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Interaction of Edible Vegetable oils with Visible Light: Implications for Food Quality

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Abstract
The practice of exposing edible vegetable oils to light and the effect on food quality was the focus of this study. Palm and groundnut oil were studied under the influence of different wavelengths of light corresponding to red, blue, and green light for about a period of one month during which the acid values, free fatty acid values, peroxide values, and iodine values were monitored. Results indicated that both acid values and free fatty acid values of the two oil types increased directly with light in the order of red > blue > green light respectively. Second, light had barely little effect on the peroxide values of the two oils during the storage period. Third, the light had a weak effect on the iodine values of the two oil types studied. Fourth, groundnut oil was safer for consumption than palm oil after a long period of exposure to light. It was concluded that indiscriminately exposing these oils to light affected their quality as it led to increased hydrolysis of triglycerides. It was recommended that oils should be packaged in amber containers to limit the absorption of incident light.

Keywords: vegetable oil, incident light, acid value, free fatty acids value, wavelength.

INTRODUCTION
The interaction between matter and electromagnetic radiation in the environment is significant and inevitable. Electromagnetic radiation affects matter in two decisive ways depending on the wavelength of the incident radiation absorbed. If the energy of the radiation is high (short wavelength), it can cause the ionization of matter (Çalişkan, 2017; WHO, 2023). Conversely, if the energy is low (longer wavelength), the molecules of matter become excited but not ionized. Excitation of matter can lead to electronic transition, vibrational, and rotational motion in molecules depending on the particular wavelength of the incident radiation that is absorbed.

When energy in the region of the gamma to ultraviolet ray is absorbed by matter, ionization occurs which could be damaging (deleterious) (Blanco *et al*., 2018; US EPA, 2023). The other spectrum of electromagnetic radiation is non-ionizing but causes significant excitation of matter that can result in certain chemical reactions (Aggarwal and Gupta, 2011; Deniz *et al*., 2017; WHO, 2016).

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In sub-Saharan Africa, it is common practice to store and display edible palm and groundnut oil (palmitic and oleic acids respectively) inadvertently on open shelves under the direct impact of the sun. The natural hot tropical environment is already primed towards stimulating senescence and decay. It should therefore be expected that these oils would be impacted by light and the consequent heat from the sun (de Souza *et al*., 2020).

Oils are differentiated from fats by their being liquids at room temperature (Centre for Food Safety, 2015; Shenai, 2023). The factor that confers this liquid status is traced to their possession of several unsaturated pi-bonds (polyunsaturation) (Klonoff, 2007). On this basis, oils are classified as monounsaturated or polyunsaturated. Examples are oleic acid (Omega-9), linoleic acid (Omega-6), and linoleic acid (Omega-3). The omega classification depicts the position of the first double bond in the fatty acid molecule.

In palm oil, the ratio of the saturated to unsaturated fatty acids proportion is approximately one (1) (Boateng *et al*., 2016; Japir *et al*., 2018). Whereas groundnut oil, is predominantly unsaturated fatty acids, this distinction makes groundnut oil more susceptible to chemical reactions, especially environment-induced chemical changes (Culler *et al*., 2021; Wang *et al*., 2021). The degree of unsaturation is a determinant of the stability of oil. Lipid oxidation occurs when olefinic (double) bonds are oxidized. Heat promotes lipase activity of FFA formation by atmospheric oxygen leading to free radical formation at mild temperatures (Rashid *et al*., 2022) above which lipase enzyme is inactivated. In the real world of domestic and commercial food preparation and storage, oils are exposed to oxygen, water, heat, and light. Common sources of light on food are Sunlight from outdoors, storefronts, windows, and skylights; incandescent lights from coolers and storage facilities; fluorescent bulbs from food processing areas, display cases, and food preparation areas (Prasad *et al*., 2020).

