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## Comparative Study on Ultraviolet Irradiation of Epoxidized and Non-Epoxidized Sunflower, Soybean, and Olive Oil

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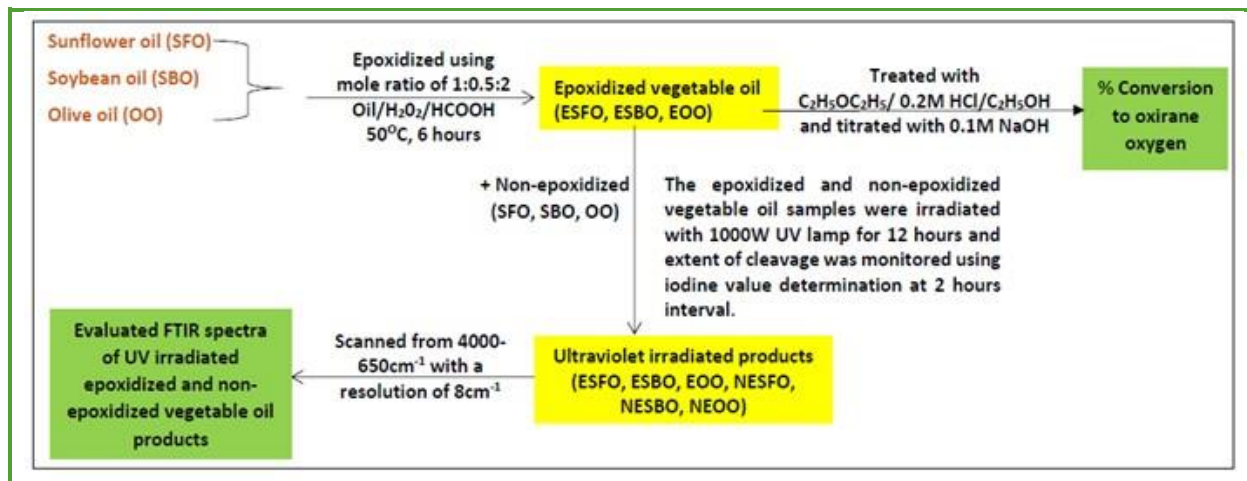
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### ABSTRACT

The degree of photochemical cleavage of epoxidized and non-epoxidized oils of sunflower (*Helianthus annuus*), soybean (*Glycine max*), and olive (*Olea europaea*) exposed to 1000 watts ultraviolet light (UV) at different times were studied using iodine value and infrared spectroscopy. The epoxidation was conducted with a mole ratio of 1:0.5:2 for the oil, hydrogen peroxide and formic acid, respectively, for 6 hours at 50 °C. The oxirane oxygen content and their percentages of conversion to epoxides for the oils were: sunflower oil (6.75, 89.52 ± 0.25%), soybean oil (7.10, 95.95 ± 0.33%), and olive oil (4.25, 84.89 ± 0.18%), respectively. The results showed that the difference in oxirane oxygen content between sunflower and soybean oils corroborate the slight increases in iodine value of the irradiated oils. The oxirane oxygen content of epoxidized olive oil established the baseline value for monounsaturated oils. The results for the UV irradiation showed that after twelve hours of irradiation, the iodine value increased for non-epoxidized sunflower oil and non-epoxidized soybean oil, while it decreased for non-epoxidized olive oil. However, the iodine values of epoxidized sunflower oil and epoxidized soybean oil increased, while the epoxidized olive oil decreased. It was suggested that the increases observed in the iodine values for non-epoxidized and epoxidized sunflower and soybean oils were as a result of molecular rearrangement of the alkene functional groups and recyclization of the cleaved epoxides residues after irradiation due largely to multiple bond effect. This effect is more marked in sunflower oil with 63% polyunsaturated fatty acid content, than in soybean oil with 61% polyunsaturated fatty acid content. This result corroborates the C-H deformation vibration at 1379 cm<sup>-1</sup> as evidences of cyclized products. The monounsaturated olive oil characterized by a marked reduction in iodine value for both the non-epoxidized and epoxidized oils indicated marked reduction in unsaturation as it has only one double bond per molecular chain. Thus, the possibility of molecular rearrangement or recyclization of epoxidized residues is unlikely as shown by the results. Hence, the monounsaturated olive oil produced more stable cleaved products as evidenced by a marked reduction in the iodine value of the products.  
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## Graphical Abstract



