

2. Lacatusu I, Niculae G, Badea N, Stan R, Popa O, Oprea O, Meghea A. Design of soft lipid nanocarriers based on bioactive vegetable oils with multiple health benefits. Chemical Engineering Journal. 2014;15(246):311-21. [Cited 26 June 2019]. Available from:https://www.sciencedirect.com/science/article/pii/S1385894714001880

3. Vaidya UV, Hegde VM, Bhave SA, Pandit AN. Vegetable oil fortified feeds in the nutrition of very low birthweight babies. Indian pediatrics. 1992;29(12):1519-27. [Cited 26 June 2019]. Available from:https://europepmc.org/abstract/med/1345325

4. Aluyor EO, Ori-Jesu M. The use of antioxidants in vegetable oils—A review. African Journal of Biotechnology. 2008;7(25). [Cited 26 June 2019]. Available from:https://www.ajol.info/index.php/ajb/article/view/59677

5. Innes J K and Calder PC. Omega-6 fatty acids and inflammation. Prostaglandins, Leukotrienes and Essential Fatty Acids 2018; 132, 41-48

6. Hansson GK, Robertson AK, Soderberg-Naucler C. Inflammation and atherosclerosis. Annu Rev Pathol. 2006; 1:297-329.

7. Libby P, Ridker PM, Maseri A. Inflammation and Atherosclerosis. Circulation. 2002;105(9):1135-43.

9. Lemaitre RN. McKnight B, Sotoodehnia N, Fretts AM. Qureshi WT. Circulating Very-Long-Chain Saturated Fatty Acids and Heart Failure: The Cardiovascular Health Study https://doi.org/10.1161/ JAHA.118.010019Journal of the American Heart Association. 2018;7: 21

10. Trevisan M, Krogh V, Freudenheim J, Blake A, Muti P, Panico S, Farinero E, Mancini M, Menotti A, Ricci G. Consumption of olive oil, butter, and vegetable oils and coronary heart disease risk factors. The Research Group ATS-RF2 of the Italian National Research Council. JAMA. 1990; 2;263(5):688-92. Erratum in: JAMA 1990;;263(13):1768. PMID: 2296124

11. Ngalal et al 2015 Ngalal RA, Ampong I, Sakyi SA and Anto EO. Effect of dietary vegetable oil consumption on blood glucose levels, lipid profile and weight in diabetic mice: an experimental case—control study. BMC Nutrition (2016) 2:28
12. Choo YM. Palm oil carotenoids: Food and Nutrition Bulletin, 1994; 15(2) The United Nations University.

13. Nagendra B, Unnithan UR, Choo YM. Characteristics of Red Palm Oil, a Carotene- and Vitamin E–Rich Refined Oil for Food Uses Food and Nutrition Bulletin. (2000;21(2):189-194 DOI: 10.1177/15648265002100213

14. Ng MH, Choo YM. Improved Method for the Qualitative Analyses of Palm Oil Carotenes Using UPLC. J Chromatogr Sci. 2016; 54(4):633-8. doi: 10.1093/chromsci/bmv241. Epub 2016 Mar 2. PMID: 26941414; PMCID: PMC4885407.

15. Nevin KG, Rajamohan T. Beneficial effects of virgin coconut oil on lipid parameters and in vitro LDL oxidation. Clin Biochem. 2004; 37(9):830-5. doi: 10.1016/j.clinbiochem.2004.04.010. PMID: 15329324

16. Liu X, Jin Q, Liu Y, Huang J, Wang X, Mao W, Wang S. Changes in Volatile Compounds of Peanut Oil during the Roasting Process for Production of Aromatic Roasted Peanut Oil. Food Science. 2011;76(3)

17. Anyasor GN, Ogunwemno KO, Oyelana O. Chemical Analyses of Groundnut (Arachis hypogaea) Oil Pakistan Journal of Nutrition. 2009;8(3) DOI: 10.3923/pjn.2009.269.272

18. Chen Y, Yin M, Cao X, Hu G, & Xiao M. Pro- and Anti-inflammatory Effects of High Cholesterol Diet on Aged Brain. Aging and disease. 2018; 9(3), 374–390. https://doi.org/10.14336/AD.2017.0706

19. Chun-Yi N, Xin-Fang L, Norliana M, Siti KA, Yusof K, Kamsiah J. Heated vegetable oils and cardiovascular disease risk factors Vascular Pharmacology. 2014; 61, (1):1-9

20. AOAC. (1990). Official methods of analysis of the AOAC, 15th ed. Methods 932.06, 925.09, 985.29, 923.03. Association of official analytical chemists. Arlington, VA, USA.