Light and food-related interactions have inadvertently been associated with aesthetics (displays to attract customers) and sometimes heat-related to keep food warm by food vendors and traders. Attention has hardly focused on what effects light energy has on the food products and the eventual impact on food quality. A few papers found in literature studied the effect of sunlight (Henry, 2016; Djikeng *et al*., 2019; and Dodoo *et al*., 2021) and heat (Araujo *et al*., 2018) on the physicochemical parameters, particularly photo-oxidation of some vegetable oils. In this present study, we examine the impact of different (visible) light energy on the wholesomeness of palm and groundnut oil as a consequence of their exposure to light.

MATERIALS AND METHODS

Samples:

Vegetable oil samples used are Groundnut oil and Palm oil. For the purpose of this study, palm oil refers to palmitic acid while oleic acid is generally referred to as groundnut oil in Nigerian parlance. These were bought fresh from the market and stored in the refrigerator before use.

Storage:

A pair of groundnut and palm oil samples in two 150 mL beakers were placed each in three identical cartons of about 35 x 50 m dimensions; that is, each carton contained a pair of groundnut and palm oil only. These cartons were separately fitted with a 40 W red, blue, and green electric bulb, corresponding to 620 to 750 nm, 450 to 495 nm, and 500 to 570 nm respectively. The cartons were perforated at the opposite sides to prevent overheating. A control sample comprising only the groundnut and palm oil samples of the same volume is placed outside the cartons by the window in the laboratory. All samples were stored and

analyzed for acid values, free fatty acid value, peroxide value, and iodine values during a period of one month taking measurements every other day; that at two days intervals.

Acid Value

The acid value (AV) of a fat or oil is the number of milligrams (mg) of potassium hydroxide required to neutralize 1 g of fat or oil. It measures the extent of the hydrolysis of triglyceride to liberate fatty acids from their ester linkage (Sakaino *et al*., 2022). For this reason, acidity is often quoted in terms of free fatty acids (Reid, 2001).

25 mL each of 96 % ethanol and diethyl ether were neutralized by titrating with 0.1 M aqueous solution of NaOH with phenolphthalein as an indicator. Then 1.0 g of the sample was weighed into a 250 mL Erlenmeyer flask and dissolved with a neutral solvent (CCl_4). This was then titrated against 0.1 M NaOH solution in the presence of a phenolphthalein indicator. The AV of fats or oil is gotten from the equation:

$$\text{AV} = \frac{56.1 \times M \times V}{w} \quad (2)$$

Analysis was done in triplicates and average titre values are reported.

Free Fatty Acid Determination

The free fatty acid (FFA) value of fat and oil is the measure of the percentage by weight of fatty acid of a specific molecular mass present according to the type of fat or oil being investigated after hydrolysis of the triglyceride.

The procedure for determining the F.F.A. of fat or oils is the same as the AV above. Analysis was done in triplicates and average titre values are reported in the tables.

The FFA value (%) was obtained from the equation:

$$\text{F.F.A (\%)} = \frac{V \times M \times m}{10 \times w} \quad (3)$$

V = Volume (in mL) of NaOH used

M = Molarity of NaOH solution

m = Molecular mass of the F.F.A

w = mass (in grams) of sample

Note: Molecular mass of oleic acid = 282 g/mol.

The molecular mass of palmitic acid = 271 g/mol.

Peroxide Value Determination

The peroxide value (PV) of fat or oil is the amount of peroxides present which is expressed in milli-equivalents of peroxide-oxygen per kilogram of fat or oil (mep-O_2/kg fat or oil).

1 g of the sample is weighed into a 250 mL Erlenmeyer flask and 15 mL solvent (glacial acetic acid and chloroform in a ratio of 2:1) is added to dissolve the content in the flask. Then 1 mL saturated solution of potassium iodide (KI) is added and the flask is stoppered, shaken, and allowed to stand for 1 min; after which 25 mL distilled water is added to the solution before titrating with 0.05 M sodium thiosulphate solution using starch solution as indicator. Three replicate determinations were done and average titre values are reported in the tables in the Results and Discussion section below. A blank solution (without the sample (analyte) is done simultaneously). The PV is obtained from the equation below:

$$\text{Peroxide value (P.V.)} = \frac{1000 \times (V - x) \times M}{w} \quad (4)$$

w = mass of sample (in grams)