## Introduction

The rapid depletion of fossil resources in the world and the increasing demand for green fuels and cleaner technology with significantly reduced carbon footprint and environmentally friendly products has spurred interest in the chemistry and conversion of oils and its applications for the chemical industry [1].

Chemicals are used to make a wide variety of consumer goods, as well as thousands of products that are essential inputs to agriculture, manufacturing, construction, and service industries. The chemical industry itself consumes about 26% of its own output converting raw materials into more than 70,000 different products [2].

Major industrial chemical consumers include rubbers and plastics, textiles, petroleum refineries, primary metals, pulp and paper industries, etc. Initially, the manufacture of these organic chemicals started with coal and alcohol from fermentation industry, petroleum, and natural gas later dominated the scene [3].

However, the ever-increasing cost of petrochemicals has diverted the attention of chemists to synthesize chemicals derived from natural fatty acids and the other biomass.

Vegetable oils are substances extracted from plants, composed mainly of triglycerides. About 90-95% of the total weight of these triglycerides are fatty acids which are primarily saturated or unsaturated (monounsaturated or polyunsaturated) and whose content is characteristic of each plant oil [4]. The fatty acid composition of vegetable oils influences their functionality, reactivity, oxidative stability, and determines their uses [5, 6].

Sunflower oil pressed from the seeds of *Helianthus annuus* contains about 90% unsaturated fatty acids (Oleic and Linoleic) and approximately 10% saturated fatty acids (Palmitic and stearic). The fatty acid composition of sunflower oil depends on environmental conditions and genetics [6].

Soybean oil (*Glycine max*) is the second most consumed oil seed in the world [7]. It contains on average, a complex mixture of Linoleic acid (54.41%), Linolenic acid (7.93%), Oleic acid (21.63%), Palmitic acid (12.12%), and Stearic acid (3.92%) [8]. Olive oil (*Olea europaea*) is a traditional crop of the Mediterranean Basin. Its fatty acid composition depends on the cultivar, maturity of the fruit, altitude, and climate.

It contains unsaturated fatty acids e.g., oleic acid (53.83%), Linoleic acid (3.5-21%), Linolenic

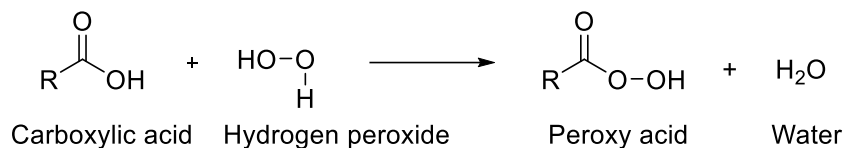
acid (0-1.5%), and saturated fatty acids such as Stearic acid, 0.5-5% and Palmitic acid, 7.5-20% [9].

Epoxidation of vegetable oils defines a process which involves the addition of an atom of oxygen to each carbon-carbon double bond present in an unsaturated fatty acid chain using

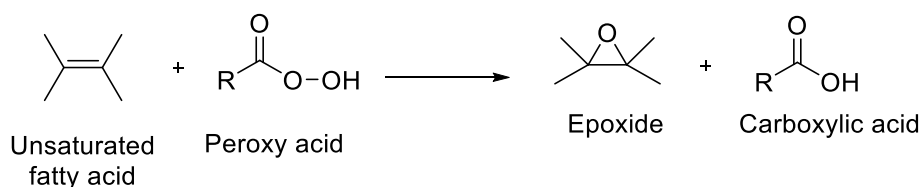
oxidizing agents such as hydrogen peroxide, which ultimately alters the carbon skeleton of the precursor unsaturated fatty acid chain into one containing an epoxy group [10].