21. Vaskova H, Buckova M. Thermal Degradation of Vegetable Oils: Spectroscopic Measurement and Analysis 25th DAAAM International Symposium on Intelligent Manufacturing and Automation, DAAAM 2014 Procedia Engineering 100 630 – 635

22. Ngassapa FN, Nyandoro S and Mwaisaka TR. Effects of temperature on the physicochemical properties of traditionally processed vegetable oils and their blends Tanz. J. Sci. 2012; 38(3), 166-176

23. Awney HA. The effects of Bifidobacteria on the lipid profile and oxidative stress biomarkers of male rats fed thermally oxidized soybean oil Biomarkers, (2011; 16 (5): 445-452

24. Giua L, Blasi F, Simonetti MS, Cossignani L. Oxidative modifications of conjugated and unconjugated linoleic acid during heating. Food Chem. 2013;140(4):680-5. doi: 10.1016/j.foodchem.2012.09.067. Epub 2012 Sep 28. PMID: 23692753.

25. Malvis A, Peter Š, Tibor D, Sládková A, Aleš Ház, Jablonsky M, Sekretár S, Schmidt S, František K, Zuzana B, Gassan H, Igor Š. "Determination of the Thermal Oxidation Stability and the Kinetic Parameters of Commercial Extra Virgin Olive Oils from Different Varieties", Journal of Chemistry, 2019; 8 .

https://doi.org/10.1155/2019/4567973

26. Adam SK, Sulaiman NA, Mat Top AG, Jaarin K. Heating reduces vitamin E content in palm and soy oils Malays J Biochem Mol Biol. 2007; 15 (2): 76-79
27. Gharby S, Harhar H, Matthäus B, Bouzoubaa Z, and Charrouf Z. The chemical parameters and oxidative resistance to heat treatment of refined and extra virgin Moroccan Picholine olive oil. Journal of Taibah University for Science. 2016;10: 100.

28. Kaleem A, Aziz S, Iqtedar M, Abdullah R, Aftab M, Rashid F, Shakoori FR and S Naz S. Investigating changes and effect of peroxide values in cooking oils subject to light and heat. FUUAST J. BIOL. 2015; 5(2):191-196

29. Codex Alimentarius 2006 : and Codex Standard for named Vegetable oils: Codex-Stand

30. Araújo JMA. Food Chemistry: Theory and Practice. UFV. 2004; 416

31. Falade AO and Oboh G. Thermal Oxidation Induces Lipid Peroxidation and Changes in the Physicochemical Properties and β-Carotene Content of Arachis Oil International Journal of Food Science Volume 2015 |Article ID 806524 |
https://doi.org/10.1155/2015/806524

32. Moreno JJ, Mitjavila MT. The degree of unsaturation of dietary fatty acids and the development of atherosclerosis (review). J Nutr Biochem. 2003;14(4):182-95. doi: 10.1016/s0955-2863(02)00294-2. PMID: 12770642.

33. Balasundram N, Ai TY, Sambanthamurthi R, Sundram K, Samman S. Antioxidant properties of palm fruit extracts. Asia Pac J Clin Nutr. 2005;14(4):319-24. PMID: 16326638.

34. Carrero Á. Pérez A. 5 - Advances in biodiesel quality control, characterisation and standards development, Advances in Biodiesel Production, Processes and Technologies, Woodhead Publishing Series in Energy. 2012. 91-130

35. Odoom W and Eduse VO. Evaluation of Saponification value, Iodine value and Insoluble impurities in Coconut Oils from Jomoro District in the Western Region of Ghana. Asian Journal of Agriculture and Food Sciences. 2015, 3(5) 494-499

36. Abayeh OJ, Aina EA and Okuonghae CO. Oil content and oil quality characteristics of some Nigerian oil seeds. J. Pure and Applied Sci. 1998;1: 17-23.