V = Volume of $Na_2S_2O_3$ (in grams)

x = Volume of $Na_2S_2O_3$ (in mL) used in blank

M = Molarity of thiosulphate solution

Iodine Value Determination

The iodine value (IV) of a fat or oil is the amount of halogen observed under specific conditions and expressed as the number of grams of iodine per 100 g of fat or oil. It is a measure of the degree of unsaturation (olefinic bonds) per molecule of fatty acid of a particular fat or oil.

1 g of fat or oil is weighed into an Erlenmeyer flask and 5 mL trichloromethane ($CHCl_3$) and shaken to dissolve and homogenize. Add 5 mL Wij's reagent containing 26.0 g of reagent grade iodine (I_2) in 2 L of reagent grade glacial acetic acid, stopper, and allow to stand in the dark for 5 min. Then add 5 mL of 10 % KI solution and 25 mL water, mix thoroughly, and titrate with 0.05 M sodium thiosulphate solution with starch solution as indicator. A blank test (without the sample) was done following the same procedure. Analysis was done in triplicates from which the average titre values were obtained and reported in the tables.
The Iodine value for the fat or oil is obtained from the equation:

$$\text{I.V} = \frac{12.69 \times M \times (x - V)}{w} \quad (5)$$

M = Molarity of $Na_2S_2O_3$
V = Volume of $Na_2S_2O_3$ solution used in the test (in mL)
x = Volume of $Na_2S_2O_3$ solution used in blank (in mL)
w = mass of sample (in grams)

Absorbance Determination

0.2 mL of the oil samples was dropped into an Erlenmeyer flask and dissolved in 10 mL iso-octane (2, 2, 4-trimethylpentane). 10 µL aliquot of the sample was withdrawn into a cuvette and the absorbance determined using a UV-vis spectrophotometer.

RESULTS AND DISCUSSION

Acid value

Table 1a: Acid values (mg/g) of palm oil samples stored under light of different colours.

Storage time (Days)	Sunlight (control)	Red Light	Blue Light	Green Light
2	1.527	5.610	7.293	6.732
4	1.687	3.366	7.854	7.855
6	2.246	3.366	7.852	7.854
8	1.680	5.610	5.330	9.257
10	2.539	6.171	5.610	7.856
12	2.528	7.293	6.171	7.514
14	2.813	7.013	5.891	7.860
16	2.801	10.10	6.191	6.452
18	2.291	4.488	5.891	5.620
20	2.248	5.244	5.675	5.235
Average	**2.236**	**5.8261**	**6.3758**	**7.2235**

The acid value of fat and oil measures the amount of KOH needed to neutralize 1 g of fat or oil. It indicates the concentration of fatty acids in 1 g of fat or oil as a consequence of triglycerides hydrolysis. Table 3.1a contains AVs for palm oil samples stored under light of different colours (wavelengths). The interest is to see how this affects the quality of palm oil during storage. The results in Table 1a above show that the AV of palm oil changed with the wavelength of light in the storage environment. Henry (2016), Karki and Bates (2018) observed similar effect of light energy on the acid (fatty) values of oil. From the table above, AVs increased in the order of Red > Blue > Green light according to the

average values obtained in Table 1a; even though the highest and lowest AVs (3.366 and 10.10) were reported in samples under the red light.

Table 1b: Acid values (mg/g) of groundnut oil samples stored under light of different colours.

Storage time (Days)	Sunlight (control)	Red Light	Blue Light	Green Light
2	1.122	1.964	1.683	1.122
4	1.683	0.561	1.122	1.122
6	1.124	0.565	1.122	1.124
8	1.122	1.122	1.123	1.122
10	1.403	1.122	1.403	1.125
12	0.506	1.122	1.122	1.124
14	1.128	1.124	1.403	1.123
16	1.125	1.403	1.406	1.964
18	1.405	1.126	1.127	1.685
20	1.125	1.237	1.212	1.527
Average	**1.1743**	**1.1346**	**1.2723**	**1.3038**

Table 1b reports the AVs of groundnut oil samples under similar light conditions of red, blue, and green light as the palm oil samples above. A similar analysis of these results shows that the wavelength of light absorbed by the oil also affected the AVs obtained. Just like the palm oil samples, the order of AVs increased in the order of Red > Blue > Green lights.