It involves two major stepwise reactions as follow:

Step 1:



Step 2:



During the first reaction- step 1, peroxy acid is formed from the reaction of a carboxylic acid (formic or acetic acid) and hydrogen peroxide while step 2 involves the production of the epoxidized oil from the reaction between the peroxy acid and the olefinic bonds present in the oil [11]. The epoxidized vegetable oil has become a promising reactive intermediate, since the epoxy group can be converted into the other functional groups through various degradation reactions [12].

The Ultraviolet light (UV) is most often used to effect photochemical change. Studies on the use and efficiency of ultraviolet radiation in splitting organic molecules and breaking of chemical bonds carried out by some researchers showed significant results [13, 14].

Absorption of ultraviolet light by a molecule introduces energy sufficient to break or reorganize covalent bonds. With most organic compounds requiring energy of 150 kJ/mol to 1000 kJ/mol to break their molecular bonds, ultraviolet light having wavelength ranging from

200-400 nm corresponding to approximately 300-600 kJ/mol [15] can dissociate relatively strong bonds such as C-O (350 kJ/mol), C=C (611 kJ/mol), and so on [16]. Consequently, an epoxidized molecule containing a C-O bond is even more susceptible to photocleavage by the ultraviolet radiation compared to that with a C=C bond. Furthermore, since light in the UV region can only be absorbed by molecules containing non-bonding atoms, C-O or pi bonds, C=C [17], both epoxidized and non-epoxidized forms of the unsaturated fatty esters are the UV active. The Fourier Transformed Infrared (FTIR) Spectrophotometry is a promising instrumental technique used in the analysis of compounds and it provides distinct information required for structural elucidation of most organic and inorganic substances based on the intensity and number of peaks that occur at specific wavenumbers and regions across the infrared spectrum [18]. This technique provides a means for analyzing/monitoring the structural modification of compounds exposed to

ultraviolet radiation. This work focuses on the infrared studies of epoxidized and non-epoxidized unsaturated fatty acid esters cleaved with the UV radiation, with a view to obtaining information about the cleaved products, thereby suggesting their likely application(s) for the growing chemical industry.

## Experimental

### Sample collection

Sunflower oil, soybean oil, and olive oil were purchased from a supermarket in Ekpoma, Esan West Local Government Area, Edo state, Nigeria. The basic information of the purchased vegetable oil is shown in Table 1 below.

The experiments were carried out August, 2021, in the Laboratory, Department of Chemistry, Faculty of Physical Sciences, Ambrose Alli University, Ekpoma, Edo state, Nigeria.

### Methods

#### Epoxidation of the vegetable oil samples

The equivalent mole ratios (1:0.5:2) of sunflower oil, formic acid, and hydrogen peroxide respectively were measured and the syntheses were carried out as described by Gamage, O'Brien and Karunanayake [19], and Meadows *et al.* [20] with slight modifications. The equivalent mole ratio (1:0.5) of sunflower oil

(1 mole) and formic acid (0.5 mole) were measured and poured into a three necked round bottom flask containing a magnetic stirrer and a thermometer. The flask was placed in a water bath on a magnetic stirrer heating mantle. The mixture was stirred continuously at 50 °C. 2 mole ratio of 30% (w/v) hydrogen peroxide (H<sub>2</sub>O<sub>2</sub>) was added gradually (dropwise over 15 minutes) to the heated mixture to begin the epoxidation process after reducing the temperature by 5 °C to prevent a drastic rise in temperature due to the exothermic nature of the hydrogen peroxide. The reaction was carried out for six hours. At the end of the reaction, the epoxidized sunflower oil was allowed to cool to room temperature. The oil was filtered and washed severally with distilled water to remove excess formic acid and hydrogen peroxide using a separatory funnel. 5% (w/v) of sodium bicarbonate (NaHCO<sub>3</sub>) was then used to neutralize the product formed. The epoxidized oil product was isolated by separatory funnel method. This process was repeated for the soybean and olive oil samples.