Free Fatty Acid Value

Table 2a: Free fatty acid values (mg/g) of palm oil samples stored under light of different colours.

Storage time (Days)	Sunlight (control)	Red Light	Blue Light	Green Light
2	0.738	2.710	3.523	3.252
4	0.813	1.626	3.794	3.794
6	1.084	1.626	3.790	3.794
8	0.813	2.510	2.252	4.472
10	1.226	2.980	2.710	3.792
12	1.220	3.523	2.981	3.659
14	1.355	3.520	2.846	3.793
16	1.358	3.533	2.980	3.117
18	1.220	2.168	2.846	2.710
20	1.084	2.500	2.742	2.513
Average	**1.0911**	**2.6696**	**3.0464**	**3.4896**

FFA of oils is the measure of the concentration of fatty acid present in 1 g of fat or oil. It is a reflection of the degree of hydrolysis from triglyceride to liberate (free) fatty from the triglyceride molecule. Although the FFA is measured in mg/g of fat or oil, it represents the percentage of free fatty acid in 1 g of fat or oil. In Table 2a, the FFA values of the oil samples under different wavelengths of light increased in the order of red to blue, and green light. The highest FFA value of 3.50 (approximately) was recorded for the samples under the green light, while a value of 2.67 was obtained as the lowest value and was recorded for the sample under the red light condition. The highest FFA value (4.47 %) was reported for the sample under the green light. Whereas, a value of 1.63 % was the lowest FFA value recorded of the three samples under these light conditions.

Table 2b: Free fatty acid values (mg/g) of groundnut oil samples stored under the light of different colours.

Storage time (Days)	Sunlight (control)	Red Light	Blue Light	Green Light
2	0.564	0.987	0.846	0.364
4	0.846	0.282	0.562	0.564
6	0.546	0.288	0.564	0.556
8	0.566	0.561	0.566	0.562
10	0.705	0.564	0.705	0.564
12	0.282	0.566	0.564	0.564
14	0.564	0.562	0.707	0.568
16	0.566	0.705	0.705	0.987
18	0.705	0.560	0.564	0.845
20	0.568	0.784	0.609	0.810
Average	**0.5912**	**0.5859**	**0.6392**	**0.6384**

The FFA values reported for the groundnut oil samples were low. Like was the AVs in the previous section for the palm oil samples, the FFA values for the groundnut oil samples recorded marginal changes. The average increments between two intervals of measurements were in the region of 0.15 to 0.62 % across the three different groundnut oil samples. Whereas, the values ranged from 1.10 to 2.00 % across the three palm oil samples between successive measurements. These obvious differences indicate the rate of hydrolysis of the triglyceride molecules in these two oil types. Ostensibly, the groundnut oil sample was more stable over time. Similar inference was also reported by Sulaiman *et al*., (2022) in a recent study.

Peroxide Value

Table 3a: Peroxide values (mep-O_2/kg fat) of palm oil samples stored under light of different colours.

Storage time (Days)	Sunlight (control)	Red Light	Blue Light	Green Light
2	30.0	17.5	12.5	17.5
4	27.5	1.30	16.0	1.50
6	4.50	4.30	8.50	8.50
8	3.50	6.00	6.00	3.80
10	6.20	3.50	3.50	4.00
12	3.50	6.00	8.50	5.70
14	1.50	6.00	6.00	6.00
16	3.00	9.50	8.50	6.60
18	9.50	7.00	3.50	8.50
20	7.00	5.00	7.50	5.10
Average	**9.62**	**6.61**	**8.05**	**6.72**