#### Determination of oxirane oxygen content (OOCe)

The oxirane oxygen content of each epoxidized vegetable oil samples of sunflower oil, soybean oil, and olive oil were determined according to the procedure described by Jabar and Olagboye [21].

**Table 1.** Basic information on the purchased samples of vegetable oil

Vegetable oil	Production date	Expiration date	Brand name and manufacturer
Sunflower oil	N/A	28/09/2022	TROPICAL SUN 100% Pure sunflower oil: Tropical Sun Foods, United Kingdom
Soybean oil	20/04/2021	20/04/2022	GOLDEN PENNY Pure soybean oil: Flour Mills of Nigeria Plc.
Olive oil	26/02/2020	26/02/2025	LASER Extra virgin olive oil (First Cold Press): Sun Mark Limited, Green Ford, England.

N/A: Not Available

Aliquots of each epoxidized vegetable oil was weighed and introduced into different 250 mL conical flask, and then 5 ml of diethyl ether and 10 mL of 0.2 M hydrochloric acid was added to each flask to facilitate opening of the oxirane ring by attaching the HCl to the carbon atoms carrying the oxirane oxygen. The mixtures were allowed to stand for 3 hours at room temperature. After that, 50 mL of ethanol was used to dissolve the oil sample and two drops of phenolphthalein indicator was added to each flask and titrated with 0.1 M solution of NaOH to determine the acid content of the oil until the solution turned pink. Each experiment was carried out in triplicate. A blank solution was further prepared using same procedure but without the oil sample.

The percentage (%) oxirane oxygen content of the epoxidized oil was calculated as follows:

$$OOC_e = \frac{(V_b - V_s) \times M \times 16 \times 100}{W \times 1000} \quad (1)$$

Where,  $OOC_e$  = Oxirane Oxygen Content, Experimental

$V_b$  = Volume of 0.1 M NaOH required for blank solution ( $\text{cm}^3$ )

$V_s$  = Volume of 0.1 M NaOH required to neutralize the acid in  $W$  grams of sample ( $\text{cm}^3$ )

$M$  = Molarity of NaOH (M)

$W$  = Weight of the sample (g)

The oxirane oxygen content predicted can be determined using Equation (2):

$$OOC_p = \left\{ \frac{\left( \frac{IV_0}{2A_i} \right)}{100 + \left( \frac{IV_0}{2A_i} \right) A_0} \right\} \times A_0 \times 100 \quad (2)$$

Where,  $OOC_p$  is the maximum predicted oxirane oxygen content,  $A_i$  and  $A_0$  are the atomic weights of iodine (126.9 amu) and oxygen (16.0 amu), respectively, and  $IV_0$  is the iodine value of the vegetable oil under study [22]. The conversion of unsaturation to epoxy group was calculated by Equation (3) [22].

$$\% \text{ conversion} = \frac{OOC_e}{OOC_p} \times 100 \quad (3)$$

Where,

$OOC_e$  = Oxirane Oxygen Content (experimental)

$OOC_p$  = Oxirane Oxygen Content predicted (theoretical)

*UV irradiation of the epoxidized and non-epoxidized samples of vegetable oil and determination of iodine values*

10 mL of the epoxidized and non-epoxidized samples of each vegetable oil were measured into different test tubes and exposed to a 1000 watts ultraviolet light for 2, 4, 6, 8, 10, and 12 hours, respectively. The reaction was monitored by withdrawing aliquot of the illuminated oil samples in accordance with the expected iodine number as described by ASTM [23]. At two hours interval, into different conical flasks. 20 ml of carbon tetrachloride ( $\text{CCl}_4$ ) and 25 ml of Wij's solution was added and shaken. The Wij's solution contains the halogens (iodine and chlorine) was added to the carbon-carbon double bonds in the unsaturated fatty acids, and then the flasks were covered with a foil paper and stored in the dark for 30 minutes. Thereafter, 20 mL of 10% (w/v) potassium iodide (KI) solution was added to reduce the unreacted ICl to free iodine  $\text{I}_2$  followed by 100 ml of distilled water, and then the solutions were titrated with 0.1 N of  $\text{Na}_2\text{S}_2\text{O}_3 \cdot 5\text{H}_2\text{O}$  solution to determine the unreacted halogens with constant shaking until the pale yellow color almost disappeared. 1-2 mL of 1% (w/v) starch indicator solution was added and titrated until the pale blue color gradually turned colorless. Each experiment was carried out in triplicate. A blank was also determined using the above procedure in the absence of the vegetable oil samples. The volumes of sodium thiosulphate used were recorded and the iodine value was calculated as follows:

$$I = \frac{(B-S) \times N \times 12.69}{W} \quad (4)$$

Where,

I= Iodine Value expressed as g I<sub>2</sub>/100 g oil

B= Volume of sodium thiosulphate used to titrate blank (cm<sup>3</sup>)

S= Volume of sodium thiosulphate used to titrate sample (cm<sup>3</sup>)

N= Normality of sodium thiosulphate (N)

W= Weight of the oil sample (g)

#### *Fourier Transform Infrared analysis of the UV irradiated epoxidized and non-epoxidized samples of vegetable oil*

The functional groups present in the epoxidized and non-epoxidized vegetable oil samples of sunflower oil, soybean oil, and olive oil were analyzed using the Fourier Transform Infrared Spectrometer before and after exposure to ultraviolet radiation for 12 hours. The Shimadzu FT-IR machine equipped with Attenuated Total Reflection was used to obtain an infrared spectrum of the absorbed emissions. Each sample was scanned from 4000-650 cm<sup>-1</sup> with a resolution of 8 cm<sup>-1</sup>.

### Results and Discussion

Table 2 presents results for oxirane oxygen content for sunflower oil (*Helianthus annuus*), soybean oil (*Glycine max*), and olive oil (*Olea europaea*). The maximum predicted OOC obtained theoretically for sunflower oil was 7.54 while the experimentally determined oxirane oxygen content was 6.75. The relative conversion to oxirane oxygen was 89.52 ± 0.25%. Similarly, the maximum predicted OOC obtained theoretically for soybean oil and olive oil were 7.40 and 5.03, respectively, while the experimentally determined oxirane oxygen content were 7.10 and 4.25, respectively. Soybean oil had a 95.95 ± 0.33% relative

conversion to oxirane oxygen while olive oil had 84.49 ± 0.18% conversion to oxirane oxygen.

The results show that almost all the double bonds in the vegetable oil analyzed were converted into the oxirane ring, with epoxidized soybean oil exhibiting the highest oxirane oxygen content. The results suggest that the relative decrease in conversion to oxirane as observed in sunflower oil and olive oil are due to reaction conditions such as temperature fluctuations. Higher temperature results in degradation/cleavage of the epoxide rings and possible side reactions. This leads to a decrease in the rate of epoxidation and consequently, lower oxirane oxygen content [11, 20]. While Meadows *et al.* [20] analyzed the epoxidation of soybean oil obtained 98% relative conversion to oxirane at 50 °C but at 60 °C while maintaining other reaction conditions, 85.35% oxirane yield was obtained. The result shows that optimum yield of oxirane conversion can be attained if the optimum reaction time (6 hours), temperature (50 °C) and molar ratio of oil to hydrogen peroxide and formic acid (1:0.5:2) are maintained as described by Derawi *et al.* and Meadows *et al.* [24]. However, in this study, the difference in oxirane oxygen content between sunflower oil and soybean oil corroborates the slight increases in iodine value of the irradiated raw oils. The oxirane oxygen content of epoxidized olive oil establishes the baseline value for monounsaturated oils. Moreover, the iodine values of the epoxidized sunflower oil, soybean oil, and olive oil (9.64 ± 0.12, 3.54 ± 0.16, and 10.05 ± 0.23 gI<sub>2</sub>/100 g of oil, respectively) in Table 3 at initial time zero compared to the non-epoxidized vegetable oils (80.71 ± 0.22, 82.23 ± 0.32, and 55.77 ± 0.24 gI<sub>2</sub>/100 g of oil, respectively) corroborates the results of oxirane conversion which shows that almost all the double bonds present in the vegetable oil samples were converted into oxirane rings [24].