P.O values are a basic indicator of lipid oxidation in fat and oils. It measures the milli-equivalent of peroxides per gram of fat or oil. An observation of the P.O. values of the palm oil samples in Table 3a above shows that the average P.O. values were random and followed no particular order. Another significant observation is that the P.O values of the control sample were higher than the three experimental samples under light of different wavelengths which may not be unconnected to the availability of more oxygen in its environment. Although moisture contents of the samples were not measured in this study, a notable inference from a previous study (not mentioned here) portends that increases in moisture contents limited the oxidation of oils. Invariably, the P.O values in Table 3a may infer that the moisture contents of the samples varied under these specific storage conditions and that the sample under the blue light condition may have contained the highest moisture content of the three experimental samples, whilst the control sample may have the highest moisture

condition of all of them. Meanwhile, P.O values were highest at the start of the experiments before dropping off slightly midway through the study and then picking up slightly afterward.

Table 3b: Peroxide values (mep-O_2/kg fat) of groundnut oil samples stored under light of different colours.

Storage time (Days)	Sunlight (control)	Red Light	Blue Light	Green Light
2	1.00	2.50	2.50	7.50
4	1.00	1.00	3.50	6.00
6	3.50	8.50	6.00	8.50
8	3.50	3.50	3.50	6.00
10	6.00	4.50	1.00	1.00
12	8.00	6.00	6.00	10.0
14	6.00	6.00	8.00	6.00
16	7.50	8.50	6.00	8.50
18	1.00	6.00	5.50	7.00
20	8.00	4.00	5.00	10.0
Average	**4.55**	**5.05**	**4.70**	**7.05**

There are no significant differences in the P.O values of the groundnut oil samples recorded in Table 3b. These results show the randomness of the P.O values of the groundnut samples being studied at these different light wavelengths. The wavelength of light energy applied in this study did not seem to dramatically impact the P.O values of the groundnut oil. That is, peroxide formation in these oils is weakly affected by the energy (expressed in wavelength) of the incident light that impacts the oils. Sattar (1976) and Djikeng and co-workers (2019) similarly observed a remarkable decrease in the P.O. values of oil with increasing wavelengths of light. By comparison, the P.O values of palm oil were significantly higher than the groundnut oil, this demonstrated that the groundnut oil was more stable during storage.

Iodine Value

Table 4a: Iodine values (gI_2/100 g fat) of palm oil samples stored under light of different colours.

Storage time (Days)	Sunlight (control)	Red Light	Blue Light	Green Light
2	51.98	52.25	53.08	52.95
4	52.10	52.30	53.10	52.97
6	52.16	52.47	53.09	52.15
8	52.14	52.38	53.20	53.22
10	52.35	52.54	53.19	53.20
12	52.50	52.77	53.36	53.31
14	52.81	52.66	53.40	53.59
16	52.90	52.90	53.49	53.40
18	53.22	53.20	53.20	53.58
20	53.45	53.10	53.85	53.65
Average	**52.561**	**52.657**	**53.296**	**53.202**

Light also had little impact on the I.Vs of palm oil. The changes recorded for the I.Vs of palm oil were negligible under various light conditions in the study. These changes appear to be random between the intervals of measurements, even though, the average values for I.V. depict that it increased from red < green < blue. Overall, these close differences – including the control sample – were barely considered significant. Dodoo *et al* (2021), also observed decreased I.Vs in oils with light which they attributed to the breakdown of pi-bonds. A value of approximately 0.10 was the difference in I.Vs between the control sample and the sample under the red light. Similarly, the same average I.V margin separates the sample under the

green light from that under the blue light; while approximately 0.60 was the average I.V margin between the green and red samples, as well as the difference between the blue and red samples.

Table 4b: Iodine values (gI_2/100 g fat) of groundnut oil samples stored under light of different colours.