**Table 2.** Data of oxirane oxygen content for sunflower oil, soybean oil, and olive oil

Vegetable Oil	OOCP	OOCE	% Conversion
Sunflower Oil	7.54	6.75	89.52 ± 0.25
Soybean Oil	7.40	7.10	95.95 ± 0.33
Olive Oil	5.03	4.25	84.49 ± 0.18

\*OOCP =Oxirane Oxygen Content predicted (theoretical); OOCE =Oxirane Oxygen Content (experimental)

**Table 3.** Iodine values for the UV irradiated epoxidized and non-epoxidized sunflower oil, soybean oil, and olive oil

Time (Hours)	NESFO (gI <sub>2</sub> /100 g of oil)	ESFO (gI <sub>2</sub> /100 g of oil)	NESBO (gI <sub>2</sub> /100g of oil)	ESBO (gI <sub>2</sub> /100 g of oil)	NEOO (gI <sub>2</sub> /100 g of oil)	EOO (gI <sub>2</sub> /100 g of oil)
0	80.71 ± 0.22	9.64 ± 0.12	82.23 ± 0.32	3.54 ± 0.16	55.77 ± 0.24	10.05 ± 0.23
2	84.26 ± 0.31	9.69 ± 0.23	83.75 ± 0.14	3.43 ± 0.23	44.00 ± 0.02	8.34 ± 0.07
4	84.26 ± 0.25	9.92 ± 0.20	84.26 ± 0.22	3.45 ± 0.20	55.77 ± 0.15	10.05 ± 0.19
6	84.77 ± 0.42	9.92 ± 0.22	83.75 ± 0.17	3.58 ± 0.19	55.77 ± 0.12	8.08 ± 0.17
8	84.77 ± 0.33	9.92 ± 0.23	83.75 ± 0.20	3.54 ± 0.22	44.00 ± 0.08	8.08 ± 0.18
10	85.28 ± 0.31	9.92 ± 0.19	84.26 ± 0.21	3.56 ± 0.20	47.42 ± 0.21	10.15 ± 0.07
12	84.77 ± 0.28	9.92 ± 0.20	84.26 ± 0.20	3.56 ± 0.22	44.00 ± 0.01	8.08 ± 0.15

\*Key: NESFO = Non-Epoxidized Sunflower Oil; ESFO = Epoxidized Sunflower Oil; NESBO = Non-Epoxidized Soybean Oil; ESBO = Epoxidized Soybean Oil; NEOO = Non-Epoxidized Olive Oil; EOO = Epoxidized Olive Oil

Table 3 summarizes the iodine values for the UV irradiated epoxidized and non-epoxidized sunflower oil, soybean oil, and olive oil. The results of the irradiation showed that after twelve hours the iodine value increased from 80.71 ± 0.22 to 84.77 ± 0.28 gI<sub>2</sub>/100 g of oil for non-epoxidized sunflower oil, 82.23 ± 0.32 to 84.26 ± 0.20 gI<sub>2</sub>/100 g of oil for non-epoxidized soybean oil, while it decreased from 55.77 ± 0.24 to 44.00 ± 0.01 gI<sub>2</sub>/100g of oil for non-epoxidized olive oil. However, the iodine values of epoxidized sunflower oil and epoxidized soybean oil increased from 9.64 ± 0.12 to 9.92 ± 0.20 gI<sub>2</sub>/100 g of oil and 3.54 ± 0.16 to 3.56 ± 0.22 gI<sub>2</sub>/100g of oil, respectively, while the epoxidized olive oil decreased from 10.05 ± 0.23 to 8.08 ± 0.15 gI<sub>2</sub>/100 g of oil. Nweke *et al.* [25] studied the rate of photo oxidation in olive oil and revealed that vegetable oils are sensitive to photochemical change. Nevertheless, the rate of photo cleavage is affected by factors such as the presence of oxygen, intensity of radiation, degree of unsaturation, and temperature [26]. The study revealed that olive oil a mono unsaturated fatty

ester is more susceptible to photochemical cleavage than sunflower and soybean oil which are poly unsaturated. It was suggested that the increases observed in the iodine values for non-epoxidized and epoxidized sunflower and soybean oils were as a result of molecular rearrangement of the alkene functional groups and recyclization of the cleaved epoxides residues after irradiation due largely to multiple bond effect. This effect is more marked in sunflower oil with 63% polyunsaturated fatty acid content than in soybean oil with 61% polyunsaturated fatty acid [27]. This result corroborates the C-H deformation vibration at 1379 cm<sup>-1</sup> as evidences of cyclized products [28]. The monounsaturated olive oil characterized by a marked reduction in iodine value for both the non-epoxidized and epoxidized oils indicates a marked reduction in unsaturation as it has only one double bond per molecular chain. Thus, the possibility of molecular rearrangement or recyclization of epoxidized residues is unlikely as shown by the results.

The FT-IR spectrum was used to identify the functional groups in the UV irradiated epoxidized and non-epoxidized samples of sunflower oil, soybean oil, and olive oil based on the peak values (wavenumbers and transmittance) observed in the infrared region in Figures S1, S2, S3, S4, S5, S6, S7, S8 and S9, respectively (Supporting information). The spectra of vegetable oil samples confirmed the presence of C=O overtone stretching vibration of esters  $3485\text{ cm}^{-1}$  and  $3473\text{ cm}^{-1}$ , =C-H stretch of alkenes in the region above  $3000\text{ cm}^{-1}$ , and symmetric and asymmetric C-H stretching of  $\text{CH}_3$  alkanes at  $2922.2$  and  $2855.1\text{ cm}^{-1}$ , respectively, C=O stretching vibration of carbonyl ester ( $1744.4\text{ cm}^{-1}$ ) a major functional group of fatty acid esters (triglycerides) which was confirmed by the C-O stretch of esters observed at  $1237.5\text{ cm}^{-1}$ ,  $1159.2\text{ cm}^{-1}$ , and  $1095.8\text{ cm}^{-1}$  (functional group region) and the -C-H bend (rocking) of methylene were all present in the samples of vegetable oil. FTIR studies on some selected vegetable oil have shown that these functional groups are typical of all triglycerides-the major components of all vegetable oil [29, 30]. Figures S1, S2 and S3 (Supporting information) demonstrate the absorption spectra for sunflower oil, the UV irradiated non-epoxidized and the UV irradiated epoxidized sunflower oil, respectively. The FTIR spectra all show similar absorption peaks with varying percentage (%) transmittance value. Transmittance is a fraction/quantity (I/I<sub>0</sub>) of incident light that passes through a substance. High transmittance means that there are fewer bonds to absorb light in the sample while a low transmittance indicates high number of bonds having vibrational energies that corresponds to the incident light. The UV irradiated non-epoxidized and the UV irradiated epoxidized sunflower oil in Figures S2 and S3 (Supporting information) showed higher transmittance values at  $3008.0\text{ cm}^{-1}$  and  $3011.7\text{ cm}^{-1}$  range (=C-H Stretch of