Storage time (Days)	Sunlight (control)	Red Light	Blue Light	Green Light
2	61.13	63.32	65.19	64.67
4	61.18	63.39	65.25	64.72
6	61.24	65.33	65.33	64.76
8	61.20	63.47	65.40	64.82
10	61.31	63.40	65.45	65.09
12	61.36	63.58	65.43	65.24
14	61.35	63.60	65.55	65.15
16	61.50	63.86	65.48	65.42
18	61.58	63.95	65.72	65.40
20	61.74	64.27	65.83	65.62
Average	**61.359**	**63.817**	**65.463**	**65.089**

Similar observations are seen in the I.Vs of the groundnut oil samples studied and results presented in Table 4b above. The I.Vs rarely changed significantly during the period of storage in this study. The effect of the different wavelengths of incident light on the samples was considered marginal during the course of storage of groundnut oil. This is obvious when we observe the difference between the I.Vs of successive intervals of measurements. Although the average I.Vs may show that there were slight increases in the I.Vs of groundnut oil in the order of red < green < blue. This order is clearly in consonance with the increasing wavelengths of light energy according to the spectrum of light (ROYGBIV). Expectedly, the I.Vs of the groundnut oil samples were higher than the palm oil samples, an observation which indicates that the former contained more unsaturation than the latter; more so as I.Vs are an indication of the degree of unsaturation in oils.

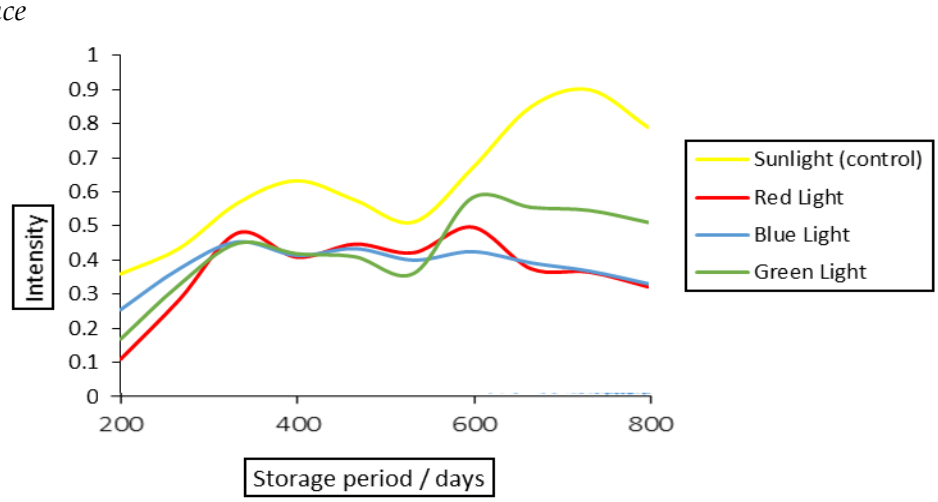

Figure 1a: Absorbance peak intensity values of palm oil samples stored under light of different colours measured at the end of the storage period.

Figure 1a is the absorbance diagram of the palm oil sample at the end of the storage period. It shows a similar pattern of absorbance for the three samples under different light conditions. From the absorbance diagram in Figure 1a, we can see that there are three different electronic transitions according to the absorption maxima. These occur at ≈320, 460, 600, and a weak one

at 740 nm especially for the red and blue light samples. These are indicative of conjugated systems (Kyushin & Suzuki, 2022) and are a reflection of the different chemical environments/positions of the pi-bonds in the fatty acid molecules. Electronic transitions occurring in the near ultraviolet and visible regions are fingerprints of pi-bonds with these transitions occurring between the highest occupied molecular orbitals (HOMO) to the lowest unoccupied molecular orbitals (LUMO). The transitions at the far visible region (especially the 800 nm) are attributed to longer wavelengths (lower energy transitions) and vice-versa. In Figure 1a, the absorbance spectrum of the control sample show two bands, which are higher and broader than the analyte samples, with the one at a longer wavelength (740 nm) being more intense.

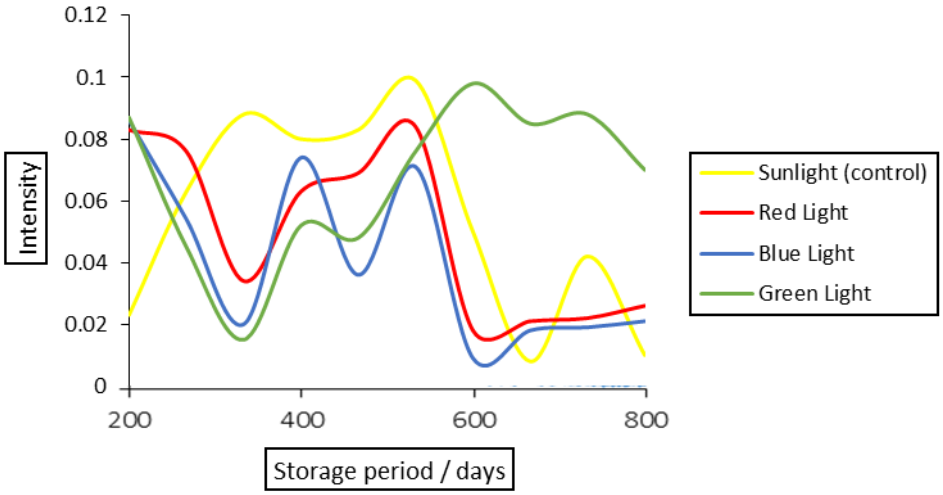

Figure 1b: Absorbance peak intensity values of groundnut oil samples stored under the light of different colours measured at the end of the storage period.

Figure 1b shows similar patterns of absorbance for the groundnut oil sample. There are three absorbance peaks in all the samples. The most notable absorbance occurred at 400, 550, and 650 nm, particularly for the red and blue sample environments. Absorbance occurred at 400, 600, and 740 nm with the most intense absorption happening at 600 nm for the sample placed under green light. For the control sample, the absorbance was recorded at 350, 520, and 740 nm, the latter being the weakest of the three. It is pertinent to note that the intensities of absorbance are related to the concentrations of the chromophores responsible for the particular absorbance.

The results in Figures 1a and 1b demonstrate that both palm and groundnut oils possess unsaturated centres which are responsible for electronic transitions in the visible region upon the acquisition of light energy. These transitions could be assigned to $\pi \rightarrow \pi^*$ transitions for the shorter wavelengths (higher energy) and the $n \rightarrow \pi^*$ for the longer wavelengths (lower energy) transitions. These represent the pi-bonds and the non-bonding electrons in the triglyceride molecules. The groundnut oil samples in Figure 1b show three bands as against the two bands for the palm oil samples in Figure 1a. This again, may be attributed to the groundnut oil having more unsaturation than the palm oil.

CONCLUSION

The interaction of palm and groundnut oil with different wavelengths of light was studied in relation to the basic chemistry of oils during the period of storage. How these wavelengths of incident light affected the AVs, FFA, P.O, and I.Vs of these oils was the main focus of this exercise. Results showed that the energy of the incident lights studied directly affected the AVs and FFA values significantly, but had a weak effect on the I.Vs of both oil types; and may

not have had a significant effect on the P.O values of the two oil types. Furthermore, of the two oils studied, the groundnut oil was the more stable during the storage period. AVs and FFA values increased in the order of red > blue > green lights. Although marketers of these oils do not typically store or display them in these specific light environments, but do so more of the time under the effect of sunlight, it was necessary to see what effect the different wavelengths randomly sampled had on the quality of these oils. Finally, absorbance spectra of these oil show transitions characteristic of unsaturated (pi-) systems with evidence of electronic transitions of nonbonding electrons. The results of this exercise expose the unsafe practice of displaying edible commercial oils to incident light post-production. Efforts should therefore be made to package these oils in amber packs to limit the absorption of light during storage.

Conflicting Interest:
The authors declare no conflicting interest.

Declaration on generative AI in Scientific writing:
The authors made no use of AI technology in writing this article.

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