alkenes) compared to the non-irradiated sunflower oil sample in Figure S1 (Supporting information) indicating that there are fewer bonds corresponding to those wave numbers present in the sample after 12 hours of the UV irradiation. Similar trend was observed in Figures S5, S6, S7, S8 and S9 (Supporting information) for the UV irradiated non-epoxidized soybean oil, the UV irradiated epoxidized soybean oil, the UV irradiated non-epoxidized olive oil, and UV irradiated epoxidized olive oil, respectively, compared to their non-irradiated (soybean and Olive) forms in Figures S4 and S7, respectively (Supporting information). Furthermore, the epoxidized forms of the vegetable oil samples had higher transmittance compared to the other vegetable oil samples investigated signifying that they contain the least number of bonds within their molecule after the UV irradiation.

Darawi *et al.* [24] analyzed the degree of epoxidation of palm olein by FT-IR and reported the presence of oxirane ring at  $844\text{ cm}^{-1}$  while Meadows *et al.* [20] analyzing the degree of epoxidation of soybean oil using FT-IR analysis reported the presence of oxirane ring at  $822\text{ cm}^{-1}$ . The UV irradiated epoxidized sunflower oil, soybean oil, and olive oil in Figures S3, S6, and S9, respectively (Supporting information), all showed absence of the oxirane ring peak between  $820\text{-}845\text{ cm}^{-1}$  though, the result from oxirane oxygen content showed significant conversion of the olefinic bonds into oxirane rings. The result suggests that exposure of the epoxidized vegetable oils to the ultraviolet light must have led to cleavage/relief of the ring strain which exist within the oxirane molecule. Figures S8 and S9 (Supporting information) showed no absorption peak of alkenes in the fingerprint region of the UV irradiated non-epoxidized and epoxidized olive oil spectra, respectively, but the non-irradiated samples of olive oil in Figure S7 (Supporting information) ( $872.2\text{ cm}^{-1}$ ), the UV



spectra of sunflower oil (913.2  $\text{cm}^{-1}$  and 887.7  $\text{cm}^{-1}$ ) and soybean oil (969.1  $\text{cm}^{-1}$  and 913.2  $\text{cm}^{-1}$ ), all showed the presence of alkene groups. The fingerprint region (1400-600  $\text{cm}^{-1}$ ) confirms the presence or absence of functional groups tentatively identified in the functional group region [31]. The result suggests that since olive oil is a mono-unsaturated vegetable oil, it is more susceptible to the UV cleavage that give rise to stable products compared to sunflower oil and soybean oil which are polyunsaturated vegetable oils. Hence, the possible absence of the peak in the UV irradiated non-epoxidized and epoxidized olive oil spectra. The FTIR analysis of the samples of vegetable oil displayed notable wavenumbers which were suitable as useful analytical markers to check not only the presence/absence of distinct functional groups, but also to quantitatively ascertain increase/decrease in the number of bonds within the samples as observed in the intensity of peaks and the transmittance studied.

## Conclusion

Photo-irradiation of vegetable oil is a viable way of effecting structural changes in vegetable oil. From the study, both the epoxidized and non-epoxidized unsaturated fatty esters of sunflower, soybean, and olive oil when exposed to ultraviolet irradiation are sensitive to photochemical reaction that can result in changes in their molecular structures. This supports earlier studies that suggests the use of plant-based oil as an alternative feedstock for the growing chemical industry. However, the study has shown that a mono-unsaturated vegetable oil (olive oil) produced more stable cleaved products than poly-unsaturated vegetable oils (sunflower and soybean).

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## Authors' Contributions

All authors contributed to data analysis, drafting, and revising of the paper and agreed to be responsible for all the aspects of this work.

## Supporting Information

Copies of FT-IR spectra of Sunflower, Soybean, and Olive Oil.

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